MODELING THE CHOICE OF TELECOMMUTING 3:

IDENTIFYING THE CHOICE SET AND ESTIMATING BINARY CHOICE MODELS FOR TECHNOLOGY-BASED ALTERNATIVES

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ABSTRACT

Previous papers in this series have presented a conceptual model of the individual decision to telecommute and explored relationships among constraints, preference, and choice. A related paper has developed a binary model of the preference for home-based telecommuting. Noting that there is a wide gap between preferring to telecommute (88% of the sample) and actually telecommuting (13%), this paper develops binary logit models of telecommuting adoption. Two approaches to dealing with constraints are compared: incorporating them directly into the utility function, and using them to define the choice set. Models using the first approach appear to be statistically superior in this analysis, explaining 63-64% of the information in the data. Variables significant to choice include those relating to work and travel drives, and awareness, manager support, job suitability, technology, and discipline constraints. The best model was used to analyze the impact of relaxing three key constraints on the 355 people in the sample for whom telecommuting was previously identified to be a Preferred Impossible Alternative. When unawareness, lack of manager support, and job unsuitability constraints are relaxed, 28% of the people in the PIA category would be expected to adopt telecommuting. The importance of behavioral models to accurately forecasting telecommuting adoption is emphasized and is suggested to have wider implications for predicting technology-based activity changes.

1. INTRODUCTION

New telematic technologies facilitate work from remote locations, such as the home or a neighborhood work center. Telecommuting is a work arrangement in which individuals perform remote work and thereby substitute the whole or part of their commute trip. Thus, it has the potential of reducing travel demand.

The adoption of telecommuting to date has been slower than anticipated by many early studies over the last decade. The gap between forecasts and actual adoption levels has called for careful analyses of the adoption behavior of telecommuting.

In a previous paper, Mokhtarian and Salomon (1994) have presented a conceptual framework for explaining the choice of telecommuting as a work arrangement. It suggests that the decision to adopt telecommuting may be motivated by one or more drives related to family, travel, work, leisure or ideology. The presence of a drive is a necessary but insufficient condition for telecommuting to be adopted. There are numerous constraints which inhibit the ability to choose this work option. Only when these constraints are not binding can the individual actually choose to telecommute.

Data collected to test the relationships derived from the conceptual model is being used to develop a series of models of preference for and choice of telecommuting. In Mokhtarian and Salomon (1996), the role of key constraints was examined, and empirical relationships among possibility, preference, and choice of telecommuting were identified. It was found that some 88% of the respondents would prefer to telecommute from home, but that only 13% currently do so. This wide gap between preference and adoption, which may also characterize other situations involving new technology-based alternatives, suggests that constraints play a major role in affecting behavior. Furthermore, it suggests that preference may be a necessary precursor for behavioral change, but a poor predictor of such change.

Thus, the modelling effort was divided into separate tasks, based on different definitions of the dependent variable. First, a distinction was made between models of preference as opposed to models of actual choice. Second, in either case the alternatives can be defined as binary (prefer/choose or not prefer/choose) or as multinomial (in which individuals face a number of alternative courses simultaneously). Except for some preliminary work reported in Mannering and Mokhtarian (1995), efforts to date (including the current analysis) have focused on the case of binary alternatives for home-based telecommuting.

In modeling the (binary) preference for telecommuting from home, it was found that both factual and attitudinal information affect the likelihood that individuals will prefer to telecommute (Mokhtarian and Salomon, 1997). However, less is known as to why preference is not translated into choice. This paper focuses on choice models and on the role of constraints. Constraints are viewed as potentially affecting behavior in different ways: either by changing the choice set an individual is facing, or by directly affecting the choice probabilities. As many constraints are external, understanding the role they play is important for evaluating technology-based options in the context of policies designed to relax constraints.

In the following section we describe the data and the various types of constraints we have identified. Section 3 discusses some key socio-economic characteristics of current telecommuters. In Section 4, two pairs of binary logit models, one pair for the whole data set and one for a subset are presented. These two pairs of models contrast two approaches to treating constraints: incorporating them directly into the utility function of the model, and using them to define the choice set that is, to identify whether telecommuting is feasible for each individual. A use of the model for analyzing the effect of relaxing two key constraints is also presented. The last section contains a summary of the results and potential steps for further research.

2. DESCRIPTION OF PREVIOUS RELATED WORK

2.1 The data

The progression of work on modeling telecommuting has included a data collection effort based on a questionnaire designed to allow the testing of the conceptual structure described by Mokhtarian and Salomon (1994). The sample consists of 628 responses obtained to a fourteen-page self-administered questionnaire administered to employees of the City of San Diego in December 1992. The data contains information regarding respondents' previous awareness of and experience with telecommuting; their job characteristics; their ability to telecommute; perceived advantages and disadvantages of telecommuting; information on other choices they may have made to satisfy the hypothesized lifestyle drives; attitudes toward telecommuting and issues related to lifestyle drives; and sociodemographic characteristics.

Key characteristics of the sample are presented in Mokhtarian and Salomon (1996), else-where in this issue. Suffice it here to say that, collectively, respondents are 53% female, predominantly professional/technical workers, relatively affluent, mainly in their 30s and 40s, and most often (64%) without children under 16 at home. The sample should not be considered representative of the workforce as a whole in terms of the population *distribution* of key variables including the choice of telecommuting. It may be argued, however, that the sample adequately represents the population *relationships* of explanatory variables to the choice and preference of telecommuting (i.e. the importance of those variables as determined by their magnitude and significance in a quantitative model).

2.2 The nature of constraints

Given the wide gap between preference for and choice of telecommuting, we attribute much importance to the role of constraints. A detailed discussion of the nature of constraints is given in Mokhtarian and Salomon (1994; 1996). In the present context we emphasize only a few aspects of constraints.

In examining the types of constraints that can potentially inhibit telecommuting, we distinguish between dichotomous and continuous constraints. The presence of the former implies that telecommuting cannot be exercised. The presence of the latter, by contrast, implies that the likelihood of choosing (or preferring) telecommuting is reduced compared to the situation in which these constraints are not present.

Three constraints are hypothesized to be dichotomous: Lack of Awareness, Job Unsuitability, and Lack of Manager Support. At least one of these constraints was found to be active for 67.7% of the respondents in our sample. Only the remaining 32.3% of the respondents were aware of the option of telecommuting, had a suitable job and their managers did not obstruct telecommuting. The dichotomous constraints also have a continuous aspect; for example, varying proportions of a job may be unsuitable for telecommuting, making it proportionately less likely that telecommuting will be chosen (or reducing its frequency). But for these three factors, in contrast to the others, the threshold points at which they are unequivocally binding are in theory readily identifiable.

Constraints that can be modeled as having a continuous impact on choice include Misunderstanding of the telecommuting concept, a Lack of Organization Support, the Unavailability of a Personal Computer or other Technology Constraint, and Cost. Note however that despite their continuous nature, these constraints may still be viewed as effectively dichotomous by the employee: I may perceive that if the cost is above a certain threshold (give or take a small margin), it will preclude telecommuting for me. And of course the outcome (choose or not choose) is dichotomous even if the explanatory variables are continuous. Nevertheless, in a situation in which the thresholds will vary by individual and are in any case unknown to the analyst, it is appropriate to model these variables as affecting the utility of (and hence the propensity to choose) telecommuting proportionally to the degree in which they are present for each person, just as with ordinary variables such as an attitudinal factor score, or commute length.

We further distinguish between internal and exogenous constraints. The latter are imposed by the environment (family, employer etc.) whereas the former emanate from psychological traits of the individual. In principle, this distinction differentiates between different levels of control the individual may have over the constraints. Such a distinction may be of relevance when a choice model is developed, as it is desired to identify that part of the sample which actually has a choice and is not constrained. This issue will be elaborated in more detail in Section 4.

3. CHARACTERISTICS OF TELECOMMUTERS

Before developing more complex models of telecommuting choice, it is of interest simply to examine various characteristics of current telecommuters. Table 1 compares telecommuters and non-telecommuters on several socio-economic characteristics that could potentially be related to the choice of telecommuting. For ease of comparison, values on the same characteristics for preferrers and non-preferrers of telecommuting, presented in Mokhtarian and Salomon (1996), are also reproduced here.

Statistical tests of the differences between telecommuters and non-telecommuters were performed: t-tests for the continuous variables household size, commute length, and vehicles per driver, a one-way analysis of variance for occupation, and chi-square tests for the remaining variables which were all categorical. Only two characteristics were found to differ significantly between choosers and non-choosers: the presence of children under 6, and occupation. Consistent with the hypothesis that a desire to balance work with family responsibilities constitutes a drive to telecommute for some, more telecommuters (28%)

Table 1: Characteristics of Telecommuting Choosers and Preferrers

Variable	Indicator	Tele-commuter (N=82[1])	Non-Tele-commuter (N=546[1])	Preferrer (N=553[1])	Non-Preferrer (N=75[1])
Age	estimated mean	39	39	[2] 38	44
Gender	percent choosing/ preferring	female: 15% male: 12%		[2] female: 92% male: 83%	
Household Size	mean size	2.7	2.6	2.6	2.7
Presence of Children under 6	percent having	[3] 28%	20%	20%	25%
Presence of Children 6-15	percent having	22%	23%	23%	24%
Presence of Someone Needing Special Care	percent having	2.4%	4.2%	4.2%	2.7%
Education	mean category	4.2	4.5	4.3	4.2
Household Income	estimated mean	$62K	$57K	$58K	$61K
Occupation	percent choosing/ preferring	[2] manager: 23% prof./tech.: 14% clerical: 6%		manager: 88% prof./tech.: 88% clerical: 88%	
One-Way Commute Length	mean miles	12.5	12.9	[2] 13.2	10.4
Vehicles per Driver	mean	1.1	1.0	1.0	1.0

[1] Some characteristics had missing data, never more than 11 cases out of 628.
[2] Difference significant at $p < 0.05$.
[3] Difference significant at $p < 0.10$.

had children under age 6 than non-telecommuters (20%). The difference in distribution is significant at p=0.09. There is no significant difference in the presence of older children (ages 6 to 15) between telecommuters (22%) and non-telecommuters (23%), indicating that at least where children are concerned, the interest in telecommuting as a way of combining work and family applies primarily to those with young pre-schoolers. Also note that

neither of these two variables differs significantly between preferrers and non-preferrers. There can be many reasons other than family for preferring to telecommute, that may partially obscure the role of family in preference formation. The significantly higher proportion of young children among telecommuters seems to suggest that family has a stronger role in choice. However, it should be kept in mind firstly that the association is relatively weak, and secondly that the presence of young children is at best an imperfect indicator of a family drive.

There are clear differences in telecommuting adoption by occupation. Interestingly, it is the managers who are most often telecommuters: 23% of them telecommute, compared to 14% of professional/technical employees and 6% of clerical staff (these were the only three categories tested, as none of the other occupational categories contained a large number of respondents). Apparently the managers enjoy greater autonomy and have the trust of *their* managers to the greatest degree of the three groups. It is also possible that more job attributes of managers are more amenable to telecommuting. Again, however, there is no significant difference in the *preference* to telecommute, with 88% in each of the three groups desiring to do so.

Conversely, although there is no significant difference in the estimated mean age of telecommuters and non-telecommuters (obtained by estimating each respondent's age with the midpoint of the category checked on the survey), preferrers are significantly younger on average than non-preferrers. It is of interest to compare the average ages of non-preferrers and non-choosers. If everyone who wanted to telecommute were doing so, all non-choosers would be non-preferrers, and the average ages would be equal for both categories. But non-choosers are younger than non-preferrers by about 5 years on average. The implication is that it is disproportionately the younger preferrers who are not telecommuting, which is consistent with the observation that managers are more likely to be doing so.

A slightly higher proportion of women (15%) than men (12%) are currently telecommuting, but the difference is not statistically significant. By contrast, significantly more women (92%) desire to telecommute than men (83%), although the proportions are quite high for both groups. As was discussed in Mokhtarian and Salomon (1997), this gender effect appears in the preference model indirectly through a number of attitudinal and situational variables linked to gender.

The average education for all four groups alike fell between the categories "four year college, university, or technical school graduate" and "some graduate school". Telecommuters had slightly higher estimated average incomes than non-telecommuters, and preferrers had slightly lower incomes than non-preferrers, but differences in distribution were not significant. Interestingly, there is no significant difference in average one-way commute length between choosers (12.5 miles) and non-choosers (12.9 miles). On the other hand, preferrers have, as hypothesized, a significantly longer average commute (13.2 miles) than non-preferrers (10.4 miles). Finally, there is no significant difference in vehicle availability across all groups, with each group having an average of at least one vehicle per driver.

4. BINARY CHOICE MODELS

4.1 The modeling process

The first step in estimating binary models of telecommuting choice is to define the estimation sample. Preference models can be and were (Mokhtarian and Salomon, 1997) estimated on the entire data set: it is assumed that everyone is able to have a preference regarding telecommuting. However, not everyone has a choice. Based on the examination of only the three dichotomous constraints described in Section 2, we found that less than a third of our sample had the choice to telecommute, and that the population proportion is probably even smaller (Mokhtarian and Salomon, 1996).

The theoretical consequences of falsely assuming that everyone has the same choice set can be severe. Genç (1994, p.15), for example, points out that "[t]wo individuals with the same attributes do not have the same probability of choosing an alternative if they have different choice sets", even though a model estimated assuming homogeneous choice sets would yield equal utilities and therefore equal choice probabilities for those two individuals. As Thill (1992, p. 364) notes, when infeasible alternatives are included in the choice set,

> "the choice model will attribute a non-negative probability to all alternatives in the assigned choice set, including those that are not in the true choice set. As a consequence, the estimates of the choice function are inconsistent. Also, an erroneous interpretation of individual behavior can proceed from this mis-specification. The choice model will explain overt behavior in terms of deliberate and unfettered decisions whereas it is mostly constrained by the structure of the individual's choice set."

On the other hand, Lerman (1985, cited in Thill, 1992) observes that the practical consequences of a mis-specified choice set may not be serious. If, in fact, the infeasible alternative has attributes considered quite undesirable by an individual, that alternative will have a very low utility, and hence a very low choice probability. In this situation, the model is probably an acceptable approximation to the reality of zero choice probability, and the impact of the choice set mis-specification on the parameter estimates is likely to be small. For example, if transit is an infeasible mode choice for an individual because the nearest transit stop is some miles away, then a model containing access time or even total travel time as an explanatory variable will predict a negligibly low probability of choosing transit for that person.

Thus, importantly, if the specification of the utility function includes variables that largely capture the availability of the alternative, then the situation posited by Genç is unlikely to occur. That is, if an alternative is possible for one individual but not another, those two individuals would have different attributes for the variables relating to availability.

Based on these observations, we have chosen to estimate logit models of home-based telecommuting choice on two nested groups of the data. The first group contains the entire data base (N = 628), but with the dichotomous and other constraints entered as explanatory

variables into the model. Thus, telecommuting is treated as being possible for everyone, but with constraints on choice being incorporated into the utility function. The second group contains the sub-sample for whom an actual choice exists; the definition of this sub-sample is described in Section 4.3 below. For this group, dichotomous and other external constraints were used to identify whether or not telecommuting was in the choice set for each individual, and thus were not incorporated into the utility function.

The final size of this sub-sample for the second group is N=99, meaning that only some 16% of the full sample can be considered to actually have the choice to telecommute. As expected, the shares of preference and choice increase the more restricted the sample becomes. For the sample as a whole, preference and choice shares are 88.1% and 13.1%, respectively; for the subset of those defined as having a choice, they are 90.9% and 68.7%. Thus, when telecommuting is feasible, more than two-thirds of our sample of 99 choose to do it. However, it is important to emphasize again that this sample is not representative, and therefore that these proportions cannot be projected to the workforce as a whole. Some proportional calculations based on Tables 3 and 4 of Mokhtarian and Salomon (1996) suggest that telecommuting may be possible for 14-16% of the workforce population, but desired by as few as 46% of those for whom it is possible, and chosen by as few as 35% of those for whom it is possible.

For each of the groups of data, a process similar to that for the preference models was undergone to develop parsimonious initial and final model specifications from the large pool of potential explanatory variables. Specifically, variables which did not significantly distinguish between choosers and non-choosers (based on t- and χ^2-tests) were screened out, and highly correlated alternate specifications of the same construct were not included in the same model. After estimating initial models, insignificant variables were successively eliminated and minor variations in specification were tested until a satisfactory final model was obtained.

Two sets of models were estimated for each of the two groups: with and without preference as an explanatory variable. Including preference most faithfully represents the conceptual model of telecommuting adoption, in which choice is a function of preference and short term constraints. On the other hand, since preference is an endogenous variable, it is also desirable to estimate a "reduced form" model in which both drive and constraint variables are allowed to directly influence choice, especially because, as will be seen below, having the preference variable in the model introduces multicollinearity. When preference was included as an explanatory variable of choice, any variables that were significant in the preference model and highly correlated with it were excluded from the choice model.

Mokhtarian and Salomon (1995, 1997) describe in detail the 64 drive and constraint/facilitator variables defined from the data set that form the set of potential explanatory variables for preference and choice. These include factor scores representing attitude measurements as well as socio-demographic and other objective characteristics. For the sake of brevity, we present in Table 2 only the variables that are significant in any of the final models reported here.

Table 2: Description of Variables Significant to Telecommuting Choice

Preference	The binary-valued preference for home-based telecommuting, based on the response to a direct question: how much would you like to telecommute (from home) assuming there were no constraints. For any response other than "not at all", this variable was set equal to one.
Drive Variables	
Disability/Parental Leave	This factor is primarily based on the perceived advantages of telecommuting in permitting continued work in the presence of a temporary or permanent disability or in lieu of parental leave. Representing aspects of the work and family drives, this factor is expected to have a positive sign.
Stress	Attributes loading heavily on this factor include the following perceived advantages of telecommuting: reduce stress of commuting; get more work done; reduce stress experienced at main office; help the environment by driving less; and have more control over physical working environment. Thus, this factor represents aspects of both work and travel drives, with some ideological overtones deriving from the statement about the environment. It is expected to have a positive sign as individuals choose to telecommute to reduce pressure and stress.
Overtime	This variable is the number of hours of paid and unpaid overtime the respondent worked within the last two weeks. High levels of overtime are assumed to indicate a workaholic nature and hence represent a work drive. Workaholics are assumed to be more inclined to telecommute, so as to increase their productivity.
Commute Stress	Statements loading heavily on this factor include: I am willing to reduce my driving to improve transportation and air quality; my commute is a big hassle; and I would usually rather have someone else do the driving. Thus, this factor primarily represents the travel drive, with again a hint of environmental ideology. It is expected to be positively related to the choice to telecommute, assuming that stressful commuting conditions can be avoided by telecommuting.
Constraint/Facilitator Variables	
Misunderstanding	Statements loading heavily on this factor include: telecommuting is inappropriate for managers; telecommuting is primarily for women with child care responsibilities; and telecommuting is synonymous with work at home. High ratings on these statements, resulting in a high score on this factor, indicate a high level of misunderstanding regarding telecommuting. This constitutes a constraint on telecommuting, as an individual may mistakenly believe that her/his situation is not appropriate for telecommuting.
Lack of Manager Support (Manconst)	The likelihood of a person choosing to telecommute is nullified if her/his manager opposes this arrangement. This dichotomous constraint is represented by a dummy variable set equal to one if the respondent's manager will not permit home-based telecommuting at all.
Job Unsuitability (Jobconst)	This is another dichotomous constraint, represented by a dummy variable set equal to one for respondents reporting that no part of their job was suitable for home-based telecommuting.

Table 2 (continued): Description of Variables Significant to Telecommuting Choice

Unavailable PC	This variable was equal to unity if the respondent needed a computer to work effectively, did not have one, and either could not or did not know if they could borrow one from the workplace (about a third of the sample did not know whether they could borrow a computer from the workplace or not, although some of these may not have needed a computer in any case). The lack of a personal computer when one is needed is viewed by the respondents as a constraint which precludes telecommuting.
Technology	This measure is an index equal to the number out of seven technological items (phone and computer products and services) that the respondent indicated needing to acquire or upgrade to be able to work effectively from home. The more technologies that are required for the routine work of an individual, the less likely she/he is to telecommute.
Internal Control	Statements loading heavily on this factor include: I am basically a pretty organized person; I generally try to spend some time each week on myself; I am generally satisfied with my life; and family and friends are more important to me than work. This factor is hypothesized to be a facilitator supporting the ability to telecommute, and hence positively correlated with choice.
Office Discipline	Telecommuting disadvantages loading heavily on this factor include: harder to get motivated to work away from main office; too much trouble to remember what to take back and forth between locations; and main office is nicer/better equipped. This is a constraint acting on individuals who prefer to work in a traditional office environment and to avoid the burden of having to work in multiple locations. Individuals with a high score on this factor are less likely to choose telecommuting.
Lack of Control	Statements loading heavily on this factor include: I often feel like I don't have much control over my life; it is hard to be fully productive in the place where I work; and work and family don't leave me enough time for myself. Originally identified as representing aspects of the independence and leisure drives, this variable appears in one choice model as a constraint (see the discussion in Section 4.3).

4.2 Models on the full data set

Based on Lerman's practicality argument, the inclusion of those who do not have the choice to telecommute in the estimation sample may not be a problem if the model specification results in alternatives having a very low utility (i.e. probability of choice) when they are infeasible. In our case, this is accomplished by incorporating a number of constraint variables (including the dichotomous constraints) into the utility function.

Table 3 presents the coefficients and t-statistics for final models on the full data set, without and with Preference as an explanatory variable. In the first model, without Preference, 30 variables (including the constant) comprising the initial specification were screened down to the eight significant parameters obtained in the final model. A χ^2 - test of the full

(30-variable) versus constrained (8-variable) models found no significant difference between the two, indicating that the more parsimonious model contains essentially the same explanatory power as the full one.

Table 3: Binary Choice Models for the Full Data Set (N=628)

Variable	Type	Without Preference		With Preference	
		Estimated Coefficient	t-statistic	Estimated Coefficient	t-statistic
Constant		-0.55	-2.40	-10.56	-0.15
Preference				10.11	0.14
Overtime	Work Drive	0.042	2.31	0.041	2.20
Commute Stress	Travel Drive	0.74	3.38	0.65	2.92
Misunderstanding	Awareness Constraint	-0.54	-2.53	-0.53	-2.51
Lack of Manager Support	Organization/Manager Support Constraint	-2.90	-6.34	-2.90	-6.35
Job Unsuitability	Job Suitability Constraint	-1.81	-4.34	-1.75	-4.20
Technology	Technology Availability Constraint	-0.28	-3.14	-0.28	-3.14
Office Discipline	Discipline/Control Constraint	-0.58	-2.89	-0.48	-2.32
Number of observations		624		624	
Log Likelihood at 0		-432.52		-432.52	
Log Likelihood at convergence		-159.95		-156.07	
ρ^2		0.63		0.64	
Adjusted ρ^2		0.61		0.62	

Examining the coefficients in the final model, it is first observed that the constant term is negative and significant, meaning that the average impact of the unobserved variables is in the direction of not telecommuting. This is not surprising, given that a preponderance of the sample (87%) consists of non-choosers. Of the seven remaining variables, five are constraints, also having (as expected) a negative impact on the probability of choice. The strongest two of the three dichotomous constraint variables (Lack of Manager Support and Job Unsuitability) are highly significant; the remaining three constraints are Misunderstanding of telecommuting, Technology, and Office Discipline. The magnitudes and signs of these coefficients confirm that individuals for whom a combination of these constraints are active (particularly the dichotomous constraints) will have a low estimated probability of choosing to telecommute.

The two remaining significant variables are drives, both with the expected positive signs. Overtime represents the work drive, and Commute Stress represents the travel drive. Note that Commute Stress is significant even though telecommuters and non-telecommuters have comparable commute lengths (see Section 3). This reinforces our contention that it is the perception of objective reality that is important to behavior, not the objectively measured characteristic itself.

As noted above, drives are necessary for a choice to telecommute to be exercised. The remaining drives identified in the conceptual model (family, independence, leisure and ideology) do not appear here to make significant contributions to the *choice* of telecommuting, although they have contributed to the formation of the *preference* to telecommute (Mokhtarian and Salomon, 1997). This may imply that, among drives, work and travel are the most decisive factors in choosing to telecommute representing the strongest, most tangible, and most immediate benefits of telecommuting whereas the other drives may play only a minor contributing role in the choice.

Rho-squared, the proportion of information in the data explained by the model, is 0.63. The ρ^2 value for a discrete choice model should be compared to that for the market share model, that is one whose only explanatory variable is the constant term (and for which the estimated choice probability for each individual will equal the aggregate share of that choice in the sample). Since the choice shares are quite unbalanced, a market share model alone explains a high proportion of the information in the data: 44% in this case. This suggests that the other seven variables in the final model only explain 19 additional percentage points of information. However, the final model re-estimated with the constant term constrained to equal zero resulted in a ρ^2 of 0.62, meaning that the seven true variables carry virtually the full explanatory power of the model.

An alternative specification included Preference as an explanatory variable in the model. If, as stated earlier, preference is a precursor of choice, its inclusion in the model is hypothesized to improve the explanatory power of the choice model. The model-estimated coefficients are also presented in Table 3.

Preference is defined on the basis of responses to a direct question in which individuals were asked how much they would like to telecommute from home if no constraints were present. Its contribution to the model, as judged by its standard error, is insignificant.

However, note that the constant term and the coefficient for Preference are large, of opposite signs, and insignificant with nearly identical standard errors of 71.84. This pattern persisted throughout all tested models containing Preference, and is characteristic of the case in which two variables are collinear. In view of the fact that 88% of this sample prefers to telecommute (and therefore has a value of one for the zero-one Preference variable), such a result is not surprising. Normally, only one variable of a collinear pair would be kept in a model. In this case, however, it is desirable to retain both variables: preference for conceptual reasons, and the constant term because it captures the average effect of unmeasured influences on choice and the effect of sampling bias (Manski and Lerman, 1977).

The interpretation is as follows: when the preference variable is zero, the large negative constant term results in a near-zero probability of choice which is as it should be (no one in the sample chose telecommuting who did not prefer it). When telecommuting is preferred, it counteracts most of the negative contribution of the constant term, although the average residual effect of unmeasured variables is still negative (against choosing to telecommute). When the significant drives are strong enough to counteract the combined effects of the rest of the constant term and any active constraints, choosing to telecommute will be the higher-probability alternative. Similar results will be observed for the model including preference on the smaller subset of 99 observations, discussed in Section 4.3.

The remaining seven variables in this model are the same two drives and five constraints found in the model without Preference. All variables are significant and have the expected signs. The ρ^2 statistic is 0.64, only slightly higher than for the first model. The adjusted ρ^2, which controls for the number of parameters being estimated, is also slightly higher for the model with Preference (0.62 versus 0.61).

4.3 Models on those who have a choice

To identify the sub-sample of respondents who truly had the choice to telecommute from home, cases were eliminated in several stages. First, those for whom any of the dichotomous constraints were active were eliminated, leaving 203 respondents. However, many constraints may preclude telecommuting besides the three defined as dichotomous ones. In the previously developed conceptual model, these other factors have been treated as continuous constraints, that is as having a continuous impact on the propensity to choose telecommuting. Since the threshold point (i.e. the point at which the continuous constraint becomes active and precludes choice) for each individual is generally not known, this is a logical approach to take when a model will be used to predict before the fact the probability that telecommuting will occur as a function of drives and constraints. In this exploratory research, however, we not only know what choice has been made, we also have information regarding why telecommuting was *not* chosen. In a case where the reason given appears to be a factor outside the person's control, there is some basis for concluding that such an individual actually did not have the choice to telecommute.

Some reasons for not telecommuting can represent a conscious choice on the part of the respondent, and should not be a basis for excluding telecommuting from the choice set. In our survey, we place the following reasons in that category: for me, the disadvantages

outweigh the advantages; it would cost me too much; and my home environment is not suitable for telecommuting. Another reason, also not used as a basis for excluding telecommuting from the choice set, was "I would telecommute from a center, but there is none available". If the unavailability of a center were the only reason given for not telecommuting (i.e. the manager didn't disapprove, and so on), it is suggested that the respondent could work from home but chose not to.

Thus, from among those for whom no dichotomous constraint was active, cases were further eliminated from this estimation sample if they gave any of the following reasons for why they were not currently telecommuting: my job is not suitable; my present work responsibilities don't permit it; I have discussed it with my supervisor, and s/he will not (yet) allow it; I have *not* discussed it with my supervisor, but I don't think s/he will permit it; I don't have all the resources I would need to work at another location; there is not enough space at home; telecommuting has not been offered to or discussed with me; and management disapproves of telecommuting.

Two of these reasons, those relating to resources and space at home, may represent conscious decisions on the part of the respondent and if so, should not be used to exclude telecommuting from the choice set. However, lack of adequate resources may also relate to factors outside the respondent's control, such as the need for specialized equipment or services to be able to telecommute effectively. And if space at home is a genuine constraint, it is suggested that the cost of providing adequate space (through remodeling, expansion, or relocation) is of such a different order of magnitude from the other costs of telecommuting (computers, telecommunications) that it may realistically preclude telecommuting for those individuals. In any case, to have the "purest" group of people who actually have the choice to telecommute in this estimation sample, the more restrictive criteria for inclusion in the sample were adopted, leaving 126 cases.

One more screen was applied to this sub-sample. Of the 126 cases included at this point, 68 (54%) were currently telecommuting and 58 (46%) were not. We examined the reasons given for not telecommuting by those 58 people. In nearly half (27) of the cases, the reason given was, "I never really thought about it." Initially, our assumption was that, since the respondents in this group are aware of telecommuting and have no other apparent constraints active, they never thought about telecommuting simply because no active drives were prompting them to do so. In that case, it is of particular importance to include this group in the estimation sample, because they are precisely the segment of the population that contributes to inflated estimates of the potential demand for telecommuting when only constraints and not drives are considered.

However, this assumption is countered by the fact that all 27 of this group have expressed a preference for telecommuting. This suggests that in some cases the preference or drive to telecommute is either quite weak, or not yet acted upon. It is quite possible that some respondents, although vaguely aware of telecommuting, had not consciously evaluated its benefits in their situation until completing our survey prompted them to do so. Thus, in completing the survey they may for the first time have expressed a desire to telecommute, while never having really thought about it previously and not yet having the time to translate that preference into choice.

This point illustrates the limitations of a cross-sectional survey in analyzing the dynamic adoption process. To avoid the effects of this temporary mismatch between unconstrained preference and actual choice, the 27 respondents who gave "never really thought about it" as a reason for not currently telecommuting were eliminated from this sub-sample. Ultimately, then, this group contained 99 cases, 68 of whom were currently telecommuting and 90 of whom preferred to telecommute.

Table 4 presents the estimation results for the models on this subset of 99 cases. As above, two separate models were estimated, without and with Preference as an explanatory variable. For the model without Preference, twenty-six variables were initially introduced, leading to a final model in which only four significant variables are included: the constant term, Stress, Misunderstanding and Internal Control. There was no significant difference between the full and final models (for the χ^2 statistic of 23.6 with 22 degrees of freedom, $p > 0.1$).

In keeping with the fact that two-thirds of this group are telecommuting, the constant term for this model is positive, indicating that the average effect of unmeasured variables is in the direction of choosing to telecommute. Stress, as expected, is a drive that is positively associated with the choice of telecommuting in this model. Either Stress or Commuting Stress appears in three of the four models presented in this paper. This leads to the conclusion that stress is a strong drive in itself, and may largely capture what we have defined as the travel drive and the work drive. Internal Control is a factor which facilitates the choice to telecommute, and therefore has the expected positive sign. The only factor in this model which inhibits choice is Misunderstanding.

The model which incorporates Preference as an explanatory variable is conceptually more appealing. As can be seen in Table 4, this model is specified by seven variables plus the constant term. It has a ρ^2 value of 0.49, and is thus judged to be significantly superior to the previous model having a ρ^2 of 0.38. The same model estimated without the constant term has a ρ^2 of 0.43, indicating that most but not all of the information explained by the model can be attributed to the seven true explanatory variables.

Preference, defined as a zero-one variable, is not statistically significant and is again negatively correlated with the constant term, as both have large and nearly identical standard errors (of 56.16) and coefficients of similar magnitude and opposite signs. Misunderstanding and Internal Control are present in this model as in the previous one, with similar coefficients. However, both variables are less significant than for the model without preference; Misunderstanding especially moves to more marginal significance.

The four other variables which are significant here but not in the model without Preference are Disability/Parental Leave, Unavailability of a PC, Office Discipline, and Lack of Control. The first represents the family and work drives and, as hypothesized, this factor encourages telecommuting. The presence of the PC Unavailability variable is somewhat unexpected, as people were eliminated from this estimation sample if they reported not having all the resources they needed to telecommute. Nevertheless, it has the expected negative impact on choice. As suggested earlier, this element may be more a matter of

perception than reality, as many respondents did not actually know whether a computer could be borrowed from the workplace or not. Also, as computer costs are constantly decreasing and more homes purchase one for household use, it is likely that this constraint will decline in importance over time. Bernardino and Ben-Akiva (1995) have recently reported that most employers in their study are willing to supply the necessary technology and to cover the communications costs.

Table 4: Binary Choice Models for those who have a Choice (N=99)

Variable	Type	Without Preference		With Preference	
		Estimated Coefficient	t-statistic	Estimated Coefficient	t-statistic
Constant		0.85	2.92	-9.88	-0.18
Preference				11.44	0.20
Stress	Work and Travel Drives	1.53	4.01		
Disability/Parental Leave	Work and Family Drives			0.64	1.90
Misunderstanding	Awareness Constraint	-0.98	-2.61	-0.82	-1.70
PC Unavailability	Technology Availability Constraint			-1.17	-1.90
Internal Control	Discipline/Control Facilitator	1.46	3.81	1.15	2.96
Office Discipline	Discipline/Control Constraint			-0.78	-1.86
Lack of Control	Discipline/Control Constraint			-0.71	-1.54
Number of observations		99		99	
Log Likelihood at 0		-68.622		-68.622	
Log Likelihood at convergence		-42.497		-35.009	
ρ^2		0.38		0.49	
Adjusted ρ^2		0.32		0.37	

As described earlier, Office Discipline is a constraint on telecommuting, and as such has the expected negative sign. Finally, the negative sign for Lack of Control requires some explanation. When this variable was initially identified (Mokhtarian and Salomon, 1997), it was hypothesized that those with a higher score on this factor would be frustrated by their lack of control and, perceiving telecommuting as a means of regaining some control, would hence be more likely to want to telecommute. This suggests that this variable, hypothesized to represent the independence and leisure drives, should have a positive coefficient. Indeed, although Lack of Control was not statistically significant in the final model of telecommuting preference, it was the case that preferrers had a significantly higher mean score on this factor than non-preferrers. The fact that this variable now has a negative (albeit only marginally significant) coefficient in the *choice* model suggests an additional interpretation: that those with a high score on this factor are *unable* to choose telecommuting *because* of their lack of control. Thus, it is classified here as a Discipline/Control constraint. However, it may be more of an external constraint than the other two Discipline/Control measures in this model, which are primarily internal.

4.4 Discussion

In comparing the performance of the models estimated for the two different groups, one immediate observation is the apparent superiority of both models on the full data set over both models on the subset of those who actually have a choice. The two models on the full data set contain the same variables (except, of course, for the presence of Preference in only the second of the two models), all of which are conceptually appealing and statistically highly significant with the expected signs. The ρ^2 statistics for the two models are relatively high at 0.63 and 0.64, respectively. For the reduced data set, by contrast, a smaller set of variables is significant (especially for the model without Preference), the significance of some variables is marginal (although they are still included for their conceptual relevance), and the ρ^2 statistic for the better of the two models is "only" 0.49.

Thus, it seems that in this study at least, incorporation of constraints into the utility function offers a more desirable model than using constraints as a basis for determining the choice set. However, two points should be kept in mind. The first is that even a ρ^2 of 0.49 is quite respectable among discrete choice models of this type. Hence, viewed in isolation, the second model of Table 4 would be considered more than acceptable.

The second point is that the models on the full data set are accounting for whether telecommuting is in the choice set as well as whether it is chosen, whereas the models on the reduced set need only account for whether or not telecommuting is chosen. Part of the explanatory power of the first group of models derives from the fact that they can readily identify (primarily through the two dichotomous constraints Job Unsuitability and Lack of Management Support) and predict (non-)choice for many of those in the estimation sample for whom telecommuting is essentially impossible. In the second group of models, this identification has been externally accomplished by the analysts, leaving only the more difficult task of predicting choice for those who actually have a choice.

In support of this point, it should be noted that when the first model of Table 3 is re-estimated without the two dichotomous constraints, its ρ^2 is equal to 0.51, essentially

comparable to the 0.49 of the second model of Table 4. When the two dichotomous constraints are eliminated from the beginning and a best new model is found on the full data set, its ρ^2 is 0.55, still substantially lower than the 0.63 for the model with the constraints. However, comparison of the adjusted ρ^2 values for these models demonstrates the advantage accruing to the larger sample size of the full data set. Since the log-likelihood increases in magnitude with the sample size, the adjusted ρ^2, which is equal to {1 - [$LL_{convergence}$ - number of parameters] / LL_0 } (Ben-Akiva and Lerman, 1985), differs from ρ^2 (calculated by the same equation without the "number of parameters" term) more substantially for smaller samples. Thus, the adjusted ρ^2 for the best new model without dichotomous constraints on the full data set is 0.53, compared to an adjusted ρ^2 of 0.37 for the second model of Table 4.

This suggests that all else being equal, the models on the full data set may be preferred because of being estimated on a larger sample. The model of Table 4 may also have had an adjusted ρ^2 value close to 0.50 if it had been estimated on a sample of 624 people who actually had the choice to telecommute. However, such a sample would almost certainly again be a subset of an even larger sample collected without regard to telecommuting feasibility, with models on that larger sample again presumably proving statistically superior to those on the smaller sample.

For both groups of models, incorporating Preference as an explanatory variable resulted in collinearity with the constant term. Although it is conceptually desirable to include preference as an explanatory variable for choice, the nearly universal preference for telecommuting in the sample led to the observed, normally undesirable, empirical result. Nevertheless, the two models containing Preference were interpretable and statistically at least equivalent if not superior to their counterparts that did not contain Preference. Additional models were estimated using the predicted probability of preference, derived from the logit model reported in Mokhtarian and Salomon (1997), in lieu of the actual preference. In those models, both the constant term and the estimated preference probability variable were statistically significant, but they were still collinear and the ρ^2 statistics were equal to (for the full data set) or inferior to (for the reduced data set) those for the models reported here.

4.5 Implications for the PIA

In Mokhtarian and Salomon (1996), we classified our 628 respondents into the eight categories defined by all combinations of the three binary variables Possibility (set equal to one if none of the three dichotomous constraints were active), Preference, and Choice. The majority of the sample (355 or 56.5% of the cases) fell into a single category: those for whom telecommuting constituted a "Preferred Impossible Alternative" (PIA). That is, for this group, telecommuting was preferred, but not possible and therefore not chosen.

It would be valuable to be able to forecast what would happen to this group should the dichotomous constraints apparently restricting choice be lifted. How many would actually choose telecommuting then? Clearly not everyone, since as we have discussed, other constraints besides the dichotomous ones may be preventing a preferred alternative from being

chosen. Of the 184 people in our sample for whom telecommuting is both "possible" (considering only the dichotomous constraints) and preferred, only 68 (37%) actually choose it.

In the absence of any more sophisticated methods, then, the most natural approach to forecasting the choices of the PIA group would be to use the same ratio as observed for the "possible and preferred" group. Using that simple method, an expected 37% of the PIA group, or 131 people, would choose telecommuting if it were possible for them.

Such a simple approach would be valid only if the distributions of *other* characteristics important to choice are similar between the PIA group and the possible-and-preferred group, which cannot necessarily be relied upon. But the development of models forecasting choice *as an explicit function* of those other important variables offers a superior approach. The models can be used to estimate the probability of choice of each individual based on that individual's specific characteristics. In that case, differences in distribution of those characteristics are automatically accounted for by the model.

To illustrate this approach, we use the second model of Table 3 to estimate the choices of the PIA group under two scenarios. In each case, the estimated choice probability $\hat{p}_i$ for the i-th member of that group is calculated from the binary logit formula

$$\hat{p}_i = 1 / [1 + \exp(-\hat{\beta}^t \mathbf{X}_i)],$$

where $\hat{\beta}$ is the vector of estimated coefficients shown for the second model of Table 3 and $\mathbf{X}_i$ is the vector of explanatory variables for the i-th individual.

The expected number of choosers from among the PIA group is just the sum of the estimated individual probabilities of choice across the group. Note however that this formula has the apparently anomalous effect of predicting some choosers even from the "impossible" group. For example, if $\hat{p}_i$ were to equal 0.05 for everyone in the PIA, then 5% of that group would be "expected" to choose telecommuting. In fact, the expected number choosing telecommuting out of the entire group of 425 people for whom telecommuting is not Possible (Cells 5-8 of Table xxx in Mokhtarian and Salomon, 1996) is 15, which is quite close to the 14 people from this group who are observed actually to choose telecommuting (Cell 5 of the table; see Mokhtarian and Salomon (1996) for further discussion of this anomalous group in the context of data collection and measurement issues). Although the model (since it contains a constant term) is guaranteed to replicate the aggregate market share of 13% telecommuters (meaning that the $\hat{p}_i$s sum across the entire sample to 82, the number of observed choosers in the sample), there was no guarantee that such a replication would hold separately for the subgroups Possible = 1 and Possible = 0.

In the discussion following, we report only the incremental increase in the expected number of telecommuters beyond the baseline level (of "impossible" choosers) for each of the two scenarios.

In the first scenario, the barriers of lack of awareness and manager resistance to telecommuting are completely eliminated. That is, the dichotomous Unaware and Lack of Manager Support constraints are set equal to zero for everyone in the PIA group (Unaware is not significant in the model and is the single active dichotomous constraint for only 5 people in the PIA group). Under this scenario, an expected 45 new people will choose telecommuting out of the group for whom it just became possible. This is 13% of the 355 people in the PIA group. However, with the removal of just two of the three dichotomous constraints, telecommuting did not become possible for everyone in this group, only for the 145 people for whom Job Unsuitability was also not active. Thus, an estimated 31% of this "liberated" group will choose telecommuting.

In the second scenario, all three dichotomous constraints are removed, making telecommuting possible for everyone in the PIA. Under this scenario, an expected 101 additional people will adopt telecommuting (compared to the original number), 28% of the PIA group.

In both scenarios, the response to lifting the dichotomous constraints is considerably less than the 37% predicted by the simple method of preserving existing ratios. This illustrates the importance of causal, behaviorally-based models in forecasting general adoption rates and responses to specific policies or trends. The models presented here can be used to estimate the impacts of removing or reducing other constraints, such as technology availability and misunderstanding.

5. SUMMARY AND NEXT STEPS

This paper analyzes the individual choice to telecommute. It builds upon previous developments of a conceptual model and an empirically-estimated binary logit model of telecommuting preference. In this paper, binary logit models of telecommuting choice were estimated. External constraints precluding the choice to telecommute were handled in two different ways: incorporated into the utility function (permitting models to be estimated on the entire data set), and used to eliminate telecommuting from the choice set for some individuals (leading to estimating models on the reduced sample of those who actually have a choice). Based on the second approach, it appears that only about 16% of the full sample truly has a choice; of those, 69% choose to telecommute while 91% prefer to telecommute. In view of the self-selection bias of the sample, these latter two proportions will be lower in the workforce as a whole, with estimated lower bounds of 35% and 46%, respectively. The gap between preference and choice for this group is largely due to a conscious and volitional tradeoff between the advantages and disadvantages of telecommuting: I may want to telecommute to some degree, but recognize that it has certain disadvantages (such as costs and my own internal constraints including an appreciation for the discipline offered by the main office), which for me outweigh its advantages.

The dynamic aspect of the adoption process also contributed to the observed gap between preference and choice. Twenty-one percent of the sub-sample that apparently had a choice (27 out of 126) stated a preference for telecommuting yet were not doing it because they had "never really thought about it". The two relevant issues for this group are how intense the

stated preference for telecommuting is, and how long, if ever, it would take to translate that ostensibly unconstrained preference into choice.

Taken together, these findings on the importance of constraints and the dynamics of the decision process cogently confirm that basing forecasts of telecommuting adoption on stated preference alone will considerably overstate the potential market. Further, it was demonstrated that simple approaches to estimating the effects of relaxing various constraints also appear to yield unreliable results. This underscores the vital role of behavioral models such as the ones presented here in developing reliable forecasts of telecommuting adoption.

Several directions for future research are being pursued with the data collected for this study. The models presented in this paper focus on the binary case, of either adopting telecommuting or not. However, as has been pointed out by Handy and Mokhtarian (1995), the effectiveness of telecommuting as a travel mitigation strategy depends not on the penetration level (i.e., how many people are engaged in telecommuting) but on the number of occasions that telecommuting is performed and substituted for travel. Consequently, a natural next step in modeling should be directed at understanding the choice of frequency of telecommuting among those who choose to telecommute.

Also, to date this study has focused on the preference and choice of telecommuting from home. But the same survey obtained preference and choice for center-based telecommuting as well. Telecommuting from a center occurred too infrequently to support development of quantitative choice models (although data are currently being collected for this purpose in a new study), but development of preference models for center-based telecommuting is currently underway. These are likely to provide valuable insight into the market for this still-experimental form of working.

Further, telecommuting choice can also be framed within a broader framework of the choice set. A multinomial approach, in which telecommuting is one of a broader set of options to adjust behavior in the face of dissatisfaction, is likely to improve our understanding of the relative efficiency of alternative demand management strategies.

Finally, another fruitful direction for further analysis is examining the dynamic aspects of the adoption process. These should be viewed in the broader context of new technology-based alternatives. Such alternatives may be very attractive at first sight, hence the wide preference. But they may not be practicable due to a variety of constraints. The issue then is really to forecast the change in the prevalence of the constraints, which may be the more important explanation for future adoption levels. For example, the growing popularity of mobile work technologies (cellular telephone and notebook computers with modems) will affect peoples' perception of constraints associated with access while mobile. Also, the acceptance of telecommuting as a social norm is likely to increase as more people do it. Although we have not defined or identified a social constraint, one may be at play.

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