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After the Resolution: Excess Commuting for Two-Worker Households in the Los Angeles Metropolitan Area

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Introduction

Urban economic theories are based on the assumption that workers choose their residences to maximize utility by trading off commuting and housing costs. This means that each urban land-use model[2] will have a corresponding minimum aggregate commuting cost[3]. Unfortunately, most of the minimum aggregate commuting costs required by urban models are quite different from what we observe from actual data. Excess commuting is commuting unexplained by the model; in other words, it is the difference between average actual commute from observed data and average minimum required commute calculated by the model.

Studies on excess commuting[4] have been done by Hamilton (1982, 1989), White (1988), Cropper and Gordon (1991), Small and Song (1992), and Giuliano and Small (1993). Among these studies, Small and Song's (1992) "Wasteful Commuting: A Resolution" clarified the conceptual issues on required commute, provided more reliable empirical results than the previous studies, and confirmed Hamilton's (1982) conclusion that the monocentric model does not predict

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2 These models use commuting cost as the most basic element. The best known and rigorously tested land-use model in urban economics is the monocentric model.

3 These costs are usually measured by distance or time.

4 The studies on wasteful commuting are also done by Suh (1990), Thurston and Yezer (1991), Hamburg et al. (1965).

actual commuting. Small and Song concluded that any model, including the monocentric model, that allocates workers to residences to minimize aggregate commuting costs is rejected by observed commuting data. Even though Small and Song's conclusions are reliable and convincing, it is worthwhile to examine the commuting cost minimization issue again, using different data and models.

In this study, I go beyond previous studies by distinguishing between single-worker households and two-worker households. Since there are many[5] two-worker households in urban areas, and since these households may have more constraints than single-worker households in choosing their work or residential locations, it is more illuminating to examine commuting behavior for two-worker and single-worker households separately. I first define simple constraints on residential location choice which two-worker households may have. I then measure excess commuting for two-worker households with or without those constraints, using 1991 micro data from the Los Angeles Metropolitan area.

I find that excess commuting for two-worker households is about 41 percent without constraints, and only about 22 percent with constraints. These results show that fixed work-place constraints reduce excess commuting by about half for two-worker households. For single-worker households, excess commuting is about 38 percent. Since my constraints are minimum restrictions[6] on required commute, my results are an upper bound on excess commuting. My findings show that minimizing aggregate commuting costs is an important factor in explaining

[5] The percentages of two-worker households and single-worker households in the study area are 46% and 39% respectively (Current Population Survey, March 1990). The remaining 15% have more than two workers in a household.

[6] Other restrictions or constraints which might influence households' residential location choice and commuting are housing tenure, income, physical characteristics of the house (size of bedrooms, number of bathrooms, etc.), neighborhood amenities, and number of children.

actual commuting behavior for certain groups of people (e.g., two-worker households with fixed work locations and unskilled workers) more strongly than for others.

The remainder of this paper is organized as follows: Section 2 briefly reviews related literature; Section 3 discusses the methods used to calculate required commute; Section 4 describes the study area and data; Section 5 explains the results. Conclusions are in the final section.

Review of related papers

1) Hamilton

Hamilton is the first economist who tested the monocentric models using excess commute. These monocentric models were developed by Mills (1967) and Muth (1969). These models assume that households value accessibility to the Central Business District (CBD) and that households maximize their utility by trading off housing costs with this accessibility. For firms, there are agglomeration of economies in the center. Therefore, land rent is higher in the area closer to the center. Assuming that housing is a normal good, higher housing prices near the center mean higher residential density. This means that residential density is negatively related to the distance from the center. Employment density also is negatively related to the distance from the center because firms use more capital than land where land rent is higher. The negative exponential density function is the most commonly used density function form in the monocentric models.

Hamilton says that if consumers maximize their utility under the standard monocentric models with centralized employment, then the minimum commuting distance is simply the mean distance of houses from the Central Business District. With decentralized employment, as long as there are no circumferential and reverse-flow commutes, the total volume of commuting will be less than that with centralized employment. He calculates the mean distance of houses from the CBD in the case of centralized employment and the mean distance of jobs from the CBD in the case of decentralized employment using Mills's (1972) estimated population and employment density gradients. He says the difference between these two mean distances is the mean required commute for the monocentric city with decentralized employment.

He defines the difference between the actual mean commute and the mean required commute as "wasteful commuting." He calculates the mean required commute of fourteen U.S. cities to be 1.12 miles and the mean actual commute to be 8.7 miles using data from the Annual Housing Survey (1979, 1980). In other words, excess commuting distance is about 87 percent of average actual commuting distance for these cities. Thus, Hamilton claims that the existence of a large wasteful commute makes the monocentric model unrealistic.

Hamilton gives two explanations for his conjecture that the existence of two-worker households will not increase the minimum required commute. First, the cost of the secondary worker's wasteful commute is too high relative to household income. Second, the monocentric model predicts that two-worker households have a propensity to locate downtown. This makes the workers' residential density gradient steeper than the population density gradient and reduces the minimum required commute.

2) White

White argues that Hamilton's approach to measuring wasteful commuting is incorrect for two reasons. First, Hamilton does not account for the actual spatial distributions of jobs and residences around the CBD. Second, he does not consider the actual road network. White recalculates wasteful commuting using her own definition. She says commuting is wasteful only when the existing commuting trips are not shortened by trading jobs and residences even when these opportunities exist. She says that possible explanations of wasteful commuting are outward or circumferential commutes in two-worker households and the racial segregation of residential areas.

Following Hamburg et al.[7] (1965) who tested journey-to-work minimization using the linear programming method[8], White used an assignment model to calculate wasteful commuting. She uses data from the 1980 Census of Population. She calculates the optimum set of job and residence combinations using the actual network data matrix and solves the linear programming optimization problem for the minimum average commuting time in the metropolitan area. The average actual commute for the same set of cities used by Hamilton is 22.5 minutes and the average minimum commute is 20.0 minutes. White's result shows that only 11 percent of commuting is wasteful compared to Hamilton's 87 percent. She concludes that the monocentric model is not as bad as Hamilton claimed.

3) Cropper and Gordon

Cropper and Gordon (1991) call Hamilton's average required commute "average distance minimizing commute," and they redefine average required commute as minimized total commuting distance subject to the constraint that no household's utility falls below the previous levels of utility after rearranging residences. Cropper and Gordon are the first economists to use

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[7] They segregated their sample by income, race and auto availability using data from the Niagara Frontier home-interview survey.

[8] The linear programming method has been used by Herbert and Stevens (1960) and by Wheaton (1974).

micro data to compute excess commute. These data are from the Baltimore Travel Demand Dataset. Their models are the variation of a standard assignment problem used by White.

Cropper and Gordon use two models to compute required commute. The first model is a standard assignment model using micro data;

$$\text{Min} \quad \sum_h \sum_j X_{hj} \cdot D^1_{hj}$$

$$\text{subject to} \quad \sum_h X_{hj} = 1 \quad \forall j,$$

$$\sum_j X_{hj} = 1 \quad \forall h,$$

$$X_{hj} \geq 0 \quad \forall h, j$$

where h is a household index, j is a residence index,

if household h occupies residence j $\quad X_{hj} = 1$

otherwise $\quad X_{hj} = 0$

D^1_{hj} are the distances that the primary worker in household h must travel from residence j to their work places.

The second model includes the secondary workers' commuting distances and constraints on households' utility;

$$\text{Min} \quad \sum \sum X_{hj} \cdot (D^1_{hj} + D^2_{hj})$$

$$\text{subject to} \quad \sum_h X_{hj} = 1 \quad \forall j,$$

$$\sum_j X_{hj} = 1 \quad \forall h,$$

$$X_{hj} \geq 0 \quad \forall h, j \quad \text{and}$$

$$U_{hj} \geq U^0_{hj} \quad \text{if} \quad X_{hj} = 1$$

where D^2_{hj} are the distances that the secondary worker in household h must travel from residence j to their work places.

U_{hj} is the utility received by household h from residence j.

U^0_{hj} is household h's present utility.

U_{hj} is a function of housing and neighborhood attributes, the commuting distances of all workers in the household, and all other goods.

Cropper and Gordon include neighborhood amenity as one of the independent variables entering households' utility functions. Further they calculate home owners' and renters' average required commute separately.

Cropper and Gordon's results on average required commute are 5.04 miles for home owners and 4.17 miles for renters with constraints on households' utility, 4.39 miles for home owners and 3.65 miles for renters without these constraints. Cropper and Gordon note that the average actual commute is 10.2 miles in Baltimore. They find that about 5 miles is an upper bound to wasteful commuting distance in Baltimore because of the limited determinants of residential location choice. They conclude that adding the secondary workers' commuting distances and constraints on utility increase the required commute by 15 percent. Since they do not distinguish single-worker and two-worker households, their study can not be used to see the difference between the commuting behavior of single-worker and two-worker households. To clearly see the secondary workers' influence on excess commute, the sample should be grouped into single-worker households which have no secondary workers, and two-worker households which do.

4) Small and Song

Small and Song clarify the conceptual issues of wasteful commuting in an effort to resolve confusion from previous studies. They define minimum required commute for three patterns of geographically distributed work and residential sites: monocentric, polycentric and zonal[9]. Small and Song explain that Hamilton's definition of wasteful commuting is based on a zonal pattern, while Hamilton's computation is based on a monocentric pattern. They also explain that White's conclusion on the monocentric model is incorrect because White's definition and computation of wasteful commuting is based on the zonal pattern. They rename Hamilton's "wasteful commuting" "excess commuting" to make the term normatively neutral.

They find that White's calculation on wasteful commuting is biased downward because of the use of large zone data. Using both Hamilton's and White's methods and 1980 Census data from the Urban Transportation Planning Package (UTPP), they calculate excess commuting in the Los Angeles-Long Beach MSA. Excess commuting is approximately 79 percent and the required commute is 2.16 miles using Hamilton's methods, and excess commuting is 65 percent[10] and the required commute is 7.82 minutes using White's methods. They also find that there is little difference between results using time data or distance data. They conclude that it is important to reformulate analytical land-use models because the discrepancy between actual commute and minimum required commute from commonly used urban models is too large.

4) Giuliano and Small

Giuliano and Small (1993) use excess commuting as an objective measure of jobs-housing imbalance and a framework for defining mismatches. Imbalances exist when the housing capacity

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9 The polycentric pattern is an extension of the monocentric pattern that I describe in Section 2. It assumes that there are many centers instead of one center. Employment and residential density are functions of distances to all centers. See Griffith (1981) and Gordon et al. (1986) for details. Zonal pattern is based on the given number of jobs and residences within each zone. Minimum average commuting cost can be calculated by a linear program using commuting costs within each zone and between each pair of zones.

10 Without the correction of large zone bias, excess commute is about 33 percent.

of an area is quite different from the number of workers who work in that area. Mismatches exist when workers in an area cannot live in the houses in that area for various reasons. They calculate the regionwide required commute and excess commute using the assignment model and data from five Southern California counties (Los Angeles, Orange, San Bernadino, Ventura and Riverside). They examine excess commuting times at the level of subareas and individual employment centers. They find that workers who have jobs in Central Los Angeles County have longer required commutes than others in Los Angeles County and workers with jobs in employment center have longer required commute than others. For jobs in centers, excess commuting is 38.2 percent and the required commute is 16.3 minutes; for jobs not in centers, excess commuting is 78 percent and the required commute is 21.4 minutes. One of their several explanations of why the journey-to-work plays only a limited role in residential location choice is that job heterogeneity may prevent two-worker households from finding jobs close together, making it impossible for both workers in a household to live close to their work. Another reason is that a variety of housing and neighborhood characteristics are simply more important than transportation costs.

Model

Following these previously mentioned authors, I initially assume that all workers, residences and work places are homogeneous and workers are indifferent to differences in residential and work locations. I use the assignment model as others did. The difference between my assignment models and the models of White, Hamilton, Small and Song, and Giuliano and Small is that my models, like Cropper and Gordon's, do not have to consider intra-zone commuting, because of my use of micro survey data. In fact, every worker's work place or residence is a zone in itself in micro survey data. The differences in the results using zonal pattern and micro survey data will disappear as the size of the zones becomes smaller in the zonal data and as the survey sample size increases. One advantage of using micro survey data is that there is no bias due to intra-zone commuting. Other advantages of using micro survey data are that micro surveys can be done relatively easily and this type of analysis can be done on a continuous basis, since most zonal data come from the U.S. Census which is only conducted every ten years. Of course, it is also possible to see a short run change in commuting behavior. The disadvantage of micro survey data is that sample size is usually smaller than zonal data, which may yield inaccurate results. In an extreme case, if I have only one worker in my sample, excess commuting will be zero. The relationship between the sample size and excess commuting does not have a solid theoretical explanation in an assignment model. I therefore use a rational assumption: the greater the density of work places and residences, the shorter the required commute. Under this condition, there is only one case in which excess commuting will decrease when sample size increases. This case is when a decrease in the actual commute is greater than a decrease in the required commute. Otherwise, an increase in sample size will increase excess commute until the limit of physical urban structure is reached. The minimum sample size to adequately represent the area presents an empirical question. I examined this issue using different sample sizes. As I expected, a smaller sample size produces smaller excess commuting in general; the variance is larger than one from the larger sample size. However, when a sample size becomes greater than 100 households, excess commuting does not vary significantly. Furthermore, when the sample size approaches 200 households, excess commuting increases slowly.

My models are similar to the models of Cropper and Gordon because both studies use micro data to solve the assignment model. My models are, however, different from Cropper and Gordon's models because the equations in my models are more general in form than those of Cropper and Gordon. This allows me to apply my models to multiple-worker household cases by simply changing constraints, and without recalculating the values in the households' commuting distance matrix. The only disadvantage of my models when compared to those of Cropper and Gordon is that they require more computer memory space.

My study looks at three different cases of minimizing aggregate commuting distance for two-worker households. The first case is designed to allow two workers in a household to simultaneously choose their workplace and residence. This first case yields an optimum solution. Hereafter I will call this case the "optimum model." My "single-worker households" case is similar to the "optimum model" for two-worker households. Both of these cases are similar to White's standard assignment model.

The second case for two-worker households is that the workplaces of both workers in each household are fixed. I assign those households to the residences so that total commuting distance of all workers in the sample is minimized. In this case, the solution is suboptimal since it does not allow for swapping workplaces. I will call the second case the "fixed work model."

The third case is the "segregated model" where I segregate primary workers' jobs from secondary workers' jobs, then minimize total distances for each group. This model can be interpreted as a sum of the two segregated groups' "optimum models."

Finally, I assume the urban structure is regimented into several classes.[11] I segregate the sample into several subgroups by their individual characteristics to see the possible effects of

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11 This is similar to the analysis done by Herbert and Stevens (1960), Hamburg et al. (1965), Wheaton

heterogeneity in measuring excess commuting, and compensate the limitation of a simple assignment model's homogeneous assumption to some degree. In other words, the assignment models are solved using categorized subsamples to correct the unreasonable job and house swapping originated from workers' heterogeneity. I use the "optimum model" and the "fixed work model" for two-worker households for this analysis.

Let i be index for workplaces and j be index for residences[12]. n is a number of residences and m is a number of workplaces. Each household has two workers who work outside their residence. Therefore $2n$ equals m. Each workplace has only one worker. D_{ij} is the distance between work place i and residence j. X_{ij} is 1 if a worker who works at workplace i lives at residence j, otherwise X_{ij} is 0.

The "optimum model" for two-worker households is as follows.

$$\text{Min} \qquad TC = \sum_i \sum_j X_{ij} \cdot D_{ij} \tag{1}$$

$$\text{subject to} \qquad \sum_i X_{ij} = 2 \qquad \forall j \tag{2}$$

$$\sum_j X_{ij} = 1 \qquad \forall i \tag{3}$$

$$X_{ij} = 0, 1 \qquad \forall i, j \tag{4}$$

$$\text{where} \qquad i = 1, 2, 3, \ldots, m \tag{5}$$

$$j = 1, 2, 3, \ldots, n \tag{6}$$

$$2n = m \tag{7}$$

Constraints (2) limit two workers per residence, constraints (3) limit one worker per workplace.

(1974), and Cropper and Gordon (1991).

12 Location of different workplaces and residences can be same.

The "fixed work model" for two-worker households has one additional constraints equation as follows.

$$X_{i-1j} = X_{ij} \quad \forall i = 2k \quad , k = 1, 2, 3, ..., n \qquad (8)$$

The difference between the "optimum model" and the "fixed work model" is whether or not there is a fixed pair of workplaces per each household. In order to fix workplaces for each worker in a two-worker household, and to have those household members move together when necessary, I set the rows of X and D matrices in any order of households. For example, the first and second rows belong to household 1, the third and fourth rows belong to households 2, etc.

The "segregated model" for two-worker households is as follows.

D_{kj} is the distance between primary workers' work place *k* and residence *j*. X_{kj} is 1 if a primary worker who works at workplace *k* lives at residence *j*, otherwise X_{kj} is 0. D_{pj} is the distance between secondary workers' work place *p* and residence *j*. X_{pj} is 1 if a secondary worker who works at workplace *p* lives at residence *j*, otherwise X_{pj} is 0.

$$\text{Min} \quad TC = Min \sum_k \sum_j X_{kj} \cdot D_{kj} + Min \sum_p \sum_j X_{pj} \cdot D_{pj} \quad (9)$$

subject to

$$\sum_k X_{kj} = 1 \quad \forall j \qquad (10)$$

$$\sum_j X_{kj} = 1 \quad \forall k \qquad (11)$$

$$\sum_p X_{pj} = 1 \quad \forall j \qquad (12)$$

$$\sum_j X_{pj} = 1 \quad \forall p \qquad (13)$$

$$X_{kj} = 0, 1 \quad \forall k, j \qquad (14)$$

$$X_{pj} = 0, 1 \quad \forall p, j \qquad (15)$$

where $k=1,2,3,....,r$ (16)

$p=1,2,3,....,t$ (17)

$j=1,2,3,....,n$ (18)

$n=r=t$ (19)

The single-worker households case is as follows.

$$\text{Min} \quad TC = \sum_i \sum_j X_{ij} \cdot D_{ij} \quad (20)$$

$$\text{subject to} \quad \sum_i X_{ij} = 1 \quad \forall j \quad (21)$$

$$\sum_j X_{ij} = 1 \quad \forall i \quad (22)$$

$$X_{ij} = 0, 1 \quad \forall i,j \quad (23)$$

where $i=1,2,3,....,m$ (24)

$j=1,2,3,....,n$ (25)

$n=m$ (26)

This model always yields an optimal solution similar to the "optimum model" for two-worker households.

Finally, subgroup categories for heterogeneity analysis are the combinations of following characteristics:

1. Single-worker households	vs	Two-worker households
2. Own residence	vs	Rent residence
3. Skilled or professional job	vs	Unskilled or common job
4. Children under 6 years old	vs	No children under 6 years old
5. White race	vs	Non-white race

6. Less than $35,000 household income vs More than $35,000 household income

Data

Individual location data come from the Transit Panel Study Survey[13] conducted by the Institute of Transportation Studies, University of California, Irvine. I use the fifth-wave data set which was collected in 1991. These data contain commuting trip information including reported commuting distances and demographic data such as sex, age, race, household income, personal income and occupation. Home and work zip codes for two-worker households are used as location identifiers.

A distance matrix $[D_{ij}]$ was constructed with the road network between "traffic analysis zones (AZ)." These AZs and the road network data were created by the Southern California Association of Government (SCAG). The road network data are based on 1990 travel data and 1980 AZ map is used. There are 1555 AZs in the study area. The study area covers five counties in Southern California: Los Angeles, Orange, San Bernadino, Ventura and Riverside. Excluding 28 AZs which have very low population density, the remaining 1527 AZs contain 9,552 square miles and a population of approximately 14,000,000 people.

I converted zip codes in my sample data to AZs. On average, each zip code[14] contains two AZs. If I had used only one set of AZs to represent a set of zip codes, I would have no way to check biased results due to data conversion. I, therefore, picked three sets of AZ network data which correspond to zip codes in my sample.[15] Possible data conversion biases were

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13 This survey project is funded by University of California Transportation Center. There are six waves of data sets. The first-wave data set was used in Brownstone and Golob's (1992) study.

14 1991 National Five-Digit Zip Code & Post Office Directory by U.S. Postal Service and 1990 MapInfo are used.

15 Zip code and AZ matching is done by visually using the same scale maps for both.

examined by using different sets of data to test the sensitivity[16] of the models used in this paper. In my sample, which is an employer-based sample,[17] there are 333 two-worker households and 449 single-worker households. I ensured that my sample represents the population in the study area reasonably well by comparing it with the March 1991 Current Population Survey (CPS) of the U.S. Bureau of the Census. Even though residence locations seem to be distributed randomly, most work places are located at employment centers defined by Giuliano and Small (1992). My results should be interpreted with this data limitation in mind. From this sample, I randomly selected three sets of 150 two-worker households and 200 single-worker households.[18] Data from these three sets of households are also used to test the sensitivity of my models. In each of these sets the gender ratio is roughly one to one. Primary worker is defined as a worker who has higher personal income than the other worker in a household. There are a total of 25 subgroups for single-worker households and 18 subgroups for two-worker households in my sample. I only tested subgroups which have more than 20 households.[19]

Results

The average actual commuting distance from the network (AZ network) data is 15.3 miles for the primary worker, 12.1 miles for the secondary worker in two-worker households and an average of 13.7 miles for both workers. It is 15.5 miles for single-worker households. Results

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16 The sensitivity tests are done in two different ways. One is done with different AZ data sets and the other is done with different sub sample sets. In both cases, I have robust results. The difference between the largest and the smallest excess commute is only 8 percent for all different data sets; most of the time it is about 2 percent.

17 Details of sampling procedures are documented in Uhlaner and Kim's (1992) paper "Designing and implementing a panel study of commuter behavior: lessons for future research."

18 The sample sizes are selected based on the computer memory capacity (12 mega bites).

19 Because of the sample size, some of the results may not be accurate. The changes in actual commute by group, however, tell us that the difference in excess commute is not just a result of small sample bias. To eliminate this sample size problem, the author is currently planning to use larger sets of data from SCAG and the California Department of Transportation (Caltrans).

show that the excess commuting of two-worker households is about 41.4 percent from the "optimum model" in the Los Angeles area and about 21.9 percent from the "fixed work model." The excess commuting of single-worker households is about 38 percent (see Table 1). I find that, with a fixed pair of workplace constraints, the average required commute of two-worker households increases by 33.3 percent.

Then, I separately compute the required commute for primary workers and secondary workers. From this "segregated model", the excess commuting of primary workers is 35.5 percent and that of secondary workers is 42.1 percent. Average excess commuting for both primary and secondary workers is 38.4 percent. There is a 14 percent decrease in excess commuting for primary workers, a 2 percent increase for secondary workers and a 7 percent decrease for the average of both from the result of the "optimum model."

I also use time to calculate the "optimum model" and "fixed model" for two-worker households. The results are that excess commuting from the "optimum model" is 38.1 percent, and excess commuting from the "fixed work model" is 20.6 percent. The actual commute is 25.6 minutes (see Table 3). This shows that there is not much difference in using time or distances when measuring excess commuting as Small and Song (1992) did.[20] Using the "segregated model," in two-worker households, primary workers commute longer and have less excess commuting than secondary workers. Single-worker households commute longer and have more excess commuting than two-worker households with constraints. Single-worker households, however, have less excess commuting than two-worker households without constraints. I find that the inability of two-worker households to freely swap workplaces raises the required

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[20] Excess commuting measured by time is about 96 percent of one measured by distance from Small and Song's estimates, and about 93 percent from my estimates.

commute in the Los Angeles Metropolitan area. I also find that minimizing aggregate commuting costs is an important factor in explaining actual commuting behavior, particularly for two-worker households with constraints.

If I assume that there are an equal number of people for each of the above five cases in the study area, then actual commute will be 14.6 miles, required commute will be 9.2 miles, and excess commuting will be about 36.8 percent.

I compared my results to Cropper and Gordon's results in Table 4, since both of us use micro data and compute for home owners and renters. Since Cropper and Gordon do not separate single-worker households and two-worker households, I use the closest models to compare with. From the upper half of Table 4, excess commuting is approximately 57 percent for home owners and 64 percent for renters in Baltimore; and is 32.6 percent for home owners and 33.2 percent for single-worker households in the Los Angeles area.

The lower half of Table 4 shows Cropper and Gordon's results which include secondary workers' commuting distances and constraints on households' utility in their model. It also shows my results using the "fixed work model" for two-worker households. Excess commuting is approximately 50.6 percent for home owners and 59 percent for renters in Baltimore; and is 21.5 percent for home owners and 19.6 percent for two-worker households in the Los Angeles area. There is a 15 percent increase in the required commute in Baltimore when Cropper and Gordon consider secondary workers and constraints on households' utility in the models. My results show that actual commuting distances are shorter and excess commutes are larger for renters from single-worker households. However, excess commutes for home owners are larger than those for renters from two-worker households. Larger excess commuting for renters is also shown in the Baltimore area.

I also compared my results to those of Small and Song in Table 5, since both of our studies use data from the Los Angeles area. Since Small and Song's sample included both single-worker and two-worker households, and they computed the optimum solution using their zonal pattern, it would be most appropriate to use the averages of my results from the "optimum model" for two-worker households and from single-worker households for comparison. However, these results are not directly comparable because I only use the sample in which most jobs are at employment centers. Therefore I use Giuliano and Small's results that separated the sample by "jobs in centers" and "jobs not in centers" (see Table 6). In this table, I also use a time instead of a distance measure. My results and those of Giuliano and Small's are almost exactly the same: excess commuting in centers is approximately 38 percent and actual commute is 26 minutes.[21] These results partially tell us that there have been no changes between 1980 to 1990 in commuting distances of workers who work at employment centers in this area (Small and Song used 1980 Census data and I used 1990 AZ data).

Segregating my sample in further detail not only by household type but also by housing tenure, occupation, presence of young children, race and household income, I find that there are big differences in the actual commute and in the excess commute for each group. Actual commutes vary from approximately 11 miles to 17 miles and excess commutes vary from approximately 4 percent to 43 percent (see Table 7(a), 7(b) and 7(c)). Sample sizes of the subgroups reveal mainly occupational differences. The results are shown in Table 7(a) and Table

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[21] 1990 Census Survey Tape File 3. shows that the mean travel time to work in Los Angeles county is 26 minutes, Orange County 25 minutes, Riverside County 28 minutes, San Bernadino County 27 minutes and Ventura County 25 minutes. Small and Song's actual commute in Los Angeles County is 22 minutes.

7(b). The results show that unskilled workers' excess commuting varies from 16.5 percent for single-worker household homeowners to 38 percent for two-worker household homeowners (optimum model). Skilled workers' excess commuting varies from 21.5 percent for two-worker household (fixed work model) renters to 40.8 percent for single-worker household homeowners. Unskilled workers' actual commutes vary from 11 miles for two-worker household renters to 16 miles for single-worker homeowners. Table 7(b) shows that the fixed work constraints affect more home owners than renters. There was a 31 percent and 15 percent increase in required commutes for home owners and for renters, respectively, when I added fixed work constraints. I also find that there are differences in excess commuting and actual commuting partly by race[22] and by the presence of young children (see Table 7(c)). These subgroup excess commutes are less, and predict actual commute better, than excess commuting calculated with homogeneous group assumptions using an assignment model.[23]

Conclusions

The new results from my study are that in two-worker households, primary workers commute longer and have less excess commuting than secondary workers[24]. Single-worker households commute longer and have more excess commuting than two-worker households with constraints. Single-worker households, however, have less excess commuting than two-worker households without constraints. I find that the inability of two-worker households to freely swap workplaces significantly reduces excess commuting in the Los Angeles Metropolitan area.

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22 Hamburg et al.'s (1965) results show that whites have longer actual commutes and larger excess commute.

23 This may tell us that there exist mismatches of workers, workplaces and residences. I also think that sample size bias contributed to partially reduce excess commuting.

24 This may be an indication that contrary to Hamilton's argument commuting is relatively cheap for the secondary worker.

I confirm some of the previous findings about actual commuting and excess commuting. Those are 1) Cropper and Gordon's finding: home owners have smaller excess commutes than renters (only for single-worker housheolds case), 2) Small and Song's finding: distance and time are interchangeable when we measure commuting costs, 3) Giuliano and Small's finding: excess commuting and actual commuting time of workers who have jobs in the employment centers in the Los Angeles area are 38 percent and 26 minutes respectively.

The subgroup analysis indicates that occupation plays an important role in commuting behavior. Moreover, it implies that commuting cost minimization using an assignment model is still an important factor in explaining actual commuting behavior and location choice among commuters.

Table 1. Two-Worker and Single-Worker Households' Excess Commute

	Actual (mi.)	Required (mi.)	Excess (%)
Two-Worker Households			
"Optimum Model"	13.69	8.01	41.41
"Fixed Work Model"	13.69	10.68	21.92
Single-Worker Households	15.50	9.59	38.11

Table 2. Primary and Secondary Workers' Excess Commute

	Actual (mi.)	Required (mi.)	Excess (%)
"Segregated Model"			
Primary Workers	15.29	9.86	35.51
Secondary Workers	12.08	7.00	42.08
Average for Both Workers	13.69	8.43	38.41

Table 3. Two-Worker Households' Excess Commute by Time

	Actual (min.)	Required (min.)	Excess (%)
Two-Worker Households			
"Optimum Model"	25.56	15.83	38.07
"Fixed Work Model"	25.56	20.29	20.62

Table 4. Excess Commute using Micro Data

	Actual (mi.)	Required (mi.)	Excess (%)
Cropper and Gordon - Baltimore (1977)*			
Home Owners	10.2	4.39	56.96
Renters	10.2	3.65	64.22
Average	10.2	4.02	60.59
My Estimates - L.A. (1991)* (Single-Worker Households)			
Home Owners	16.10	10.86	32.55
Renters	15.05	10.06	33.16
Weighted Average	15.89	10.70	32.66
Cropper and Gordon - Baltimore			
Home Owners**	10.2	5.04	50.59
Renters**	10.2	4.17	59.12
Average	10.2	4.61	54.8
My Estimates - L.A. (Two-Worker Households)			
Home Owners***	14.71	11.55	21.48
Renters***	12.93	10.39	19.64
Weighted Average	14.37	11.38	20.81

* The year of data collection.

** Secondary workers' commuting distances and constraints on households' utility are included.

*** Results from the "fixed work model."

Table 5. Excess Commute in the Los Angeles Area by Distance

	Actual (mi.)	Required (mi.)	Excess (%)
Small and Song -- Whole Area			
Aggregated Zones with Bias Correction	10.03	3.36	66.3
Disaggregated Zones	10.03	3.10	69.1
My Estimates -- Jobs in Centers			
Single-Worker Households	15.50	9.59	38.11
Two-Worker Households ("Optimum Model")	13.39	8.01	41.41
Average	14.45	8.80	39.10

Table 6. Excess Commute in the Los Angeles Area by Time

	Actual (min.)	Required (min.)	Excess (%)
Giuliano and Small -- Aggregated Data			
Jobs in Centers	26.38	16.31	38.2
Jobs not in Centers	21.38	4.71	78.0
My Estimates -- Micro Data (Two-Worker Households "Optimum Model")			
Jobs in Centers	25.56	15.83	38.07

Table 7(a). Excess Commute by Subgroups
(The following subgroups have no children under 6 years old, are white, and all have an annual household income of more than $35,000)

	Actual (mi.)	Required (mi.)	Excess (%)
Single-Worker Households, Home Owner			
Skilled Worker	16.01	9.48	40.77
Unskilled Worker	15.87	13.25	16.52
Weighted Average	15.97	10.66	33.25
Single-Worker Households, Renter			
Skilled Worker	15.14	9.24	38.97
Unskilled Worker	14.92	11.28	24.40
Weighted Average	15.05	10.06	33.16

Table 7(b). Excess Commute by Subgroups
(The following subgroups have no children under 6 years old, are white, and all have an annual household income of more than $35,000)

	Actual (mi.)	Required (mi.)	Excess (%)
Two-Worker Households*, Home Owner			
(Optimum Model)			
Skilled Worker	15.24	8.62	43.42
Unskilled Worker	14.01	8.70	37.91
Weighted Average	14.82	8.65	41.63
Two-Worker Households, Renter			
(Optimum Model)			
Skilled Worker	14.60	9.61	34.19
Unskilled Worker	11.26	8.52	24.31
Weighted Average	12.93	9.07	29.85
Two-Worker Households, Home Owner			
(Fixed Work Model)			
Skilled Worker	15.24	11.45	24.82
Unskilled Worker	14.01	11.20	20.04
Weighted Average	14.82	11.36	23.35
Two-Worker Households, Renter			
(Fixed Work Model)			
Skilled Worker	14.60	11.47	21.45
Unskilled Worker	11.26	9.30	17.40
Weighted Average	12.93	10.39	19.64

* Two-worker households' occupation and race are based on survey respondents' characteristics.

Table 7(c). Excess Commute by Subgroups
(The following subgroups are home owners, skilled workers, and have an annual household income of more than $35,000)

	Actual (mi.)	Required (mi.)	Excess (%)
Single-worker Households, Have Children under 6 Years Old, White			
	17.00	12.20	28.25
Two-Worker Households, No Children under 6 Years Old, Non-White (Optimal Model)			
	13.62	10.96	19.52
Two-Worker Households, (Fixed Work Model)			
	13.62	13.03	4.34

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