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Comment

"Wasteful" Commuting: A Resolution

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A debate over the empirical underpinnings of urban economic models is emerging under the unlikely rubric of "wasteful commuting." Hamilton (1982) shows that a commonly used monocentric model, in which employment and population densities decline exponentially from a center, greatly underpredicts actual commuting distances in typical U.S. and Japanese metropolitan areas. He concludes that the monocentric model is fundamentally flawed. This conclusion is challenged by White (1988*b*), who examines the cost-minimizing assignment of households to residential locations, taking density patterns as they are and measuring cost by travel time. White finds that for a sample of U.S. metropolitan areas, only 11 percent of actual commuting cost is in excess of the cost-minimizing amount, rather than the 87 percent found by Hamilton. Hamilton (1989) and Cropper and Gordon (1991), using variations of White's technique, obtain results intermediate between these extremes.

The diversity of definitions and data sources creates unnecessary confusion. Not only is there doubt about the empirical magnitude of the phenomenon, but it is unclear what model of urban structure is being tested. Do these measurements test the monocentric model, as stated by the authors, or the broader class of models in which residential location minimizes aggregate commuting costs? Rejecting the monocentric model might not surprise many people, although doing

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so by a factor of eight is pretty dramatic: rejecting cost minimization has more drastic implications.

This note clarifies the conceptual issues and provides new and more reliable empirical evidence. We first distinguish among different theoretical notions of a minimum required commute by defining it for an arbitrary pattern of land use. We then measure it, using 1980 data from Los Angeles, for two such patterns that correspond, respectively, to the calculations described by Hamilton (1982) and White (1988*b*). We find that with the pattern corresponding to White's calculation, the required commute is only about one-third of the actual average commute; under the monocentric pattern (Hamilton's calculation), it is smaller still. Put differently, a large portion of commuting is excess ("wasteful" in Hamilton's terminology) in the sense that it cannot be explained by applying standard assumptions of urban economic models to either pattern.

These results confirm the general order of magnitude of Hamilton's original calculations for the monocentric case. However, our calculation using the technique developed by White indicates far more excess commuting than she found for Los Angeles or any other area. By comparing estimates using small and large zones, we show that much of the discrepancy between our results and White's is due to aggregation bias resulting from the large zones in her data set. We also find, in contrast to a conjecture by Hamilton (1989), that the required commute (as a fraction of actual) is about the same whether commuting cost is measured by time or by distance.

These findings have two consequences. First, the standard monocentric model is overwhelmingly rejected by observations of commuting distances and times, as Hamilton originally showed. Second, these same observations reject *any* model that allocates workers to residences so as to minimize aggregate commuting cost. This latter finding, which is new and more important, implies an urgent need to reformulate the analytical land-use models most commonly used in urban economic theory.

I. Types of Required Commute

Urban form is described by geographical distributions of work and residential sites, which we call a *pattern* of sites. When workers select their jobs and residences from these distributions, they presumably pay some attention to commuting cost. The lowest possible average commuting cost consistent with the pattern of sites is the *average required commute* for that pattern. Any commuting cost beyond that amount represents *excess commuting*. (Hamilton called it wasteful commuting, but we prefer a normatively neutral term.) Cost may be proxied by time or distance.

Models of housing or job selection in which utility is deterministic (containing no geographically defined stochastic element) typically predict that aggregate commuting costs are minimized for whatever pattern of sites prevails. That is, they predict that the average actual commute equals the average required commute.[1] In particular, the standard monocentric models of urban economics (e.g., Mills 1972; Straszheim 1984; White 1988*a*) predict zero excess commuting, as do extensions to account for ring or point subcenters (e.g., Papageorgiou and Casetti 1971; White 1976; Wieand 1987).

The debate over "wasteful" (excess) commuting has confused two patterns of urban form: (1) that predicted by a monocentric model with dispersed employment and (2) that defined by the actual distributions of workplace and residence sites. Hamilton (1982) defines wasteful commuting using the second pattern but calculates it using the first. White (1988*b*) both defines and calculates it using the second but discusses it as though she were testing monocentricity.

In order to clarify this essential point, we proceed by carefully defining the required commute for each of three patterns of urban form.

Monocentric Pattern

In this pattern, employment and population are distributed in a circularly symmetric manner with density functions $f(r)$ and $g(r)$, where r is the distance from the single urban center. Theoretical derivations of such functions have mostly yielded special cases such as fully segregated jobs-housing patterns or fully integrated regions with zero commuting distance (Mills 1972; Straszheim 1984). But White (1988*a*) shows that much more general functions are possible, and it is common to characterize decentralization empirically using declining exponential functions for both f and g (Mills 1972, chap. 3).[2]

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[1] In such an urban model, each household minimizes its housing plus commuting cost, with housing quality held constant. In the resulting equilibrium, aggregate commuting cost is minimized given the distributions of housing and job locations. This can be demonstrated using the linear programming formulation of Herbert and Stevens (1960), as amended by Wheaton (1974) and interpreted by Senior and Wilson (1974). Briefly, if aggregate transportation costs could be reduced by some reallocation of households to residential locations, say among a set H of such locations, then some household could outbid the current resident for one or more locations within H; thus the current allocation could not be an equilibrium.

[2] See Mills (1969) and Muth (1969) for theoretical derivations of the negative exponential density function for employment and population, respectively.

If we assume that jobs are more centralized than residences,[3] average commuting cost is minimized given such a pattern if every worker commutes inward along a radius from housing location r^h to employment location r^e, for a commute distance $r^h - r^e$. There is no outward or circumferential commuting (White 1988*a*).

Hamilton (1982) calculates the required monocentric commute distance for 14 U.S. cities and 21 Japanese cities in the late 1970s. He does this by estimating exponentially declining density functions f and g; the average required commute turns out to be just the difference between the average values of r^h and r^e for all workers, using these density functions. For the U.S. cities, Hamilton finds that the required commute distance averages 1.12 miles, only 13 percent of the actual.

Polycentric Pattern

One possible explanation for Hamilton's result is that employment and housing are distributed in a pattern that has many centers, not just one (White 1988*b*). A natural extension of the monocentric pattern just described is one in which employment and residential densities are functions of distances $r_1, \ldots, r_n$ to n such centers. Such density functions have been proposed and estimated empirically by Griffith (1981) and Gordon, Richardson, and Wong (1986). Any such estimated set of density functions can serve as the basis for calculating a minimum required commute. We are attempting such a calculation in other work.

Zonal Pattern

A third pattern is obtained by simply aggregating jobs and residences by area, using some division of the region into small zones. Given an empirical description of commuting costs within each zone and between each pair of zones, a linear programming calculation can be used to compute the flows that minimize average commuting cost.

White (1988*b*) carries out this calculation for 25 U.S. cities using travel time as a proxy for cost and using municipalities as zones. The central business district (CBD) of the primary central city is also distinguished as a separate zone of employment location. Travel time for each of the relevant flows is the average reported by commuters making that journey in the journey-to-work census data for 1980.

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[3] In this paper, a residence means the home location of a worker. If two workers live in the same house, that house is counted as two residential locations, and both workers are assumed able to find jobs for which the house is optimally located. Failure of this assumption is one possible explanation for the existence of excess commuting.

White's estimates of the required commute for this pattern average 20.0 minutes, which is 89 percent of the average actual commute. (For Los Angeles, she estimates the required commute to be 19.6 minutes, 83 percent of actual.) It is on the basis of these numbers that she claims that "wasteful" commuting is small.

II. Evidence from Los Angeles

In this section, we carry out the monocentric and zonal calculations on a data set far more detailed than that used by either Hamilton or White. We also carry out the zonal calculation using aggregated zones that approximate the size used by White, in order to see how much upward bias may have resulted from the degree of aggregation she was forced to use.

Our study area consists of the Los Angeles–Long Beach metropolitan statistical area, which is Los Angeles County. Our zones are "traffic analysis zones," as defined by the Southern California Association of Governments (SCAG); for simplicity, we delete 65 very low density outlying zones, leaving 706 zones (covering 1,289 square miles) for analysis. Traffic analysis zones, like census tracts, are aggregates of census blocks, but they need not include a fixed population. We analyze the 3.04 million workers who both live and work in the study area. The journey-to-work data from the 1980 census provide information on intra- and interzonal travel flows; SCAG has provided the corresponding travel times and distances, based on a peak-period representation of the road network created as part of the Urban Transportation Planning Package.

Monocentric Pattern

Column 1 of table 1 shows the results of estimating two exponential density functions, one for employment and one for worker residences. Each estimate applies ordinary least squares to the log-linear form of the density function; the independent variables are road distance from the CBD and a constant. The table shows the estimated gradient and the coefficient of determination (R^2) for each equation. Taking these estimated functions to represent smoothly varying distributions, as in Hamilton's original calculations, we find that the average job is 14.77 miles from the center and the average worker lives 16.93 miles from the center.[4] The difference, 2.16 miles, is the aver-

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[4] This procedure is the same as that in Hamilton (1982), eqq. (3) and (4), except we use resident workers instead of population to measure residential density.

TABLE 1

RESULTS FOR MONOCENTRIC PATTERNS

	BASED ON DISTANCE (1)	BASED ON TIME (2)
	Los Angeles Estimates (Network Distance and Time)	
Density gradient, per mile or per minute:		
Employment	−.07665	−.05143
	(.00525)	(.00336)
Resident workers	−.03725	−.02404
	(.00413)	(.00270)
Coefficient of determination (R^2):		
Employment	.23	.25
Resident workers	.10	.10
Average location, in miles or minutes from CBD:		
Employment	14.77	30.23
Resident workers	16.93	33.82
Required commute (miles or minutes)	2.16	3.59
Actual commute (miles or minutes)	10.03	22.06
Excess commute (percentage of actual)	78.5	83.7
	Hamilton (1982): 14 Cities (Straight-Line Distance)	
Required commute	1.12	
Actual commute	8.7	
Excess commute	87.1	

NOTE.—Standard errors are in parentheses.

age required commute for the monocentric model; it accounts for just over one-fifth of the average actual commute of 10 miles. Redoing the density estimations using travel time instead of distance yields a similar proportion, as shown in column 2.

These results verify Hamilton's finding that the standard monocentric model with dispersed employment greatly underpredicts commuting distances. To the extent that Hamilton's paper is intended to show that this model is hopeless for analyzing commuting distances, there can be no doubt that he is right.

Zonal Pattern

In order to minimize aggregate commuting cost subject to the actual location of jobs and residences, we use the linear programming calculation proposed by White (1988*b*) and also used by Hamilton (1989). Let n_{ij} be the number of commuters from zone i to zone j, and let c_{ij} be the corresponding network commuting cost (either time or distance). The travel flows satisfy

$$\sum_j n_{ij} = N_i, \quad \sum_i n_{ij} = E_j, \quad n_{ij} \geq 0, \text{ for every } i, j, \tag{1}$$

where N_i is the number of commuters living in zone i and E_j is the number working in zone j. The actual average commuting cost is

$$\bar{c} = \frac{1}{N} \sum_i \sum_j c_{ij} n_{ij}, \tag{2}$$

where $N \equiv \Sigma_i N_i \equiv \Sigma_j E_j$ is the number of commuters in the study area. The linear program finds flows n^*_{ij} to replace n_{ij} in this expression so as to minimize the average commuting cost subject to constraints (1). The required commute is then $\bar{c}^* = (1/N)\Sigma_i \Sigma_j c_{ij} n^*_{ij}$; it is the lowest average commuting cost attainable by allowing workers to swap houses or jobs.

Table 2 presents the results at various levels of zonal aggregation. The row labeled "aggregated zones" attempts to replicate White's (1988*b*) results for Los Angeles County (shown in the first row) by aggregating our analysis zones into a set of much larger areas, roughly comparable in size and number to the municipalities that White used.[5] The calculation based on travel time verifies White's finding that the excess commute is fairly small, although our figure is still nearly twice as large as hers.

The next two rows show what happens when aggregation bias is reduced. The estimate labeled "disaggregated zones" should be the most accurate: it simply performs the entire minimization of equation (2) using our fully disaggregated system of 706 analysis zones. The estimate labeled "aggregated zones with bias correction" is based on the aggregated zonal system but adjusts for the fact (noted by Hamilton [1989]) that aggregation biases the calculation against finding excess commuting. The reason is that the aggregated calculation uses actual commute distance within each aggregated zone as the minimum distance for such a commute, implicitly assuming that observed within-zone commutes are cost-minimizing. If they are not, the re-

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[5] To do this, we first aggregate into one zone the seven analysis zones that constitute the CBD. We then aggregate all other analysis zones into the 15 areas defined by SCAG as regional statistical areas (RSAs). We then combine into a single zone those RSAs outside the CBD that are mainly within the city of Los Angeles; its total employment matches that of the city (excluding CBD) to within 4.2 percent, and its average within-zone commute (based on networks) is 19.1 minutes, compared to 22.5 minutes (reported value) in the census journey-to-work report used by White (U.S. Census Bureau 1984, sec. 2, pp. 457, 505). Finally, we divide some of the remaining RSAs (starting with those with the largest number of within-area commuting trips) until we have 31 zones in total, representing 30 municipalities plus the CBD, the same number as in White's calculation for Los Angeles.

TABLE 2

Results for Zonal Patterns

	Number of Zones	Percentage of Trips Intrazone	Average Commute Distance			Average Commute Time		
			Actual (Miles)	Required (Miles)	Excess (%)	Actual (Minutes)	Required (Minutes)	Excess (%)
				A				
White (1988*b*) (Los Angeles)	31					23.6	19.6	16.9
Our estimates (Los Angeles):								
Aggregated zones	31	42.8	10.03	6.32	37.0	22.06	14.86	32.6
Aggregated zones with bias correction	31	42.8	10.03	3.36	66.3	22.06	7.82	64.5
Disaggregated zones	706	7.8	10.03	3.10	69.1	22.06	7.59	65.6
				B				
White (1988*b*) (Boston)	17					22.2	18.7	15.8
Hamilton (1989) (Boston)	18	30	9.11	4.82	47.1			
Our estimates (Los Angeles):								
RSAs	35	29.6	10.03	4.85	51.6	22.06	12.15	44.9
RSAs with bias correction	35	29.6	10.03	3.45	65.6	22.06	8.08	63.4

quired commute can be greatly overestimated because a high proportion of the optimal flows (90.7 percent in our aggregated calculation) are intrazone. Because we have the disaggregated zones, we can calculate directly the cost-minimizing within-zone commute for each aggregated zone, using the same linear programming algorithm restricted to just these trips; we then replace the intrazone distances or times with these (smaller) numbers[6] and redo the overall optimization.

Both of the reduced-bias calculations yield estimates of excess commuting time about twice our large-zone estimate and nearly four times that calculated by White. This confirms that excess commuting is greatly understated by the aggregated calculations. The disaggregated calculation provides the most definitive estimate yet of what excess commuting really is: approximately two-thirds of the actual commute.[7]

Panel B of table 2 presents calculations using a different zonal aggregation, intended to roughly approximate Hamilton's (1989) zonal calculation for Boston.[8] The aggregated calculation produces excess commuting (as a fraction of actual) close to Hamilton's estimate, even though it pertains to a different city; the bias correction raises this fraction substantially, to about the same as our fully disaggregated calculation.

Hamilton conjectures that his use of distance, as opposed to White's use of time, explains the large difference between their estimates of excess commuting in Boston. Our Los Angeles results do not support this conjecture. Although we do find a difference between the distance-based and time-based estimates, it is not nearly large enough to explain the discrepancy. Furthermore, the difference largely disappears when aggregation bias is removed.[9]

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[6] The biggest difference occurs for the zone that approximately represents the city of Los Angeles less its CBD. The actual and optimized within-zone commutes for this zone are 8.4 miles and 2.4 miles; based on time, they are 19.1 minutes and 6.1 minutes.

[7] We also calculated excess commuting for a larger area consisting of 1,135 traffic analysis zones that cover the urbanized portion of the five-county Los Angeles–Anaheim-Riverside consolidated metropolitan statistical area; the result is 66 percent using distance, 63 percent using time.

[8] We do not attempt to match Hamilton's number of municipalities because Boston is smaller than Los Angeles. Instead we match the proportion of trips that are intrazone, which is more directly related to the aggregation bias. We do this by aggregating analysis zones to RSAs and then dividing the RSAs (starting with those with the most intrazone trips) until the desired match is achieved.

[9] These results may reflect the fact that time and distance have a more exact and a more nearly proportional relationship in our data than they do in Hamilton's. We discovered this by running the same regression as Hamilton (1989) relating travel time t to distance d, based in our case on 4,984 selected observations from the journey-to-work

III. Conclusions

The measurement and interpretation of excess ("wasteful") commuting depend on the baseline model of density patterns from which the minimum required commute is calculated. White (1988*b*) measures an entirely different quantity than Hamilton (1982). White's calculation is a test of cost minimization, whereas Hamilton's is a test of cost minimization with monocentricity. Hence it is no surprise that White finds less excess commuting than Hamilton.

Even so, White's finding of very little excess commuting is due mainly to the bias from using large zones. Our Los Angeles data yield relatively little excess commuting (33 percent of actual commuting time) when aggregated, like hers, to large jurisdictions, but far more (66 percent) when smaller zones are used. The reason is that most of the excess commuting takes place within jurisdictions of the size available to White. Once aggregation bias is removed, the excess commute relative to actual density patterns is about two-thirds of the actual commute.

If excess commuting is measured relative to the predictions of the monocentric model with exponentially declining employment and residential density functions, as in Hamilton (1982), it is greater still: about four-fifths of the actual commute in the Los Angeles metropolitan area. This verifies Hamilton's original argument that the monocentric model is very poor at explaining commuting.

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matrix. (We are grateful to Michelle White for suggesting this calculation.) The result, with standard errors in parentheses, is

$$\underset{(.17)}{t = 7.31} + \underset{(.02)}{1.64d} - \underset{(.00030)}{.00255d^2}, \quad R^2 = .97.$$

Hamilton's result (p. 1500, n. 1) is $t = 16.97 + 1.54d - .0166d^2$, $R^2 = .43$.

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