Chapter 36

URBAN AREAS WITH DECENTRALIZED EMPLOYMENT: THEORY AND EMPIRICAL WORK

MICHELLE J. WHITE*

University of Michigan

Contents

* I am grateful for comments from Charles Becker, Paul Cheshire, Ken Small, John Yinger and Stephen Ross. I am also grateful for research support from the Economic Policy Research Unit, Copenhagen Business School, Copenhagen, Denmark, where I was a visitor while writing this chapter.

Handbook of Regional and Urban Economics. Edited by E.S. Mills and P. Cheshire

Abstract

This chapter discusses theoretical and applied research in urban economics on decentralized cities, i.e., cities in which employment is not restricted to the central business district. The first section discusses informally the incentives that firms face to suburbanize. The next section summarizes the theoretical literature on decentralized cities, including both models which solve for the optimal spatial pattern of employment and models in which the spatial pattern of employment is exogenously determined. In other sections, I discuss rent and wage gradients in decentralized cities and review the empirical literature testing whether, or not, wage gradients exist in urban areas. A section covers the question of whether people follow jobs or jobs follow people to the suburbs and the last section discusses the "wasteful" commuting controversy.

Keywords: Suburbanization, polycentric (urban) models, monocentric (urban) models, wage gradients, decentralized cities, wasteful commuting

1. Introduction

Although urban economists often assume that employment in urban areas is concentrated at the central business district (CBD), in actuality urban employment has been suburbanizing for a long time. The best evidence available over a long timespan comes from the two-point density gradients for employment and population first estimated by Mills (1972, Chap. 3) and updated by Macauley (1985). Two-point population density gradients are calculated by solving for the exponential function that fits the two observations of population density and average distance from the CBD for the central city and the suburbs. Two-point employment density gradients are calculated by the same procedure using data for the employment density. The resulting density gradient measures the percentage decrease in population or employment density per mile of distance from the CBD, where a smaller density gradient indicates greater suburbanization. For 18 metropolitan areas in the US, the average density gradients in 1948 were 0.58 for population, compared to 0.68 for manufacturing employment, 0.88 for retailing employment, 0.97 for service employment and 1.00 for employment in wholesaling. For the same metropolitan areas in 1977/80, the figures were 0.24 for population, 0.32 for manufacturing, 0.30 for retailing, 0.38 for services and 0.37 for wholesaling. The decline over the period was 59% for population, 53% for manufacturing employment, 66% for retailing employment, 61% for service employment and 63% for wholesaling. Thus, while population was, and still is, more suburbanized than employment, employment (except in manufacturing) has been suburbanizing faster than population. Overall, the levels of suburbanization of employment and population are converging, with manufacturing and retailing employment the closest to convergence.[1]

In this chapter, I discuss theoretical and applied research in urban economics on decentralized cities, i.e., those in which employment is not restricted to the CBD. In Section 2, I discuss informally the incentives that firms face to stay at the CBD versus to move to the suburbs. In Section 3, I summarize the theoretical literature on decentralized cities. Separate subsections deal with (a) models that derive the optimal spatial location pattern for employment, and (b) models that assume an exogenously determined spatial location pattern for employment and explore its effects on other aspects of resource allocation in urban areas. In Section 4, I discuss the basic model of rent and wage gradients in a decentralized city. In Section 5, empirical research testing for whether, or not, wage gradients exist in urban areas is reviewed. Section 6 discusses the empirical literature on whether population suburbanization follows employment suburbanization or vice versa, i.e., do jobs follow people or people follow jobs? Section 7 discusses and appraises the controversy concerning whether, or not, more commuting occurs in decentralized cities than in urban economic models predict.

A few notes on terminology. Incommuting refers to radial commuting that is toward the CBD in the morning, while outcommuting refers to radial commuting that is away from the CBD in the morning. Circumferential commuting refers to any commuting journey that begins and ends on different rays from the CBD. The original urban models in which all jobs are located at the CBD are often referred to as monocentric models, but this term has also been applied to models in which some jobs are located outside the CBD, as long as jobs remain more centralized than housing and all commuting is incommuting. Nonmonotonic or polycentric models are then those in which employment is decentralized and at least some outcommuting and/or circumferential commuting occurs. In this chapter I refer to all models in which there is non-CBD employment as decentralized urban models.

[1] Mills also finds similar results for a smaller sample of US metropolitan areas over a longer time period.

2. Why do firms suburbanize?

The original urban models assumed that all jobs were located at the CBD. This assumption made for tractability—an important consideration. It was also appealing since, historically, CBDs tended to develop at a transportation node, usually a port. Firms located at the CBD minimized the cost of goods transportation since doing so was valuable because workers could walk but goods could not. A CBD location also allowed firms access to power and utilities that originally were only available near the CBD.

Now consider the basic factors that cause employment in cities to move out of the CBD. Suppose a hypothetical firm is located at the CBD but is considering moving to a more suburban location. Firms that consider moving out of the CBD face tradeoffs since some costs rise while others fall. As long as the firm's move causes its workers' commuting distances to fall, then workers save on commuting costs and the firm can capture some of this savings in the form of lower wages. Second, the price of land declines at a decreasing rate with the distance from the CBD. Therefore, firms that move out of the CBD benefit from lower land costs which allow them to trade capital for land, i.e., they occupy low, horizontal buildings instead of tall, vertical buildings. Third, goods transportation costs may decline since the firm avoids the traffic congestion of the CBD. Fourth, loss of agglomeration economies at the CBD may cause the firms' productivity to fall. Finally, other costs faced by firms may also change when they move to the suburbs. Costs related to information technology—which are changing rapidly—are an example. Consider these factors individually.

First, firms have an incentive to suburbanize because they can pay lower wages, which workers are willing to accept because they commute less. Since wages are the largest single cost for many firms, this is likely to be an important consideration. However, the extent to which suburbanizing allows firms to pay lower wages depends on labor demand and supply. Suppose all firms are initially located at the CBD and workers commute along straight lines connecting their homes and their workplaces.[2] An arbitrary firm X moves from the CBD to a new location five miles south of the CBD, shown as point A in Fig. 1. All other firms still remain at the CBD. At its new location, suppose firm X hires only workers who live further out than the firm in the same direction away from the CBD, i.e., along the line segment Aa. Therefore, all the firm's workers save 10 miles of commuting per day by shifting from CBD jobs to jobs at firm X. If

[2] A more realistic model would take the specifics of the transportation network into account, so that workers would commute from their homes to their workplaces along existing road or rail networks. This modification would not change the general results discussed here.

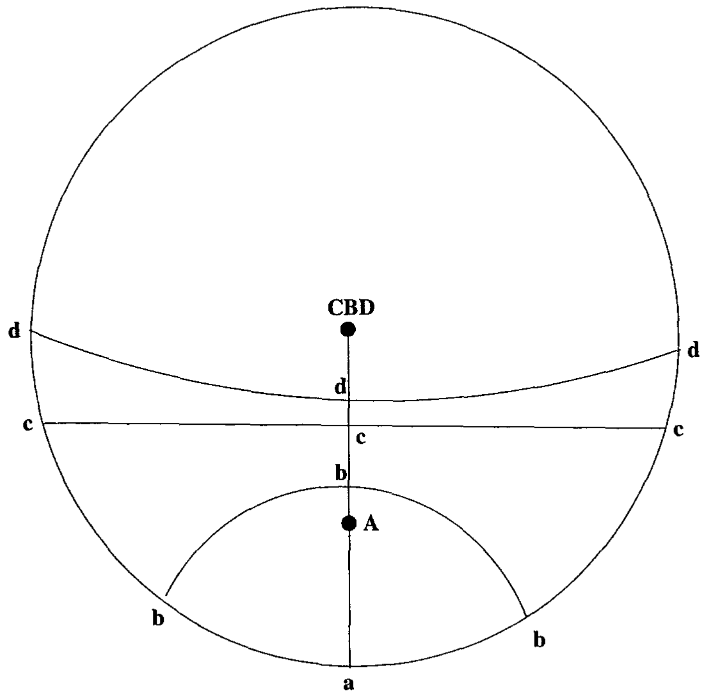

Fig. 1. Commuting regions when a firm moves from the CBD to point A.

the daily wage at the CBD is w^* and the cost of commuting per mile is t, then workers will be willing to work at A for a daily wage of $w^* - 10t$ and the firm can save $10t$ per worker per day by moving. However, only workers who live along line segment Aa will be willing to work at A for this wage; all others prefer to continue working at the CBD. Now suppose firm X wishes to hire more workers than are willing to work for it at the wage $w^* - 10t$. If it raises its wage above $w^* - 10t$, then its commuting region will expand from the line segment Aa in Fig. 1 to a larger region such as that enclosed by the line bbb. At the higher wage, some workers commute to firm X from homes that are not on the same ray from the CBD as firm X (i.e., they commute circumferentially) and a few workers outcommute.[3] As firm X continues to raise its wage, its commuting region continues to get larger. Now suppose the suburban firm pays the same wage w^* as CBD firms. Then its commuting region will be the area below the

[3] Commuting is still along straight lines connecting workers' residences and their workplaces, but the commuting routes are no longer radial. The outer boundary of the urban area also bulges outward in the area closest to the suburban firm, but this effect is not shown in Fig. 1.

horizontal line *ccc*, which bisects the line segment connecting the CBD and point A. If firm X pays a higher wage than w^*, then its commuting region will be the area below an upward curving line such as *ddd*. However, even if firm X pays higher than the CBD wage w^*, its commuting region will be smaller than the CBD firms and restricted to workers who live in the southern region of the urban area. Thus, firms that move out of the CBD can pay lower wages only if their commuting regions shrink from covering the entire urban area to covering just a region around their suburban sites. If suburban firms are relatively large and have relatively high demand for labor, then they may have to pay wages as high or higher than CBD firms.[4]

Now suppose an additional firm Y moves out of the CBD. As long as there are no agglomeration economies outside of the CBD, firm Y has an incentive to locate north rather than south of the CBD. This is because if firm Y locates north of the CBD, then it will gain from the same wage reduction (discussed above) in connection with firm X. But if firm Y locates south of the CBD, then it must compete with firm X for labor and both firms will have to pay higher wages. Thus, as firms suburbanize, they have an incentive to locate in different directions around the CBD and, in particular, to avoid suburban regions that already have high concentrations of firms.

Now consider the firms' gain from suburbanizing due to the lower cost of suburban land. The extent to which the firms' land costs fall in the suburbs also depends on the workers' commuting patterns. Suppose we change the previous model by assuming that all workers commute via a fixed rail network, that consists of radial lines leading out from the CBD in different directions. Firm X again plans to move out of the CBD. Only sites located near public transit stations would be plausible suburban locations for firm X, since workers must be able to walk to work from the station. But this means that the supply of suburban sites suitable for use by firm X is limited to sites close to transit stations and the price of these sites is high because their accessibility makes them valuable for high density residential use. These factors reduce firm X's gain from suburbanizing. In addition, the gain to firm X from reduced wages at suburban locations is also small in this case, because only workers who live along the same radial transit line as firm X's suburban location have shorter commuting journeys when they commute to firm X rather than to the CBD. (If workers must travel to the CBD along one transit route and then outcommute to firm X along another transit route, then they will be unwilling to work at firm X if it pays less than the wage

[4] See Wieand (1987) and White (1988b) for discussion.

at the CBD.) Thus, firms gain little due to lower land costs or wages in the suburbs when workers commute by fixed rail transit systems.

But now suppose that workers begin to commute by car and the road network is more dense than the fixed rail network. As a result, firm X is less restricted in its choice of suburban sites because workers who commute by car can reach sites that are inaccessible by public transit. The resulting increase in the supply of suburban sites suitable for non-residential use lowers the firms' cost of land, which increases their gain from suburbanizing. In addition, the region from which workers are willing to commute to suburban firms at any given wage also increases and, therefore, wage costs in the suburbs fall. These trends are self-reinforcing. As more workers commute by car, suburban firms' labor supply increases, which makes it more attractive for firms to suburbanize. But as more firms suburbanize, an increasing proportion of suburban jobs becomes inaccessible to workers unless they commute by car, so that more workers shift from commuting by public transit to commuting by car.

Let us turn now to transportation costs other than commuting costs. While the monocentric model assumes that firms export their output from the urban area via a transportation node located at the CBD, in fact the transportation node is now more likely to be an airport or a circumferential freeway surrounding the urban area, both of which are located in the suburbs. Thus, firms that move to the suburbs are likely to gain because they avoid the cost of transporting goods to and from the congested CBD. However, some types of firms may be better off remaining at the CBD. Suppose firms sell to customers who are located in the urban area rather than outside and/or they buy from suppliers who are located in the urban area. Also assume that these customers or suppliers are uniformly distributed around the CBD. Then transportation costs are minimized if the firm stays at the CBD. These firms tend to lose customers or suppliers if they move to the suburbs.

Now consider agglomeration economies and their effect on the employment location pattern in urban areas. These are difficult to measure and there is little agreement as to how they work. One assumption that has been used widely in the literature to represent agglomeration economies is that each firm in an urban area transacts with every other firm in the urban area and the cost of these transactions depends on the distance between pairs of firms.[5] This assumption obviously implies that there is a gain from urban area's firms being concentrated at a CBD, since the centralized location pattern reduces the distance between firms. While this model is useful as a starting point, it has some counterintuitive implications.

[5] See Capozza (1976), O'Hara (1977), and Ogawa and Fujita (1980).

Suppose we compare two urban areas having a different number of firms. Then the smaller urban area will have an advantage over the larger because total transactions costs among a smaller number of firms are lower. Thus, larger urban areas are predicted to have lower rather than higher agglomeration economies. But this goes against the notion that higher agglomeration economies are responsible for the existence of larger cities. An alternative approach, used by Henderson (1977) and Straszheim (1984) in the urban context and also commonly used in other fields, assumes that production is characterized by external increasing returns as the number of firms or the number of jobs in the city rises.[6] This gives larger cities an advantage over smaller ones which offsets their disadvantage of higher aggregate commuting costs. However, this approach has the drawback that the level of agglomeration economies is the same all over the urban area, regardless of where firms locate. It might be useful to combine these two approaches, since the latter represents the gain from more firms being present in an urban area, while the former represents the cost of capturing these gains through interactions among firms.

What about the issue of how agglomeration economies vary within an urban area? A variation of the external increasing returns approach, used by Wieand (1987), makes agglomeration economies depend on the number of firms located at particular employment sites. Thus, firms located at the CBD benefit from a high level of agglomeration economies, but firms located at a suburban employment subcenter that is smaller than the CBD benefit from a lower level of agglomeration economies. A more general version of this approach is used by Fujita and Ogawa (1982), who allow the level of agglomeration economies to vary continuously over space, depending on the density level of firms at each location. These approaches are useful in exploring what type of firm location pattern is efficient in a decentralized urban area.

It should also be noted that agglomeration economies may differ for different types of firms. For example, computer firms benefit from locating in the "Silicon Valley" area of San Francisco/San Jose because these firms can hire skilled computer engineers without having to bear the costs of their training. But the computer firms themselves are stretched along at least a 20-mile region, which suggests that they do not need to locate close together to benefit from agglomeration economies. In other industries, firms may benefit from being close together because individual firms can closely observe and react to the behavior of competitors. Agglomeration economies also occur across types of firms, for example, job

[6] Firms' production function is multiplied by a shift variable N^{α}, where N equals the number of firms or jobs in an urban area and $\alpha > 1$.

Table 1

Profit variations for two firms locating at two alternative sites

		Firm 2	
		A	B
Firm 1	A	5, 2	1, 2
	B	1, 1	3, 3

sites are more attractive to workers when there are shops and restaurants nearby. These agglomeration economies seem to require proximate location. In general, there has been little research on how agglomeration economies operate within urban areas and how they affect firm location patterns.

An important implication of agglomeration economies, when applied to issues of location within an urban area, is that they may cause development to occur at inefficient locations. Consider a simple model in which there are two alternative sites for a subcenter in a particular urban area or portion of an urban area. The two sites, denoted A and B, are both adjacent to freeway intersections. There are two firms, denoted 1 and 2. While either or both firms may locate at either site, agglomeration economies make both firms better off if they locate at the same site. Table 1 shows both firms' profits from locating at each site. Firm 1 makes a profit of 5 at site A and a profit of 3 at site B if both firms locate at the same site, but firm 1 makes a profit of only 1 if the two firms locate at different sites. Firm 2 makes a profit of 3 at site B and a profit of 2 at site A if both firms locate at the same site, but it makes a profit of only 1 if the two firms locate at different sites. If firm 1 moves first and chooses site A, then firm 2 will also choose site A and the outcome will be economically efficient since the sum of both firms' profits (7) is maximized. However, if firm 2 moves first and chooses site B, then firm 1 will also locate at site B. In this case, the outcome will be economically inefficient since the sum of both firms' profits (6) is lower than if they both located at site A. The game has multiple equilibria, of which only one is economically efficient. If the game were played many times in different regions by different firms, then we would expect subcenters to develop at a mixture of efficient sites like A and inefficient sites like B. Because the model has multiple equilibria, it is difficult to predict in advance where suburban subcenters will develop.[7]

[7] Obviously firm 1 can bribe firm 2 to choose site A even if firm 2 moves first. But firm 1 may not be present when firm 2 makes its move and, once firm 2 has chosen site B, the costs of moving may exceed the gains from both firms being located at site A rather than site B.

Finally, a much-discussed issue affecting firms' incentives to suburbanize is the rapid development of information/communications technology, including use of computers, the internet, high-volume telephone/fax services, picture phones and video conferencing. Many of these new technologies are likely to affect the relative advantage of the CBD versus suburban locations. One example is that when mainframe computers became available, many banks moved their data-processing operations out of the the CBD to suburban sites, because use of computers made it possible to supervise these operations without locating them at their headquarters. But, with high volume telephone lines and personal computers, this type of work can now be done by workers at home, workers living in small towns, or workers located overseas. Video conferencing also substitutes for face-to-face contact and, therefore, reduces the accessibility advantage of being at the CBD. In general, the implications of these new technologies for firm location patterns have not been carefully thought out.

To summarize, firms' incentives to suburbanize are quite complicated and at least some parts of the story are not well understood. Different types of firms are likely to be affected differently depending on the factor intensities of their production processes. Thus, manufacturing firms benefit strongly from suburban locations, because they can spread out their assembly lines horizontally and accommodate their workforces with large surface parking lots. In contrast, specialized service firms and/or headquarters operations may prefer to stay at the CBD where they can observe their competitors and have face-to-face meetings with suppliers or customers located in all directions.

3. Theoretical models of decentralized cities

Suppose suburban locations are more profitable for at least some urban firms than CBD locations. In this case, what overall spatial pattern of employment will develop?; is it economically efficient?; and what are its effects on other aspects of resource allocation in urban areas? There are actually two versions of these questions. In one, the main issue is how agglomeration economies and commuting costs affect the optimal and actual spatial patterns of employment and residences in urban areas. The city is assumed to be built from scratch, so there is no presumption that a CBD will exist. In the second, some firms are assumed to move to exogenously determined suburban locations, but the change is incremental and the historic CBD remains. The main focus is on examining the effects of firm suburbanization on residential location and other aspects of resource allocation in cities. I refer to these two literatures as models of endogenously versus exogenously determined employment location. They are discussed separately below.

3.1. Models with endogenously determined employment location

Consider the optimal spatial location pattern for firms in an urban model with no history. The earliest approach to this problem was by Mills (1972: chap. 5). Mills analyzed a model of an urban area in which identical firms produce a good using a fixed amount of land, and housing is also produced using a fixed amount of land. Identical workers commute to the firms at a constant cost per unit of distance traveled. Output produced by firms is transported to the CBD, where it is exported, and the cost of goods transport is also constant per unit of distance. The optimal allocation of land to production and housing is the allocation which minimizes the sum of goods transport costs plus workers' commuting costs. Mills (1972) shows that there are two efficient solutions: the "segregated" solution in which land around the CBD is devoted exclusively to production while land surrounding the production area is devoted exclusively to housing, and the "integrated" solution in which production and housing are mixed at all urban locations. The segregated solution holds when the cost of goods transport is high relative to the cost of commuting, since locating production in the CBD minimizes the cost of transporting goods. The integrated solution holds when the cost of commuting is high relative to the cost of goods transport, since commuting is eliminated when all workers work at home. Mills also shows that in this model, the market equilibrium solution is economically efficient.[8]

I documented above the fact that employment has tended to suburbanize more rapidly than population in US cities over the past several decades. This suggests that urban areas in reality have moved from approximating the "segregated" solution to approximating the "integrated" solution in Mills' model. This suggests that the cost of goods transportation must have fallen relative to the cost of commuting—a testable hypothesis.

The paper by Fujita and Ogawa (1982) uses assumptions similar to those of Mills (1972), but adds agglomeration economies to the model. Fujita and Ogawa analyze a straight-line city. Identical firms are again assumed to produce goods using fixed amounts of land and labor and to transport the goods to the CBD for export. The level of agglomeration economies depends on the density of firms at particular locations and may be constant all over the urban area or may differ at different locations. Workers each occupy a constant amount of land and the

[8] See Braid (1988) for a dynamic version of Mills' model.

costs of commuting and transporting goods to the export node are both constant per unit of distance. Fujita and Ogawa (1982) solve numerically for the equilibrium outcome, assuming that firms enter the city until profits fall to zero. Because the costs of commuting and of goods transport trade off against variable agglomeration economies, a number of different land use patterns may occur. If agglomeration economies are high at the CBD and decline with distance from the CBD, then firms concentrate at a single CBD surrounded on both sides by housing. If agglomeration economies are constant at all locations and the cost of commuting is high relative to the cost of goods transportation, then a dispersed land use pattern occurs in which all workers work at home. Another possible outcome is an "incompletely mixed urban configuration", in which the center of the urban area is occupied by mixed firms and housing, surrounded on both sides by regions occupied exclusively by firms, while the outer regions of the urban area are occupied exclusively by residences. Workers occupying the central region work at home, while workers occupying the exclusively residential regions commute to firms located in the exclusively business regions. Finally, other possible outcomes include two employment subcenters without a CBD and a CBD plus two subcenters. In all of the solutions, the left and right sides of the urban area are symmetric.[9]

In a model with agglomeration economies, equilibrium outcomes are likely to be inefficient since individual firms ignore the effects of their behavior on the overall level of agglomeration economies and therefore on other firms' costs. Henderson and Slade (1993) extend Fujita and Ogawa's model by making it into a game between two developers. This introduces another set of reasons why the equilibrium outcome may differ from the optimal outcome.[10] In their model, one of the developers develops the lefthand side of the city and the other develops the righthand side. Each builds a development that contains a residential neighborhood and a business district (land uses are not allowed to mix). When the city is small, it is efficient for both developers to locate their business districts at the inner edge of their respective territories, so that they merge and the combined city has a CBD. As the city increases in size, the costs of goods transportation and commuting rise faster than agglomeration economies, so that eventually it becomes efficient for the business district to split in two.

[9] Fujita and Ogawa (1982) do not investigate whether, or not, the equilibrium land use outcome differs from the optimal outcome. But in a later paper, Ogawa and Fujita (1989) discuss the relationship between equilibrium versus optimum land allocations in a similar model.

[10] See also Tauchen and Witte (1984), who analyze equilibrium versus optimum land use allocations in a model of a CBD with agglomeration economies. They show that an inefficient number of firms enters the urban area in the equilibrium outcome. Helsley and Sullivan (1991) investigate the possibility that different employment subcenters could have different production technologies or could have external effects.

At that point, each developer locates its business district at approximately the center of its territory, with residential neighborhoods on both sides, so that there are two equal sized business districts—one on each side of the city. However, Henderson and Slade (1993) show that when there are two developers, they have an incentive to split the CBD prematurely, i.e., the split occurs at a lower than optimum population level. The reason is that each developer takes account of the agglomeration economies realized by firms in its half of the city, but ignores the agglomeration economies realized by firms in the other half. Thus Henderson and Slade's model provides an example of how strategic considerations, combined with agglomeration economies, may cause the spatial layout of the urban area to be inefficient. In a sequential version of their model, they provide another example of how strategic considerations may distort the spatial layout of the city. In that model, the first developer to enter makes its development inefficiently large in order to capture first mover advantages; while the second developer then makes its development inefficiently small. The result is that the two sides of the city are asymmetric, which is inefficient.

A recent model by Anas and Kim (1994) also examines the equilibrium spatial location pattern in a discrete version of a straight-line city. Anas and Kim do not assume that there are external agglomeration economies, but they make an assumption that urban firms sell their output directly to the households who live in the urban area. These shopping interactions between firms and households are similar to the transactions between pairs of firms that formed the basis of early models of urban agglomeration economies. Workers (or their families) thus take shopping trips to buy from firms, as well as making commuting trips. Because goods produced at different locations are assumed to be spatially differentiated, workers demand them all, although they have the highest demand for goods produced by nearby firms. The model also incorporates traffic congestion and endogenous congestion tolls. The results is a dispersed land use pattern: both jobs and housing are present in all regions of the urban area, although the density level of both is highest at the center because of greater accessibility. The dispersed location pattern occurs for a combination of two reasons: first, congestion and congestion tolls make it worthwhile to reduce travel costs by mixing firms and households and, second, when firms transact with households, they have an additional incentive to mix with households so as to reduce the length of shopping trips.

These models have given us a much improved understanding of how agglomeration economies, congestion, the costs of commuting and of goods transportation, and strategic considerations interact to determine the spatial layout of employment in urban areas. The basic factors that cause firms to benefit from congregating at a central point—the CBD—are external agglomeration economies and the cost of goods transportation being high relative to the cost of commuting. As cities increase in size, the CBD becomes congested, which raises both commuting costs and goods transportation costs. Eventually these factors overwhelm the gains from agglomeration economies and make it more efficient for some or all firms to suburbanize. When firms suburbanize, the models just discussed suggest that it is economically efficient for suburban employment to develop at more than one location because this pattern reduces workers' commuting costs. Assuming that at least some firms suburbanize, two basic location patterns are possible: firms may disperse to isolated suburban locations, or they may congregate in one or more discrete suburban subcenters on each side of the CBD. (If models of one-dimensional cities were translated into two dimensions, then an additional location pattern would be one or more ring subcenters.) Factors that tend to cause the dispersed suburban location pattern include high commuting costs, lack of agglomeration economies once firms leave the CBD, firms' demand for land and labor being very price elastic, firms being fairly pollution-free so that households are willing to live near them, and firms selling their output directly to households, which necessitates shopping trips. An additional consideration that emerges from the literature is that firms may not actually locate in the most economically efficient land use pattern, both because individual firms have an incentive to ignore their effects on the level of agglomeration economies and because of strategic considerations.

3.2. Models with exogenously determined employment locations

In these models, the set of possible employment location within the urban area is exogenously determined. Wages at suburban employment locations may be either exogenously or endogenously determined. The models focus on how workers decide where to live and work and the resulting spatial patterns of land rents, population densities and commuting regions. In one sense, models with exogenously determined employment locations are special cases of the previous set of models in which the employment location pattern is endogenously determined and optimal versus actual employment patterns can be compared. However, the difficulty of solving models with endogenous employment locations usually means that these models focus on the tradeoff between agglomeration economies and transportation costs and they assume away most other issues. Models with exogenous employment patterns often focus instead on modeling other issues in the context of a decentralized urban area, such as the spatial location pattern when there are multiple household types, the effect of gasoline taxes on employment suburbanization or the effect of zoning regulations that limit development.

The earliest model of a decentralized urban area was that of White (1976). In her model, firms may locate either at the CBD or a constant number of miles away from the CBD in any direction. All firms are initially located at the CBD, but some move to the suburbs because they export their output from the urban area and the cost of doing so is lower in the suburbs. As discussed above, firms that suburbanize have an incentive to spread themselves out in all directions around the CBD, so that the suburban employment locations become a ring subcenter. Workers are assumed to commute along straight lines between their homes and their workplaces. If the wage at the ring equals the CBD wage minus twice the workers' cost of commuting between the ring and the CBD, then all commuting in the model is radial incommuting. All workers located between the CBD and the ring commute to the CBD, while workers located further out than the ring are indifferent between working at the CBD or the ring. But now suppose the wage at the ring rises above this level. Then there will be three commuting regions: a circular region around the CBD composed of workers who commute to the CBD, a doughnut-shaped region around it but inside the ring subcenter composed of suburban workers who outcommute to jobs at the ring, and an outer doughnut-shaped region beyond the ring composed of workers who incommute to jobs at the ring. As long as firms are spread evenly around the ring subcenter, no circumferential commuting occurs. In this situation, the land rent gradient and population density both fall with distance from the CBD, then rise to a local maximum at the subcenter and then fall again beyond the subcenter. Because White's (1976) model did not incorporate agglomeration economies, the optimal location for the ring subcenter was entirely outside the CBD's commuting region.

Sullivan (1986) also considered an urban area with a CBD and a ring subcenter. But rather than making the wage pattern exogenous, he assumed that firms at both locations have downward sloping labor demand functions. This allows wages to be determined endogenously by the condition that labor supply must equal labor demand at each employment location. In Sullivan's model, firms located at the CBD are assumed to be subject to agglomeration economies, while firms at the subcenter are not. His model, which is solved numerically, shows how wages at the two employment locations are linked via the land market. For example, suppose demand for labor at the CBD shifts outward. Then the wage at the CBD rises and some workers who live between the CBD and the subcenter shift from working at the subcenter to working at the CBD. This causes the CBD's commuting region to become larger and the subcenter's commuting region to become smaller. The backward shift in labor supply to the subcenter causes the subcenter's wage to rise. Thus, wages at the two employment locations tend to move together.[11]

Ross and Yinger (1995) consider an urban model in which there are firms both at the CBD and at either a point or a ring subcenter. Like Sullivan (1986), they assume that firms have downward sloping demands for labor, so that wages at each employment location are determined endogenously. Ross and Yinger solve for a closed form solution to their model and they focus on examining comparative statics results and whether, or not, these results are the same in a decentralized urban model as in a model with only CBD employment. Although their model has no agglomeration economies, their comparative statics results are similar to those found by Sullivan (1986), i.e., exogenous shocks cause wages at both employment locations to move in the same direction and a change in wages at one employment location causes wages to change in the same direction at the other. An increase in the exogenous utility level of urban residents is shown unambiguously to raise wages at both employment locations. But because the direct effect of the increase in utility and the indirect effect of the increase in utility via wages have opposing effects on land rents, the direction of the effect on land rents cannot be signed.[12]

Wieand (1987) analyzes a similar model with a CBD and a point subcenter, but he assumes that both employment locations have agglomeration economies and he allows the location of the subcenter to vary. He assumes that the level of agglomeration economies at each subcenter depends on the number of jobs at that subcenter, so that firms at the CBD are more productive as long as the CBD contains more firms. Given that establishing a subcenter is worthwhile, Wieand (1987) explores the question of the optimal subcenter location. He finds that if the subcenter will contain only a small number of jobs, then it is optimal for it to locate near the outer boundary of the urban area; while if the subcenter will be large, then it is preferable for it to locate near the CBD. This is because the further the subcenter is located from the CBD, the fewer the number of workers willing to commute to it for any given wage. If the subcenter contains few firms, then the small commuting region is not a drawback and the best location for it is near the urban periphery where land costs are low. But if the subcenter contains many firms, then it is better for it to remain near the CBD where it can attract more workers for any given wage. Wieand (1987) also points out that if the total population of the urban area is fixed, the establishment of a suburban subcenter

[11] Sullivan (1986) also considers the effects of land use controls in the CBD or the residential areas.

[12] Yinger (1992) explores a similar model in which workers commute along a network of radial and circular roads, rather than along straight lines between their homes and workplaces.

causes problems for the CBD since its loss of jobs causes loss of agglomeration economies and the nearby population density also falls.[13]

In White (1990), a simulation model is used to explore public policy concerns about long commuting trips by analyzing the extent to which policy measures that encourage more firms to suburbanize would reduce commuting. An urban model that originally has two suburban point subcenters is assumed to add two additional point subcenters located further out and, for comparison, an urban area that originally has a ring subcenter is assumed to add an additional one located further out. The model has no agglomeration economies, but congestion raises commuting costs near the CBD and the subcenters. The model is designed to allow any number and any spatial configuration of subcenters to be simulated. The main result of the simulation is that adding two additional suburban point subcenters or an additional suburban ring subcenter reduces workers' average commuting journey length by about 15–50%—more for the ring subcenters than the point subcenters.[14]

In Hotchkiss and White (1993), a simulation model is used to explore an urban area where there are multiple household types—two-worker households, "traditional" households with one male worker, and female-headed households. Wages at each of the employment locations are exogenously determined (male workers are assumed to earn more than female workers). The purpose of the model is to explore the spatial implications of such social trends as the high divorce rate, the increasing rate of labor force participation by married women, and the increasing dispersion of income within urban areas that these two trends cause. In general, two-worker households outbid other households for sites that are most accessible to their job locations, traditional households occupy the most suburban sites and female-headed households occupy the intermediate distances. Because high income households occupy central rather than suburban locations, the spatial allocation more closely resembles a European rather than an American city.[15] An increase in the cost of commuting causes a reduction in the number of female-headed households in the urban area, and a decrease in wages for female workers causes traditional households to replace two-worker households in the urban area. Thus, the model suggests that seemingly unrelated policy

[13] The Wieand (1987) model implies a testable hypothesis that firm or subcenter size should vary inversely with distance from the CBD. To the author's knowledge, this hypothesis has not been tested empirically.

[14] Even four subcenters is probably too few to realistically represent a large urban area. See Giuliano and Small (1991) for a discussion of how to identify employment subcenters. They find 32 subcenters in the Los Angeles metropolitan area.

[15] These results suggests that to get the typical spatial location pattern of a large US city, explicit disamenities of living near the center of the city would need to be introduced into the model.

changes can have important spatial implications. Hotchkiss and White (1993) also introduce a random component to wages, that allows the model to represent worker/household heterogeneity. The effect of introducing even a small random component is that the commuting region boundaries become very fuzzy. All household types occupy sites all over the urban area (instead of occupying sites only in their particular commuting regions) and the number of different household types represented in the urban area increases. Randomness in income greatly dampens the responsiveness of the model to exogenous shocks.

Finally, the paper by Sivitanidou and Wheaton (1992) also explores a model in which there are two employment locations, but firms compete with households for land. One subcenter is allowed to have a cost advantage in production over the other and relative wages at the two subcenters are determined endogenously. The goal of the model is to determine to what extent differences between the two subcenters are capitalized as differences in commercial land rents versus differences in wages. The authors first show that if the two subcenters have the same costs, then the urban area is symmetric and both subcenters have identical size, wages and commercial land rents. Also the residential land rent patterns around them are identical. Now suppose subcenter A has a cost advantage over subcenter B. Then, firms in subcenter A expand by offering higher wages. This leads to an expansion in subcenter A's commuting area, which bids up residential land rents around subcenter A. Because firms compete with households for land, the expansion of subcenter A also raises commercial land rents. Thus, the cost differentials between subcenters lead to both higher wages and higher commercial and residential land rents at and around the subcenter that has the cost advantage. Now suppose again that the two subcenters have equal cost, but zoning imposes a binding restriction on the land area of subcenter A. Then commercial land rents at subcenter A rise above those at subcenter B, but subcenter A's wages fall below those of subcenter B. Because of the zoning restriction, commercial land rent at subcenter A is higher than (rather than equal to) land rent for residential land just adjacent to subcenter A. Residential land rent around subcenter A is also lower than that around subcenter B, which means that workers are willing to work for lower wages at subcenter A because their land costs are lower. Thus, zoning restrictions on one subcenter lead to that subcenter having higher rents, but lower wages. The authors conclude that differences in commercial rents across subcenters within an urban area may not accurately measure differences in the subcenters' productivity.

Models in which the spatial pattern of employment is exogenously determined obviously cannot be used to analyze what spatial location pattern is efficient, but they can be used to analyze other implications of decentralized employment in a more realistic setting. Future research, perhaps using numerical techniques, may be able to combine the strengths of both sets of models.

4. Rent and wage gradients in decentralized urban areas

When jobs decentralize, the structure of an urban area becomes much more complicated. To start with, all urban areas—monocentric and decentralized—have rent gradients that relate the price of land to distance from the CBD. Rent offer curves describe how much each household is willing to pay for land at each location, and the market rent gradient is the upper envelope of all households' rent offer curves. In the monocentric city, rent offer curves and the market rent gradient always decline at a decreasing rate with the distance from the CBD.[16] But in the decentralized city, households' rent offer curves may be affected by workers' job locations and this may affect the shape of the market rent gradient. Decentralized cities also have a wage gradient, that relates wages to distance from the CBD for identical jobs. Workers living at particular residential locations have a wage offer curve that indicates the minimum amount they must be paid to be willing to work at any job location. The lower envelope of workers' wage offer curves is the market wage gradient. The characteristics of individual workers' wage offer curves and the market wage gradient, both of which may be affected by where workers live, need to be established. In this section I explore how rent and wage gradients in decentralized cities are determined and how they relate to each other.[17]

Suppose an urban area has an employment pattern consisting of a CBD and suburban firms that are dispersed at isolated locations in all directions around the CBD. Residential distance from the CBD is denoted u and workplace distance from the CBD is denoted v. All workers are assumed to incommute, so that their commuting distance is $u - v$. Wages per day are $w(v)$, the out-of-pocket cost of commuting is m per mile, and the speed of commuting is $1/s$. Since there is no congestion, the cost of commuting a mile in each direction is always $2(sw(v) + m)$. Each household has one worker. Suppose the rent on land per unit is denoted $r(u, v)$, land consumption per household is $l(u, v)$ and hours of leisure consumption are $h(u, v)$. Households' rent offer curves must satisfy the property:

$$r_u(u, v) = \frac{-2(sw(v) + m)}{l(u, v)}, \tag{4.1}$$

[16] See Mills and Hamilton (1989).

[17] The main references for this section are Straszheim (1984) and White (1988a).

and workers' wage offer curves must satisfy the property:

$$w_v(u, v) = \frac{-2(sw(v) + m)}{24 - 2s(u - v) - h(u, v)}, \tag{4.2}$$

where the subscripts denote partial derivatives. Equation (4.1) looks familiar from the analysis of the monocentric city: it says that land rents fall with residential distance at a rate equal to the cost of commuting a mile further from the CBD divided by the households' demand for housing. However, the presence of terms depending on v in Eq. (4.1) suggests that the rent offer curve may be affected by workers' job locations. Equation (4.2) is the wage offer curve. It says that the rate of change in the wage at which workers are willing to work for firms located further from the CBD equals the cost of commuting a mile further per day divided by the number of hours of work, where the latter equals 24 minus time spent commuting ($2s(u - v)$) minus time spent in leisure. The presence of terms in u in the equation suggests that the wage offer curve may be affected by workers' residential locations.

Since the rent offer curve has the same form as in the monocentric city case, individual households' rent offer curves in decentralized cities must always have a negative slope and must always decline at a decreasing rate with distance. Now consider whether and how individual households' rent offer curves vary with job location by differentiating Eq. (4.1) with respect to v. The result is:

$$\frac{\partial r_u}{\partial v} = \frac{-1}{l(u, v)}[2sw_v + r_u l_v]. \tag{4.3}$$

The signs of w_v and r_u are both negative, but the sign of l_v—the change in land consumption when job location becomes more suburbanized but residential location remains constant—is ambiguous. The most likely case is that l_v is positive, because when workers spend less time commuting (job location shifts outward while residential location remains fixed), they save money and are likely to increase consumption of both land and other goods. In this case, the sign of $\partial r_u/\partial v$ must be positive. Then households' rent offer curves become flatter as workers' job locations become more suburbanized. Since the market rent gradient is the upper envelope of households' rent offer curves, this means that the rent gradient in the decentralized city will decline more slowly than the rent gradient in a monocentric city. In addition, households in the decentralized city will tend to segregate into different residential areas depending on their workers' job locations. For example, suppose that jobs are located only at the CBD and a ring subcenter v' miles from the CBD, while residences are located everywhere.

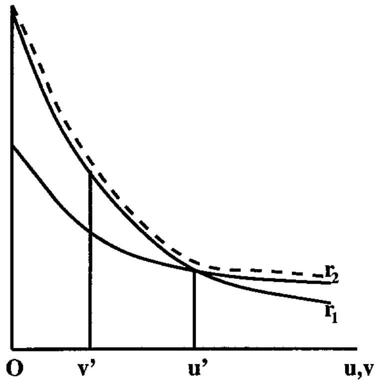

Fig. 2. Rent offer curves of households whose workers work at the CBD and at v', and the market rent gradient.

Figure 2 shows the rent offer curve r_1 of households whose workers work at the CBD, and the rent offer curve r_2 of households whose workers work at v'. The market rent gradient, shown as a dashed line, is the upper envelope of the two rent offer curves. The boundary between the two rent offer curves occurs at u', where $u' > v'$. Households whose workers hold CBD jobs live in the inner residential area between $u = 0$ and u', while households whose workers work at v' live in the outer residential area further out than u'.[18]

If we combine the rent and wage offer curves, Eqs. (4.1) and (4.2), we can determine the relative rate at which the wage offer curve falls with distance from the CBD compared to the rent offer curve, or,

$$\frac{w_v/w}{r_u/r} = \frac{rl}{wn}, \tag{4.4}$$

where $n = 24 - 2s(u - v) - h(u, v)$ denotes hours of work. The rate of decline of the wage offer curve relative to the rent offer curve equals the ratio of the rent on land to total earnings. If the ratio of land rent to earnings is approximately constant, then the wage offer curve—like the rent offer curve—is predicted to decline at a decreasing rate with distance from the CBD. In the US, households spend about 20% of their incomes on land and housing combined and the cost of land is approximately one-quarter of the combined cost. Therefore, $rl/wn \simeq (0.2)(0.25) = 0.05$, suggesting that on average urban wages decline with distance from the CBD at only about 5% of the rate at which urban land

18 Because all workers incommute to their jobs, the rent gradient declines monotonically and does not have a local maximum at v'.

rents decline. This figure is probably higher in Europe. Nonetheless, because the fraction of earnings spent on land rent is low, the wage offer curve is predicted to decline quite slowly with distance from the CBD. Therefore, measuring it empirically turns out to be difficult.

Finally, consider whether and how individual workers' wage offer curves vary with residential location by differentiating Eq. (4.2) with respect to u. The result is

$$\frac{\partial w_v/\partial u}{w_v} = -\frac{n_u}{n}. \tag{4.5}$$

The percentage change in the slope of the wage offer curve when workers move their residential locations a mile further out, but keep their job locations fixed, equals minus the percentage change in hours of work when workers move their residential locations a mile further out. Since w_v is negative, the sign of $\partial w_v/\partial u$ is the same as the sign of n_u. The sign of n_u is ambiguous, but the most likely case is that it is negative, since when workers spend more time commuting (residential location shifts outward while job location remains fixed), they are likely to compensate by reducing both the number of hours of leisure and the hours of work. In this case, $\partial w_v/\partial u$ must be negative and workers' wage offer curves become steeper as their residential locations become more suburbanized. Suppose there are only two residential locations, consisting of rings located at distances u^* and $u^{**} > u^*$, while jobs occur at all locations. Figure 3 shows the wage offer curve w_1 of the group of workers living at u^* and the wage offer curve w_2 of the group of workers living at u^{**}. The market wage gradient, shown as a dashed line, is the lower envelope of the two curves. Workers living at u^* take jobs located between $v = 0$ and v'', while workers living at u^{**} take jobs located further out than $v = v''$. The market wage gradient has a negative slope and becomes steeper with distance from the CBD.[19]

We have shown that the decentralized urban area has a market wage gradient that relates wages to workplace location, in addition to having a market rent gradient that relates the price of land to residential location. The prediction that urban wages vary with distance from the CBD is one of the major testable hypotheses of the urban model. In the model just discussed, only incommuting was assumed to occur and wage gradients were therefore downward sloping.[20] However, as discussed in Section 1, when suburban firms have high labor demand, they must raise wages in order to attract enough workers. This causes

[19] See White (1988a) for further discussion.

[20] Note from Fig. 3 that the theoretical urban model has no prediction for the sign of the second derivative of the market wage gradient, although the wage offer curves have declining slopes.

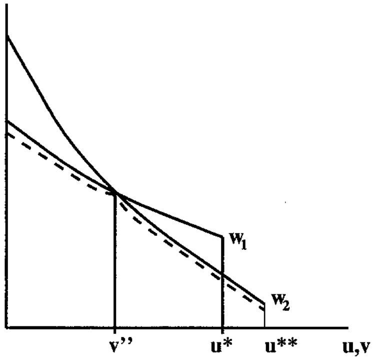

Fig. 3. Wage offer curves of workers who live at u^* and u^{**}, and the market wage gradient.

wage gradients to become less negative, or even to turn positive, and it also causes outcommuting to occur. Flat or positive wage gradients are most likely to occur in a particular subregion of an urban area, since they are caused by firms at a large subcenter offering high wages in order to expand their commuting regions.

5. Empirical evidence concerning urban wage gradients

One of the major empirical hypotheses generated by the urban model with decentralized employment is that wages for otherwise identical jobs vary with distance from the CBD. In general, the urban model predicts that wages decline with distance from the CBD, but wages could be constant, or even rise, with distance if there is concentrated suburban employment. Rising wage gradients are likely to occur only in a particular direction from the CBD.

The theory predicts that researchers attempting to measure urban wage gradients will confront several problems. First, as discussed above, finding evidence of wage gradients is likely to be difficult since wages decline at a much slower rate than rent as distance from the CBD increases. Second, finding a sample of jobs and workers that are identical except for distance from the CBD is difficult. But if observations of nonidentical jobs or workers are used to estimate wage gradients, then the results may reflect location-specific job differences or location-specific differences among workers rather than a true wage gradient. For example, police jobs are likely to be less dangerous in the suburbs than the central city because suburban crime rates are lower. This factor would tend to cause police wages in the central city to rise relative to police wages in the suburbs. An estimated wage gradient for police wages that did not control for crime rates would therefore decline too steeply. As another example, suburban teachers tend to be more experienced than central city teachers and, as a result, their wages are higher. An estimated wage gradient for teachers that did not control for experience might therefore be flat or even positively sloped, when the true wage gradient would have a negative slope. Third, suppose a metropolitan area has a negative wage gradient in one direction away from the CBD, but a positive wage gradient in another direction—perhaps reflecting the presence of a large subcenter in that direction. Then, if a single wage gradient were estimated for the entire metropolitan area, it would probably result in no gradient being found.

An additional problem with the empirical literature on urban wage gradients is that it combines tests of two distinct hypotheses under the same name. One literature tests for a relationship between wages and distance from the CBD. The other literature tests for a relationship between commuting journey length and wages. The latter relationship results from the hypothesis that workers are willing to commute further in return for higher wages, just as they are willing to commute further in return for lower housing prices. Evidence supporting the commuting journey/wage relationship has sometimes been interpreted as providing support for the hypothesis that wages decline with distance from the CBD (see, for example, Madden, 1985), but this conclusion is not always correct. For example, suppose wages rise rather than fall with distance from the CBD in a particular city. Then suppose a set of workers who outcommute to their jobs is used to test the commuting journey/wage relationship. These workers would have the predicted positive relationship between commuting journey length and wages, even though wages rise rather than fall with distance from the CBD. An alternate possibility is that wages fall and then rise with distance from the CBD in a particular city. In this case, an empirical test of the commuting journey/wage relationship using randomly selected workers might fail to find a relationship at all. In what follows, I survey only papers that directly test the wage/distance from the CBD relationship.[21]

Because of lack of availability of data on workplace location, many of the papers that test for the existence of wage gradients have used data that the authors collected specifically for the purpose. An early effort was that of Rees and Shultz (1970), who collected data on wages, job characteristics, and job location as part of a study of the Chicago labor market. They compared wages in the CBD (the Loop) to those in the region south of the CBD and in the regions north and west of the CBD, for workers in both white and blue collar jobs. At the time of their study,

21 See Crampton (Chap. 39, this volume) for a discussion of papers on the commuting journey/wage relationship.

the region south of the Loop contained most of the Chicago metropolitan area's heavy industry, while the regions north and west were mainly residential. Rees and Shultz (1970) found that wages in the north/west region were significantly lower than at the CBD for both blue and white collar occupations. But wages in the south region were higher than at the CBD for blue collar occupations and not significantly different from the CBD for white collar occupations. Their evidence is consistent with the theoretical model discussed above in that wages rise with distance from the CBD in the region of Chicago where jobs are plentiful but workers living nearby are scarce, so that suburban employers need to raise wages in order to induce enough workers to commute to suburban jobs. In contrast, wages fall with distance from the CBD in the regions of the metropolitan area where workers are plentiful and jobs are scarce.

A more recent study by Eberts (1981) also used data from Chicago. Eberts obtained wage data for employees of 100 municipalities in all regions of the Chicago metropolitan area. He estimated regressions explaining the log of wages as a function of the log of the municipality's distance from the CBD for five categories of public sector workers: police, fire, administration, clerical and public works. These data have the drawback that they are for municipalities rather than individual workers, but job characteristics and workers' average characteristics may vary across municipalities. As discussed above, these variations may bias the estimate wage gradients either upward or downward. In fact, Eberts (1981) finds that that the wage/distance from the CBD relationship is negative for all five categories of workers and statistically significant for all except fire. The elasticity of wages with respect to distance was about −0.2 for public works and police employees, and −0.3 for administration and clerical. The absolute decrease in monthly wages per mile of distance was \$24 for administration, \$10 for clerical, \$12 for police and \$9 for clerical (in 1974 dollars). Despite these problems, Eberts' results provide some support for the hypothesis that urban wage gradients are negatively sloped.

More recent studies of urban wage gradients have taken advantage of the Public Use Microsample (PUMS) of the 1980 US Census of Population and Housing. This dataset includes all the information collected as part of the US Census of Population for a large sample of individual households. For each worker, it indicates whether the worker's job location is in the CBD, the rest of the central city or in any of a set of suburban zones, where the number of suburban zones varies between 1 and 28 for different metropolitan areas.

Ilhanfeldt (1992) uses PUMS data for Philadelphia, Detroit and Boston (the metropolitan areas having the largest number of zones) to estimate urban wage gradients separately for a variety of occupational groups and for white versus

African-American workers. Commuting journey length was measured by straight-line distance from the largest town within each zone to the CBD. Ilhanfeldt's main results come from estimating wage gradients for white workers in seven job categories in the three metropolitan areas. Of these 21 wage gradients, 18 have negative slopes, and 15 of the 18 are statistically significant. The remaining three wage gradients have positive slopes but are not statistically significant. Thus, Ilhanfeldt's results also support the hypothesis that wages decline with distance from the CBD. The rate of decline is approximately 1% per mile of additional distance from the CBD—a figure suggested as reasonable by Mills and Hamilton (1989).[22] For African-American workers, Ilhanfeldt (1992) estimated 14 wage gradients and found that only two were negative and statistically significant, while one was positive and statistically significant and 11 were not significantly different from zero. Thus, African-American workers appear to have flatter wage gradients than white workers. African-American workers are more likely to live in the central city than white workers, so that if they faced the same negative wage gradients as white workers, they would find it less worthwhile to commute to suburban jobs. Finally, Ilhanfeldt tested whether, or not, wage gradients differed for male versus female workers. He found no significant differences between male versus female black workers, while he did find a significant difference by gender for white workers only for the professional/managerial category, where the wage gradient for women was significantly more negative than for men workers. The general finding of no gender differences in wage gradients is probably not surprising since if male and female workers occupy the same job categories and are paid equal wages, then they must face the same market wage gradient. The finding of different wage gradients by race suggests that white workers tend to take different jobs than African-American workers.

McMillen and Singell (1992) also use PUMS data to estimate urban wage gradients, but they use the information in the PUMS to infer individual workers' job location choices. For each of seven cities, they estimate two simultaneous probit equations explaining whether workers choose jobs in the central city versus the suburbs, and whether they choose residences in the central city versus the suburbs. From the probit equation explaining workplace location, they predict the utility-maximizing workplace location for each worker in the sample, in miles from the CBD. They then assume that the utility-maximizing workplace location can be used as a proxy for workers' actual workplace location. Finally, they use the proxy for workplace location, combined with data on workers' wages and

[22] Ilhanfeldt (1992) also found that the slope of the wage gradients became flatter (less negative) as distance from the CBD increased. This result is consistent with, although not predicted by, the theory discussed above. It may reflect the fact that average commuting speeds are greater in the suburbs than in the central city.

other characteristics, to estimate an urban wage gradient. The estimated wage gradient is negative and statistically significant for their base city, Detroit, and the results for five of their six other cities are not significantly different from those found for Detroit.

Thus, despite important data limitations, the literature on urban wage gradients finds surprisingly strong support for the hypothesis that wages for otherwise similar jobs decline with distance from the CBD

6. Suburbanization: Do jobs follow workers or workers follow jobs?

At the beginning of this chapter, I documented the long-term trend toward suburbanization of both population and employment. A controversy in urban economics concerns the issue of causation: does the spatial pattern of population in a metropolitan area depend on the spatial pattern of employment, or does the employment pattern depend on the population pattern? As discussed above, the urban models literature made widespread use of the assumption that the spatial pattern of employment is exogenously determined—either because all jobs are assumed to be located at the CBD, or because employment is decentralized but its spatial pattern is exogenously specified. This implicitly assumes that the residential location pattern is determined by the employment location pattern, rather than the reverse. The direction of causation issue is testable and a literature has developed that attempts to test whether jobs follow workers or workers follow jobs.

Before examining this literature, however, it seems worthwhile to note that the assumption of the urban models literature that employment location is exogenously determined is mainly made for convenience. In the early models, understanding the economics of residential location within urban areas was difficult enough by itself, and the problem was made much more tractable by assuming away the need to explain employment location. Since then, economists have worked on explaining the pattern of firm location within urban areas and have made progress, but our understanding of firm location remains sketchy relative to our understanding of residential location. Furthermore, theoretical models that explain both simultaneously remain highly simplified and static rather than dynamic, as the discussion in Section 3.1 suggests. Thus, while the empirical question of whether jobs follow people or people follow jobs is interesting and important in its own right, the empirical models do not provide a test of any hypothesis of the theoretical model. The theoretical model itself has not developed to the point where it provides clear predictions on this issue.

Steinnes (1977) was the first to test the causation issue. His technique was to estimate a two-equation simultaneous model using a pooled time-series cross-section dataset. Suppose $P_{i,t}$ denotes the proportion of metropolitan area population located in the central city in city i in period t, and $E_{i,t}$ denotes the proportion of metropolitan area employment located in the central city in city i in period t. In the first equation, the dependent variable is $P_{i,t}$ and the independent variables are the lagged values $P_{i,t-1}$ and $E_{i,t-1}$, plus other exogenous variables that affect the population pattern. In the second equation, the dependent variable is $E_{i,t}$ and the independent variables are the lagged values $E_{i,t-1}$ and $P_{i,t-1}$, plus other exogenous variables that affect the employment pattern. The test of the "people follow jobs" hypothesis is whether, or not, the coefficient of $E_{i,t-1}$ in the equation explaining $P_{i,t}$ is statistically significant and positive, which would indicate that greater suburbanization of employment causes greater suburbanization of population in the following period. The test of the "jobs follow people" hypothesis is whether, or not, the coefficient of $P_{i,t-1}$ in the equation explaining $E_{i,t}$ is statistically significant and positive.

Steinnes (1977) tested the model separately for manufacturing, service and retail employment. The results for manufacturing and services supported the "jobs follow people" hypothesis, while the results for retail employment supported the "people follow jobs" hypothesis. Cooke (1978) redid Steinnes' estimation using residential and employment density gradients (rather than proportion located in the central city) as his measures of the extent of suburbanization. He also found that employment follows population, although the results for manufacturing employment were more significant than those for retail and service employment. Mills and Price (1984) also found that jobs follow people in a model explaining population and employment density gradients and using data from the 1960 and 1970 Censuses of Population.[23] However, Thurston and Yezer (1994), also explaining density gradients but using annual data from the Local Personal Income Series of the US Department of Commerce, found evidence that jobs follow people in the services and retail sectors, but did not find evidence supporting causality in either direction for five other employment sectors

An interesting recent paper on this issue is that of Boarnet (1994). Rather than using metropolitan areas as observations, Boarnet uses data from 365 municipalities in northern New Jersey and, rather than explaining levels of population and employment, he explains the changes in municipal population and employment between the years 1980 and 1988. Thus, Boarnet focuses the analysis on

[23] The main conclusion of the Mills and Price (1984) paper is that adding to the model a set of variables measuring central city problems—crime, race and taxes—does not add any explanatory power to the basic model explaining suburbanization of population and employment.

the submetropolitan area level. For each municipality i, Boarnet defines a labor market consisting of all other municipalities in the sample. Each municipality is weighted by $1/d_{ij}^{\beta}$, where d_{ij} is the distance between municipality i and municipality j and β is a separately estimated parameter that indicates how labor market relationships across municipalities decay with distance. Employment in municipality i's labor market area is defined as the weighted sum of employment in all the other municipalities in the sample, and population in municipality i's labor market area is defined as the weighted sum of population in all the other municipalities in the sample. Thus, an individualized labor market is defined for each municipality.

In Boarnet's model, the change in population in municipality i between 1980 and 1988 depends on the change in employment over the same period in municipality i's labor market area, the lagged value of population in municipality i, the lagged value of employment in municipality i's labor market area, and other control variables. The change in employment in municipality i similarly depends on the change in population in the labor market area surrounding municipality i, the lagged value of employment in municipality i, the lagged value of population in municipality i's labor market area, and other control variables. The two equations are estimated using simultaneous techniques. Boarnet's results indicate that the change in the municipal employment level is significantly related to changes in the population of the labor market area, but the change in the municipal population level is not significantly related to changes in employment in the labor market area.

Thus, Boarnet's results, like earlier papers, provide support for the hypothesis that jobs follow people, but not vice versa. Since Boarnet's test uses municipalities within a particular metropolitan area rather than more aggregated metropolitan area data, his results suggest that the hypothesis that jobs follow people holds for explaining both overall spatial patterns across metropolitan areas, and more detailed spatial patterns within metropolitan areas.

Boarnet's work is unlikely to represent the final word on this subject, but nonetheless his results and those of previous authors seem sensible and intuitively appealing. If we think about the problem from the viewpoint of the theoretical considerations discussed above, it seems clear that the employers' location decisions are tied to the spatial pattern of population. Employers benefit from moving to the suburbs because they can pay lower wages, but only if the move results in workers having shorter commutes. Therefore, the gain to an employer from suburbanizing depends on the density of population near the intended suburban location and on the employer's level of demand for labor. As shown by Wieand (1987), a small firm can benefit from locating near the periphery of the urban area because it only needs to hire a small number of workers, but a large firm has an incentive to remain close to the CBD, since otherwise the high cost of attracting many workers to the suburban site may more than offset the large firms' other gains from suburbanizing. Thus, the gains to firms from suburbanizing are directly linked to the distribution of population: firms have an incentive to follow—but not to lead—workers to the suburbs. In contrast, households gain from moving to the suburbs regardless of the spatial distribution of employment. Even if all firms were located at the CBD, households would still benefit from moving to the suburbs because workers' longer commutes are compensated by lower housing prices—the basic tradeoff of the urban economic model. Thus, it should not be surprising that empirical studies have tended to find that jobs follow people, while people do not follow jobs. The assumption in the theoretical urban models literature that the spatial distribution of employment is exogenous and determines the spatial distribution of population (i.e., people follow jobs) was, and is, merely a convenient simplification that made difficult models easier to solve. Future work in urban economics needs to devote more attention to modeling firm location choice, so that the simplification will no longer be necessary.

7. Are commuting patterns in decentralized cities "wasteful"?

Hamilton (1982) raised the question of whether, or not, commuting in US metropolitan areas is inefficient. He argued that 10 times more commuting actually occurs in metropolitan areas than is predicted by urban economic models, from which he concluded that 90% of urban commuting is "wasteful". He concluded, therefore, that urban economic models have little predictive power.

In order to measure how much commuting occurs in metropolitan areas beyond what is predicted by urban economic models, we need to first establish how much commuting is predicted by urban economic models and is therefore efficient. In theory, we would do this by first establishing the optimal spatial location pattern for each metropolitan area for housing, jobs and roads (which might vary across metropolitan areas because of factors such as differing amounts of land being available for urban use or differing distributions of jobs across industries). Then the efficient commuting pattern would minimize the total commuting time required for the metropolitan area's workers to travel from its houses to its jobs.

But as the previous discussion suggests, urban economic models in fact provide incomplete guidance on these issues. While the model of residential location in metropolitan areas has been extensively researched, the model of firm location in metropolitan areas is still under development and, in particular, the role of agglomeration economies is not well understood. Similarly, the problem of the optimal allocation of land to roads is also relevant and research in this area is also rather sketchy. Thus, in order to measure the efficient amount of commuting, we need to understand whether and how the spatial allocation of land uses in cities is inefficient.

But suppose we wish to proceed anyway and, in order to do so, we make the simplifying assumption that the actual spatial allocation of land uses prevailing in metropolitan areas is efficient. Then the efficient amount of commuting is defined as the minimum amount that would be required for the metropolitan area's workers to travel from its existing housing stock to its existing jobs along its existing roads.

Hamilton's (1982) method of calculating the efficient amount of commuting was based on Mills' (1972) two-point density gradients for population and employment in US metropolitan areas. From the density gradient for population, Hamilton calculated the average distance of houses from the CBD for each of the metropolitan areas in Mills' sample. And from the density gradient for employment, he calculated the average distance of jobs from the CBD in the same metropolitan areas. The difference between them, he argued, is the average minimum commuting journey length required for workers in each metropolitan area to travel from its housing to its jobs. Hamilton then compared this average minimum commuting journey length figure to data on the average actual commuting journey length in each metropolitan area and found that the ratio was 1:10.

Hamilton's (1982) calculation of the average minimum commuting journey length differs from actual minimum commuting journey length for two reasons. First, his calculations assume that houses and jobs are both uniformly distributed in all directions around the metropolitan area's CBDs. This assumption is implicit in the use of density gradients, that treat the metropolitan area as though it can be represented by a one-dimensional ray from the CBD because it is identical in all directions around the CBD. Thus, Hamilton's method ignores the possibility that a metropolitan area's jobs and houses may not be uniformly distributed around the CBD. But if the distributions of jobs and houses around the CBD are not uniform, then they may differ from each other and, therefore, at least some workers must commute circumferentially. But circumferential commuting raises the minimum amount of commuting in the metropolitan area. Since Hamilton's calculations of the minimum average commuting journey length treat the distributions of jobs and housing around the CBD as identical, his method therefore overstates the proportion of urban commuting that is "wasteful". Second, Hamilton's method assumes that all workers commute along straight lines from their houses to their jobs. But actually, workers must commute along the existing road network. If roads are not straight, then the minimum amount of commuting in the metropolitan area rises. The assumption that all commuting journeys occur along straight lines also causes Hamilton's calculations of the proportion of urban commuting that is "wasteful" to be biased upward.[24]

White (1988b) proposed that both the problem of jobs and housing being differently distributed around the CBD and that commuters must travel along the existing road network, could be solved by using an assignment model to calculate the minimum average commuting journey length. An assignment model requires that a metropolitan area be divided into zones, and that we know (1) the commuting journey length between each pair of zones, (2) the number of residences in each zone, and (3) the number of jobs in each zone. The model then calculates an assignment of each worker to a job and residence that minimizes the aggregate amount of commuting for all workers in the metropolitan area. Because of the zonal structure, the assignment model can take into account any spatial distributions of jobs and houses around the CBD. Also, because the characteristics of the existing road network determine the commuting journey length between each pair of zones, the assignment model takes account of the fact that commuting journeys must be made along actual rather than straight-line roads.

Suppose we also know the number of workers who actually commute in each direction between each pair of zones. Conceptually, we can think of the model as starting from the existing allocation of workers to jobs and housing and then making any trades of job or housing assignments that would allow aggregate commuting to be reduced, keeping the number of jobs and houses in each zone fixed. For example, suppose worker A lives at the CBD and works five miles south, while worker B works at the CBD and lives 10 miles south. Then the total commuting could be reduced by 10 miles if workers A and B traded either jobs or houses. Efficient trades tend to reduce the amount of outcommuting and circumferential commuting that occurs. Circumferential commuting cannot be eliminated completely as long as the distributions of jobs and housing around the CBD differ from each other. But outcommuting can be eliminated completely as long as employment is less suburbanized than housing. Thus, efficient commuting patterns tend to involve relatively more incommuting, less outcommuting and less circumferential commuting than actual commuting patterns.

White (1988b) used data from the 1980 US Census of Population to calculate the average minimum commuting journey length for 25 US metropolitan areas.

[24] Hamilton's (1982) commuting calculations were in terms of distance, but later researchers used commuting time. See Hamilton (1990) and Small and Song (1992) for discussion of the effects of using commuting distance versus time.

For these areas, the total number of zones ranges from five to 32, where the CBD is a separate zone for the purposes of workplace location, but not residential location.[25] Census data on how many workers actually travel from each zone to every other zone are used to calculate the average actual commuting journey length. Comparing these figures, White found that the average actual amount of commuting was only about 10% greater than the average minimum amount of commuting.

Table 2 gives the matrix of actual commuting and optimal commuting flows for the Buffalo metropolitan area, which has four suburban zones plus the central city (zone 1) and the CBD. The lefthand column in both panels gives the number of housing units in each zone and the top row in both panels gives the number of jobs in each zone. (All figures are in thousands.) The top panel gives the optimal assignment of workers to jobs and housing units and the bottom panel gives the actual assignment. In the optimal assignment, all jobs in the CBD are occupied by residents of the central city, whereas, in reality 62% of CBD jobs are held by suburban residents. Thus, the optimal assignment eliminates long incommuting journeys. Except in zone 4, all jobs in the four suburban zones are held by residents who live in the same zone, while the remaining suburban residents mainly commute to jobs in the central city.[26] Thus, most outcommuting and circumferential commuting journeys are also eliminated. Although Buffalo has only a few zones, the results are typical of the pattern for cities having a greater numbers of zones.

A problem with using the assignment model is that as long as commuting journeys within zones are shorter than those between zones, within-zone commutes are treated as efficient and the assignment model does not change them. However, if individual zones are relatively large, then additional trades within zones would probably reduce commuting further. But the Census provides commuting data only for a relatively small number of zones within each metropolitan area and, in addition, the central city is a single zone even when it constitutes a large fraction of the metropolitan area. In later papers, Cropper and Gordon (1991) and Small and Song (1992) applied the assignment model to much more detailed transportation data for particular metropolitan areas. Cropper and Gordon (1991) used data for Baltimore that divided the metropolitan area into 498 zones; while Small and Song (1992) used data for Los Angeles–Long Beach that divided the metropolitan area into 706 zones. Cropper and Gordon found that the actual average commuting journey length in Baltimore was two-and-a-half times as high as

[25] The zones for these data are the same as the zones in the PUMS data.

[26] Zone 4 includes Niagara Falls, a suburban subcenter.

Table 2

Optimal versus actual commuting patterns in Buffalo (1980)

			Optimal commuting pattern Jobs (000)					
			CBD	1	2	3	4	5
			37	146	13	184	32	49
Housing units	1	116	37	79	0	0	0	0
(000)	2	20	0	7	13	0	0	0
	3	241	0	57	0	184	0	0
	4	26	0	0	0	0	26	0
	5	59	0	4	0	0	6	49
			Actual commuting pattern Jobs (000)					
			CBD	1	2	3	4	5
			37	146	13	184	32	49
Housing units	1	116	17	70	2	25	1	1
(000)	2	20	2	7	5	7	0	0
	3	241	18	65	6	142	6	4
	4	26	1	3	0	6	26	6
	5	59	2	2	0	4	9	29

the minimum average commuting journey length, while Small and Song's results for Los Angeles-Long Beach indicated a ratio of 3. Both of these results are between Hamilton's (1992) actual-to-minimum commuting journey length ratio of 10, and White's (1988b) actual-to-minimum commuting journey length ratio of 1.1. Thus, there is evidence that much more commuting occurs than the minimum amount required for workers to commute between a metropolitan area's existing houses and its existing jobs, but the best evidence suggests that the ratio of actual to minimum commuting is 2.5:3 rather than 2.5:10.

But does any of this demonstrate that commuting beyond the minimum in metropolitan areas is inefficient or "wasteful"? To address this question, consider what the assignment model omits. One problem is that many households contain two workers and they may choose seemingly inefficient commuting patterns in order to live together. Suppose one spouse works at the CBD and the other in the suburbs and they minimize their combined commuting by living between their two jobs. Therefore, one spouse outcommutes. The assignment model is likely to trade away the outcommuting journey, since the procedure does not take account of the spouses' desire to live together. As another example, suppose an African-American worker lives near the CBD but works in the suburbs. Again, the assignment model will tend to eliminate the outcommuting journey, but in actuality the worker's household may remain at its current residential location because it faces race discrimination in suburban housing markets, or prefers to live in a more familiar environment. Or suppose a worker who lives south of the CBD finds a new job north of the CBD, but remains in the same residential location. This might be because (1) the cost of moving is high, (2) the worker does not expect to keep the new job for long, and/or (3) the worker's household likes the schools or parks in its current neighborhood and makes many (nonwork) trips to them. The assignment model ignores these factors and tends to trade away long circumferential commuting journeys. Finally, all jobs and houses are not identical. Some trades might reduce commuting but would allocate high income workers to small apartments and/or low income workers to large houses; while other trades would allocate high skill workers to low skill jobs and vice versa. All these examples, with the exception of the one involving race discrimination in housing markets, suggest that households choose some amount of commuting beyond the minimum. Such choices are economically rational and efficient as long as households receive other benefits in return for commuting more, and that they voluntarily choose the combination of the longer commute and the other benefits. Nothing in the "wasteful commuting" controversy proves that commuting beyond the minimum is inefficient.

The first model that attempted to allow for any of these factors is Cropper and Gordon (1991). They estimate a multinomial logit model explaining residential location choice as a function of individual household and neighborhood characteristics, and commuting journey length. Using this model, they calculate the utility level of each household in their sample if the household were to locate in each of a set of zones. Then, when the assignment model is used to calculate minimum aggregate commuting, an extra constraint is imposed for each household that the household cannot be moved to a residential zone where it achieves a lower utility level than at its current residential zone. Additional corrections prevent African-American households from being reassigned to zones that are less than 10% African-American, prevent two-worker households from being split up, and allow for differences between the location choices of owner versus renter households. Thus, the Cropper–Gordon model corrects for at least some of the factors that in actuality lead households to choose longer commutes. However, the results suggest that these corrections make relatively little difference. The ratio of actual-to-minimum commuting is 2.0 for owners and 2.4 for renters when the relocation constraints are imposed, compared to 2.3 and 2.8, respectively, when no constraints are imposed. One possible reason for the constraints having little effect is that, in many cases, the same commute-reducing effect can be obtained by workers trading either jobs or houses. Cropper and Gordon's (1991) constraints mainly reduce possible trades of houses, so that the assignment process can obtain the same commute-minimizing result by trading jobs. The results of imposing the constraints might be greater, therefore, if additional constraints on trading jobs—such as workers with high skills not being allowed to trade jobs with workers with low skills—were imposed.

A more recent paper by Kim (1995) divides urban households into those with one-worker and those with two-workers. He runs separate assignment models for one-worker and two-worker households. For the former, both jobs and residences can be traded to reduce commuting but, for the latter, only jobs can be traded so that spouses are not separated. Kim uses data for Los Angeles-Long Beach which divide the metropolitan area into approximately 1500 zones. He finds surprisingly low actual-to-minimum commuting ratios: 1.5 for one-worker households and 1.26 for two-worker households.[27]

Overall, the "wasteful" commuting controversy has shown that workers on average commute no more than about three times the minimum required by the spatial distributions of jobs and housing and the actual road networks in their metropolitan areas. Imposing constraints to reflect the fact that not all trades of housing or jobs to minimize commuting are economically beneficial reduces the ratio to about 1.5–2. Given the low marginal cost of travel in the US, where automobiles and gasoline are lightly taxed and there are few road tolls, this amount of extra commuting seems rather low. It would be interesting to have comparable results for cities in Europe, where the marginal cost of travel is much higher and much more commuting is via public transport.

References

Anas, A. and I. Kim (1994), "General equilibrium models of polycentric urban land use with endogenous congestion and job agglomeration", Journal of Urban Economics 40:232–256

Boarnet, M. (1994), "The monocentric model and employment location", Journal of Urban Economics 36:79–97.

Braid, R.M. (1988), "Optimal spatial growth of employment and residences", Journal of Urban Economics 24:227–240.

Capozza, D. (1976), "Employment/population ratios in urban areas: a model of the urban land, labor and goods markets", in: G.J. Papageorgiou, ed., Mathematical Land Use Theory (Lexington Books, Lexington, MA).

Cooke, T. (1978), "Causality reconsidered: a note", Journal of Urban Economics 5:538–542.

Crane, R. (1995), "The influence of uncertain job location on urban form and the journey to work", Journal of Urban Economics 39:342–356

[27] Also see Crane (1995) for a discussion of how uncertainty concerning job locations would affect the ratio of actual-to-minimum commuting.

Cropper, M. and P. Gordon (1991), "Wasteful commuting: a re-examination", Journal of Urban Economics 29:2–13.
Eberts, R.W. (1981), "An empirical investigation of intraurban wage gradients", Journal of Urban Economics 10:50–60.
Fujita, M. and H. Ogawa (1982), "Multiple equilibria and structural transition of non-monocentric urban configurations", Regional Science and Urban Economics 12:161–196.
Giuliano, G. and K.A. Small (1991), "Subcenters in the Los Angeles region", Regional Science and Urban Economics 21:163–182.
Hamilton, B. (1982), "Wasteful commuting", Journal of Political Economy 90:1035–1053.
Hamilton, B. (1990), "Wasteful commuting again", Journal of Political Economy 97:1497–1504.
Helsley, R.W. and A.M. Sullivan (1991), "Urban subcenter formation", Regional Science and Urban Economics 21:255–276.
Henderson, J.V. (1977), Economic Theory and the Cities (Academic Press, New York).
Henderson, J.V. and E. Slade (1993), "Development games in non-monotonic cities", Journal of Urban Economics 34:207–229.
Hotchkiss, D. and M.J. White (1993), "A simulation model of a decentralized metropolitan area with two-worker, 'traditional' and female-headed households", Journal of Urban Economics 34:159–185.
Ilhanfeldt, K.R. (1988), "Intra-metropolitan variation in earnings and labor market discrimination: an econometric analysis of the Atlanta labor market", Southern Economic Journal 55:123–140.
Ilhanfeldt, K.R. (1992), "Intraurban wage gradients: evidence by race, gender, occupational class, and sector", Journal of Urban Economics 32:70–91.
Kim, S. (1995), "Excess commuting for two-worker households in the Los Angeles metropolitan area", Journal of Urban Economics 38:166–182.
Macauley, M. (1985), "Estimation and recent behavior of urban population and employment density gradients", Journal of Urban Economics 18: 251–260.
Madden, J.F. (1985), "Urban wage gradients: empirical evidence", Journal of Urban Economics 18:291–301.
McMillen, D. and L.D. Singell (1992), "Work location, residence location and the intraurban wage gradient", Journal of Urban Economics 32:195–213.
Mills, E.S. (1972), Studies in the Structure of the Urban Economy. (Johns Hopkins University Press, Baltimore).
Mills, E.S. and B. Hamilton (1989), Urban Economics (Scott, Foresman, Glenview, IL).
Mills, E.S. and R. Price (1984), "Metropolitan suburbanization and central city problems", Journal of Urban Economics 15:1–17.
Muth, R. (1969), Cities and Housing (University of Chicago Press, Chicago).
Ogawa, H. and M. Fujita (1980), "Equilibrium land use patterns in a nonmonocentric city", Journal of Regional Science 20:455–475.
Ogawa, H. and M. Fujita (1989), "Nonmonocentric urban configurations in a two-dimensional space", Environment and Planning A 21:363–374.
O'Hara, J.D. (1977), "Location of firms within a square central business district", Journal of Political Economy 85:1189–1207.
Rees, A. and G.P. Schultz (1970), Workers and Wages in an Urban Labor Market (University of Chicago Press, Chicago).
Ross, S. and J. Yinger (1995), "Comparative static analysis of open urban models with a full labor market and suburban employment", Regional Science and Urban Economics 25:575–605.
Sivitanidou, R. and W.C. Wheaton (1992), "Wage and rent capitalization in the commercial real estate market", Journal of Urban Economics 31:206–229.
Small, K. and S. Song (1992), " 'Wasteful' commuting: a resolution", Journal of Political Economy 100:888–898.
Steinnes, D. (1977), "Causality and intraurban location", Journal of Urban Economics 4:69–79.
Straszheim, M. (1984), "Urban agglomeration effects and employment and wage gradients", Journal of Urban Economics 16:187–207.
Sullivan, A.M. (1986), "A general equilibrium model with agglomerative economics and decentralized employment", Journal of Urban Economics 20:55–75.

Tauchen, H. and A.D. Witte (1984), "Socially optimal and equilibrium distributions of office activity: models with exogenous and endogenous contacts", Journal of Urban Economics 15:66–86.

Thurston, L. and A. Yezer (1994), "Causality in the suburbanization of population and employment", Journal of Urban Economics 35:105–118.

Wieand, K. (1987), "An extension of the monocentric urban spatial equilibrium model to a multi-center setting: the case of the two-center city", Journal of Urban Economics 21:259–271.

White, M.J. (1976), "Firm suburbanization and urban subcenters", Journal of Urban Economics 3:323–343.

White, M.J. (1988a), "Location choice and commuting behavior in cities with decentralized employment", Journal of Urban Economics 24:129–152.

White, M.J. (1988b), "Urban commuting is not 'wasteful' ", Journal of Political Economy 96:1097–1110.

White, M.J. (1990), "Commuting and congestion: a simulation model of a decentralized metropolitan area", Journal of the American Real Estate and Urban Economics Association 18:335–368.

Yinger, J. (1992), "Urban models with more than one employment center", Journal of Urban Economics 31:181–205.