Chapter 1: Introduction

1.1 Study Area

This study examines the work related commuting patterns of residents in the five non-metropolitan Counties of Culpeper, Fauquier, Madison, Orange and Rappahannock in Northern Virginia (NOVA). These counties are adjacent to the larger Washington DC metropolitan area including Loudoun County, Prince William (Prince William County, Manassas and Manassas Park Cities), Fairfax (Fairfax County, Fairfax and Falls Church Cities), Alexandria City and Arlington County (Figure 1-1).

1.2 Problem Statement

1.2.1 Observed trends in Northern Virginia

1.2.1.1 Rapid population growth

Over the last few decades the metropolitan and non-metropolitan counties in NOVA have shown rapid growth. Overall, the annual population growth rates from 1960 to 1990 are 3.09% and 1.96% for the metropolitan and non-metropolitan NOVA, respectively. A significant portion of this growth has been manifest in increasing population density in Fairfax, Loudoun, Prince William, Fauquier and Culpeper counties. Table 1-1 presents population for each county and city in the study area. From 1960 to 1990, Prince William, Fairfax, Loudoun, Fauquier and Culpeper have experienced annual population growth rates greater than 2% with the greatest annual growth rate for the thirty-year period experienced by Prince William County. The growth patterns are different for the non-metropolitan and metropolitan counties. When 1960-70 and 1980-90 growth rates are compared, it is easy to see that growth rates of all the non- metropolitan counties have increased while those of almost all the metropolitan counties (except Arlington) have decreased. This phenomenon is not difficult to explain. Growth has been pushing rural-urban fringe out from the DC core. Arlington and Alexandria were urbanized before 1960. Fairfax and Prince William then witnessed the greatest growth in the 1960's. Following them, Loudoun also grew rapidly in the 1960's. Fairfax, Prince William and Loudoun continued to grow rapidly up to 1990, but the growth rates had

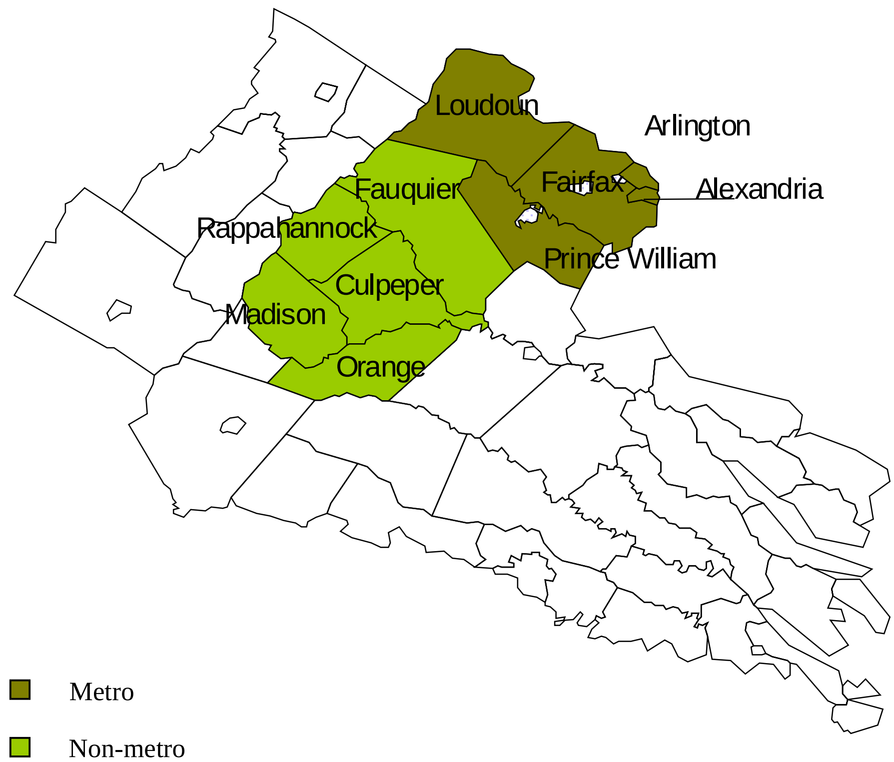


Figure 1-1: Study Area

decreased over time. The non-metropolitan counties, especially Fauquier and Culpeper, however, started their urbanization in the 1970's and the high growth rates were maintained in the 1980's. Data after 1990 is not included in the table, however, a quick review of recent data suggests that Loudoun and Fauquier counties continue to grow rapidly.

Rapid population growth poses a unique set of challenges for the non-metropolitan counties with strong links to the metropolitan areas. Individuals living in the non-metropolitan counties, but commuting for work in metropolitan areas, are an increasingly important component of these linkages. This cohort, however, has been the focus of only limited empirical analysis to date.

1.2.1.2 Suburbanization of residences and employment

Table 1-1: Population Growth in Northern Virginia

	Population				*Annual Growth Rate(%)*			
	1960	1970	1980	1990	60-70	70-80	80-90	60-90
Non-metro:								
Culpeper County	15,088	18,289	22,722	28,095	1.94	2.19	2.15	2.09
Fauquier County	24,066	26,483	36,070	49,097	0.96	3.14	3.13	2.41
Madison County	8,187	8,659	10,246	12,019	0.56	1.70	1.61	1.29
Orange County	12,900	13,914	18,097	21,548	0.76	2.66	1.76	1.72
Rappahannock County	5,368	5,192	6,087	6,660	-0.33	1.60	0.90	0.72
Non-metro Total	65,609	72,537	93,222	117,419	1.01	2.54	2.33	1.96
Metro:								
Arlington County	163,401	173,825	153,363	170,793	0.62	-1.24	1.08	0.15
Fairfax[1]	261,417	489,999	631,502	850,739	6.48	2.57	3.02	4.01
Loudoun County	24,549	37,288	57,765	87,127	4.27	4.47	4.20	4.31
Prince William[2]	50,164	112,424	168,538	252,357	8.40	4.13	4.12	5.53
Alexandria City	91,023	110,508	103,620	111,583	1.96	-0.64	0.74	0.68
Metro Total	590,554	924,044	1114,788	1,472,599	4.58	1.89	2.82	3.09

1. Fairfax County+Fairfax City+Falls Church City;
2. Prince William County+Manassas City+Manassas Park City;
Source: 1. County and City Data Book 1967, U. S. Bureau of the Census, pp 382-402;
2. Regional Economic Information System (REIS) CD-ROM 1969-1995, Bureau of Economic Analysis.

Residential location, worker commuting and firm location are closely related events. Workers can choose residential locations, workplaces and commuting patterns. Firms can also choose locations, or existing firms can choose new locations and expand or shrink in an attempt to minimize costs or maximize profits. Imbalance and mismatch between demand for residences and supply of job opportunities in a certain area can increase commuting. Suburbanization and exurbanization[1] of residences and employment have been observed in NOVA. On one hand, households are usually assumed to be utility maximizers. Household’s utility is a function of consumption of composite private goods, housing services, public services, and non-fiscal amenities (Hoyt and Rosenthal, 1997). The rational worker jointly decides residential and job locations subject to constraints of income and time. However, there are also social, environmental, psychological, as well as economic and fiscal reasons for household choices of locations of residences and jobs.

[1] Exurbanization denotes the process when urban households and firms settle down in non-metropolitan areas.

Suburbanization and exurbanization of residences can be attributed to the following reasons:

a) Desire for rural life and other preferences have made suburban, exurban and rural residences more attractive to many households than urban residences.

b) Households also prefer to live in non-metropolitan areas to lower their housing costs or to consume more housing with the same level of costs.

c) While households choose to live in non-metropolitan areas to take advantage of lower housing costs, they may still commute to take advantage of higher wages at the urban core, especially when consuming more housing requires higher wage income. So households will prefer to live on urban-rural fringe to minimize housing and commuting costs and to maximize wage rates.

d) Modern technologies, especially communication technologies, make it possible for households to settle farther from the urban core than they did in the past (Nelson and Sanchez, 1997).

On the other hand, firms are profit maximizers. They can lower production costs by choosing to locate or relocate near their employees or to expand or shrink. When firms are nearer to their employees, workers' willingness to supply labor at a given wage increases since their commuting costs are lower, so firms can pay lower wage rates to their employees. Despite this, jobs are often relatively abundant in urban areas and scarce in rural areas for two reasons.

a) Suburbanization and exurbanization of jobs may lag behind suburbanization and exurbanization of residences.

b) Firms may also stay in urban and suburban areas because of difficulty in finding enough workers with relevant and adequate skills in rural areas.

1.2.1.3 Increasing work-related commuting

At the national level, the total mileage associated with work-related commutes in the U.S. has been increasing steadily over the last few decades. During the 1980's, the rate of increase in vehicle miles of travel was greater than the rate of increase in population, workers, and even vehicles. Similarly, the share of total travel consisting of commuting between home and work rose from 20.1 to 22.7 per cent (Pisarski, 1992).

Table 1-2: Commuting Trends: Top Five Workplaces for Workers Residing in Each of the Five Non-metropolitan Counties

Place of Residence	*Place of Work*	*1960*	*1970*	*1980*	*1990*	*Annual Growth Rate(%)*
	1. Culpeper	4,271	4,924	7,011	7,793	2.02
	2. Fauquier	138	265	748	1,646	8.61
Culpeper	3. Fairfax[1]	154	201	589	1,483	7.84
	4. Prince William[2]	0	126	291	669	N/A
	5. District of Columbia	35	73	170	247	6.73
	Outcommuters Subtotal	327	665	1,798	4,045	8.75
	1. Fauquier	6,463	6,760	9,556	12,967	2.35
	2. Fairfax[1]	627	999	2,183	5,308	7.38
Fauquier	3. Prince William[2]	198	796	2,167	3,643	10.19
	4. District of Columbia	211	263	723	997	5.31
	5. Loudoun	196	248	606	993	5.56
	Outcommuters Subtotal	1,232	2,306	5,679	10,941	7.55
	1. Madison	1,985	1,837	2,091	2,381	0.61
	2. Culpeper	115	350	828	1,142	7.95
Madison	3. Orange	391	424	430	589	1.38
	4. Albermarle[3]	106	341	388	580	5.83
	5. Fairfax[1]	0	0	40	130	N/A
	Outcommuters Subtotal	612	1,115	1,686	2,441	4.72
	1. Orange	3,807	4,088	4,870	5,646	1.32
	2. Albermarle[3]	235	522	924	1,056	5.14
Orange	3. Spotsylvania[4]	66	67	459	745	8.41
	4. Culpeper	39	146	428	725	10.23
	5. Fairfax[1]	0	22	75	335	N/A
	Outcommuters Subtotal	340	757	1,886	2,861	7.36
	1. Rappahannock	1,091	897	1,203	1,320	0.64
	2. Fauquier	88	103	263	495	5.93
Rappahannock	3. Fairfax[1]	0	153	201	415	N/A
	4. Culpeper	82	132	323	293	4.34
	5. Prince William[2]	0	20	7	275	N/A
	Outcommuters Subtotal	170	408	794	1,478	7.48

1. Fairfax County+Fairfax City+Falls Church City; 2. Prince William County+Manassas City+Manassas Park City; 3. Albermarle+Charlottesville; 4. Spotsylvania+Fredericksburg;
Source: REIS CD-ROM 1969-1995, Bureau of Economic Analysis.

Commuting between metropolitan and non-metropolitan areas and within non-metropolitan areas has also been increasing for several decades. For workers residing in the five counties in this study, commuting has increased greatly from 1960 to 1990. Table 1-2 lists the top five job locations, based on 1990 figures, of residents in each of the studied five non-metropolitan counties. For example, between 1960 and 1990 the number of residents of Fauquier county commuting to work in Fairfax, Prince William, the

District of Columbia and Loundoun increased by an annual rate of 7.55%. When cross-county commuting growth rates are compared with population growth rates in the five counties from 1960 to 1990, it is apparent that commuting has grown faster than population. The number of workers who live and work in the same place has nearly doubled, but the number of workers who live and work in different places has increased more than five times. While the trend of increasing commuting from non-metropolitan counties to metropolitan counties will continue and possibly accelerate, most empirical research has focused on commuting within metropolitan areas.

1.2.2 Causes and implications of increased commuting

Rapid population growth, increased labor-force participation, suburbanization of residence and employment, increased income, improved commuting infrastructure and job-housing imbalance and mismatch all contribute to increases in work related commuting.

Jobs-housing imbalance and mismatch have been widely acknowledged by policy-makers and regional scientists to contribute to the increased commutes. Imbalance occurs when the number of jobs in an area differs substantially from the number of workers who can be housed there. Mismatch occurs when either prices or other characteristics make housing in the area unsuitable for those holding jobs there or make it more suitable for some other groups who don't have jobs there (Giuliano and Small, 1993). Job-housing imbalance and mismatch can sometimes be partially attributed to zoning ordinances which attempted to prevent low-income households, especially those with more school-aged children, from entering areas on the rationale that these low-income people contribute less to local finance than they require from public services (Burnell, 1984). Cities, counties and regional employers have been encouraged to develop policies to create a better balance between jobs and housing (Cervero, 1986; Wachs, Taylor, Levine and Ong, 1993). The concern has already been reflected in land use policies and zoning ordinances of many counties (Giuliano, 1991; Giuliano and Small, 1993; Peng, 1997).

Commuting has private and social costs. Negative externalities such as congestion and air pollution can create social costs of commuting. Markets fail when those who cause a negative externality are not required to pay appropriate compensation. In the case of transportation, congestion appears because each traveler does not consider the cost she or he may exert on other travelers on the road through the delay (Vickrey, 1969). A secondary externality associated with commuting is air pollution. Social costs of air pollution include increased health costs, reduced productivity, and reduced amenity values of the polluted area. Social costs associated with road congestion and air pollution can be high and are usually underestimated (Small, 1997). Congestion pricing is proposed to make each traveler responsible for the delay he or she causes to others. It imposes charges, which are high during peak periods and much lower off-peak, on moving traffic for the explicit purpose of managing congestion. However, attempts to use congestion pricing in the United States failed because no sufficient attention was given to concerns about its adverse effects and to development of a constituency by explaining the benefits and identifying and designing mitigating and compensatory actions (Bhatt, 1993). Another solution, extending road infrastructure to reduce the congestion entails the use of public funds and often promotes additional road usage. Thus, infrastructure investment is often ineffective in reducing congestion unless accompanied by other measures to mitigate usage. The externalities of air pollution can be precisely internalized only if social costs are estimated. Air pollution costs can be estimated with various methods, including assessing direct health costs, identifying statistical correlation between air pollution and mortality, revealing by surveys people's valuation of specifically described environmental amenities, and statistically relating air pollution to residential property values. These methods only produce rough estimations of social costs. More aggregate effects like global warming are even more difficult to analyze because the magnitude of the effects depend on poorly understood scientific relationships (Cline, 1991; Nordhaus, 1991).

Commuting also has its private costs. Households are utility maximizes. They maximize utility with a given amount of private costs such as vehicle expenses and time spent on commuting. Conversely, they minimize private costs to obtain certain wage gains. Both wage and non-wage factors influencing household commuting behaviors. Wage gradients are possible factors underlying household commuting decisions. Non-metropolitan residents can usually get higher wage rates by commuting to metropolitan areas to work. Differences arise from fundamentally differential rates of return on individual characteristics between the labor market in metropolitan and non-metropolitan areas. These different returns to human capital and structural characteristics in the two areas should be estimated in order to calculate the wage gradient and measure its importance in the choice of workplace. Non-wage factors such as commuting costs, number of children in a household, occupation, birthplace, and moving history also influence household commuting behaviors. For example, female workers having more children usually have to work at places near their homes because of greater household responsibilities.

Policy makers need to know the wage as well as non-wage factors underlying household commuting decisions in order to make relevant policies to minimize the negative effects of increased commuting. Clarification of the relationship between demographic differences and commuting decisions can identify the benefits and costs of commuting and help policy-makers understand how workers will respond to potential policies.

Local officials are also increasingly interested in the fiscal implications of work related commuting. The fiscal implications of non-metropolitan residents employed in adjacent metropolitan areas will depend on their personal and household characteristics. For example, if they have more school-aged children than locally employed residents, additional schooling expenditures will be demanded from local government. This can translate into a major fiscal impact because school education expenditures often account for over 60 percent of total local expenditures. On the other hand, non-metropolitan to metropolitan commuters may also have a differential contribution to local revenues. Specifically, differences in property values and taxes between locally employed residents and those not locally employed can have a significant fiscal impact since property taxes make a major contribution to local finances.

The fiscal implications of out-commuting residents are a major concern of regional planners and policy makers. However, only a few studies have been carried out on fiscal implications of commuting patterns within metropolitan areas (Burnell, 1984). No study has been identified that focuses on fiscal implications of non-metropolitan to metropolitan commuting patterns for non-metropolitan counties.

1.3 Objectives

1.3.1 Study Goal:

The goal of this study is to explain household commuting decisions and their potential fiscal implications for five non-metro counties of NOVA.

1.3.2 Specific Objectives:

1. Develop a conceptual framework to explain commuting decisions. Residential location will be assumed to be exogenously determined in the theoretical framework.
2. Present descriptive statistics on commuting flows and commuter characteristics in the five non-metropolitan counties. Differences in personal and household characteristics between workers residing and employed within the five non-metropolitan counties and those commuting for work in metropolitan NOVA counties will be examined.
3. Specify an empirical model to simultaneously estimate the wage and non-wage related components of commuting decisions. Specifically, for the sample of employed workers residing in the five counties, the metropolitan and non-metropolitan area wage equations will be estimated along with a probit equation of workplace choice. Selectivity bias is thus controlled for in determining whether returns in non-metropolitan and metropolitan labor markets to human capital and structural characteristics are significantly different. Wage and wage gap between the two labor market areas, and distance of the metropolitan labor market draw will then be simulated based on the estimates.
4. Discuss potential fiscal implications of commuting and non-commuting households for the five non-metropolitan counties based on their household demographic characteristics. Also discuss potential ways to reduce commuting.

1.4 Organization of the Study

Chapter one contains a description of the study area, problem statement, objectives and organization of the study. Chapter two briefly reviews related literature on commuting decisions, residential and workplace locations, as well as rent gradients and wage gradients. Through the literature review, the assumption of exogenous residential location in the non-metropolitan areas in this study is justified. Chapter three provides a theoretical framework to explain factors affecting household commuting decisions. Exogenous residential location and potential job location at any point on a wage gradient are assumed in this model. Chapter four describes the data used in this study, presents descriptive statistics of relevant variables, and introduces a switching regression system of equations to control for selectivity bias in explaining different returns to human capital characteristics in the non-metropolitan and metropolitan labor markets and identifying the non-wage factors underlying the choice of workplace. Chapter five reports the results of the regression model, including returns to productive and structural characteristics in the non-metropolitan and metropolitan labor markets and non-wage factors affecting household commuting decisions. Wage and wage gap, and distance of the metropolitan labor market draw are then simulated. Fiscal and other policy implications and suggestions for further studies are discussed in Chapter six.

Chapter 2: Review of Related Literature

2.1 Traditional Location Theory

The framework of traditional location theory starts with an exogenous central workplace that is abundant in employment opportunities. Distance to this central workplace is a common measure of the easiness to ‘access’ this central workplace. Other things being equal, households prefer easy access to this central place, generating increased demand for central land sites and bidding up the unit price of these sites. Alonso (1964) derives the bid-rent curve, which is each household’s bids for land at each location along the rays toward this central place. Households have differential preferences for access and land. Households preferring inexpensive land to good access will bid for suburban land sites while those preferring good access to inexpensive land will bid for expensive central land sites. Successful land bids continue until urban fringe land prices match agricultural land prices at those locations. Systematic variations in land prices, or rent gradients, appear for land at each location along the rays toward the central workplace. Putting it differently, land prices are lower the farther the location is from the central employment place.

Apparently consistent with the traditional location theory, many empirical papers examine only workers employed at the same place to analyze the relationships between housing location behaviors and personal and household characteristics. For example, a sample of workers employed at a single company is used by Zax (1990) to analyze the effects of segregation on commuting distance. Zax (1991) also estimates the effects of commuting time and housing characteristics on earnings of white male, white female, and black female employees of a single company. Wachs, Taylor, Levine and Ong (1993) study the commuting patterns between home and work among 30,000 employees of Kaiser Permanente, a major health care provider in Southern California.

The assumption of an exogenous residential location in the above studies can be challenged, or at least supplemented, on the following grounds.

First, workers are likely to be faced with workplace choice decisions more frequently than residential location decisions because rates of employment separation exceed rates of residential relocation (Simpson, 1992). Simpson (1980) finds that 21.1

per cent of workers in Greater London in 1971 changed jobs in the previous year while only 10.6 per cent changed place of residence.

Second, behaviors of different households require different explanatory models. Some households choose a residential location without the intention of changing workplace. If this is the case, a monocentric model with a predetermined workplace is the most appropriate. However, other households choose a workplace without the intention of changing residential location for reasons such as lower property tax rates, good neighborhoods and good schools for their children. In a place of more decentralized employment and suburbanized residences, more people first choose residential locations, then look for jobs with predetermined residential locations. If so, models with an exogenous residential location may be preferred.

There still exists another type of households, which decide workplace and residence simultaneously. However, empirical data are extremely scarce for the estimation of an identified simultaneous decision model that incorporates information of both residential and employment location. A clear understanding of exogenous residential location model provides a useful basis for further development of models of simultaneous decision of residential and workplace location.

2.2 Decentralized Employment and Wage Gradients

Rent gradients alone are not appropriate when the central workplace is not a unique workplace. Decentralized employment, or multiple workplace locations, makes it necessary to incorporate wage gradients into the monocentric model. Similar to rent gradients, wage gradients are systematic variations in wage rates. With the same wage rates, firms in decentralized locations will be able to recruit workers more easily because residents prefer the jobs there to those in the central place. Firms in the central place, therefore, will have to offer higher wages to offset the advantages of decentralized firms in attracting workers (Moses, 1962; Muth, 1969).

Both rent and wage gradients influence locations of households and firms, and transportation networks in an area. Urban rent gradients have been confirmed in numerous empirical studies. However, few empirical studies examine wage gradients within the city. One reason for these omissions is the unavailability of data to measure or even detect wage gradients. Wage rates cannot be attributed to specific job locations because most labor market data on wages are collected from households rather than from firms. When wage data collected at the firms are available, usually no sufficient information exists to isolate spatial factors from differences in human capital characteristics in wage determination (Madden, 1985).

In accordance with Madden's paper, Simpson (1987) examines a model in which workplace location and residential location are simultaneously determined. This model is empirically supported by its application to Toronto. Simpson also extends the model to explain urban commuting distances. It is found that the model in which workplace and residential locations are simultaneously determined explains urban commuting distances better than models in which either residential location or workplace is endogenous. Ihlanfeldt (1992) estimates intraurban wage gradients for various groups of workers with 1980 data from the Philadelphia, Detroit, and Boston metropolitan areas. His findings indicate that wage gradients are statistically significant, steeper for higher wage earners, and steeper as the central business district is approached.

2.3 Models of Commuting Decisions in Non-Metropolitan Areas

Increasing commuting between metropolitan and non-metropolitan areas and within non-metropolitan areas makes it inappropriate to focus on only commuting within metropolitan areas.

Nelson and Sanchez (1997) conduct the only study known of commuting behavior of residents in non-metropolitan areas. Their finding shows that exurbanities are different from suburbanities in household characteristics, occupation of household heads, accessibility to employment, residence characteristics, and geographic clustering based on those factors. They also use a variety of non-parametric and cluster analysis techniques and find that the rise of polycentric urban areas seems to have pushed the suburban fringe further out.

However, little research, if any, has been found to focus on commuting patterns of non-metropolitan households. More research on the commuting patterns of residents in non-metropolitan areas should be conducted in a period of suburbanization, decentralization, and increased long commutes to manage commuting and to internalize fiscal externalities.

2.4 This Study

Unlike traditional location theory that assumes a fixed workplace, this study assumes a predetermined residential location. The empirical portion of the study focuses on residents in five non-metropolitan counties that are adjacent to the DC metropolitan area and are a primary source of growth in non-metropolitan to metropolitan area commuting.

Wage gains are a major incentive for non-metropolitan to metropolitan commuting. Different returns to human capital between the labor markets in non-metropolitan and metropolitan areas will be estimated and tested to examine the importance of wage gradients in non-metropolitan to metropolitan commuting flows.

Non-wage factors are also potentially important in non-metropolitan to metropolitan commuting decisions and will be estimated. Dubin (1991) finds that gender, ethnicity, and household responsibilities (e.g. number of children in a household) are significant factors underlying commuting behaviors, given decentralized firm location and wage gradients. If these factors, as well as others, are also proven to be significant in this study, then locally employed residents and those commuting to the metropolitan area may have different fiscal and other policy implications for local government.

Identifying significant wage and non-wage factors in non-metropolitan to metropolitan commuting decisions may also help local planners identify fiscal externalities and find more effective ways to reduce commuting which has private costs, as well as usually high social costs that are not fully considered.

Chapter 3: Theoretical Model

Household commuting decisions can be modeled in a utility-maximizing framework where households maximize utility subject to income and time constraints. For the reasons mentioned in Chapter 2, residential location is assumed exogenous for the basic model developed in this chapter. Given a wage gradient between the central place and suburban areas, households make commuting choices based on the disutility of commuting time, money spent on commuting, and utility of wage gains.

3.1 Model of Household Commuting Decisions

In this model, each household maximizes utility

$$U=U(X, L), \qquad (3\text{-}1)$$

subject to income constraint

$$X=Y+w(t)h-(f+c(t)) \qquad (3\text{-}2)$$

and time constraint

$$L=T-h-t, \qquad (3\text{-}3)$$

where X is composite goods, L is leisure, Y is unearned income, t is commuting time, h is hours worked, w(t) is wage rate, f is fixed costs of commuting, c(t) is variable costs of commuting, T is total available time.

The following assumptions are made:

(1) Residential location is exogenous. In the empirical model, the observations are chosen from five non-metropolitan counties. Households make commuting choices without the option to change residential locations.

(2) A worker chooses his or her wage rate by choosing commuting time. That is, jobs are available anywhere along the paths toward the central place. For a given worker, education, experience, ethnicity, gender and marital status can be assumed exogenous, so his or her wage rate w_t is a continuous function of commuting time and $dw/dt>0$. Also assume $d^2w/dt^2<=0$.

(3) No job searching cost is associated with choice of job location or wage rate.

(4) Explicit commuting costs are a function of commuting time (t) and $dc/dt>0$. The fixed costs (f) are independent of commuting time and include parking cost and insurance

cost. The variable costs (c(t)) include gasoline usage and wear-and-tear cost and are a linear function of commuting time, passing the original point. So c(0)=f and $d^2c/dt^2=0$.

(5) Household trades off composite goods and leisure. Utility is increasing in composite goods and leisure, i.e., $\partial U/\partial X>0$ and $\partial U/\partial L>0$. Also assume that the law of diminishing marginal utility prevails, i.e., $\partial^2U/\partial X^2<0$ and $(\partial^2U/\partial L^2)<0$. Additionally, assume $(\partial^2U/\partial X^2)(\partial^2U/\partial L^2)-(\partial^2U/\partial X\partial L)^2<0$, which is satisfied if U(X, L) is negative definite. The utility function satisfying these conditions is still very general. Note here that additivity is not assumed, i.e., $\partial^2U/\partial X\partial L=0$ is not assumed.

(6) Work time (h) does not change with commuting time. Because hours worked is often determined by employers and is often fixed for the specific worker with certain occupation no matter where he or she works. But different workers may have different values of h.

(7) Unearned income (Y) and total available time (T) are also assumed to be fixed for a given individual.

Under the above assumptions, the utility is ultimately a function of commuting time, i.e., $U=U_t$. Differentiating the utility function with respect to t, one can get the first order condition as follows:

$$dU/dt=(\partial U/\partial X)[(\partial X/\partial w)(dw/dt)+(\partial X/\partial c)(dc/dt)]+(\partial U/\partial L)(dL/dt)=0, \qquad (3\text{-}4)$$

By assumption, $\partial X/\partial w=h$, $\partial X/\partial c=-1$ and $dL/dt=-1$, so

$$dU/dt=(\partial U/\partial X)(dw/dt)h-(\partial U/\partial X)(dc/dt)-\partial U/\partial L=0. \qquad (3\text{-}5)$$

Hence,

$$(dw/dt)h=(dc/dt)+(\partial U/\partial L)/(\partial U/\partial X). \qquad (3\text{-}6)$$

From the first order condition, an optimal commuting time, t*, can be found. Since $(\partial U/\partial L)>0$ and $(\partial U/\partial X)>0$, $(dw/dt)h-(dc/dt)>0$ should be satisfied for any household to commute.

However, a unique optimal solution t* exists only when the second order condition is also satisfied. Differentiate (3-5) again with respect to t,

$$d^2U/dt^2=(\partial^2U/\partial X^2)[(dw/dt)h-dc/dt]^2 - 2(\partial^2U/\partial X\partial L)[(dw/dt)h-dc/dt] + \partial^2U/\partial L^2+(\partial U/\partial X)[(d^2w/dt^2)h- d^2c/dt^2]. \qquad (3\text{-}7)$$

Since $\partial U/\partial X>0$, $d^2w/dt^2<=0$ and $d^2c/dt^2=0$ by assumption, the last term on the right hand side is always less than or equal to zero. Now consider the first three terms on the right hand side. $(\partial^2U/\partial X^2)[(dw/dt)h- dc/dt]^2 - 2(\partial^2U/\partial X\partial L)[(dw/dt)h-dc/dt] + \partial^2U/\partial L^2<$ $(\partial^2U/\partial X^2)[(dw/dt)h-dc/dt]^2 + 2[(\partial^2U/\partial X^2)(\partial^2U/\partial L^2)]^{1/2}[(dw/dt)h-dc/dt] + \partial^2U/\partial L^2=-\{(-\partial^2U/\partial X^2)^{1/2}[(dw/dt)h-dc/dt]-(-\partial^2U/\partial L^2)^{1/2}\}^2<=0$, since $\partial^2U/\partial L^2<0$, $\partial^2U/\partial X^2<0$ and $(\partial^2U/\partial X^2)(\partial^2U/\partial L^2)-(\partial^2U/\partial X\partial L)^2<=0$. Hence the sum of the first three terms is less than zero. Therefore, $d^2U/dt^2<0$ is always satisfied under the assumptions in the model and the household can find a unique maximal utility by finding an optimal commuting time (t*) or an optimal wage rate (w*). Here $d^2w/dt^2<=0$ is found to be necessary because otherwise the second order condition might not be satisfied.

3.2 Discussions of the Model

From (3-6), (dw/dt)h-(dc/dt)>0, that is, marginal wage gains should be greater than the marginal explicit commuting cost, should be satisfied for any household to commute. From now on assume (dw/dt)h-(dc/dt)>0. Also note here that (dw/dt)h-(dc/dt)>0 is a necessary condition for a worker to commute, but far from sufficient.

There are three parts in (3-6): marginal wage gains (dw/dt)h, marginal explicit commuting costs (dc/dt), and marginal implicit commuting costs $(\partial U/\partial L)/(\partial U/\partial X)$. The representative worker will commute to a point where his or her marginal wage gains equal the sum of marginal explicit and implicit costs of commuting. The three terms on both sides of equation (3-6) decide the optimal commuting time t*. Marginal explicit costs of commuting including gasoline usage and wear and tear costs, are assumed to be constant in our empirical model and no variable is constructed to represent their effects on commuting time. Note here that the explicit commuting costs, however, have decreased over the last few decades and have contributed to the observed increases in commuting. The assumption that the representative worker can find jobs anywhere along the lines toward the central workplace is also relaxed in the empirical model by incorporating variables to represent constraints to job acquirement.

The empirical model will be specified based on groups of factors affecting the following three components of household choice of optimal commuting time (t*): (1)

marginal wage gains, (2) marginal implicit costs of commuting, and (3) constraints to job acquirement.

(1) Marginal wage gains

Higher marginal wage gains are associated with longer commuting time. Wage gains are determined by both the hourly wage gradient (dw/dt) and the number of hours worked (h). According to the human capital framework, wage rates are determined by two groups of labor market variables: worker productivity, which mainly includes education and work experience, and market structure, which mainly includes gender, ethnicity and marital status. A given worker faces determined wage rates in non-metropolitan and metropolitan labor markets and, therefore, a constant wage gradient along the lines toward the central place. However, workers with differential human capital or structural characteristics may face different wage gradients because of different returns to these characteristics in metropolitan and non-metropolitan labor markets.

Both the number of hours worked per week and the number of weeks worked per year are used as independent variables in the empirical model. The more hours worked, the more are marginal wage gains the worker can harvest by increasing one unit of commuting time. However, the number of hours worked also has an effect on the marginal implicit costs of commuting.

(2) Marginal implicit costs of commuting

Higher implicit costs of commuting reduce commuting time, *ceteris paribus*. L_0, X_0 and $(\partial U/\partial L)/(\partial U/\partial X)$ determine the marginal implicit costs of commuting, where L_0 is total available time for commuting and X_0 is unearned income. If the total available time is low, the marginal implicit costs of commuting would be higher. On the other hand, if the unearned income is low, the marginal implicit costs of commuting would be lower because low income households prefer less leisure. The term $(\partial U/\partial L)/(\partial U/\partial X)$ represents household preferences.

The total available time for commuting (L_0) is greatly influenced by household responsibilities, which are determined by gender, the number of children in a household, and marital status. Females tend to commute shorter distances because they devote more time to household responsibilities such as childbearing and childcare which make commuting implicitly more costly. The number of children in a household can be expected to have different effects on husbands and wives because women usually hold primary childcare responsibility. For the wife, more children per household mean less total available time. She will then be less likely to commute long distances to work because time is more valuable. The number of children probably does not affect the time of husband to the same degree because he devotes less time to childcare. Married workers are also expected to have shorter commuting time or distances because they invest more time in the household.

The total available time is also determined by number of hours worked. The more hours worked, the less is the total time available for commuting and the higher are the marginal implicit costs of commuting. Because the number of hours worked increases both marginal wage gains and marginal implicit costs of commuting, the net magnitude of its effect is an empirical question.

The unearned income (X_0) has an income effect on the household selection of commuting time. More income from other sources makes individuals put higher value on the commuting time and leisure if the leisure is a normal good. The income of other members in a household is included as a right hand side variable to represent this effect and is expected to be positively related to the observed choice of commuting time.

The household preferences represented by $((\partial U/\partial L)/(\partial U/\partial X))$ also affect the commuting time. Ownership status and number of rooms represent preferences for consumption of housing. Homeowners and workers living in houses with more rooms have higher preferences for housing and should be willing to endure longer commutes. The elderly place a higher value on leisure and are expected to be less likely to commute long distances.

(3) Constraints to job acquirement

Jobs are not continuously available along the lines toward the central workplace. Workers facing constraints to metropolitan job opportunities have to work in local areas while those facing constraints to local job opportunities have to work in metropolitan areas. Constraints to job acquirement should be controlled for in order to obtain more accurate estimates of effects of household and personal characteristics on workplace choice.

Employment status and occupational type are one constraint to job acquirement. Class is a dummy variable for self-employed workers versus other workers. Self-employed workers are often more able to choose the locations of their workplaces. So they are expected to have shorter commutes. Several dummy variables are constructed for different occupational groups. Occupations are different both in concentration within space and dispersion over space. For example, farming, forestry and fishery occupations are often loosely distributed within non-metropolitan areas and rarely exist in metropolitan areas. Workers in these occupations are expected to have shorter commuting time. On the other hand, managerial, professional, technical, administrative support and constructional occupations are usually concentrated in metropolitan areas. Workers in these occupations are expected to have longer commuting time. Control for occupations will make estimates of other variables more accurate.

Place of birth, moving history, ethnicity and age represent the other constraint to job acquirement. Individuals born and remaining in the same State may have stronger employment roots in local communities. They are probably less likely to commute. Moving history, however, has an undetermined effect on commuting choice. As the NOVA labor market expands outward, recent movers are more likely to retain metropolitan labor markets links through commuting while older movers are better able to find local jobs. On the other hand, recent movers are better able to minimize mismatches in job and residential locations. Net effect of moving history on commuting time is a combination of the two effects. In a recent empirical study, Levinson (1997) finds that recent movers maintain commute duration rather than having a major increase or decrease. If black workers living in non-metropolitan areas can not find jobs locally in non-metropolitan areas because of labor market segmentation or discrimination, they are expected to have longer commutes. Younger workers living in non-metropolitan areas perhaps do not have enough social relationships to find jobs in metropolitan areas. They possibly have shorter commuting times. Because the elderly have higher implicit costs of commuting and young non-metropolitan residents are less able to find metropolitan jobs, middle aged workers are expected to have the longest commute. Age and age-squared will be used as independent variables in the empirical study to capture these two effects.

3.3 Limitations of the Model

Households choose residential and job locations simultaneously to maximize utility. If residential location is endogenous, variables that reflect the residential environment such as housing rents, school quality, scenery, property tax rates, accessibility to shopping centers, and crime rates, need to be considered. If the observations studied have a homogenous residential environment, the assumption of exogenous residential location is not a problem. However, the study area is a five county non-metropolitan area, which is also a planning district. The large size of the study area suggests that a good deal of heterogeneity in the residential environment can not be captured due to data limitations.

Available data for relevant variables will be analyzed in Chapter four, firstly through descriptive statistics, then by estimating a system of equations including a probit equation of workplace choice and two log-wage equations.

Chapter 4: Empirical Methods

4.1 Data

The Public Use Microdata Sample (PUMS) contains household and person records for a five-percent sample of housing units that received the “long form” of the 1990 Census questionnaire. Data items cover a range of population and housing information collected in the 1990 Census. Household information includes tenure, number of rooms, property value, property tax and year moved into the house or apartment. Personal information includes gender, age, education, ethnicity, marital status, workplace, birthplace, commuting time, commuting means, income, wage, weeks worked last year, hours worked per week, employment status and occupational type. Each person identified in the sample can be associated with a corresponding household record. Some useful variables such as the number of children less than 16 following each household record, income of other household members and hourly wage rates are also created using relevant variables. Particularly, hourly wage rates are created by dividing the sum of wage/salary income and self-employment income by weeks worked per year and hours worked per week.

PUMS has its own set of geographic demarcations, known as “Public Use Microdata Areas” (PUMAs), established by the Census Bureau with assistance from each State Data Center. The PUMAs in the five-percent sample are based on counties and places within states. A PUMA is usually a county or set of counties with a population more than 100,000 but less than 200,000. A county with more than 200,000 inhabitants is divided into several PUMAs. Counties with less than 100,000 inhabitants are grouped into one PUMA. Place of residence and place of work are identified by PUMAs. This study focuses on residents in PUMA 1200, which covers five non-metropolitan counties of Culpeper, Fauquier, Madison, Orange, and Rappahannock.

4.2 Descriptive Statistics

The sample of PUMA 1200 contains 5,391 individuals, of which 2,649 are employed workers. Workers with disability problems including work limitation status,

Table 4-1: Commuting Methods

Means	*Frequency*	*Percentage*
Car, truck, or van	1,830	91.1
Bus or trolley bus	8	0.4
Taxicab	3	0.1
Motorcycle	2	0.1
Bicycle	4	0.2
Walked	63	3.1
Worked at home	84	4.2
Other method	14	0.7
All	2,008	100

Source: PUMS 1990.

Table 4-2: Commuting Time for Workers Employed within the Five Non-Metropolitan Counties and for Those Commuting to Work in the Metropolitan Area

	All workers		*Workers employed within the five non-metro counties*		*Workers commuting to work in the metro area*	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
*Commuting time (minutes)	28.92	23.38	18.58	14.55	50.44	23.64
No. of obs.	1,830		1,236		594	

Two tailed t-tests are conducted for testing the hypotheses that the means of the two groups of observations are equal. An asterisk denotes significantly different means at the 5 percent level.
Source: PUMS 1990.

work prevented status, mobility limitation and personal care limitation are removed from the sample because commuting decisions of these workers are greatly affected by these limitations. Several workers working less than 10 weeks last year or 10 hours per week have abnormally high hourly wage rates and are also removed from the sample. Those who attend school and work less than 20 hours a week are also excluded because they are not full-time workers. Only laborers working in the five non-metropolitan counties and the metropolitan counties in NOVA and Washington DC are retained to focus the analysis on commuting decisions between these two areas. Table 4-1 presents commuting methods of the remaining 2,008 workers. Most workers commute by car, truck or van. Some workers either walk to their workplace or work at home. Workers who don’t commute by car, truck, and van are removed to make the sample more homogeneous. Overall, only 1,830 observations are retained for the statistical analysis.

Travel time and metropolitan commuting show a 0.64 correlation coefficient. This suggests that metropolitan commuting choice is a good proxy for the commuting time developed in the theoretical model. Analysis of average commuting time lends further support for using metropolitan commuting choice as a proxy. Table 4-2 presents average commuting time for two groups of workers. On average, workers employed in the non-metropolitan area spent only 18.58 minutes on commute, while workers commuting to work in the metropolitan area spent 50.44 minutes. Additionally, because jobs are not continuously available along the paths from residences of non-metropolitan households to the central place, metropolitan commuting is a better proxy to represent discrete job locations. Hence, workplace rather than commuting time is used as dependent variable in the statistical analysis.

Table 4-3 presents the cross-tabulations for 1,830 workers residing in the non-metropolitan area and either working within this area or commuting to work in the metropolitan area. It can be seen from this table that the commuting group has a lower proportion of females. While the proportions of males and females employed within the non-metro area are almost the same, only 34 percent of workers commuting to work in the metro area are females. On average, locally employed workers are slightly older than commuting workers are but the means between the two groups are not statistically different. The commuting group has a lower proportion of workers with less than high school education and a higher proportion of workers with some college education. The proportions of other educational levels are not statistically different. The locally employed group has a higher proportion of Hispanic workers and a lower proportion of white workers but no significantly different proportions of black workers from the commuting group. No significant difference exists in marital status between the two groups of workers.

Workers commuting to work in the metropolitan area show a significantly lower average number of children with age between 6 and 15 years old inclusively. A higher percentage of locally employed workers were born in the Sate of Virginia. Workers commuting to the metropolitan area are found to have more rooms. Surprisingly, the commuting group is found to have higher percentages of homeowners and recent movers than the locally employed group, where recent movers are those moving into their current housing units in the last five years. The locally employed group has a higher proportion of self-employed workers. Additionally, this group has higher proportions of sales, services and agricultural occupations but no significantly different proportions of

Table 4-3: Characteristics of Workers Employed within the Five Non-Metropolitan Counties and Those Commuting to Work in the Metropolitan Area

	All workers		*Locally employed workers*		*Workers commuting to the metro area*	
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation
*Gender (female=1)	0.444	0.497	0.493	0.500	0.342	0.475
Age	38.260	12.080	38.540	12.540	37.67	11.060
Education:						
*Less than high school	0.207	0.405	0.235	0.424	0.148	0.356
High school	0.373	0.484	0.386	0.487	0.345	0.476
*Some college	0.245	0.430	0.212	0.409	0.315	0.465
College	0.125	0.331	0.118	0.323	0.138	0.345
More than college	0.050	0.219	0.049	0.215	0.054	0.226
Ethnicity:						
Black	0.115	0.319	0.121	0.327	0.101	0.302
*Hispanic	0.027	0.161	0.032	0.177	0.015	0.122
*White	0.849	0.358	0.837	0.369	0.874	0.332
Married (yes=1)	0.691	0.462	0.686	0.464	0.700	0.458
No. children in a household:						
No. children<6	0.309	0.623	0.299	0.607	0.330	0.656
*No. children>=6, <16	0.562	0.884	0.597	0.897	0.490	0.852
No. children<16	0.872	1.113	0.896	1.111	0.820	1.115
*Born in the State (yes=1)	0.566	0.496	0.625	0.484	0.444	0.497
*Rooms	6.397	1.712	6.224	1.674	6.758	1.735
*Owner	0.732	0.443	0.707	0.455	0.785	0.412
*Recently moved	0.551	0.497	0.510	0.500	0.638	0.481
Income of other household members	22352	25538	21889	25036	23316	26547
*Self-employed (yes=1)	0.098	0.297	0.113	0.317	0.066	0.248
Occupations:						
Managerial, professional	0.240	0.427	0.230	0.421	0.261	0.440
Technical, administrative support staff	0.215	0.411	0.206	0.405	0.234	0.424
*Sales, services	0.198	0.399	0.216	0.412	0.162	0.368
*Agricultural	0.046	0.209	0.054	0.227	0.029	0.167
Construction	0.085	0.279	0.077	0.266	0.101	0.302
Other	0.216	0.412	0.217	0.412	0.214	0.410
*Weeks worked last year	48.580	7.956	48.090	8.347	49.600	6.971
*Hours worked per week	40.880	9.735	39.860	9.770	42.990	9.322
*Log wage	2.268	0.663	2.151	0.662	2.512	0.596
No. of obs.	1,830		1,236		594	

Two tailed t-tests are conducted for testing the hypotheses that the means of the two groups of observations are equal. An asterisk denotes significantly different means at the 5 percent level.
Source: PUMS 1990.

managerial, professional, technical, administrative support and constructional occupations from the commuting group.[2] Workers commuting to the metropolitan area are also found to have worked more hours and weeks and receive significantly higher log wage rate.

Table 4-4 presents observed average hourly wage rates and average wage differences for specific cohorts of metropolitan commuters and non-commuting non-metropolitan workers. Wage differences are mostly positive.

On average, male workers employed in the metropolitan area earn higher wage than males in the non-metropolitan area do. Females employed in the metropolitan area also earn higher wage rates. Furthermore, male workers earn higher hourly wage rates than females do whether they commute or not. Age has a non-linear relationship with average wage rates. Those with age from 36-65 have relatively higher wage rates. There exist positive wage differences for all age groups. At all levels, education is positively related to average wage rates and wage differences. There are also wage differences between different racial groups. In both workplaces, Whites earn a higher average wage rate than blacks. Wage differences are positive for black, Hispanic and white groups. Little can be said about the other two groups due to the limited numbers of observations. Finally, married workers receive higher wages than unmarried workers and the wage differences are positive for both groups.

Table 4-4 also presents average hours worked last week and weeks worked last year for various groups. Workers employed in the metropolitan area have higher average hours worked per week than those employed in the non-metropolitan area and generally have higher average weeks worked last year. Females work fewer hours than males no matter where they work. Again we have postulated that this is due to greater household responsibilities such as raising children. In both locations, blacks work fewer weeks than whites; married workers work more weeks than unmarried workers.

Policy makers may also want to know whether workers employed in metropolitan areas have higher property value and thus pay higher property taxes. Table 4-5 presents average property value and taxes for all 1,340 homeowners. Homeowners commuting to

[2] Occupations are grouped into six categories according to the 3-digit occupation code: managerial and professional specialty occupations (0-199); technical and administrative support occupations (200-235 and 303-389); sales and services occupations (243-285 and 403-469); farming, forestry and fishery occupations

Table 4-4: Observed Wage Differences between Workers Employed within the Five Non-Metropolitan Counties and Those Commuting to Work in the Metropolitan Area

		Workers employed within the five non-metropolitan counties			*Workers commuting to work in the metropolitan area*			
		Observed hourly wage	Hours worked per week	Weeks worked last year	Observed hourly wage	Hours worked per week	Weeks worked last year	Wage difference
Gender	Male	13.09	42.84	49.25	16.62	44.74	50.06	3.53
	Female	8.58	36.79	46.89	11.00	39.62	48.72	2.42
Age	16-25	6.73	38.32	44.53	9.38	42.37	46.17	2.65
	26-35	10.34	39.73	48.20	12.93	42.61	50.08	2.59
	36-45	12.34	40.19	48.73	16.40	43.12	50.37	4.06
	46-55	12.91	41.00	49.73	19.15	45.22	50.56	6.24
	56-65	12.41	40.93	49.09	15.43	39.95	48.51	3.02
	65-	7.99	35.62	46.97	14.12	40.00	52.00	6.13
Education	Less than high school	8.66	38.94	47.98	12.81	42.05	48.95	4.15
	High school	9.35	39.88	48.56	13.28	43.12	49.45	3.93
	Some college	11.17	39.03	47.81	15.07	42.58	49.92	3.90
	College	15.75	42.02	46.92	16.08	44.40	52.00	0.33
	More than college	20.34	42.50	48.92	23.32	43.53	49.09	2.98
Race	Black	8.47	39.09	47.27	10.17	39.50	46.72	1.70
	Asian	21.55	33.83	46.00	5.63	36.67	34.67	-15.92
	Hispanic	9.59	38.53	48.13	14.42	41.67	49.33	4.83
	White	11.21	40.03	48.21	15.33	43.49	50.04	4.12
	Other	8.32	44.80	49.60	6.15	36.67	46.33	-2.17
Marital status	Married	11.48	40.01	48.54	15.65	43.23	50.26	4.17
	Not married	7.97	39.18	49.94	10.45	41.93	46.68	2.48
No. of obs.		1,236			594			

Source: PUMS 1990.

work in the metropolitan area have remarkably higher average property value, which implies that they may generate a larger tax base. Although owners employed in the metropolitan area pay higher average property taxes, they have lower property tax rates, if tax rate is simply average total tax they paid over average value of their property.

(473-499); construction trade (553-599); other. See the occupation code list provided by U.S. Census Bureau for details.

Table 4-5: Average Property Value and Tax of Homeowners[1]

	Owners working within the five non-metropolitan counties	*Owners commuting to work in the metropolitan area*
Average property value[2]	132717.39	176614.81
Average property tax[2]	4288.90	4355.15
Average property tax rate[2]	3.23%	2.47%
No. of obs.	874	466

1.Reported household property value and tax fall into 25 intervals and 60 intervals, respectively. Median of each interval is used to calculate the averages.
2.Household property value and tax are assigned to each worker.
Source: PUMS 1990.

Descriptive statistics provides us a general understanding of factors affecting workplace choice but can be quite misleading. For example, when looking at workplace choice of two gender groups, readers can see that a higher percentage of males commute to work in the metro area. Some readers tend to assert that males are more likely to commute. But this assertion may be misleading because the phenomenon that a higher percentage of males commute may arise from other differential characteristics between the two gender groups such as education, work experience, ethnicity and marital status. We need to control for other important factors when attempting to identify the effect of each of the wage and non-wage factors influencing household commuting decisions. In the next section, other methods are used to provide more precise and less misleading insights.

4.3 Switching Regression Model with Endogenous Switching

Some of the residents in the cluster of the five non-metropolitan counties demarcated by PUMA 1200 work within the non-metropolitan area. Others commute longer distances to work in the metropolitan area including Loudoun County, Prince William County, Manassas City, Manassas Park City, Fairfax County, Fairfax City, Falls Church City, Alexandria City, Arlington County and Washington DC. According to the theoretical framework of this research, workers decide where to work by comparing differences in available wage rates and non-wage benefits of working within the non-metropolitan area relative to commuting to work in the metropolitan area. A worker will commute for work in the metropolitan area if increased wage income from commuting is more than the increased commuting costs and equivalent monetary value of loss of leisure and amenities. Selectivity bias in the choice of workplace should be controlled for in estimating wage earnings equations, because any correlation between non-wage factors affecting workers' choice of workplace and factors affecting potential earnings will lead to biased estimates of returns to individual characteristics and make comparisons across workplaces invalid. The empirical model used in this study is a system of equations with two earnings functions and a criterion function of workplace choice. Maddala and Nelson (1975) call it a "switching regression model with endogenous switching."[3] Multiple examples can be found in Trost (1977), Lee (1978), Dickens and Lang (1985), Mills (1997), Hu and Schiantarelli (1998), and Perloff, Lynch and Gabbard (1998).

4.3.1 Earnings Functions for Two Groups of Commuters

The logarithm of hourly wage rates for workers working within the five counties, LnWAGEp, and that for workers commuting to work in the metropolitan area, LnWAGEc, are specified as functions of observed personal characteristics, Xp and Xc, respectively, and unobserved personal productive differences, Up and Uc, respectively. The earnings functions for the non-metropolitan and metropolitan labor markets are, respectively,

$$\text{LnWAGEp} = \text{XpBp}+\text{Up} \tag{4-1}$$

and

$$\text{LnWAGEc} = \text{XcBc}+\text{Uc}. \tag{4-2}$$

Here Xp and Xc include the same list of human capital variables such as gender, education, work experience, ethnicity and marital status. Bp and Bc are parameter vectors of Xp and Xc, respectively. Unobserved errors are denoted by Up and Uc. Here error terms are assumed to be normally distributed with zero means, i.e., $Up \sim N(0, \sigma_p^2)$ and $Uc \sim N(0, \sigma_c^2)$. According to human capital theory, wage rates are determined by workers' productivity and market discrimination. Workers with higher education are usually more productive and should have higher wage rates in both non-metropolitan and metropolitan labor markets, *ceteris paribus*. Another important proxy for productivity, work experience, can both accumulate and depreciate and is therefore expected to have a

[3] See details in Maddala (1983).

nonlinear relationship with wage rates in both labor markets. When age is used as a proxy for work experience, females are expected to earn less because they spend time on childbearing and more time on household responsibilities such as childcare. Therefore, they typically have less work experience than males of the same age. Females may also obtain additionally lower wage rates in both labor markets because of market segmentation or discrimination. Blacks are also expected to obtain lower wage rates in both labor markets for persistent racial discrimination. Finally, marital status is included because married workers are found to receive higher wage rates in some empirical papers.

4.3.2 Workplace Choice Criterion Function

If fundamentally different returns to personal productive characteristics exist between workers employed within the five non-metropolitan counties and those commuting to work in the metropolitan area, or if fundamentally different levels of labor market discrimination exist between labor markets in the two areas, parameter vector Bp will not equal parameter vector Bc, i.e., $Bp \neq Bc$. In this case, wage gradients between the two labor markets exist. And log wage gradients can be specified as

$$W=LnWAGEc-LnWAGEp. \qquad (4\text{-}3)$$

According to the theoretical framework, the log wage gradients alone can not fully specify workplace choice. Workers also consider non-wage factors such as differences in commuting costs and amenity values. D represents the differences in commuting costs and amenity values of working within and outside the PUMA. Here D is a function of observed personal and household characteristics, Z, and unobserved characteristics, U. Personal and household characteristics (Z) affecting workplace choice include gender, marital status, the number of children less than 6 years old in the household, the number of children between 6 and 15 years old in the household, age, place of birth, ethnicity, number of rooms, ownership status, years moved into the house, income of other household members, hours worked per week, weeks worked per year, employment status and occupational type. Also, a normal distribution of the error term with mean zero and variance σ^2 is assumed, that is, $U \sim N(0, \sigma^2)$. Hence,

$$D=ZQ+U, \qquad (4\text{-}4)$$

where Q is the parameter vector of Z.

Workers will compare W, the increased wage income, and D, the decreased utility of long commute, to decide where to work. If W-D>0, a worker will choose to work in the metropolitan area. If W-D<=0, a worker will choose to work within the five non-metropolitan counties.

Define

$$I=1 \text{ if } W-D>0 \tag{4-5}$$

and

$$I=0 \text{ if } W-D<=0. \tag{4-6}$$

Plugging (4-1) and (4-2) into (4-3), and then plugging (4-3) and (4-4) into (4-5) and (4-6), one can obtain the criterion function

$$I=1 \text{ if } XcBc-XpBp-ZQ-V>0 \tag{4-9}$$

and

$$I=0 \text{ if } XcBc-XpBp-ZQ-V<=0, \tag{4-10}$$

where V=U+Up-Uc.

Assuming that Up, Uc and V have a trivariate normal distribution, with mean vector zero and covariance matrix

$$\sum = \begin{bmatrix} \sigma_P^2 & \sigma_{PC} & \sigma_{PV} \\ \sigma_{CP} & \sigma_C^2 & \sigma_{CV} \\ \sigma_{VP} & \sigma_{VC} & 1 \end{bmatrix}$$

The likelihood function for this model is

$$L(Bp, Bc, \sigma_P^2, \sigma_C^2, \sigma_{PV}, \sigma_{CV}) = \prod \{ [\int_{-\infty}^{XcBc-XpBp-ZQ} g(LnWAGEp - XpBp, V)dV]^{Ii} \int_{XcBc-XpBp-ZQ}^{+\infty} f(LnWAGEc - XcBc, V)dV]^{1-Ii} \}$$

where g and f are the bivariate normal density functions of (Up, V) and (Uc,V) , respectively. Note that σ_{PC} and σ_{CP} can not be estimated, even if they are assumed to be nonzero. A full information maximum likelihood estimator is used to jointly estimate Bp, Bc, σ_P^2, σ_C^2, σ_{PV} and σ_{CV}.

Chapter 5: Results

Parameter estimates of the probit equation and the two log-wage equations are reported in this chapter. Structural tests for the different returns to human capital and structural characteristics between two labor markets areas are also conducted. Based on the parameter estimates, wage rates, wage gradients between the two labor market areas, and distance of the metropolitan labor market draw are then simulated using a male, 35-year-old, college-educated and non-black worker as the base.

5.1 Parameter Estimates

The parameter estimates for the probit equation of workplace choice are reported in Table 5-1. The results indicate that female workers are significantly less likely to commute to work in the metropolitan area. The number of children between 6 and 15 years old also has a significant negative effect on the choice of workplace for female workers but has no effect for males. Workers born in the State of Virginia are found to be less likely to commute. Black workers are also found to be more likely to commute. Number of rooms is found to be positively related to the propensity to commute. Homeowners are significantly less likely to commute. Recently movers are more likely to commute. Hours worked per week and weeks worked last year are also found to be positively related to the propensity to commute. Occupations also influence commuting choices. Self-employed workers are found to be less likely to commute. Workers in managerial, professional, technical, administrative and construction and trade occupations are found to be more likely to commute. Those in farming, forestry and fishery occupations are less likely to commute. Sales and service occupations, however, are not found to be significantly different in the propensity to commute from the rest of occupations.

Estimates of the covariance σ_{PV} and σ_{CV} are statistically significant. This suggests that wage equation estimates would be biased without controlling for worker's self-selection.

Table 5-2 reports the estimation results of the two earnings equations. For residents employed within the five non-metropolitan counties, gender has a significant

Table 5-1: Reduced Form Probit Equation Estimates from a Switching Regression System of Equations (Employed in the metropolitan area=1)

	System	
	Parameter Estimate	t-statistic
Intercept	-2.372	-6.161**
Gender	-0.337	-3.815**
Married	-0.117	-1.519
No. children <=5	-0.087	-1.451
No. children >5, <16	-0.014	-0.317
Gender and No. children <=5	0.060	0.679
Gender and No. children >5, <16	-0.177	-2.790**
Age	0.018	0.954
Age squared	2.73E-3	-1.229
Born in the State	-0.319	-5.098**
Black	0.282	2.641**
Number of rooms	0.103	5.628**
Homeowner	0.237	3.284**
Recent movers	0.310	4.714**
Income of other household members	0.520E-7	0.049
Hours worked per week	0.010	3.581**
Weeks worked last year	0.012	3.567**
Self-employed	-0.575	-6.026**
Managerial and professional specialty occupations	0.320	3.318**
Technicians and administrative support occupations	0.258	2.754**
Sales and service occupations	-0.122	-1.315
Farming, forestry and fishing occupations	-0.374	-2.298*
Construction and trades	0.296	2.527**
High school	0.017	0.180
Some college	0.187	1.717
College	-0.102	-0.804
More than college	-0.311	-1.804
σ_P^2	0.585	23.985**
σ_C^2	0.651	33.660**
σ_{PV}	-0.656	-10.759**
σ_{CV}	0.702	13.031**
Log likelihood ratio	-2508.508	
No. of observations	1,830	

σ_P^2 and σ_C^2 are variance estimates for the non-metropolitan and metropolitan earnings functions, respectively. σ_{PV} and σ_{CV} are covariance estimates between the non-metro earnings function and the probit equation, between the metro earnings function and the probit equation, respectively.
An asterisk denotes significance in a two-tailed t test at the 5 percent level.
Two asterisks denote significance at the 1 percent level.

negative effect on the wage rate. A female earns 74.7 % of that of a male worker, *ceteris paribus*. Age is non-linearly related to the wage rate. Other things being held equal, a 49-year-old worker has the highest wage. Education has a positive effect on the wage rate. The base is for workers with less than high school education. Workers with higher level of education earn significantly higher wage rates. Compared with workers with less than

Table 5-2: Earnings Equations Estimates from a Switching Regression System of Equations

	Dependent Variable: ln(hourly earnings)			
	Workers employed in the non-metropolitan area		Workers commute to work in the metropolitan area	
	Parameter Estimate	t-statistic	Parameter Estimate	t-statistic
Intercept	0.699	3.721**	1.532	5.584**
Gender	-0.253	-6.155**	-0.270	-5.370**
Age	0.052	5.640**	0.056	3.887**
Age squared	-0.001	-5.099**	-0.001	-2.933**
High school	0.133	2.575**	0.119	1.752
Some college	0.212	3.590**	0.101	1.416
College	0.449	7.323**	0.180	2.270*
More than college	0.675	7.816**	0.472	4.274**
Black	-0.105	-1.782	-0.218	-2.958**
Married	0.081	1.789	0.064	1.132
No. of obs.	1,236		594	

An asterisk denotes significance in a two-tailed t-test at the 5 percent level.
Two asterisks denote significance at the 1 percent level.

Table 5-3: Log-Likelihood Ratio Tests

	Likelihood ratio tests for workplace differences in earnings functions	*2[L(U)-L(R)]*
Base model	-2508.508	
All parameters equal	-2562.041	107.066*
Intercept parameters equal	-2512.296	7.576*
Gender parameters equal	-2508.552	0.088
Experience parameters equal (age, age squared)	-2510.490	3.964
Education parameters equal (high, some college, college, more than college)	-2514.230	11.444*
Racial parameters (black) equal	-2509.357	1.698
Marital status parameters equal	-2508.544	0.072
No. of observations	1,830	

An asterisk denotes significance of the chi-square statistic at the 5 percent level.

high school education, workers with high school education earn 13.3% more. Those with some collage education earn 21.2% more. Those with college education earn 44.9% more. Those with more than college education earn 67.5% more, *ceteris paribus*. Ethnicity and marital status do not significantly affect earnings.

For residents commuting for work in the metropolitan area, gender still has a significant negative effect on the wage rate. A female worker earns 73.0% of that of a male, *ceteris paribus*. Age is also significant. Other things being held equal, a 54-years-old worker has the highest wage rate. Education has a positive effect on the wage rate. Compared with workers with less than high school education, those with college education earn 18.0% more. Those with more than college education earn 47.2% more, *ceteris paribus*. Finally, blacks receive only 78.2% of the wage rate of other ethnic groups. Marital status is not a significant factor.

5.2 Testing for Structural Differences

Log-likelihood ratio tests are conducted to see whether structural differences exist in the returns to personal characteristics for commuting and non-commuting populations. The testing results are reported in Table 5-3. Log-likelihood ratios are calculated for seven hypotheses and compared with the ratio of the base model where no restrictions are imposed. The first hypothesis holds all the parameters equal for commuting workers and non-commuting workers. The second holds intercept parameters equal. The third holds gender parameters equal. The fourth holds returns to work experience represented by age equal. The fifth holds returns to different education levels equal. The sixth holds race parameters equal. The seven holds parameters of marital status equal. Asymptotically, 2[L(U)-L(R)] is distributed as $\chi^2(J)$, where L(U) is the unrestricted log-likelihood ratio calculated from the base model, L(R) is the restricted log-likelihood ratio for each restricted model, J is the number of restrictions. The result shows that returns to gender, age, ethnicity and marital status are not structurally different between the commuting workers and the locally employed workers. However, significant differences exist in intercept parameters, as well as returns to education between the labor markets in the metropolitan and non-metropolitan areas. Overall, the log-likelihood ratio tests suggest that workers received fundamentally different returns on individual characteristics in the metropolitan and non-metropolitan labor markets.

5.3 Wage Determination and Wage Gradients

Wage determination in the metropolitan and non-metropolitan areas is simulated based on the estimates of parameter vectors of working in the metropolitan and non-

Table 5-4: Predicted Wage Rates and Gradients for Specific Individuals

Gender	Age	Education	Race	Marital Status	Predicted wage rate in non-metro areas ($/hour)	Predicted wage rate in metro areas ($/hour)	Wage gradient ($/hour)
Male	**35**	**College**	**White**	**Married**	**10.22**	**20.67**	**10.46**
Female	35	College	White	Married	7.94	15.78	7.85
Male	*20*	College	White	Married	7.25	13.75	6.50
Male	*50*	College	White	Married	11.29	24.59	13.29
Male	*65*	College	White	Married	9.80	23.12	13.32
Male	35	*Less than high school*	White	Married	6.52	17.27	10.75
Male	35	*High school*	White	Married	7.45	19.46	12.01
Male	35	*Some college*	White	Married	8.06	19.10	10.05
Male	35	*More than college*	White	Married	12.80	27.70	14.90
Male	35	College	*Black*	Married	9.19	16.63	7.44
Male	35	College	White	*Not married*	11.07	22.04	10.97

The row with bold letters is for the base worker. Italic letters represent changes from the base.

metropolitan areas. Predicted wage gradient is the difference between the predicted wage rates in the metropolitan and non-metropolitan labor markets. Table 5-4 reports simulation results for predicted hourly wage rates and gradients for specific individuals. A 35-year-old male non-black worker with college education is chosen as a base. If he works in the non-metropolitan area, he receives an hourly wage rate of 10.22 dollars. If he commutes to work in the metropolitan area instead, he receives 20.67 dollars per hour. The base wage gradient is then 10.46 dollars. For other individuals, italic letters represent changes from the base. The table shows effects of gender, age, education, ethnicity and marital status on the wage rates and gradients. For instance, if the worker is female instead, she receives 7.94 dollars in the non-metropolitan area and 15.78 dollars in the metropolitan area, *ceteris paribus.* The female has lower wage rates, in both metropolitan and non-metropolitan labor markets, and a smaller wage gradient of 7.85 dollars than the base worker. Similarly, one can look at the effects of other personal characteristics. All individuals specified in the table are found to have positive wage gradients.

Comparing Table 4-5 with Table 5-4, one may find that the predicted wage gradients are much higher than the observed wage differences. The observed wage differences can not serve as an accurate measure of wage gradient because they are the differences in wage rates between individuals who may have different human capital and structural characteristics. To measure pure wage gradients which are not due to human capital and structural differences, one needs to look at a specific individual, who could get high wage rate if choosing to work in the metropolitan area and low wage rate if choosing to work in the non-metropolitan area. Therefore, the wage gradients controlled for human capital and structural characteristics in Table 5-4 should be a more accurate measurement of pure wage gradients than the observed wage differences from the descriptive statistics presented in Table 4-5.

Remarkable predicted wage gradients exist between labor markets in the metropolitan and non-metropolitan areas, as reflected in Table 5-4. For the 35-year-old male non-black worker with college education, the wage gradient is about 10.46 dollars per hour. If the base worker works 8 hours per day, the daily wage gradient or wage gains would be as large as 83.68 dollars.

5.4 Distance of Metropolitan Labor Market Draw

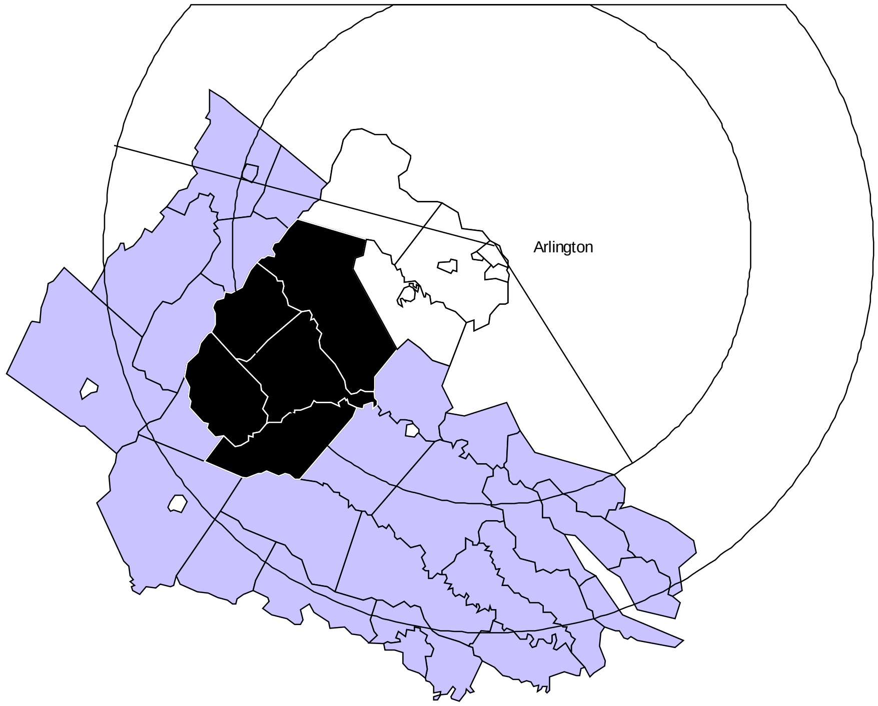
Daily wage gains should equal or exceed commuting costs, which include explicit costs and time value of commuting, if a worker neglects other dis-amenities of commuting. Different workers may put different value on their commuting time. However, the per unit value of the commuting time should fall into a range between non-metropolitan and metropolitan wage rates. Further assume the commuting speed to be 50 miles per hour and the commuting costs to be 0.25 dollars per mile.[4] With these assumptions, we then use the non-metropolitan wage rate to calculate the outer radius of commuting and metropolitan wage rate to calculate the inner radius of commuting through equations (5-1) and (5-2), respectively.

(NonMetroWageRate * 2 * OuterRadius / 50) + (2 * OuterRadius * 0.25)
= HourlyWageGradient * 8 (5-1)

(MetroWageRate * 2 * InnerRadius / 50) + (2 * InnerRadius * 0.25)
= HourlyWageGradient * 8 (5-2)

Given the wage gap between labor markets in the non-metropolitan and metropolitan areas, the outer employment radius is about 92 miles; the inner employment radius is about 63 miles, compared with the observed average commuting distance of

[4] Details can be found in Small (1997).



Most of the study area is within the inner radius of commuting (63 miles).
All the study area is within the outer radius of commuting (92 miles).

Figure 5-1: Simulated Distance of Labor Market Draw of the NOVA and Washington, D.C. Metropolitan Area

around 25 miles for all workers in the sample (Figure 5-1). That is, the central workplace can attract workers living within a radius of 63 miles, if the metropolitan wage rate is used to compute the value of commuting time, and those within a radius of 92 miles, if the metropolitan wage rate is used to compute the value of commuting time instead. The great difference between the observed average commuting distance and the inner and outer radius arise from the dis-amenities other than value of commuting time.

Chapter 6: Policy Implications and Suggestions for Further Study

6.1 Fiscal Implications

Not surprisingly, fiscal implications of the non-metropolitan residents employed in the metropolitan area are an important concern of non-metropolitan policy makers. Below fiscal implications are briefly considered by differences in the number of rooms, ownership status, value of home and the number of children in a household between the locally employed non-metropolitan residents and those commuting to work in the metropolitan area.

The regression results show that workers with more school-aged children are less likely to commute. This means that, on average, the non-metropolitan localities need to spend less money for educational purposes on children of their residents employed in the metropolitan area. Education expenditures of Culpeper, Fauquier, Madison, Orange and Rappahannock Counties reported in Table 6-1 account for more than 72% of total county expenditures in fiscal year 1989-1990. Fewer school-aged children of out-commuters, therefore, are a major relief for local finances of the five non-metropolitan counties. Since the average number of school-aged children is 0.896 for locally employed residents and 0.820 for residents employed in the metropolitan area as reported in Table 4-5, the average resident employed in the metropolitan area demands approximately 7.5% less educational expenses, or at least 5.4% (72%*7.5%=5.4%) less total expenses, from local governments, if each school-aged child costs an equal amount of educational expenses.

Real property taxes account for around 46% of total local revenues of the five non-metropolitan counties according to Table 6-1. The empirical results indicate that workers commuting to work in the metropolitan area are both more likely to own, rather than rent, their house and more likely to reside in houses with more rooms. Non-metropolitan residents employed in the metropolitan area, therefore, typically hold more real property value and supply a larger base of real property taxes for the non-metropolitan governments. According to Table 4-7, on average, each homeowner employed in the metropolitan area has a real property value of about 180,000 dollars while each locally employed homeowner has only about 130,000 dollars. If a real property tax rate of 3% could be effectively imposed, then each year each homeowner

Table 6-1: Education Expenditures and Real Property Taxes of the Five Non-Metropolitan Counties, Fiscal Year Ended June 30, 1990 Unit: Million of Dollars

	Culpeper	*Fauquier*	*Madison*	*Orange*	*Rappahannock*	*Total*
Total expenditures	29.13	56.68	10.86	21.68	6.81	125.16
Education expenditures	21.85	39.52	8.28	16.51	4.28	90.44
Education expenditures as a percentage of total expenditures	75.0%	69.7%	76.2%	76.2%	62.8%	72.26%
Total local revenues	18.38	39.42	5.15	11.17	4.19	78.31
Real Property taxes	7.60	18.45	2.32	4.89	2.38	35.64
Real Property taxes as a percentage of total local revenues	41.3%	46.8%	45.0%	43.8%	56.8%	45.51%

Source: Auditor of Public Accounts, Commonwealth of Virginia, 1991.

employed in the metropolitan area can potentially supply around 1500 dollars more real property taxes than each locally employed homeowner.

Non-metropolitan residents employed in the metropolitan area impose less fiscal burden on the local finances when only educational expenses and property taxes are considered. However, they may impose additional demand for road construction and traffic control, which subsequently require more local expenditures. Spillover effects of these workers on local economies are also reduced since they tend to spend more money in the metropolitan area than those who work locally and spend locally a higher proportion of disposable income (Keeling, 1986). A conclusion that non-metropolitan residents employed in metropolitan areas have a positive effect on metropolitan governments is premature, especially in the long term, without further comprehensive research on other impacts within the local economy.

6.2 Other Policy Implications

Due to the observed congestion in Northern Virginia, local planners may intend to reduce commuting. One way is to remove job-housing imbalance and mismatch due to zoning ordinances which restricted low income households, especially those with more school aged children, from seeking residences in zoned areas on the rationale that these households demand for more local services than they contribute to local revenues

(Burnell, 1984). These ordinances unnecessarily caused job-housing imbalance and mismatch. This limitation of zoning ordinances has been addressed by some researchers (e. g. Cervero, 1986) and already been modified by many local planners. Increases in commuting due to job-housing imbalance and mismatch can be minimized by appropriate planning. For example, housing development policies should be such that housing prices and quantities in job concentrated areas or nearby match the demand of workers holding jobs these areas.

As analyzed at the end of Chapter five, significant differences exist in returns on human capital characteristics between labor markets in the metropolitan and non-metropolitan areas. Therefore, another way to reduce commuting is to decrease the substantial wage gradients by improving poor labor markets in the non-metropolitan area and attracting well paying businesses to settle into the area or supporting the improvement of existing ones. When deciding where to locate or relocate, firms usually look for places with a low rate of business tax, a high level of public services, a close approximation to raw materials and markets, and a well matched labor force. Although all these considerations are important, the lack of a closely matched labor force often discourages firms from locating in the non-metropolitan area. Firms will be willing to stay in or relocate to the non-metropolitan area when qualified workers are available in these areas. However, many communities in the five non-metropolitan counties are primarily concerned with preserving the rural character of their locality and may actively oppose development of local labor markets. Furthermore, if improved labor markets in the non-metropolitan area are accompanied by a loss of rural character, additional commuting can occur when workers preferring large space and beautiful scenery move further out. Therefore, while improving non-metropolitan labor markets is necessary to reduce commuting, preserving rural character is perhaps at least equally important.[5]

Non-wage factors are not less important than the remarkable wage gradients. Household responsibilities and preferences are main factors in determining implicit costs of commuting. Workers with greater household responsibilities have higher implicit costs of commuting and prefer to work near their homes. Gender, the number of children in a

[5] Other policies such as slight compensations and taxation to reduce wage gradients can hardly be effective because of the huge wage gaps.

household and marital status are used mainly to represent household responsibilities. Females and females with more children between 6 and 15 are found to be less likely to commute. Both ownership status and the number of rooms occupied by the household represent household preferences. Homeowners are found to be more likely to commute. The number of rooms is found to be positively related to the propensity to commute. Understanding the influence of these characteristics on the propensity to commute is important for local planning, although the policy mechanisms for controlling commuting may be relatively limited.

Finally, some groups face significant constraints to job acquirement in labor markets in either the non-metropolitan or the metropolitan area. For instance, black workers, recent movers and those who were not born in Virginia are found to be more likely to commute probably due to difficulty in finding jobs in the non-metropolitan area. Therefore, policies removing labor markets segmentation and helping workers quickly find satisfactory jobs in the non-metropolitan area are also potential ways to reduce commuting.

6.3 Suggestions for Further Study

Most research to date has emphasized commuting patterns within metropolitan areas. More studies are necessary to increase our understanding of commuting decisions of non-metropolitan residents. Data is available to conduct a similar analysis of commuting decisions of households in other areas of the country, including both non-metropolitan and metropolitan areas.

This study assumes exogenous residential location. However, households usually simultaneously determine residential and job locations. A model incorporating a residential location choice equation into the system of equations in this study can make residential location endogenous. In the new system of equations, residential location choice could be a binary choice variable, which is zero for non-metropolitan areas and one for metropolitan areas, as is workplace choice in this study. When a household chooses residential location, residential characteristics such as school quality, crime rate, neighborhood, scenery and access to shopping centers can serve as explanatory variables. However, incorporating these variables requires a larger data set across many counties.

Development of a model with endogenous residential and workplace locations requires further research.

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