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REPORT ON TRENDS AND CONDITIONS RESEARCH

POPULATION ADJUSTMENT TO TRANSPORTATION INVESTMENT AND TRANSPORTATION PLANNING

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Population Adjustment to Transportation Investment and Transportation Planning

EXECUTIVE SUMMARY

Florida's 2020 Transportation Plan clearly states Florida's Transportation Mission and focuses on the need to plan for future growth. Indeed, Florida has been at the forefront of modern growth management efforts. However, planning for the future in a highly populated, dense, and rapidly growing state like Florida is a truly Herculean task. While it may be possible to have better policies for dealing with growth in some areas, indeed the objective of this report is to help FDOT and Florida with long-range planning efforts, those who complain that Florida does not do enough to plan for or manage growth should realize these facts.

How to achieve Florida's Transportation Mission—which is essentially to maximize the net benefit of Florida's transportation investments to the state's residents—depends upon whether the regions of Florida are fully open economies or partially closed economies. In a fully open economy, households and firms migrate rapidly across regions in response to policy decisions or other changes in basic conditions that make one region more or less desirable than others. A large body of academic economic evidence suggests that regional economies in the United States are fully open. Even though Florida's 2020 Transportation Plan explicitly states that the state will make investment decisions to respond to trends in population growth so as to maximize its goals, it makes no mention of any impact of road investment on the level of Florida's population, and indicates no mechanism for dealing with such an effect in its long-range transportation planning efforts. Thus, at best, Florida's 2020 Transportation Plan does not clearly set forth a framework for dealing with the linkage between population and transportation investment in an open economy. At worst, significant parts of Florida's 2020 Transportation Plan appear to treat population as closed with respect to transportation infrastructure in the sense that the amount of future population growth is determined entirely by factors outside the influence of transportation policymakers

A planning approach in which population is not taken as explicitly adjusting to transportation investment leads to the conclusion that transportation investment—by making firms more productive and attracting better jobs but not attracting more workers—boosts Florida's real wages relative to the Nation's. Investment patterns that are optimal if Florida's economy is partially closed will not be optimal if it is fully open. Accurately evaluating the benefits of transportation investments requires knowing how they affect population growth.

This suggests three questions. First, does Florida's population respond to transportation investments quickly relative to the life of transportation investments? Second, how should transportation planning account for such a response in trying to maximize net benefits to Floridians—that is, what is the difference between planning for Florida in an open, versus a closed or partially closed, framework? Third, is the difference between investment decisions under the two frameworks large enough to worry about? In this report we seek to answer these questions.

In answer to the first question, we find that the elasticity of state level population with respect to state road capital stock lies between .23 and .59, with .4 being our best estimate. This means that, all else equal, a 10% increase in Florida's stock of quality adjusted highway infrastructure will increase Florida's population by 4%. This finding is highly significant statistically and is quite robust to alternative empirical specifications.

> *We find that a 10% increase in quality adjusted state highway infrastructure causes between a 2.3% and a 5.9% increase in total state population, with 4% being our best estimate. Thus, we estimate the elasticity of population with respect to road capital stock to be approximately 0.4.*

In answer to the second question, we find that how transportation investment options are evaluated is quite different conceptually if the decision maker adopts an open economy perspective instead of a closed, or partially closed, economy perspective. In an open economy, the lion's share of the net benefits of state transportation investments to state residents (as opposed to spillover benefits the rest of the nation) are reflected in increases in property values. Residents that own businesses with monopoly power in local markets may also benefit. Other sources of potential benefits to the state's residents are competed away by migration of workers and firms. On the other hand, if population is closed with respect to transportation infrastructure, transportation investments boost wages and reduce commuting costs without attracting more workers to compete with existing residents for the better jobs or re-congesting roads. Thus, the evaluation of the benefits of transportation investment is quite different between open economy and closed economy (or partially closed economy) approaches.

In answer to the third question, we find that the loss of net benefits to Florida's residents from making transportation decisions as if the economy were partially closed could be quite large. Further, as indicated above, the benefits of transportation investments must be evaluated in terms of their impacts on rent gradients - the levels and patterns of land rents in urban areas. Most other potential sources of net benefits to Florida's residents will be competed away by migration of firms and households. Thus, the difference between the two frameworks is significant enough that Florida's planning efforts are likely to be helped by being explicit about the relationship between transportation infrastructure investments and population.

> *We find that a regional open economy framework is the appropriate setting in which to formulate Florida's transportation investment policy. Further, the benefits of Florida's transportation investments to the state's residents (as opposed to spillover benefits) must be measured explicitly through their impact on aggregate property values.*

This is both good news and bad news. The good news is two-fold. First, it is possible to articulate a clear framework for thinking about the benefits and costs of Florida's transportation investments. Second, it is relatively straightforward to estimate the economic benefits of Florida's transportation investments to Floridians in this open economy framework (not the total benefits, which include spillovers to the rest of the nation). The bad news is that this framework, which is the only one consistent with economic theory and empirical evidence, appears to be at odds with parts of the framework embodied in Florida's 2020 Transportation Plan. Among advanced economies, the United States is regarded as the one with the most flexible labor markets. Transportation planning not based explicitly on an open regional economy approach contradicts that fundamental view of a major strength of our economy.

If we are correct that a regional open economy framework is appropriate for making transportation investment decisions, FDOT may wish to hire a regional economist. We recommend a full-time position so that the economist will master transportation issues, enabling him or her to interact easily with other FDOT planners and to make useful presentations to advisory and legislative committees. If a full time position is not established, FDOT may still wish to bring in expert regional economists to make presentations to advisory and legislative committees when major investment decisions are to be made. This, at least, would help to provide a useful framework for thinking about such decisions.

In a related topic, we also consider the impact of uncertainty associated with population projections on transportation investments. We find that the confidence intervals for state and metropolitan statistical area level population projections based upon our regional open economy equilibrium approach are quite narrow. Similarly, recent related research by the Population Program of the Bureau of Economic and Business Research has resulted in narrower confidence intervals for BEBR's population projections in 2002 (Smith and Nogle, 2002) than in the past. The impact of this form of uncertainty will be less important than the gain from using the open economy framework and estimating the responsiveness of population to transportation infrastructure investments correctly. Nonetheless, additional work to quantify the exact effects of uncertainty on Florida's optimal transportation investments may be useful.

1. INTRODUCTION

Florida is the fourth most populous state in the nation. Of the three more populous states—New York, Texas, and California—only New York has more people per square mile, and none have grown faster than Florida since 1940-1950, when California did. Florida's rapid growth has placed high demands on public infrastructure of all types. While Florida has been a national leader in growth management efforts, residents, analysts, interest groups, and decision makers commonly voice their displeasure with what they perceive to be problems created by failing to plan adequately for this rapid growth. It is easy to find examples of such complaints. As one example, Jacksonville's Mayor John Delaney contends government does not think long term and cites cases in Orlando and Jacksonville in which a slightly larger investment in a transportation project in the recent past would have resulted in vast savings today (Delaney, 2002). As another example, a recent article in Florida Trend (Klas, 2002) about the recent creation of the Florida Turnpike Enterprise and relaxation of rules governing toll roads in Florida cites Audubon of Florida's senior vice president chastising politicians and decision makers at the Florida Department of Transportation (FDOT) for being unwilling to make hard decisions about growth in Florida.

While it may be possible to improve planning efforts in some areas, it must be recognized that the issues involved are complex and making useful long-term plans and then implementing them is a Herculean task, even with the most farsighted planners and politicians. This is particularly true when it comes to planning for and carrying out transportation investment projects in Florida. While government agencies in all states face budget constraints, Florida's rapid growth coupled with the fact that it is a net donor to the Federal Aid system means that FDOT faces a more difficult task than other state transportation departments—it must plan for a transportation system for one of the largest, densest, fastest-growing states in the nation while subsidizing the rest of the nation's transportation system.

FDOT's task is also harder than that faced by many other agencies in Florida for two reasons. First, transportation investments are so long-lived that today's investments will impact our state many decades into the future. Second, since major transportation projects take many years from initial stages to completion, it is very difficult to respond to new needs as they arise and planning far ahead becomes particularly crucial. These facts shape Florida's 2020 Transportation Plan. Page 12 of Florida's 2020 Transportation Plan calls for careful cooperation and coordination among state, metropolitan, and local planning agencies, and Page 9 calls for investing only after understanding the economic consequences and for coordinating transportation and land use decision making in order to maximize the efficiency of the transportation system. These and similar statements in Florida's 2020 Transportation Plan appropriately emphasize the need to carefully husband Florida's transportation resources.

To accomplish its difficult task of planning to invest in transportation infrastructure in the most beneficial way, in a rapidly growing state, while on a very limited budget, decision makers at FDOT need clearly defined goals and an appropriate framework for thinking about the impact of transportation investments in Florida. In broad terms, Florida's 2020 Transportation Plan sets out the state's transportation goals and FDOT's framework for thinking about transportation policy decisions. The state's broad goals are summed up in the following mission statement:

Florida's Transportation Mission

> *Florida will provide and manage a safe transportation system that ensures the mobility of people and goods, while enhancing economic competitiveness and the quality of our environment and communities*. (Florida Department of Transportation, 2000)

In essence, the mission is to maximize the net benefits of Florida's transportation system to its residents.

Regarding the framework in which these goals are to be pursued, Florida's 2020 Transportation Plan stresses looking to the future, especially anticipating future population levels and planning to meet the resulting transportation demand before it arrives, thus addressing the spirit of much past criticism of Florida's transportation planning. The first graphic in the plan, which comes even before the introduction, lists Florida's population by decade including projections through 2020. On the next page, the introduction emphasizes the fact that the system will need to serve a projected population of 21 million residents by 2020. This is also reflected by the prominent position of population projections in previous Trends and Conditions Reports published by FDOT. In fact, the introduction to Florida's 2020 Transportation Plan explicitly states "The goals and objectives in this plan form a policy framework to guide critical investments in Florida's 21st Century transportation system to respond to this growth in a manner that strengthens our economy, provides mobility choices for all and supports our environment and communities." Thus, the approach seems to be to plan for projected growth so today's investments will be responsive not only to deficiencies arising from events in the past, but also to expected population growth.

There are two basic frameworks for thinking about policy decisions taken by particular states or localities that are part of a larger economic system. The first is to think of the region as a closed economy. In this view, while the region may have important ties to the broader system when viewed over a long enough and broad enough horizon, the composition of the region's population, its industrial mix, and other similar economic variables, are taken to be predetermined from the point of view of the region's decision makers, or as inputs to the decision making process. The second is to think of the region as an open economy. In this view, all such economic variables are allowed to adjust according to the preferences and abilities of the underlying economic agents (households and firms). That is, households and firms migrate rapidly across regions in response to policy decisions or other changes in basic conditions that make one region more or less desirable than others. Of course, combinations are possible in which some variables respond quickly to the policy being considered (relative to the lifetime of the policy's impacts) while other variables respond slowly or not at all.

Open economy models are also what economists refer to as general equilibrium models, in which all related markets are allowed to adjust to equilibrium, thus the equilibrium is general. Closed or partially closed models may be general equilibrium models or partial equilibrium models. For example, a model may be fully closed in the sense that neither workers nor capital migrate between regions, but general equilibrium in the sense that wages, the price of capital, the price of land, and prices within all related markets within each region adjust to supply and demand conditions within the region. If we modified the same fully closed model by taking all prices except wages and land prices as fixed at levels determined outside the model, we would have a closed economy partial equilibrium model.

While Florida's 2020 Transportation Plan explicitly states that the state will make investment decisions to respond to trends in population growth so as to maximize its goals, it makes no mention of any impact of road investment on the level of Florida's population, and indicates no mechanism for dealing with such an effect in its long-range transportation planning efforts. Further, the population projections in FDOT's Trends and Conditions Reports have been drawn from the U.S. Census Bureau and BEBR's published population projections. These treat Florida's population as if it were closed with respect to the state's transportation investment decisions, in the sense that they make no effort to indicate how sensitive the projections are to alternative infrastructure policies.[1] Thus, it would appear that the Florida 2020 Transportation Plan either treats the state's economy as closed when it comes to potential effects of transportation investments on population, or that at least, Florida lacks a clear framework for thinking about such effects.

However, the goals stated in Florida's 2020 Transportation Plan also clearly indicate that transportation planners think transportation investments will have important impacts on Florida's economy. One example is the mission statement, which clearly expresses the view that transportation investments can impact Florida's economic competitiveness. Another example may be found on Page 5, which points out that Florida has relatively low wage jobs and states that the transportation system is "key to Florida's economic prosperity …" Since transportation investments improve connectivity between individual cities of Florida and the rest of the nation, it is certainly reasonable to expect that transportation investments make Florida a more desirable place for firms to locate, either making existing firms more profitable or bringing in new firm's with better jobs, or both. What this possibility means for the state depends crucially on whether the state's population adjusts to transportation investments. If population adjustment to transportation investment—that is, adjustment of the national workforce to economic opportunities created by Florida's investments in transportation infrastructure—is ignored or takes place very slowly, transportation investments appear to be a way to bring in a better mix of jobs for Florida's growing population, making its residents safer, more mobile, and richer.

The effort at planning for the future reflected in Florida's 2020 Transportation Plan is commendable. Indeed, Florida and FDOT are national leaders in this area. Those who criticize the state for being shortsighted in its transportation investments should not ignore this fact. However, even though the plan does an admirable job of setting out the state's transportation goals, the approach taken to accounting for future population and labor mobility is seemingly at odds with modern understanding of the way regional economies work. Among advanced economies, the United States is regarded as the one with the most flexible labor markets. Transportation planning based on a closed regional model contradicts that fundamental view of a major strength of our economy.

A large body of published economic evidence suggests that Florida's economy should be treated as fully open when it comes to planning for transportation investments—that is, population will adjust relatively rapidly to transportation investments. Blanchard and Katz (1992) argue that the state level labor force (thus population) adjusts almost fully to economic shocks in less than a decade, in fact adjusting more rapidly than the capital stock (firms). Barro and Sala-i-Martin (1992) show that per-capita incomes across states have tended to converge over time. Gyourko and Tracy (1989, 1991) reveal that housing costs and wages adjust to account for local public goods provision. These four works are only examples—there are too many others to list.

[1] Denslow and Dewey (2000) discussed the methodology behind these sources in previous Trends and Conditions research for FDOT.

No econometric work that we know of specifically examines the response of regional population to regional transportation investments, although a growing body of evidence shows that aggregate regional vehicle travel responds to regional transportation investments, a phenomenon known as induced travel demand. Hansen and Huang (1996) Goodwin, Hass-Klau, and Cairns (1998), and Noland (2001) are examples of this line of research.

This suggests three questions. First, does Florida's population respond to transportation investments quickly relative to the life of transportation investments? If so, how should transportation planning account for such a response in trying to maximize net benefits to Floridians—that is, what is the difference between planning for Florida in an open versus a closed or partially closed framework? And last, is the difference between investment decisions under the two frameworks large enough to worry about? In this report we seek to answer these questions.

In answer to the first question, after carefully constructing a quality-adjusted measure of state-level road capital stocks for the 48 contiguous states, we find that the elasticity of population with respect to the level of road capital stock is .4. This means that a 10% increase in Florida's transportation infrastructure causes a 4% increase in Florida's equilibrium population. This finding is highly statistically significant and is robust to alternative empirical specifications.

We find that the elasticity of population with respect to road capital stock lies between 0.23 and 0.59, with 0.4 being our best estimate.

In answer to the second question, in a fully open economy the lion's share of benefits of transportation investments to the state's residents accrue to property owners (home owners, apartment landlords, owners of commercial and industrial sites, and owners of undeveloped land on the region's fringe) in the form of increased property values, and firms with monopoly power in the form of increased sales for their products. This happens because workers will continue to move into the state as long as the mix of wages, the cost of living, and quality of life, including congestion, is higher in the state than elsewhere. Thus, a high degree of labor mobility assures that both before and after any change in Florida's transportation infrastructure, the marginal workers—that is, the workers that determine local wages housing prices—will be indifferent between living in Florida and living in another state. If this were not the case, more workers would move into or out of Florida. Thus, the net economic effect on residents of the state (in their role as workers, not as property owners) must be approximately zero. Thus, all sources of potential gains other than increases in property values and increases in profits to firm's with market power are eliminated by migration (though some gains will accrue to the residents of other states that will be marginally less congested).

In a partially closed economy, as apparently reflected by at least significant portions of Florida's 2020 Transportation Plan, transportation investments increase perceived net benefits by boosting labor incomes, reducing the user cost of dwellings, and reducing aggregate transportation costs in addition to impacting property values and firm profits. This is because, since population does not adjust rapidly when transportation infrastructure is increased, congestion falls and firms find themselves competing for a fixed supply of workers in what has become a more attractive environment in which to do business. Thus, mistakenly choosing investments to maximize net benefits in an economy perceived as partially closed when it is actually open systematically moves transportation investments away from their optimum level because it results in an incorrect tally of benefits and costs. Thinking in terms of a partially closed economy model means that decision makers will tend to think about managing growth that is forecast to occur at a particular rate. Thinking in terms of a fully open economy means that decision makers will tend to think about trying to guide the economy to the best mix of workers, firms, and transportation infrastructure, realizing that their decisions have effects upon all three, but that those effects are not independent of one another and that any change in infrastructure will, in turn, impact the number and distribution of firms in a way that is dictated by the workings of the modern U.S. economy.

A decision maker using a partially closed approach might focus on projected growth in Vehicle Miles Traveled (VMT) and conclude that Florida needs to plan to accommodate or manage increased travel demand. On the other hand, a decision maker thinking in terms of a fully open model would realize that the projected increase in VMT was based upon a particular projected increase in Florida's population, and that any effort to accommodate this increase in VMT by adding infrastructure or by managing traffic so as to increase the effective amount of infrastructure will in turn further increase VMT. Thinking form this perspective, the decision maker would seek to help guide the state to the combination of VMT and lane-miles that would result in the highest net benefit for Florida's residents, meaning higher property values and more profits for firms with market power. The decision maker would make this is calculation realizing that they had the ability to influence both VMT and the effective amount of infrastructure, but that only one level of VMT is consistent with any particular level of infrastructure in equilibrium, and that the relationship between the two is dictated not by policy decisions but by economic relationships over which they have only indirect influence.

As another example, a decision maker thinking from a partially closed perspective might see published evidence of links between job and income growth and conclude state highway investments are justified because of the economic growth they might bring. On the other hand, a decision maker thinking from the perspective of an open economy model would know that such results do not have any direct bearing upon whether the state's residents are made better off or worse off in the lung run by transportation investments and would not be distracted by what she felt to be irrelevant information. If an open economy model is the best approximation of the state's economy for transportation investment purposes, the well being of workers that are not property owners will be equal to the national average both before and after the investment. Instead, the relevant concern is whether or not the wealth of homeowners and other property owners and the profits of businesses with market power will increase enough to offset the costs of the investment.

Finally, to answer the third question, we construct a very simple mathematical model of the net benefits to Florida from transportation infrastructure investments. Within the framework of this model, we calculate the value of infrastructure investment that would maximize these net benefits if the economy were fully open. We also calculate the level of infrastructure that would maximize net benefit if the economy were fully closed. We then compare the level of net benefit that would result if infrastructure were to maximize benefits as if the economy were fully closed when it is actually fully open. The percentage loss of net benefit will be small if the effect of transportation investments upon the per-mile cost of travel is small. But in this case, transportation policy would not be of crucial importance anyway. As the impact of transportation infrastructure on per-mile travel costs becomes large, so does the percentage loss from adopting the wrong framework as a guide to investment decisions. For example, if a 10% increase in transportation infrastructure would results in a 3% reduction in per mile transportation costs, we estimate that 40% of potential net benefits would be lost if investment decisions were consistently based upon a closed economy framework when the state's economy is actually open. Thus, we find that the difference between outcomes under the fully open economy framework and the closed economy framework is probably significant and may be quite large.

Taken together, these answers imply that transportation planning that does not explicitly account for the response of population to investment decisions will not maximize net benefits to Florida's residents. Further, since the only benefits that are not competed away by migration occur in changes to the region's rent gradient, even models that allow for migration in response to investments will provide at best misleading estimates of the benefits of transportation investments if they do not explicitly focus on property values and profits to firms with local market power.

This is both bad news and good news. The bad news is that this framework—which is the only one consistent with economic theory and empirical evidence—appears to be at odds with parts of the framework embodied in Florida's 2020 Transportation Plan. The good news is two-fold. First, it is possible to articulate a clear framework for thinking about the benefits and costs of Florida's transportation investments. Second, it is relatively straightforward to estimate the economic benefits of Florida's transportation investments to Floridians in this open economy framework (not the total benefits, which include spillovers to the rest of the nation).

> *We find that a regional open economy framework is the appropriate setting in which to formulate Florida's transportation investment policy. Further, the benefits of Florida's transportation investments to the state's residents (as opposed to spillover benefits) must be measured explicitly through their impact on aggregate property values.*

There are a number of technical ways in which this finding might be used to help formulate Florida's transportation policy. The most immediate and easily implemented recommendation that comes from our analysis is, however, not technical. When the state forms committees to evaluate transportation policies, it typically spends time and effort, perhaps by bringing in outside experts to give presentations, to educate the committee members on relevant issues and data. Since we have found that a regional open economy framework is the most appropriate for making transportation investment decisions, we recommend that someone be brought in to provide grounding in regional economics, including the impact of transportation investment on population, when Florida makes transportation investment decisions. FDOT may wish to hire a regional economist. A full-time position would allow the economist to master transportation issues, enabling him or her to interact easily with other FDOT planners and to make useful presentations to advisory and legislative committees. If a full-time position is not established, FDOT may still wish to bring in expert regional economists to make presentations to advisory and legislative committees when major investment decisions are to be made. This, at least, would help to provide a useful framework for thinking about such decisions.

The report addresses one additional issue—uncertainty. Since transportation investments are sizeable and long lived, it is important to consider the impact of uncertainty when making investment decisions. In particular, uncertainty might lead to slower investment by prompting decision makers to wait until growth actually occurs rather than trying to build ahead of the curve so that investments never turn out to be wasted. In the past, the confidence intervals associated with BEBR's county level long-term projections were quite wide, reflecting a significant possibility that several of Florida's counties might lose population. However, these confidence intervals were based upon national error distributions. Recent work by BEBR's Population Program has narrowed these intervals considerably. We consider appropriate population confidence intervals in the context of road building in Florida. We find that these confidence intervals are also quite narrow. Therefore, while additional work is needed for a more precise evaluation, we think the impact of uncertainty on optimal investments will be small.

The remainder of this report is organized as follows. Section 2 examines why population might adjust rapidly to transportation investments and defines the Road Capital Stock (RCS) Elasticity of Population as our measure of this response. Section 3 presents both our empirical strategy for trying to determine whether or not population actually adjusts rapidly to transportation investments and our empirical results. Section 4 considers the implication of our finding of positive RCS Elasticity of Population for transportation planning and policy in Florida. Section 5 quantifies the degree of uncertainty associated with our suggested population projection method. Section 6 concludes and points out where more work is needed. Sections A1 and A2 contain appendices that present more technical details of our empirical methods and findings on the impact of infrastructure on population levels and uncertainty, respectively.

2. THE ROAD CAPITAL STOCK ELASTICITY OF POPULATION

Fundamentally, Florida's transportation system moves people and goods from where they are to where they want or need to be. It is often convenient to think of this basic function in two parts—providing connectivity or mobility between cities or other broad geographic areas such as counties or metropolitan statistical areas (MSA's) and providing access to particular destinations within a broad area, such as particular shops or neighborhoods within a city. In order to provide this connectivity and access, the transportation system must link areas *between* which people travel with enough capacity to allow for reasonably efficient movement and also provide a sufficient network *within* areas to provide each area's populace and visitors with access to sites within the area. Providing connectivity between areas is important to businesses who need inputs from suppliers in other areas and who need to get their products to markets in other areas as well. Doing a better job of providing this connectivity makes Florida a more attractive place to do business. Providing better access within an area allows workers to commute more easily to their jobs and to shopping or recreational destinations. This in turn makes a wider choice of housing arrangements feasible, allowing people to get a better job/housing match, and ultimately holds down effective housing prices (the combination of the user cost of housing and commuting time from the location chosen) by increasing the supply of land available for residential use within any given commuting time of an urban area. Doing a better job of providing this type of access makes an area a more desirable place to live for its residents. By improving connectivity and access, FDOT makes Florida a better place to live and to do business. That is why making the most of limited transportation dollars is appropriately considered to be a high priority by government agencies at all levels.

Why might changing the level of transportation infrastructure alter population growth patterns in important ways? There are two primary reasons. First, if the additional lane-miles improve connectivity between regions, they will increase productivity, making the area more attractive to firms and increasing the demand for workers. Second, adding lane-miles, holding population constant, allows more rapid commuting and/or commuting from longer distances within regions—that is, it improves access within cities or areas. This generally reduces the marginal effective price of *residential* land within the area (including monetary costs and commuting time). The initial decline in the effective cost of land attracts additional residents until it has been offset by an increase in the demand for land and increased congestion.

There are two non-response cases (neither of which is likely to characterize any of Florida's urban areas) in which transportation investments might not reduce the effective price of land. One occurs when population is so small relative to the existing road network that the supply of cheap land near the urban area is so large that all residents can be accommodated while leaving a significant amount of land in agricultural uses within a minimal commute of the city. In this case, no one would want to build roads anyway. The second occurs when all roads are nearly 100% bond-financed and the access improvement engendered by the new construction is small. The increased tax burden placed on future residents will lower the price a developer can get for land converted from agricultural uses. However, even if 100% of the project is bond-financed, new residents attracted by the investment will be a small portion of the future population and thus, will pay only a fraction of the burden anyway. Therefore, only improvements that are very bad investments anyway—so that the value of the road is far less than the cost of building it in aggregate—will result in no additional land conversion. As an aside, we note that it would also be possible to redevelop residential land at a higher density—the relevance of our discussion is not limited to cases where there is a significant amount of developable land waiting in the wings. Denslow and Dewey (2000) show that more roads per person produce statistically and economically significant decreases in the cost of living both across the cities of the nation and across the counties of Florida, and that median land costs are lower across the counties of Florida when there are more roads per person. The evidence confirms our assertion that neither of the non-response cases applies to the cities and counties of Florida.

How do we measure this effect? Demographers divide population growth in any particular geographic area into two components—natural increase and net migration. Natural increase is simply births minus deaths. The rate of growth due to natural increase shows relatively little variation across areas, although fertility and mortality rates do vary somewhat with age composition. This component is relatively straightforward to predict since the composition of the current population by age is known. Net migration, the difference between in-migration and out-migration, is by far the more variable component, and in fast-growing states such as Florida it is by far the larger component of population growth. Numerous studies have examined the determinants of migration flows.[2] In general, net migration depends upon factors such as wages, unemployment rates, the cost of living (especially housing costs), and amenities such as weather and proximity to the coast.[3]

To predict net migration, two strategies are available. The first is to model the relationship of migration flows to their causes and use predicted future values of the determinants of migration to predict migration. This requires an accurate model of migration flows and an accurate way of predicting the future values of the determinants of migration flows. The second method is to simply extrapolate future migration flows from past migration flows. The extrapolation need not be linear, and it can build in regression to the mean and allow for different extrapolative rates between different pairs of geographic regions. The advantages of this method lie in its simplicity. First, it requires no modeling of the relationships that underpin migration flows. Therefore, it eliminates a number of sources of complexity and error. Second, it needs only minimal data since it requires no additional modeling to predict the future values of the variables that, in turn, determine migration. These advantages are gained by assuming that any factors that determine migration will remain relatively constant over time, or at least their future trend will resemble the past. If a user has no reason to think that this assumption will be violated, projections based upon this methodology can be very useful.

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[2] See, for example, Greenwood, Hunt, Rickman, and Treyz (1991) and Graves and Waldman (1991).

[3] One objection is that in-migrants might lack full information about some of these characteristics—for instance, housing costs or relative tax burdens. Even if this is so, out-migrants will have very good information on such characteristics, so net-migration will depend upon these characteristics.

The population projections from BEBR and the Census Bureau that FDOT has used in the past are based on the extrapolative method. However, suppose FDOT wishes to evaluate the consequences of alternative investment strategies. Any investment program that deviates from past investment trends will cause connectivity between areas and/or access to destinations within areas to change in ways that deviate from past trends. Therefore, conditions in labor markets and housing markets will diverge from trend, in turn, causing net migration to deviate from the extrapolated trend. Thus, if transportation investments make an area a more desirable place to live or to do business, population projections based upon extrapolative techniques cannot be used to evaluate the consequences of alternative transportation investment strategies since a key assumption underlying the extrapolative projection is violated. Increasing transportation investments above trend in an area will make that location more desirable and increase population above the level indicated by the extrapolation that assumed only trend growth in transportation infrastructure.[4] Of course, if the net effect of the investments on in-migration is small enough, ignoring it will cause no significant problems. If, however, it is substantial, ignoring it could lead to planning that is significantly sub-optimal.

We define the RCS Elasticity of Population as the percentage change induced in the equilibrium population of a region when the region's RCS is increased by 1%. We will let *a* denote this elasticity at various places in our presentation. To see clearly what this elasticity will represent, consider the following example. Suppose a committee is concerned with the fact that as of 2000, Florida had 5.7% of the nation's population but only 3.1% of the nation's lane-miles, or 16 lane-miles per 1,000 residents, compared to 29 nationally (Florida is similarly below the national average on other, broader, quality-adjusted measures of the highway capital stock). Although Florida is not the largest state geographically, it is not small (it is the median in terms of land area). Thus, even allowing for fairly extreme economies of density, they find it hard to imagine that it is "efficient" from the national perspective for Florida to be this far below the national average RCS, given the importance of transportation in moving goods to customers, workers to jobs, and opening up land for homes in desirable locations.

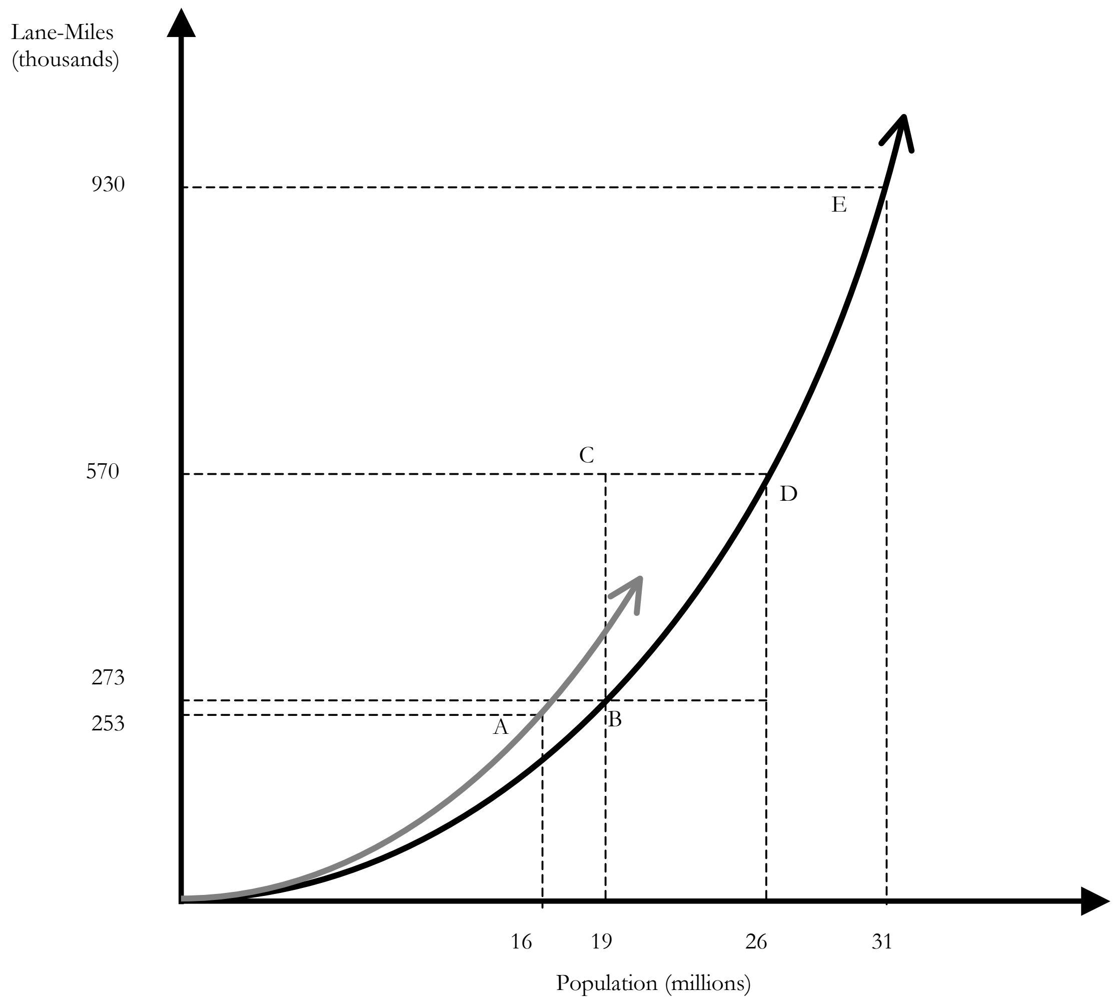
Feeling that Florida should not be so far below the national average on any measure so important, our committee is considering pushing for funding to increase Florida's lane-miles per 1,000 residents to 30 by 2010. Since the national average has been falling, this should put Florida safely above the national average. While this calls for an initial increase of approximately 227,000 lane-miles, the committee realizes that Florida's population will continue to grow rapidly, so Florida would have to construct lane-miles at a faster rate than it has in the past in order to maintain this target. The committee might consult BEBR's estimates of Florida's 2010 population, 19 million (Smith & Nogle, 2002), to estimate how many additional lane-miles would be needed by 2010—317,000 to bring the total to 570,000. The 317,000 additional lane-miles they are considering pushing for will prove to be very costly to build over 10 years, and it is doubtful they will get Florida to their goal of 30 lane-miles per 1,000 residents. This is because BEBR's published projections are explicitly based on the assumption that trends and conditions underlying past population growth will remain unchanged. This includes trends in location preferences, standards of living, and the provision of important government services. Since 1980,

[4] To some extent this depends upon the financing mechanism. If all transportation infrastructure were bond-financed and the bonds were to be paid back through gas tax and/or property tax revenues collected after the project were completed, this effect would be smaller since the extra taxes paid by residential use relative to agricultural use would reduce the rate of land conversion because the future tax payments would be capitalized into the price of land once converted. In this case, transportation investments that had little impact might actually make the area less desirable due to the tax burden. In practice, however, the state and local share is not 100% bond-financed and the Federal government pays a sizeable share. Most actual road investment is likely to make the area more desirable to potential migrants.

Florida has built only about 2,000 lane-miles per year, so their investment program represents a clear violation of the assumptions under which the projections would be valid. Essentially, BEBR has projected that population will grow to 19 million *if* Florida builds about 20,000 additional lane-miles in the next 10 years.

We depict the situation graphically in Figure 1. Population is measured on the horizontal axis and lane-miles on the vertical. The curve through point A represents the relationship between equilibrium population and lane-miles in 2000 if the RCS Elasticity of Population is .4 (assuming lane-miles are closely related to RCS). The curve through B, D, and E depicts the same relationship in 2010. The second curve lies to the right because the national population will be higher in 2010. The curves show that as lane-miles increase, so will equilibrium population in an open economy. Equilibrium population increases with RCS, but at a diminishing rate since we have assumed the elasticity is less than 1 (later we find this to be reasonable). In this case, a region's population will not explode as transportation infrastructure is increased.

Figure 1. Road Stock Elasticity of Population



In Figure 1, we begin in 2000 with 16 million residents and 253,000 lane-miles at point A. The usual trend would take Florida to approximately 273,000 lane-miles and 19 million residents by 2010, point B, at which there are 14 lane-miles per 1,000 residents. If Florida does build

297,000 lane-miles beyond trend, hoping to land at point C, additional in-migration due to building roads more rapidly than trend will instead leave us at point D with 26 million residents and 22 lane-miles per 1,000 residents—8 less lane-miles per 1,000 residents than hoped for and 7 million more residents than expected. Reaching the goal of 30 lane-miles per 1,000 residents would require 930,000 lane-miles (total) and would result in an equilibrium population of 31 million at point E in the Figure.

Of course, keeping lane-miles per resident above the national average is not the primary goal of transportation policymakers. While Level of Service (LOS) within a geographic area is affected by infrastructure—in the sense that, other factors constant, a higher population requires more transportation infrastructure to maintain a given level of service—in practice, determining LOS is much more complicated than simply dividing lane-miles by population (Steiner, 1999). Further, factors other than simply the amount of traffic the road system carries impact policymakers' preferences. Also, this is an extreme and unrealistic increase in infrastructure. We emphasize that this example is used only to make the concept of RCS Elasticity of Population clear for later discussions. The analysis would be qualitatively the same if we were instead considering increasing to 18 lane-miles per 1,000 residents or if we were dealing with only one county within the state. If a large change were made in such a short period, it is unlikely that the entire population adjustment could be accommodated in a single decade, and we would likely hit such strongly diminishing returns that the model would simply break down. However, in areas of Figure 1 closer to point B, we feel the model does approximate what would happen to population from 2000 to 2010 if lane-miles were allowed to fall to 240,000 or boosted to 300,000—but even then some of the adjustment might actually happen after 2010. It also does provide useful insight into where we would be if Florida had kept up with the national average RCS per resident since 1950 (when we had nearly the national average) but the other large states had not altered their highway investments; we would be the second most-populous state, not the fourth.

3. ESTIMATING THE ROAD CAPITAL STOCK ELASTICITY OF POPULATION

If the effect of transportation investments on equilibrium population is small enough or takes long enough to occur, it will not matter. If, however, equilibrium population is significantly affected by transportation investments over a short time period relative to the lifespan of the investment, policymakers must account for it in order to make optimal transportation investment decisions, as shown in Section 4 below. Thus, obtaining an estimate of this response was the central concern of this research. While it would be preferable to perform the estimation at the MSA level, we were unable to construct a sufficient dataset for that purpose. Instead, we used data on highway investment for the 48 contiguous states, together with the highway capital stock depreciation from the U.S. Bureau of Economic Analysis' (BEA) National Income and Product Accounts and state-specific price indexes for highway investment to create a road capital stock variable, RCS, which may be thought of as an index of quality-adjusted lane-miles but which includes all highway related investments. In appendix A, we show that the model represented by

$$Population_t = K_t Population_{t-10} \left(\frac{NatPopulation_t}{NatPopulation_{t-10}} \right) \left(\frac{NatRCS_t}{NatRCS_{t-10}} \right)^{-a} \left(\frac{RCS_t}{RCS_{t-10}} \right)^{a} e^u \qquad (1)$$

closely approximates population growth over 10-year intervals. In Equation 1, *Nat* denotes national totals, the subscript *t* denotes a particular year, *a* measures the Elasticity of Population with respect to a state's RCS, ignoring the minor effect of the state RCS on the national total, *u* is a normally distributed error term with mean 0 and standard deviation approximately 0.07, and K_t denotes a constant (within a given year but not over time) that depends upon a state's geographic characteristics in year *t-10* and the national population distribution pattern in year *t-10*. The term elasticity simply refers to the percentage change in a dependent variable in response to a 1% change in an independent variable. The RCS Elasticity of Population, *a*, therefore, measures the percentage increase in population due to a 1% increase in RCS, all else equal.

Equation 1 is based upon the basic open city regional general equilibrium model, in which labor supply adjusts between cities so as to create compensating wage and price differentials that balance the amenity and productivity characteristics of each location and the skill requirements of each type of job against the purchasing power of particular jobs in particular locations. The applicability of this model to transportation planning was discussed in some depth in our previous Trends and Conditions research (Denslow & Dewey, 2000). Rosen (1979), Roback (1982, 1988), and Gyourko and Tracey (1989, 1991) are important examples of works confirming the basic predictions of this type of model. Blanchard and Katz (1992) and Barro and Sala-i-Martin (1992) provide additional evidence in favor of this model. Denslow and Dewey (2000) show that this model fits the modern U.S. economy very well—wages exhibit very little variation across cities once the price level, amenities, and job demands are accounted for. (A regression of a city-specific wage index which accounts for occupational variation across cities and has a national average of 1, adjusted by a city-specific price level index which also has a national average of 1, on climate variables such as coastal location and January and July temperatures produces a standard error of the regression of less than 0.05. This indicates that less than 5 percentage points of wage variation across U.S. cities is not accounted for by these factors). None of these works, however, directly measures the response of equilibrium population to transportation investments, though they point strongly in that direction.

In this modeling approach, the physical characteristics of an area, such as the productivity of the land in agricultural uses or the attractiveness of the land to potential residents, the stock of transportation infrastructure, other types of public fixed capital, and private fixed capital such as the housing stock jointly determine the regional equilibrium pattern of wages, prices, employment, and population. We do not control for variables such as the level or composition of economic output or income because the capital stock and physical characteristics of the region determine these variables in the long run (along with public policies).

We estimate the RCS Elasticity of Population to be somewhere between 0.23 and 0.59, with what we feel to be the "better" estimates closer to 0.4.

For the remainder of this discussion, we adopt 0.4 as our favored estimate of the RCS Elasticity of Population. This implies that Florida's trend lane-mile growth (about 20,000 additional lane-miles from 2000 to 2010) contributes approximately one-fifth of BEBR's published projected population growth. If lane-miles were increased by 50,000 (20%) rather than 20,000 (trend), these numbers imply population would increase to nearly 20 million rather than 19 million. While we are assuming all of the adjustment occurs over the same decade as the change in RCS, the adjustment almost certainly will take more time for larger changes. Also, lagged effects are possible even for smaller changes. More work and better data are needed to determine the exact lag structure.

Is the finding that the state level RCS Elasticity of Population is in the area of 0.4 reasonable—is it consistent with theoretical expectations? Clearly, it must be greater than zero—

it is hard to imagine any way in which increasing transportation infrastructure, thus increasing access to developable land and connectivity within and between cities, could decrease equilibrium net-migration. The analysis has focused on state-level averages and totals. Of course, particular transportation investments are contained in sub-state regions. If a particular investment really opens up an area that was previously quite isolated, as the completion of I-75 opened Collier county up for extremely fast growth, the effect could be much greater. However, there are two strong reasons to suspect the average effect at the state level to be less than 1. First, there are likely to be diminishing returns since, within a particular area, there is a fixed factor—developable and desirable land. Second, migrants drive up prices in the areas they move into, while causing prices to fall and lane-miles per resident to rise in the areas they leave.

4. FLORIDA'S TRANSPORTATION PLANNING AND THE RCS ELASTICITY OF POPULATION

To understand why the RCS Elasticity of Population is crucial for optimal planning, we need a framework to account for what is important to Florida's transportation policymakers. We also need a framework to account for how transportation investments impact the state and its residents. We now develop such frameworks. It turns out that the appropriate framework for accounting for how transportation investments impact the state and its residents depends crucially upon whether or not the RCS Elasticity of Population, measured over a time span that is short relative to the life of transportation investments, is positive. Further, getting the framework wrong can lead to large losses due to less-than-optimal investment strategies.

4.1 Alternative Approaches to Analyzing the Role of Florida's Transportation Investments

When analyzing transportation policy options in Florida, a closed economy approach, an open economy approach, or some hybrid might be used. In a purely closed economy model, the size and skill level of the workforce, the number and type of firms, and other important variables are taken as fixed. In a pure open economy model, all firms choose the location that yields the highest profit and all households choose the location that gives the highest level of satisfaction considering wages, prices, taxes, congestion, and other amenities. If a firm could make higher profits in a Florida city than in a city out of Florida, firms would move to that city, driving up wages, rents, and congestion until profit opportunities are equalized between all pairs of cities. Similarly if a household could obtain a more favorable combination of wages, prices, taxes, congestion, and amenities in a city in Florida than in other cities, households would move to that city, lowering wages and increasing prices and congestion until no more households wished to move to the city. In equilibrium in a full open economy model, both firms and households are indifferent between possible locations.

If firms adjust rapidly relative to the useful life of transportation infrastructure but households do not, a partially open economy approach in which the number of firms, wages, and prices adjust until profit opportunities are equalized but the number of households is fixed could be used. In fact, this is the model implied by Florida's 2020 Transportation Plan, as discussed above. While it is possible that firms adjust rapidly to transportation conditions but households are relatively fixed, a large body of evidence suggests that households as well as firms adjust relatively rapidly. Our work discussed in Section 3 found that changes in transportation infrastructure have large and statistically significant impacts on population. This implies that a pure open economy approach provides the correct guide for Florida's transportation policy.

4.2 The Objective of Florida's Transportation Policy

To determine how important the difference between an open economy approach and an approach in which firms adjust but households do not is to transportation planning, we begin by assuming that Florida's policymakers want to make transportation investments so as to maximize the net benefits to the state's residents. Benefits that will accrue to typical Floridians include labor market income, non-labor market income, and amenities associated with location choice, such as good weather. Costs include taxes, the cost of housing services (rent), and transportation costs (including time, money, and accident costs). We assume for now that goods other than housing cost the same everywhere. Thus, benefit per resident is given by:

Benefit = Labor Market Income + Non-Labor Market Income – Taxes – Housing Costs – Transportation Costs + Amenity Value (2)

Since non-labor market income does not depend upon the household's location choice, the portion of the typical resident's net benefit that varies with their location is given by:

Location Variable Benefit = Labor Market Income – Taxes – Housing Costs – Transportation Costs + Amenity Value (3)

The total benefit to Floridians is then simply population multiplied by the net benefit per resident. That is:

Benefit to Floridians = Population x Location Variable Benefit + Total Non-Labor Market Income. (4)

Rental income from property in Florida will play an important role in our discussion, so we need to be clear about what we mean by rental income. In the case of payments made to landlords by firms, apartment dwellers, or households renting single-family residences, the concept of rent is straightforward. We treat owner-occupied housing in the standard way—as if the owners charge themselves the rent a similar property would rent for on the market. Obviously, this is a wash from the owner's perspective, but it simplifies our accounting framework. Since the market value of a property should just equal the net present value of the flow of income it will generate, policies that increase the imputed rent on owner-occupied housing increase the wealth of those owners. Since residents of other states own a portion of property in Florida, we can rewrite the expression for the total benefit to Floridians as:

Benefit to Floridians = Population x Location Variable Benefit Per Resident + Fraction of Florida Property Owned by Residents x Total Rental Income from Florida Property + Total Other Non-Labor Market Income. (5)

Finally, we subtract the benefit that would occur under some minimum allowable transportation infrastructure, so that we are talking about ***net*** benefit due to investment decisions. While we will later take this minimum allowable investment level to be zero, it need not be. Further, even if the minimum is zero, focusing on net benefit plays a role in clarifying the differences between transportation investments in a partially closed economy compared to an open economy. We define Location Variable Net Benefit Per Resident as the difference between actual Location Variable Benefit Per Resident and Location Variable Benefit Per Resident under the minimum investment. Total Net Rental Income from Florida Property is defined the same way. Florida's transportation planning objective, then, is to maximize these net benefits given by:

Net Benefit to Floridians = Population x Location Variable Net Benefit Per Resident + Fraction of Florida Property Owned by Residents x Total Net Rental Income from Florida Property + Total Other Non-Labor Market Income. (6)

We consider equation 6 to be simply a formal statement of Florida's Transportation Mission as stated in Florida's 2020 Transportation Plan.

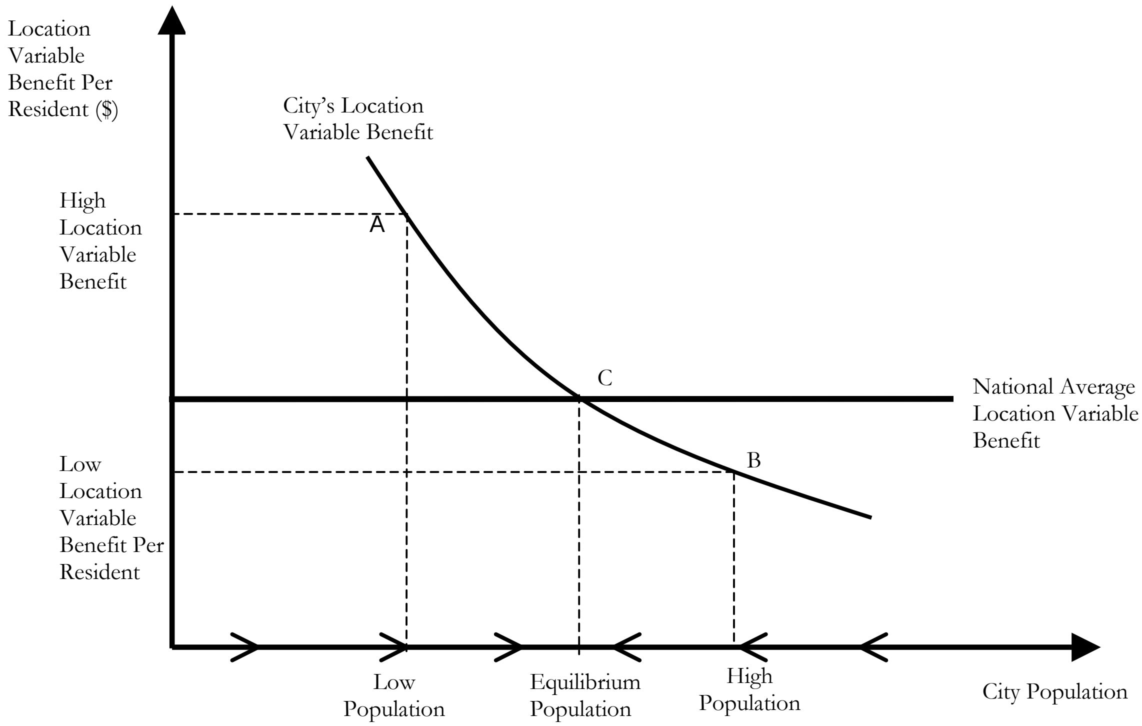
4.3 Maximizing Net Benefit to Floridians If Expected Population is Fixed

Consider the decision regarding how much to invest in roads in a single city in Florida. If firms adjust rapidly but population is relatively fixed, location variable net benefit per resident might be enhanced by transportation policy in a number of ways. Providing better access to the city center from outlying areas will keep rents in more central areas down. This will (1) increase wages as firms compete for workers in a lower-cost setting (due to low rents), (2) reduce rents paid by residents for their homes, and (3) reduce the costs of commuting. The increased wages will be partially offset by reduced rental payments for commercial and industrial property, but a portion of that reduction is borne by residents of other states. Similarly, reduced residential rents will reduce non-labor income for those who own property in Florida, but again a portion of this reduction is borne by residents of other states. Of course, building roads can also serve to improve connectivity between cities and regions. This might reduce costs of certain goods or reduce firms' production costs. Since the qualitative effects would be the same, we ignore these effects to keep the presentation simple. For quantitative accuracy, say to guide specific actual investment decisions, a richer framework that included these effects would be needed. The optimal transportation investment strategy in a particular city in Florida would be to build roads as long as the increase in net benefit to Floridians yielded by another lane-mile just equaled the reduction in net benefit to Floridians due to the tax cost of building an additional lane-mile.

4.4 Maximizing Net Benefit to Floridians in an Open Economy

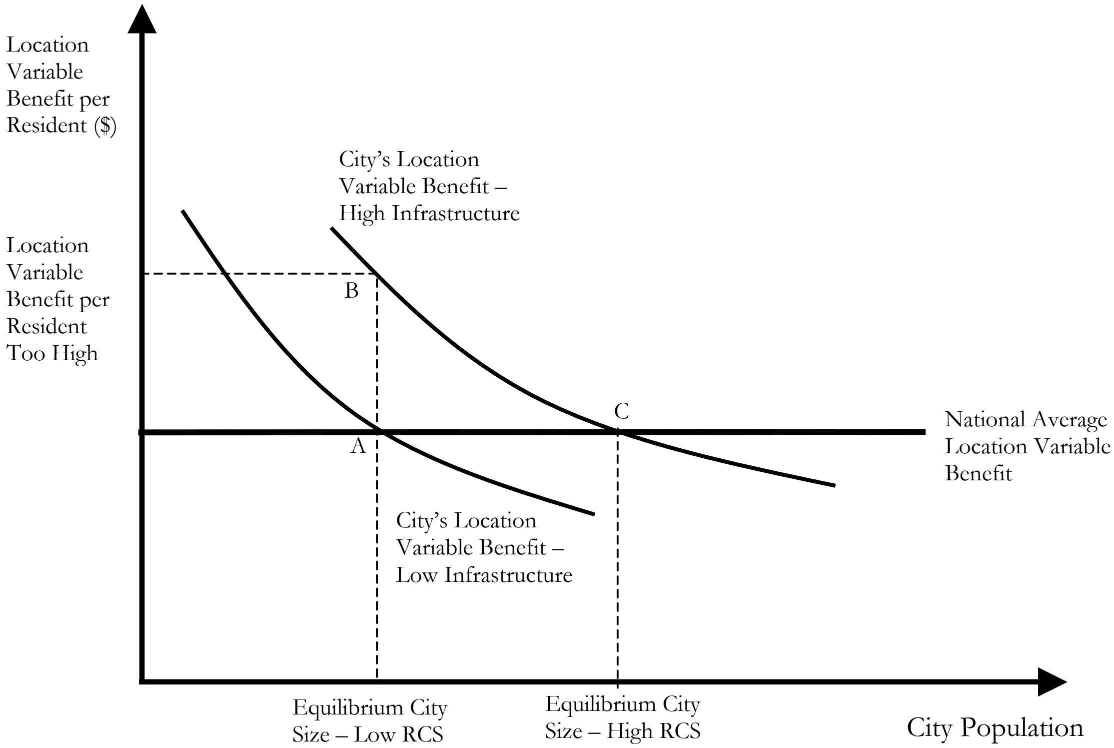
The picture is quite different if both population and firms adjust rapidly. In this case, location variable benefit per resident is equal to the national average location variable benefit per person, regardless of the level of transportation infrastructure investment. This is depicted in Figure 2 and Figure 3. In Figure 2, Location Variable Benefit Per Resident is measured on the vertical axis and the number of residents in a particular Florida city is measured on the horizontal axis. Since even Florida's largest city contains a negligible fraction of the total national population, national average Location Variable Benefit does not depend upon conditions in this particular city. Therefore it is shown as a horizontal line. The downward sloping curve represents the relationship between Location Variable Benefit Per Resident and the number of residents for a particular level of transportation infrastructure. If population is relatively low, so that the city is at a point like A, wages will be high, rents and congestion will be low, and Location Variable Benefit Per Resident will be above the national average, attracting more in-migration. If population is relatively high, so that the city is at a point like B, the reverse is true. The city will be in equilibrium only when Location Variable Benefit Per Resident equals the national average at point C.

Figure 2. Equilibrium City Population



In Figure 3, the downward sloping curve on the left represents the relationship between Location Variable Benefit per Resident and the number of residents for an initial level of transportation infrastructure, with an initial equilibrium at point A. Now consider the impact of increasing the level of transportation infrastructure. At any given population, transportation costs and rents will be lower and competition for workers will push wages higher, so the effect is to shift the Location Variable Benefit curve up and to the right. The tax consequences of the investment will not prevent this rightward shift as long as the transport cost savings at the city's most distant point is larger than the per capita share of taxes needed to finance the infrastructure (this condition is sufficient, not necessary). If this condition were violated, there would be no reason to build the road anyway. At the initial population, Location Variable Benefit per Resident rises to point B, leading to in-migration and a new equilibrium at point C. Thus, investment decisions cannot impact Location Variable Benefits per Resident.

Figure 3. Effect of Transportation Investments on Location Variable Benefit per Resident in an Open Economy That Adjusts Rapidly is Zero



If firms and households both adjust relatively rapidly to the changes brought about by increased investment in transportation infrastructure, Location Variable Benefit per Resident can not be enhanced by transportation policy, and maximizing Net Benefit is the same thing as maximizing Total Net Rental Income from Florida Property. (Rental Income is net of any property tax assessments used to finance transportation infrastructure.) While the general objective is the same, investment decisions based on this framework are likely to be quite different from those arising from the partially closed economy framework reflected in the 2020 Transportation Plan. In the partially closed framework, increased rental income from Florida property tended to result in lower Net Benefit since a portion represented transfers from residents to non-residents and the remainder was simply transfers between residents. Thus, the finding that transportation investments have a relatively rapid impact upon population has potentially large implications for transportation investments.

Even the somewhat more sophisticated argument that attracting more people to become customers of our state's businesses will make businesses more profitable by spreading fixed costs is not valid. In what economists refer to as monopolistically competitive markets where there is too much product differentiation to support truly atomistic competition, competition will erode profits to zero. Concentrating population will spread fixed costs, but reduce prices just enough to compensate. Thus, while we did not explicitly model such firms, the question of optimal distribution of population to minimize fixed costs is a nationally important question, but one that an individual state can do little about. The only businesses that can capture such gains within a region are those that are immune from serious market competition. To the extent that such businesses are only a small part of Florida's economy, the main beneficiaries of good transportation policy are property owners—homeowners, apartment landlords, owners of commercial and industrial parks, and owners of land on the fringe of development.

4.5 What is the Cost of Getting the Approach Wrong?

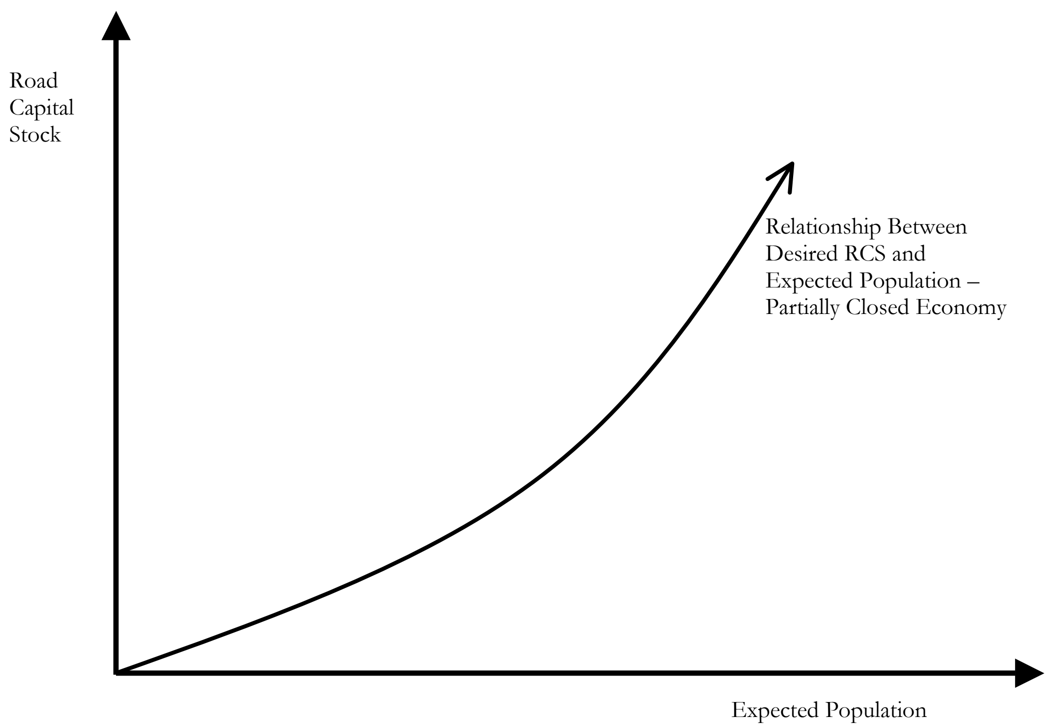
To get a feel for how large these effects might be, we need to model firms and the structure of cities explicitly. We adapt the simplest possible urban model to our regional setting for this purpose. We make the following assumptions. Each of these could be relaxed to be more realistic in future work, but for now we focus on keeping the analysis clear and tractable.

1) Each household needs one unit of land for its residence.
2) Firms use labor and land in fixed proportions and sell their output in competitive national markets at the nationally determined price.
3) Firms choose to locate together closer to the center of the city than do households, but have no further preference for location. (In future work this could be endogenized by placing a transportation node at the city's center and modeling goods shipment, but for now we simply assume it.)
4) Commuting costs within the business district are negligible.
5) The elasticity of household commuting costs with respect to distance from the business district is 1.
6) The elasticity of household commuting costs with respect to the size of the city, (representing congestion and denoted g) is constant and between 0 and 1.
7) The elasticity of household commuting costs with respect to transportation infrastructure (denoted e) is constant and between -1 and 0.
8) So that planning under a "mistaken" assumption that population is fixed converges to a stable outcome (rather than infinite roads and population in one city), we assume that $-2e<(1+g)$.
9) The cost of transportation infrastructure is linear.
10) All transportation infrastructure not financed by federal subsidy is financed by a lump sum assessment on property. This is only to facilitate an analytic solution to the model. Other tax structures should not change the results but would make the analysis more cumbersome.

This model essentially combines the models of Mohring (1961) and Roback (1982). The result is a model in which (1) land use by firms in addition to land use by households is explicitly modeled, (2) household income other than rental income is not fixed outside the model but rather depends upon the wages paid by local firms, and (3) the rent gradient is explicitly modeled rather than assuming a fixed amount of land with equal accessibility. From these assumptions, it is possible to calculate the amount of infrastructure that maximizes Net Benefit in an open economy and in a partially closed economy in which firms adjust rapidly but households do not. We can then calculate the loss that would occur if transportation infrastructure were chosen to maximize Net Benefit in a partially closed economy when the economy is actually open. Assuming an open economy, it follows (after a lot of tedious algebra) that the elasticity of equilibrium population with respect to transportation infrastructure (the RCS Elasticity of Population, denoted "a") is constant and equal to twice the absolute value of the elasticity of commuting costs with respect to transportation infrastructure divided by the sum of 1 and the elasticity of commuting costs with respect to city size: $a=-2e/(1+g)$. Further, the elasticity of Net Benefit with respect to transportation infrastructure is equal to the RCS Elasticity of Population.

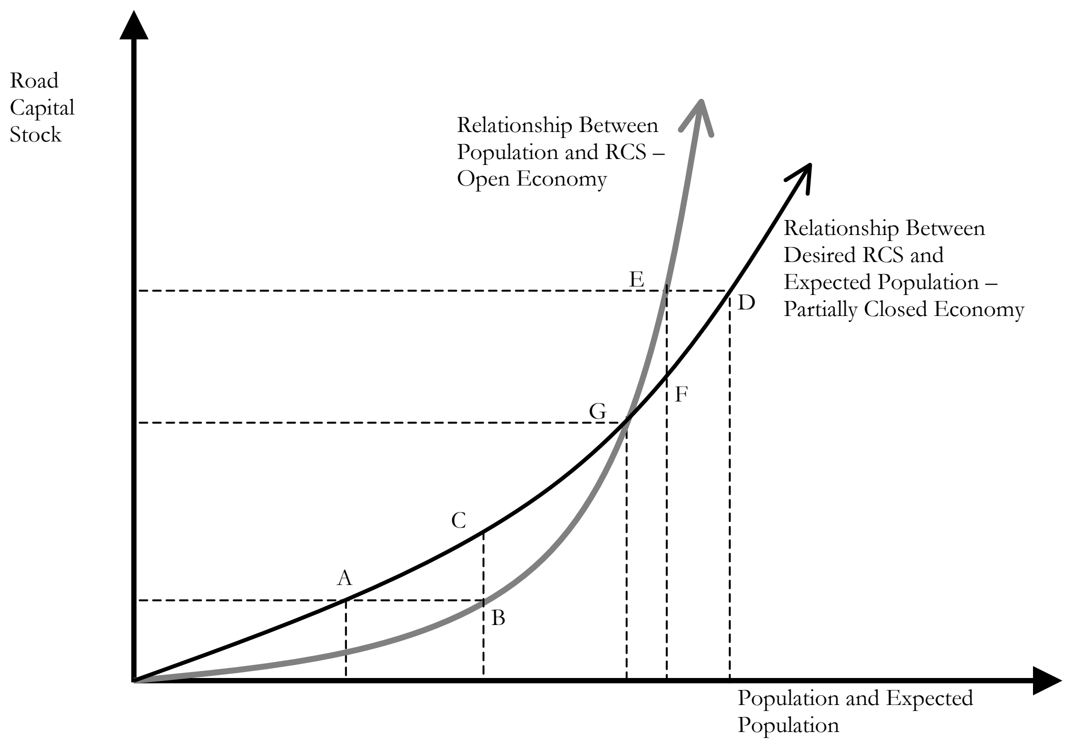
One complication to this exercise is that the level of infrastructure chosen, if population is believed to be fixed, depends upon the level at which population is believed to be fixed. Any level of transportation infrastructure is a valid solution for some belief about the fixed population. This is illustrated in Figure 4. In the figure, as expected population increases, the level of transportation infrastructure that maximizes net benefit for that fixed population increases. In our model, desired RCS increases with population at an increasing rate. There are three reasons for this in our model. First, as the city grows, new people must be served and they also congest the roads used by previous residents, leading to more than proportionate increases in roads. Second, we assumed the cost of an additional unit of infrastructure (say a lane-mile) was constant for simplicity. If the marginal cost in fact rises rapidly as RCS increases, the desired RCS would increase at a decreasing rate with expected population. Allowing road costs to be non-linear would not change our results in any fundamental or qualitative way, and would introduce an additional parameter. Therefore, while it might be important to some future work in this area, we did not feel the potential gain merited the complication. Third, we have ignored roads that connect this city with other cities. To model them we would need to model a network of cities explicitly. As long as such roads remain uncongested, they will not be enlarged as the city's expected population grows. Thus, the figure might be thought of as depicting the stock of "access" providing roads around peak times, not the total stock of roads within the cities boundaries.

Figure 4. Relationship Between Desired RCS and Expected Population – Partially Closed Economy



While any "expected" population is possible, equilibrium in an open economy dictates that only one actual level of population is consistent with each level of transportation infrastructure. Thus, if a level of RCS is chosen based upon a very low level of expected population, the city would find that it had more people than it expected and too few roads, leading it to revise up its population expectations (assuming an extrapolative projection technique) and increase its rate of road building next period. Similarly, if a level of RCS is chosen based upon a very high level of expected population, the city would find that it had fewer people than it expected, leading it to revise its population projection downward for next period (again assuming an extrapolative projection technique) and to reduce its rate of road building. This is shown in Figure 5. If decision makers expect population to be at the level of point A, they will build the corresponding level of RCS. This however leads to an actual population consistent with point B and a desired RCS at point C, which would lead to a higher population, and so on until point G is reached. Similarly, if population were initially expected to be at a level consistent with point D, they would build the corresponding level of RCS. Population, however, would turn out to be lower than expected at point E, and at that population level, point F would reflect the desired RCS, leading to reduced road building in the future until population catches up. Equilibrium can only happen at a point like G (on a new curve since the relationship between equilibrium population and RCS will shift out to the right over time as the nation's population grows).

Figure 5. Stable Levels of RCS and Population when Population is Mistakenly Taken as Fixed



This means that at any point in time there will be only one level of desired RCS and expected population that will be stable in the sense that expected population and actual population are the same. Further, RCS chosen based upon a mistaken assumption that population is fixed will converge to this level over time, assuming population expectations are formed based upon extrapolations from past population growth. Therefore, this is the RCS level we use to compare the outcome when population is mistakenly taken as fixed to the outcome when population is correctly presumed to adjust rapidly. Given our assumptions, it may be shown that the lost net benefit, as a fraction of the maximum possible net benefit, depends only upon the fraction of land in the city owned by Florida residents, the elasticity of commuting costs with respect to transportation infrastructure, and the elasticity of commuting costs with respect to city size.

How big is the loss? If the elasticity of commuting costs with respect to transportation infrastructure is very small, the loss becomes very small. This is not surprising since, in this case, transportation infrastructure is not very important. If the RCS Elasticity of Transportation Costs is large, specifically greater than .5 in absolute value, the loss in this model is over 100%—the level of RCS converges to a point at which the cost of the road stock exceeds the benefits it provides. (To state residents, the spillover benefits might be larger than costs, but they accrue to non-Floridians.) For more reasonable intermediate levels of the RCS Elasticity of Transportation Costs, the answer depends upon the levels of three parameters—the fraction of property in Florida owned by residents, the RCS Elasticity of Transportation Costs (e), and the city size Elasticity of Transportation Costs (g).

From analysis of the tax roll database maintained by the Florida Department of Revenue, we find that the owners of 84% of property in Florida, by value, reside in Florida. This is true for both improved and unimproved property (the difference is beyond the second decimal place). We think this might be a slight overestimate, since corporations own some land, and some is owned by corporations based in Florida that have stockholders who live out of Florida.[5] Therefore, we also present estimates of the loss of net benefits based on an alternative assumption that Florida residents own 80% of the property in the state.

An RCS Elasticity of Population of .4 implies $g = -5e-1$. Since g was reasonably assumed to be between 0 and 1, e varies from -.2 if $g = 0$ to -.4 if $g = 1$. The black curve in Figure 6 depicts the Loss of Net Benefit for varying values of e when Florida residents own 84% of the property in the state. The gray curve depicts the same relationship when Florida residents own 80% of the property in the state. The black curve in Figure 7 depicts the Loss of Net Benefit for varying values of g when Florida residents own 84% of the property in the state. The gray curve depicts the same relationship when Florida residents own 80% of the property in the state. Figures 6 and 7 portray the same relationship from two different perspectives. For most reasonable combinations of e and g such that the RCS Elasticity of Population is .4, the Loss of Net Benefit is significant. For example, if g is .2, e is -.24, and 15% of potential net benefits are lost if 84% of property in the state is owned by residents. (Recall that g is the city size Elasticity of Transportation Costs. The population Elasticity of Transportation Costs is equal to $g/2$ in a circular city with equal lot sizes. So $g = .2$ means a doubling of population will increase per unit transportation costs by only 10%, all else constant.) If g is .5, e is -.3, and 41% of potential net benefits are lost if 84% of property in the state is owned by residents. The Loss of Net Benefit is larger if residents own less property in the state.

[5] Some corporations out of Florida own land in Florida, and some of their stockholders live in the state. However, if their shareholders are spread across states proportionally to state population, this effect will be small. It will be smaller still if the shareholders are disproportionately concentrated in the state in which the corporation is based.

Figure 6. Percentage Loss of Net Benefit Due to Partially Closed Approach

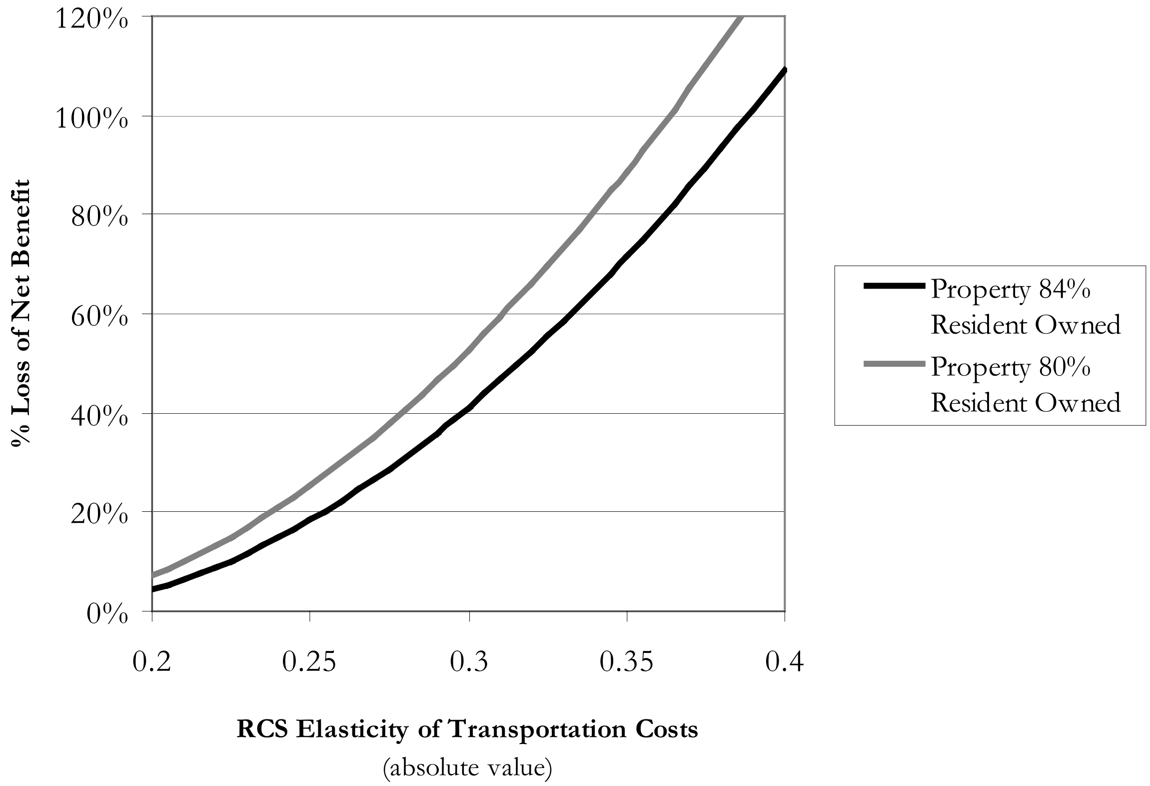
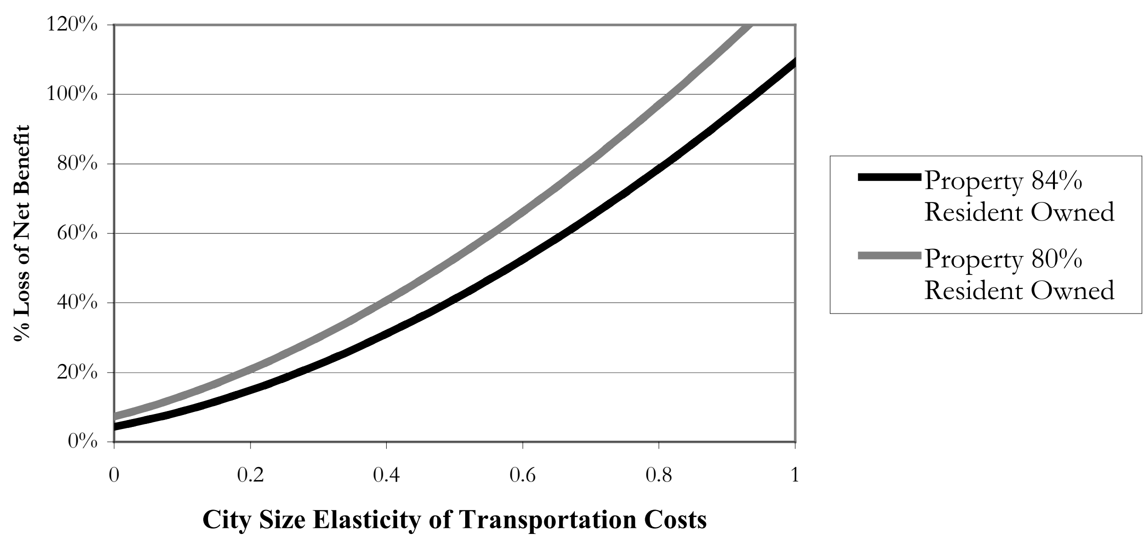


Figure 7. Percentage Loss of Net Benefit Due to Partially Closed Approach



4.6 Implications for Planning Investments in Transportation Infrastructure

This analysis strongly suggests that if Florida wants to maximize net benefits to its residents, the framework adopted for decision-making is crucial. Further, our empirical work presents strong evidence that the RCS Elasticity of Population is positive, so an open economy approach to transportation investment planning is called for. Utilizing an approach in which population is taken as fixed may lead to large losses over the long run. This is consistent with findings from modern urban and regional economics that wages and prices adjust for amenity and public goods differences across states (e.g., Roback, 1982, 1988; Gyourko & Tracey, 1989, 1991), and that workers adjust as rapidly as firms (Blanchard & Katz, 1992). This section has shown that those insights hold together in such a way that the lion's share of benefits from transportation investments that accrue to residents of the area in which they are made are captured in the area's rent gradient in a world where: (1) labor market income as well as property rents vary by location, (2) the city's rent gradient is not assumed to be flat, and (3) transportation infrastructure can alter accessibility of land within the region.

While Arnott and Stiglitz (1981) showed that the relationship between property values and the benefits of transportation infrastructure as evaluated from an economy-wide (national) perspective is not direct, we are interested in the benefits accruing to Florida's residents. The most recent academic work we are aware of in this area is Sheppard and Stover (1995). Their model is partially closed in the sense that state or local governments impose land use controls that strictly limit the size and population of the region (their use of the terms open and closed is slightly different than ours). In this case, they find all transportation benefits are captured by the locality but they still are manifested in the rent gradient. They, however, take non-property income to be exogenous. Explicitly modeling wage determination in their locality could cause significant portions of the benefits to bleed out to the rest of the economy. Even so, all of the benefits to their locality would be found in property values. We do note, however, the potential for "efficient" land use controls coupled with transportation policy to capture more of the benefits of Florida's transportation investments in the value of property in the state.

What insights about transportation planning may be drawn at this stage? While our specific results concerning the degree of the loss of net benefits due to planning for a partially closed economy depend upon the specific assumptions of our model, the finding that most benefits of Florida's transportation investments that accrue to the state's residents are captured in the rent gradient is fully general. Further, preliminary work indicates that explicitly modeling firm level transportation costs, transportation hubs, connectivity, and finished goods distribution will not alter the substance of our findings about the costs of taking the wrong approach. The generality of our basic result implies that it should be straightforward to estimate the benefits of transportation investments from data on aggregate land values and transportation investments by regions of the state. Historical data on aggregate property values by county is available from the Florida Department of Revenue. Coupled with data on public and private capital stock and state and county roads, this data would allow a reasonably good first pass estimate of the benefits of Florida's transportation investments to the state. Measurements of transportation benefits that do not focus on the rent gradient will be wrong even if they allow for population adjustment in response to infrastructure investments. For example, while the approaches outlined in NCHRP Report 389 (Transportation Research Board, 1998) may (or may not) be appropriate for measuring linkages between transportation investments and economic performance in the aggregate, they are not appropriate for measuring the benefits to Florida's residents. Similarly, the views outlined in NCHRP Synthesis 290 (Transportation Research Board, 2000) give a very misleading view of what benefits actually accrue to the state from its transportation investments and how transportation policy might be linked with land use policy to increase the share of those benefits that accrue to the state.

At the broad level of planning which the trends and conditions reports and the 2020 plan are intended to serve, transportation planning should be firmly and explicitly rooted in a regional open economy general equilibrium framework. The advantage of setting transportation planning in such a framework is that it focuses on reasonable goals. For example, it is not reasonable to expect to make people in a particular region better off by building or managing roads in such a way as to attract better paying jobs or to minimize the effects of congestion that will come from a given number of new residents—the number of new residents can adjust as fast as the transportation system (or faster), pegging the well being of non-property owners at the national average level regardless of the state's actions. Of course, such improvements implemented nationwide will make all residents better off. That is one of the reasons why the federal government should have a strong continuing interest in subsidizing state and local transportation investments. Planning at this broad level should simply focus on making the state a more "desirable" place to live, investing up to the point where the cost of another transportation investment is just equal to the gain in the present value of the economic rents that flow from properties in the state.

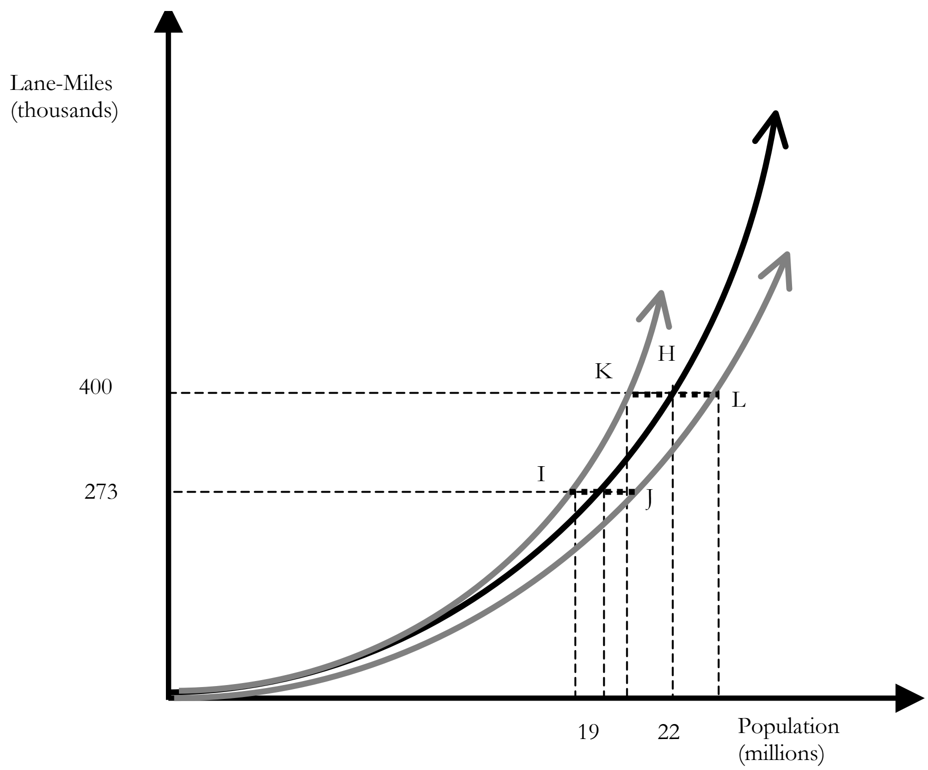
When transportation decisions are to be made, Florida often forms advisory committees to provide input to the decision making process. Further, some effort is usually made to educate the members of these advisory committees about relevant background information and important related issues. Often this takes the form of bringing in outside experts to make presentations to the committee members. Since we have found that a regional open economy framework is appropriate for making transportation investment decisions, we recommend that a regional economist be brought in to provide grounding in regional economics, including the impact of transportation investment on population, when Florida forms committee to consider transportation investment decisions. The framework provided by a competent regional economist would help the members of the committee critically evaluate other information, for instance, that provided by outside consultants.

The fact that all benefits accrue to property owners does not mean that all property owners will be in agreement about the desired level of transportation investments. Many owners of property that is already developed will want to make minimal investments to keep their taxes down and to restrict the supply of other properties with which they are in competition. At the same time, owners of properties that are on the cusp of development will want more roads to bring in more people and expand access to their property so that they can gain economic rents as well. The policy that maximizes net benefits to the state will fall somewhere in between, but is less likely to be reached if we base decisions on an incorrect view of the regional and urban economy.

5. FLORIDA'S TRANSPORTATION PLANNING AND UNCERTAINTY IN POPULATION PROJECTIONS

To illustrate why uncertainty might be important, we return to our earlier example of a policymaker considering sizeable increases in transportation infrastructure. Suppose that upon reading the previous sections of this report, our committee decided that increasing to 30 lane-miles per resident would be too costly and that the externalities created by such vast population growth—for instance, additional pressure on sensitive wetlands—would be too great. While considering whether or not to push for reaching 18 lane-miles per 1,000 residents by 2010—Figure 8 below shows that this would require approximately 147,000 additional lane-miles (400,000 total) and result in an equilibrium population of 22 million—they notice that BEBR also produces a "low" projection of 18 million and a "high" projection of 20 million. (Smith & Nogle, 2002). While the medium projection is thought most likely, the high and low projections are intended to serve as a rough two-thirds confidence interval. The interpretation placed upon the confidence interval is that intervals so constructed will contain the actual value two-thirds of the time. In percentage, the published confidence intervals are much wider at the sub-state level.

Figure 8. Forecast Errors and Road Stock per Resident



Once roads are built, they cannot be un-built to recover the investment if it is found to be a mistake. Because transportation investments are expensive, long-lived, and fixed in place, accounting for uncertainty has potentially important implications for optimal planning. If there is more than a very small chance that Florida's 2010 population will be significantly below the projected level under alternative investment patterns, and if there are high valued alternative uses for the public funds or rapidly diminishing returns to having more than the planned amount of lane-miles per 1,000 residents, it may well be wise to hold back a bit on the investment program. Similarly, if there is a significant chance that the population in 2010 will be well over the projected level and the policymaker feels that increasing Level of Service is a very high priority, they should be aware that there is a significant chance that population growth will outstrip road building, reducing LOS below the level they were expecting. In short, the policymaker needs to be able to construct reasonable confidence intervals around the equilibrium relationship between population and RCS in order to make efficient policy decisions.

Figure 8 depicts the situation graphically. While 19 million residents is the medium projection at 273,000 lane-miles, there is approximately a 67% chance of being between points I and J. If it were appropriate to extend this confidence interval proportionately around the curve through point H (which represents equilibrium 2010 population) as lane-miles are varied, the gray curves through I and K and J and L would form the boundaries of a 67% confidence interval for various levels of the road stock. Our work reported in Appendices A and B below indicates this to be a reasonable approximation—given the maintained hypothesis that the RCS Elasticity of Population is exactly 0.4—except that our intervals will be a bit wider at the 67% level than the BEBR high and low projections, and we will be constructing 80% confidence intervals, not 67% intervals. The scale of Figure 8 is approximately correct, with the gray curves representing the bounds of an 80% confidence interval.

The problems created by uncertainty are potentially much larger than the figure indicates, because the policymaker must decide not only how much to invest in total, but also how much of the total to invest in each area of the state, and the sub-state confidence intervals are much wider—in the past, sometimes actually including a significant possibility that many of Florida's counties will lose population. Thus, if the policymaker decides to target areas projected to have high growth that currently have less than their share of the state's roads, to head off severe congestion, they might well find that some of the targeted areas actually did not grow at all, while some areas that were neglected because they already had more than their share of the state's roads and were not forecast to grow much are bursting at the seams by 2010. Facing such a situation, they might well decide to hedge their bets by investing a little everywhere but less overall, so as to avoid tying up valuable resources in areas where they will turn out to be of little use.

Yet, since 1960 only an average of two counties in Florida have lost population over any 10-year period. None of these were counties of over 50,000 residents, and most were counties of well under 20,000 residents. Thus, it would seem possible to develop a methodology that would incorporate changes in the road stock, produce relatively tight bounds on uncertainty, and rule out population loss in Florida's non-rural counties except for exceptionally rare events. Working with the state's 20 MSA's and a single remainder of state county grouping, rather than 67 individual counties, and using estimates of equation 1 to forecast future population produces confidence intervals approximately the same width as the methods employed by BEBR's published projections. However, none of these 80% MSA level confidence intervals entails population losses (although among the small counties that make up the remainder of state area, much more random variation may occur). Even though more detailed results are presented in the appendix, as a rule of thumb we are confident that MSA-level percentage growth over a decade will fall between 10 points above and 10 points below the rate implied by BEBR's published medium 10-year projection adjusted for changes in RCS 80% of the time. Similarly, while the improvement in precision for the state as a whole is smaller, we find that state-level percentage growth over a decade will fall between 8 points above and 8 points below the rate implied by BEBR's published medium 10-year projection adjusted for changes in the road stock 80% of the time (again, this is approximate, but very close).

Relying upon previous findings that the size of forecast errors increases roughly linearly with the number of years in the projection horizon, (Smith, 1987; Smith & Nogle, 2002), we can arrive at a simple but very useful way of constructing approximate MSA-level confidence intervals.

For MSAs, adding and subtracting 1 percentage point for each year of the forecast horizon to and from the projected percentage growth over that horizon produces an approximate 80% confidence interval for BEBR's published medium projections adjusted for changes in the road stock over that forecast horizon. At the state level, only 0.8 percentage points per year need be added or subtracted to produce an 80% confidence interval.

At the county level, we would probably have to add a bit more, although we did not study projections at this level. We also point out this rule is based upon the standard deviation of forecast errors in 2000 (where the projections were based upon data known by 1990). Since the standard deviation of forecast errors has trended down continuously since 1960, this may represent a conservatively wide confidence interval.

While we have reported a rule of thumb for constructing confidence intervals around BEBR's published projections, adjusted for RCS, we also produced an independent set of 2010 projections based upon equation 1, but omitting the RCS variable (which amounts to assuming trend RCS growth). These are shown in Table 1 below, along with the upper and lower limits for an 80% confidence interval. Although this projection is slightly different than the BEBR

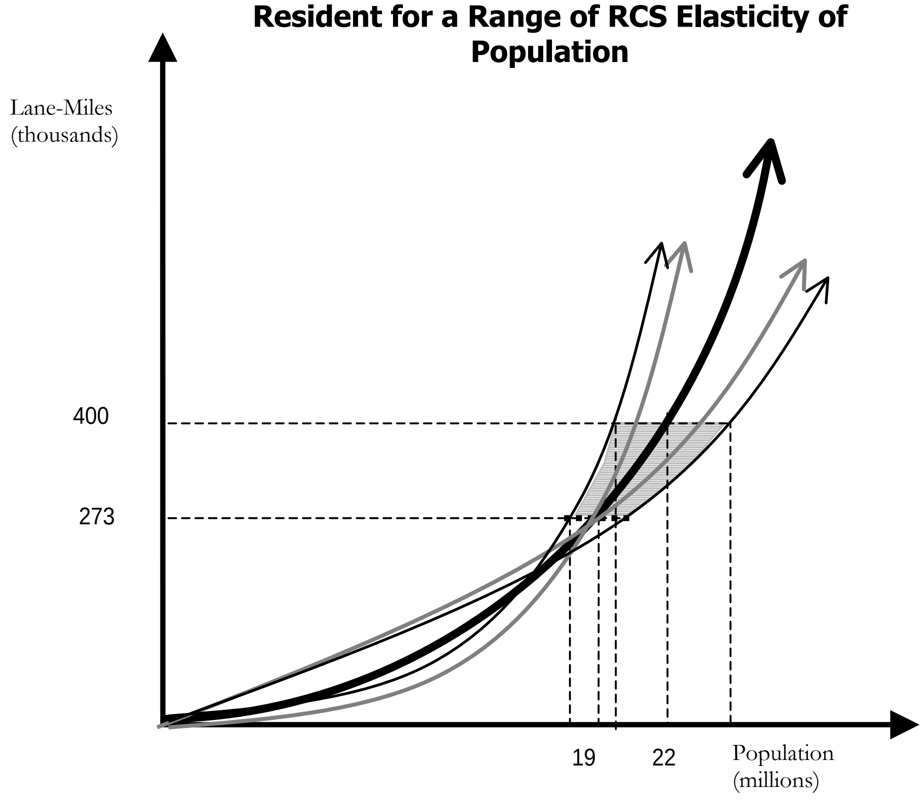
Table 1. Projected 2010 Population Based on Equation 1 and Trend RCS Growth

Metropolitan Statistical Area	Projected 2010 Population	2010 80% Confidence Interval Upper Bound	2010 80% Confidence Interval Lower Bound	2000 Population
Daytona Beach	587,215	655,696	525,886	493,175
Ft. Lauderdale	2,095,053	2,339,378	1,876,245	1,623,018
Ft. Myers-Cape Coral	545,664	609,299	488,674	440,888
Ft. Pierce-Port St. Lucie	402,495	449,434	360,458	319,426
Ft. Walton Beach	192,004	214,395	171,951	170,498
Gainesville	248,378	277,343	222,437	217,955
Jacksonville	1,255,978	1,402,451	1,124,803	1,100,491
Lakeland-Winter Haven	583,768	651,847	522,799	483,924
Melbourne-Titusville-Palm Bay	625,820	698,803	560,459	476,230
Miami	2,912,604	3,252,273	2,608,411	2,253,362
Naples	327,865	366,101	293,623	251,377
Ocala	304,238	339,719	272,464	258,916
Orlando	1,960,252	2,188,857	1,755,523	1,644,561
Panama City	168,130	187,737	150,570	148,217
Pensacola	470,499	525,369	421,360	412,153
Punta Gorda	178,046	198,810	159,451	141,627
Sarasota-Bradenton	718,138	801,888	643,136	589,959
Tallahassee	316,935	353,896	283,834	284,539
Tampa-St. Petersburg-Clearwater	2,843,807	3,175,452	2,546,799	2,395,997
West Palm Beach-Boca Raton	1,443,594	1,611,946	1,292,825	1,131,184
Remainder of State	1,385,761	1,547,369	1,241,032	1,144,881

projection, the forecast accuracy of the two is almost identical at the MSA level. BEBR's published state-level projections are based upon a cohort component method, not the simple extrapolation used for the sub-state level. A cohort component adaptation of Equation 1 could be constructed and tested against state-level cohort component projections, but this was beyond the budget and scope of the current study. We suspect estimating Equation 1 for a few different age groups, for example, under 16, 16-65, and over 65 would produce very good results, but that is only speculation at this point.

Figure 8 was based upon the maintained assumption that the RCS Elasticity of Population was 0.4. While this represents our best estimate at this time, our estimates ranged from 0.23 to 0.59. Lower values would shift the projections above trend RCS to the left, and higher values would shift it to the right. As an outer bound, we can use the low side of a confidence interval based on an RCS Elasticity of Population of 0.23 and the high side of a confidence interval based on an RCS Elasticity of Population of 0.59. Figure 9 depicts this graphically. In Figure 9, the thin black curves represent the relationship between population and RCS for high and low values of the RCS elasticity, and the outermost curves bound the 80% range of uncertainty. For moderate sizes of transportation investments, our judgment is that the impact of uncertainty of the level of population will be less than the impact of getting the framework and the RCS Elasticity of Population right, although it may still matter enough to worry about. More work is needed to reach a more precise answer.

Figure 9. Forecast Errors and Road Stock Per Resident for a Range of RCS Elasticity of Population



6. CONCLUSION

In this report, we estimated the sensitivity of equilibrium population to changes in transportation infrastructure. Specifically, we found that a 10% increase in a state's road capital stock leads to approximately a 4% increase in the state's equilibrium population. We then showed that mistakenly planning as if Florida were a partially closed economy when it is in fact fully open could lead to significant and possibly large losses of net benefits. This, taken together with other evidence that population adjusts as fast as firms to maintain regional equilibrium, indicates that Florida's transportation planning should be firmly grounded in an open economy regional general equilibrium framework. In such a framework, the lion's share of the benefits from state transportation investments that accrue to state residents are in the form of increases in property values. Some may be in the form of increased profits for the owners of firms with monopoly power in regional markets. Migration of firms and households between regions in response to changes in transportation infrastructure will insure that other sources of benefits to Florida's residents are competed away, although some benefits will accrue to residents of other states. Using our framework, collection of a panel of basic data on transportation investments and aggregate property values by county for Florida would allow a reasonably good first pass estimation of the net benefits of Florida's transportation investments to the state. Further research might proceed along several lines, as discussed below.

There are several avenues for further work regarding the RCS Elasticity of Population. First, it would be very useful to have estimates of the RCS Elasticity of Population at the MSA level. We were unable to collect data sufficient for this task, although we exerted a great deal of effort in that pursuit. An important area for future research will be to construct a time series on transportation investments by county for Florida so that we can construct RCS by county and conduct a similar analysis at the MSA level, at least for Florida's MSAs. Second, state-specific depreciation rates are needed for the construction of a better RCS series. Third, we were unable to control for changes in other public capital. If there is a large positive (negative) correlation between changes in RCS and changes in other public capital stocks, our reported estimate might be too high (low). Therefore, an accurate public capital stock series at the state level for all states and also for each of Florida's counties must be developed before this issue can be fully resolved. Finally, we treated increases in the road stock in some sort of average way. It is possible that the elasticity might vary by the composition of the road stock. If the additional data described above is assembled, it might be possible to test this.

Several areas for further work regarding population projections and uncertainty might be pursued as well. First, the approximate methodology outlined in the report could be used to develop a spreadsheet program that would take as inputs BEBR's medium county projections and alternate MSA-level transportation investment scenarios and generate projected population for each MSA under the various scenarios, together with approximate confidence intervals. These could be linked to mapping programs to show the impact on the level and distribution of population. This tool might be very useful for some planning purposes where a general notion of the impact of alternative investment scenarios was desired. Second, if long term population projections are going to be put to serious uses where more definitive numbers are needed, we should explicitly develop 10-, 20-, and 30-year projections and confidence intervals based upon Equation 1 for several age categories, rather than relying upon the rule of thumb adjustments to existing population projections developed in the discussion above. Even though this is a straightforward extension of the work reported in this study, it would represent a fairly large amount of work over the course of probably 18 months. While this would not be cheap, for FDOT's purposes, projections would not need to be revisited annually. Perhaps every five years—depending upon exactly what was to be provided—would be adequate to this task. Third, this technique could be applied to the county level. Fourth, explicitly accounting for the stock of durable fixed public and private capital (school buildings, public parks, recreation facilities, jails, court houses, etc.) might allow us to narrow the confidence intervals a bit more, because the level of the capital stock is an important determinant of the attractiveness and productivity of an area.

Finally, further work should be done on the proper framework for evaluating Florida's transportation investments in an open economy regional general equilibrium framework. Many of the assumptions made in our simple examination should be relaxed to make the model more realistic. We should allow for a richer tax structure including gas taxes and allow households to choose lot sizes rather than assuming all lots are the same size. Also, we should explicitly model the mobility function of roads along with the location preferences of firms, perhaps by including a transportation hub linking the region to other regions.

TECHNICAL APPENDIX A: ESTIMATING THE RCS ELASTICITY OF POPULATION

Equation 1 formed the empirical basis for our estimates of the RCS Elasticity of Population. The first step in estimating the parameters of Equation 1 was to construct estimates of RCS at the state level over time. We began by collecting data on highway investment by state since 1950 from the Federal Highway Administration's (FHWA) Highway Statistics Series. Since right of way (ROW) varies tremendously in price by area but does not add more to the road stock just because it costs more, and since it does not depreciate, we used non-ROW investment. We assume all highway capital depreciated according to the rate (δ, equal to 0.02028) implicit in the U.S. Bureau of Economic Analysis's (BEA) National Income and Product Accounts tables dealing with government fixed investment. To estimate RCS, we use the perpetual inventory method, in which the current capital stock is equal to last period's capital stock less depreciation plus investment, to create a capital stock series. Fraumeni (1999) provides a useful discussion on using the perpetual inventory to measure the RCS. The perpetual inventory method is expressed by

$$RCS_{st} = (1-\delta)RCS_{s(t-1)} + \frac{I_{st}}{P_{st}} \tag{A1}$$

In Equation A1, s indexes states, t indexes years, I_{st} is investment less ROW in state s and year t, and P_{st} is the price of RCS in state s and year t.

To implement the perpetual inventory method, we need an RCS price and an initial capital stock for each state. First, we imputed lane mileage (LM) in 1950 by regressing the log of lane mileage from 1980-2000 on the log of centerline miles, the log of population, a state-specific effect, and a time trend and used these results to "predict" LM in 1950 to obtain an initial RCS. We use a two-step procedure to create state price level measures. First, assuming that lane mileage (LM) is highly but imperfectly correlated with RCS, we rearrange Equation A1 to find:

$$P_{st} = \frac{I_{st}}{LM_{st} - (1-\delta)LM_{s(t-1)}} \tag{A2}$$

Using Equation A2 we estimate "implicit" prices over five year periods with I being cumulative over the preceding five years. The price of RCS should depend upon the wage rate, the prices of materials and equipment, and geographic characteristics that make road building more or less difficult. Wages adjust to create compensating differences from the national average for the climate and geographic characteristics of an area that are valued by residents or firms. Therefore, climate and geographic variables along with a time trend to capture changes in the national average wage rate and inflation in equipment and materials prices should explain much of the variation in P. We regress these implicit prices on a set of climate and geographic variables and a time trend and use the predicted values as for state and time specific RCS prices. The variables used were: annual mean temperature and its square; annual January and July mean temperatures; annual average precipitation; average annual humidity; population-weighted average elevation; population-weighted standard deviation of elevation; distance from the coast; distance from the great lakes; and population (all in logs); and t and its square. The results of the regression are recorded in Table A1.

Table A1. Regression Generating State-specific RCS Prices

Variable	Coefficient	p-Value
(Year-1950)	0.070405	0.000
(Year-1950) Squared	-0.000260	0.022
Log Annual Mean Temperature	90.734540	0.000
Squared Log Annual Mean Temperature	-10.203100	0.000
Log January Temperature	-1.897490	0.000
Log July Temperature	-9.835430	0.000
Log Average Annual Precipitation	0.373300	0.010
Log Average Humidity	-5.991980	0.000
Log Coast Distance	-0.070680	0.004
Log Lakes Distance	-0.128250	0.001
Log Mean Elevation	-0.253680	0.002
Log St. Dev. Elevation	0.076347	0.290
Log Population	0.091802	0.021
Constant	-121.734000	0.000
R-Squared	0.864500	
Observations	370	

All variables but the log of the standard deviation of elevation are highly significant, and 86% of the variation in the implicit prices is explained. Thus, we feel the predicted values are reasonably good measures of state-specific RCS prices. With predicted values for 1950 to 2000 in hand, application of Equation A1 to the panel of investment data readily yields an RCS panel for the 48 contiguous states from 1950 to 2000. The RCS measures may be thought of as quality adjusted lane-miles.

With the RCS panel in hand, we turn to estimating the parameters of equation 1. We transform Equation 1 by taking logs and rearranging to form an expression that relates the difference between the local 10-year growth rate and the national 10-year growth rate to K_t and the difference between a state's 10-year RCS growth rate and the national average RCS growth rate. This is expressed in Equation A3.

$$\ln\left(\frac{Population_t}{Population_{t-10}}\right) - \ln\left(\frac{NatPopulation_t}{NatPopulation_{t-10}}\right) = \ln(K_t) + a\ln\left(\frac{RCS_t}{RCS_{t-10}} \bigg/ \frac{NatRCS_t}{NatRCS_{t-10}}\right) + u \qquad \text{(A3)}$$

It remains to specify K_t. Initially, we estimate the model in levels (the log of population share on the log of RCS share), not differences, but include state-specific effects and state-specific time trends which account for both the first difference and $\ln(K_t)$ in Equation A3. We estimate models with non-linear state-specific time trends (state dummies interacted with a time trend and its square, corresponding to second differences, or K_t varying with time). Since the physical characteristics of a state, its public and private stock of durable capital, and national trends in productivity are the only primitive determinants of equilibrium population in our model, and since we lack good data on state-level private capital and non-road public capital, these specifications should control as well as possible for the effects of factors other than transportation investments on equilibrium population. We estimate models allowing for first order serial correlation, constraining the error process to be the same across states in some cases and allowing it to vary across states in others. All models allow for heteroskedasticity and contemporaneous error correlation across states and are based on 288 observations.

Table A2 presents the results of these six regressions. Since the R-squared is over .99 in all cases, we do not report it (this is not surprising since we are using a number of parameters to explain the level of the log population share). The regression in the first column contains state-specific effects and state-specific time trends. The regression in the second column adds state-specific coefficients on the square of the time trend. Thus, the first two columns correspond to first difference and second difference models with state-specific effects, respectively. The results in columns three and four are the same control variable structure, allowing for the presence of first order serial correlation but imposing that the error process is the same across states. Columns five and six then allow the error process to differ across states.

Table A2. Alternative Estimates of the RCS Elasticity of Population

RCS Elasticity of Population	0.2348	0.2720	0.2450	0.3819	0.2659	0.4090
Standard Error	0.0994	0.0440	0.0952	0.0961	0.0970	0.0764
p-Value	0.0180	0.0000	0.0100	0.0000	0.0060	0.0000
State-specific Non-Linear Trend	No	Yes	No	Yes	No	Yes
AR1	No	No	Yes	Yes	Yes	Yes
Panel Specific AR1	No	No	No	No	Yes	Yes

The smallest estimated RCS Elasticity of Population in .2348 and the highest is .409, and all are statistically significant. Since theory suggests that state-level population growth rates are likely to exhibit trends over time, we tend to favor the models with state-specific non-linear time trends. Similarly, since Durbin Watson tests show presence of strong negative serial correlation however the model is estimated, we favor the models with correction for serial correlation. Therefore, we feel this evidence indicates the RCS Elasticity of Population is in the vicinity of .4.

One potential problem with the specification is that the RCS is endogenous. We could simply be picking up that people build more roads where population is growing faster. We don't think this is the case. First of all, we are finding population growth to be a fraction of road growth, all else equal, not the other way around. Second, given the degree of non-market factors driving road investment at any particular point in time, controlling for state-specific non-linear time trends (approximately the same as estimating the model in second differences instead of levels) likely mitigates this problem to a large extent. As evidence of that, the simple correlation between the log of relative RCS growth and the log of relative population growth is only 0.0984. Estimating the model in first or second differences produces very similar results. We estimate the model with non-linear time trends instead to include more years of data for estimating the error structure. Others might argue that current growth in RCS is correlated with lagged population growth, which is correlated with current population growth either due to some partial adjustment mechanism or else serial correlation in error terms. The fact that the simple correlation between the log of relative RCS growth and the lagged log of relative population growth is only 0.1093 argues against this possibility.

While state-specific time trends provide good controls to identify the impact of RCS on population, there are two potential problems with the models in Table A2. First, the specifications are not at all parsimonious—the ratio of parameters to observations is high. Second, out-of-sample predictions based upon models with state-specific effects and time trends are problematic because those trends may not remain constant in future time periods. This is a problem since we want to use this approach for predicting future population responses to today's transportation investments. We address these problems by putting forth a parsimonious specification which we think captures many state-specific effects and state-specific non-linear time trends of the models in the last two columns of Table A2. Since it is reasonable to estimate future population by adding a predicted change to a known current population, we estimate these models in first differences to allow for state-specific fixed-level effects. We include other controls that do not vary over time to allow for state-specific time trends in the levels. We also include controls that vary over time to mirror the state-specific level nonlinear time trends. These specifications allow us to examine whether or not the state-specific effects and trends controlled for in the regression in Table A2 are related to predictable and therefore arguably stable phenomena, and also to gain additional confidence that the model is behaving in ways that are consistent with a regional open economy framework.

We include annual January and July mean temperatures, average annual humidity, the log of population-weighted average elevation, population-weighted standard deviation of elevation, distance from the coast, distance from the great lakes, the land area of each state as share of the U.S. total, and a categorical variable that takes a value of 1 if the state is on the coast and 0 otherwise. We also include the lagged values of the following variables: the population-weighted average of the square root of the distance from the population center of each of the 48 contiguous states to the population-weighted center of the other 47; the population density relative to national average density; land per resident relative to the national average (the reciprocal of the previous variable); relative land per resident x January mean temperature; relative land per resident x July mean temperature; and relative land per resident x coast (categorical).

Assuming that "amenities" are a normal good, people will "demand" more of them as incomes rise over time. This means more desirable locations should grow faster than the national average rate over time. Warmer January temperatures are expected to lead to more growth, especially where there was more land per person (thus cheaper housing) at the beginning of the period. Warmer July temperatures could lead to less growth because people don't like them, or more due to the increasing use and efficiency of air conditioning over the period. More humid areas will likely grow more slowly, while areas on the coast will grow more rapidly, especially where there is much land per person. If mountainous regions are desirable places to live, a higher standard deviation of elevation will attract population, while if mountains raise transportation and construction costs, they will have the opposite effect. We also control for mean elevation since we include the standard deviation of elevation, but we hold no real expectations as to its sign. Mean elevation enters as a log, since the high values are so large relative to the low values. Whether states with more land area will grow more or less rapidly is not immediately clear, but we control for area because the effect of changes in RCS may vary with the geographic size of the state. Dense states, or states where there is less land per person, will likely grow more slowly, since land will be more expensive. People may also have a preference for more "open space"—more land per person. Including both variables essentially just allows this relationship to be non-linear.

Since transportation costs fall over time, more distant locations might grow more rapidly, but since being close to other populous areas can lower some costs and provide other benefits, being close to other populous areas might induce more rapid growth. We take the square root of distance before averaging because being far from your nearest neighbor is likely more important than being far from your furthest neighbor. While being near the coast was important for shipping goods historically, leading to large port cities and large inland populations close to ports, declining transportation costs make it less important to be near the coast (if not actually on the coast to enjoy the amenity benefits), thus, areas further from the coasts should grow more rapidly over time. We also include distance from the great lakes, where history dictated large populations at the beginning of the period, just in case, but we are uncertain what to expect of it since distance to the coast is measured as the distance to the nearest coast, being far from the coast already means being near the great lakes. The results of an OLS regression on these variables are presented in Table A3.

Table A3. Population Growth (1950-2000)

Variable	Coefficient	Standard Error	p-Value
Log Relative RCS Growth	0.3442	0.0743	0.0000
January Mean Temperature	0.0066	0.0014	0.0000
July Mean Temperature	-0.0044	0.0022	0.0530
Average Annual Humidity	-0.0061	0.0011	0.0000
Log Mean Elevation	-0.0429	0.0176	0.0160
Log St. Dev. Elevation	0.0137	0.0179	0.4440
Land Area (Share)	1.0422	0.5498	0.0590
Coast (0,1)	0.0596	0.0184	0.0010
Distance to Coast	0.0001	0.0000	0.0010
Distance to Great Lakes	-0.0001	0.0001	0.0490
Lag Sq. Root Weighted Distance	0.0061	0.0042	0.1480
Lag Relative Density	-0.0061	0.0018	0.0010
Lag Relative Land Per Resident	0.0347	0.0078	0.0000
Lag Relative Land Per Resident x January Mean Temperature	0.0002	0.0000	0.0000
Lag Relative Land Per Resident x July Mean Temperature	-0.0001	0.0000	0.0000
Lag Relative Land Per Resident x Coast (0,1)	-0.0089	0.0062	0.1530
Constant	0.5844	0.2967	0.0500
R-Squared	0.6677		
Root Mean Square Error	0.06684		
Observations	240		

The regression explains nearly 67% of the variation of the difference between 10-year state growth rates and 10-year national growth rates. This seems to be a very good fit, considering we are explaining variation in the difference in population from the national average difference in population. Nearly all of the variables are significant. This is partly due to a specification search among the various ways of combining the group of variables that were selected *a priori*. For instance, this mostly log-linear specification was found to perform better than a log-log specification. Further, no significant variable has an unexpected sign.

The key result is the RCS Elasticity of Population of 0.34, with a standard error of 0.07. Table A4 reports the key results for several variants of the same regression. Since the coefficients on the control variables are very close to those reported in Table A3 across all regressions, they are not reported in Table A4. The first column of Table A4 represents the same regression as in Table A3. The second column represents the same regression for the period through 1980, when the building of the Interstate Highway System likely produced a lot of clearly exogenous movement in state-level RCS. The elasticity estimate is even larger, 0.53. The third and fourth columns present the same basic regressions, but add corrections for heteroskedasticity and contemporaneous error correlation across panels. This, of course, leaves the coefficients unchanged, and it leads to only slight increases in standard errors. Columns five and six add a correction for negative serial correlation (present in all models considered in this report). Finally, columns seven and eight present the results of regressions in which the AR1 process is allowed to vary across states. The RCS Elasticity of Population estimates vary from .32 to .59, and all are statistically significant. These results, together with those presented above, constitute very strong evidence that the RCS Elasticity of Population is in the vicinity of .4.

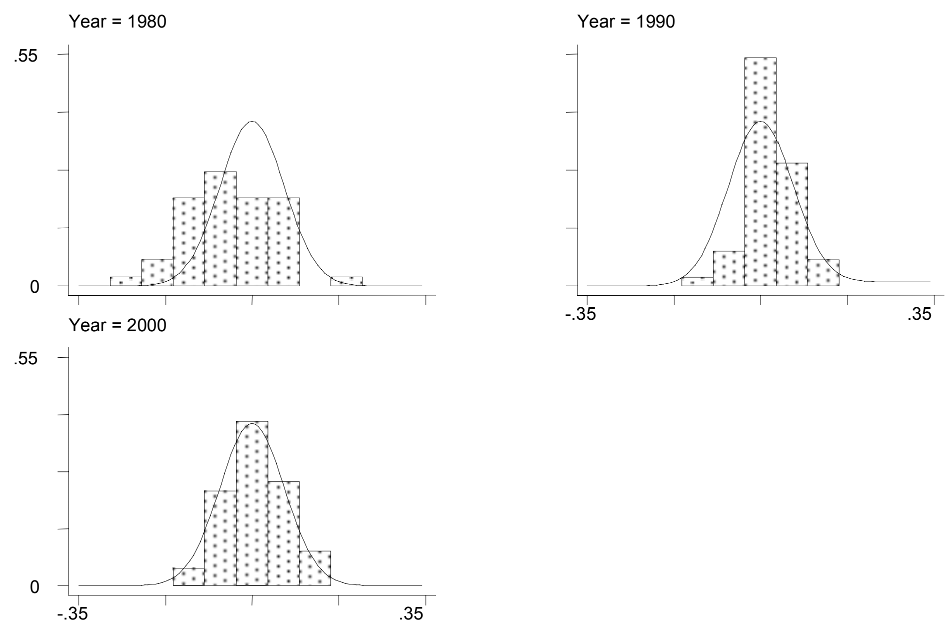
Table A4. Alternative Estimates of the RCS Elasticity of Population

RCS Elasticity of Population	0.3442	0.5260	0.3442	0.5260	0.3154	0.5066	0.4121	0.5910
Standard Error	0.0743	0.1027	0.1037	0.1242	0.1200	0.1403	0.0923	0.1006
p-Value	0.0000	0.0000	0.0010	0.0000	0.0090	0.0000	0.0000	0.0000
Sample Period	1950-2000	1950-1980	1950-2000	1950-1980	1950-2000	1950-1980	1950-2000	1950-1980
Observations	240	144	240	144	240	144	240	144
Panel Correction	No	No	Yes	Yes	Yes	Yes	Yes	Yes
AR1	No	No	No	No	Yes	Yes	Yes	Yes
Panel Specific AR1	No	No	No	No	No	No	Yes	Yes

TECHNICAL APPENDIX B: CONFIDENCE INTERVALS FOR STATE AND MSA POPULATION PROJECTIONS

We begin by estimating Equation A3 at the state level over 20 years and using the results to forecast growth over the next 10 years, assuming future RCS levels are known. To the extent that RCS growth responds to population growth within the same decade, this is not quite right, but the extremely weak correlation between RCS growth and contemporaneous or lagged population growth suggests this will not be a problem. Also, this is consistent with the ability of policymakers to choose the amount of RCS growth. This allows us to produce three sets of forecasts—1980, 1990, and 2000. The root mean square errors are 0.093, 0.056, and 0.063, respectively. Thus, with foreknowledge of RCS growth, the state-level forecasts are ***very*** accurate. Figure B1 presents histograms for the three years. The smooth normal curve overlaid has a mean of zero and a standard deviation of 0.065. The errors in 1990 and 2000 are approximately normally distributed, as may be seen in the graph.

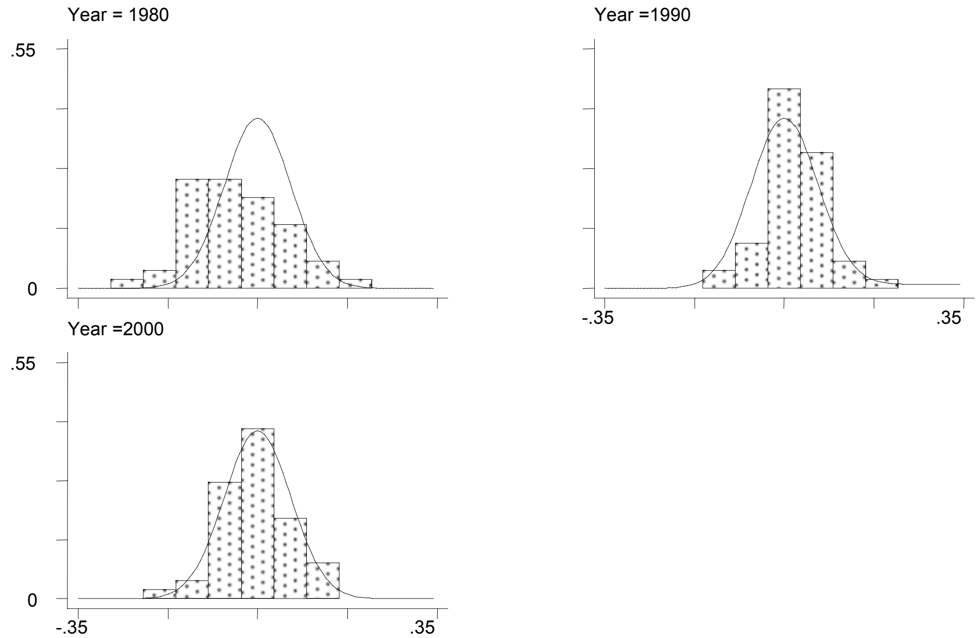
Figure B1. Errors - Regional Equilibrium Model With Road Stock



Histograms by year

Since RCS growth is not actually known in advance, form three forecasts based on the same method, but ignoring RCS growth. The correlation between predicted growth with and without accounting for RCS growth is 0.95. The Root Mean Square errors for 1980, 1990, and 2000 are 0.102, 0.059, and 0.063, respectively. Thus, the model with RCS growth is slightly more accurate. The close resemblance between the two sets of forecasts is likely due to the fact that RCS growth usually deviates from trend by only a small amount. Figure B2 presents histograms for these errors. Again the errors are approximately normally distributed in 1990 and 2000.

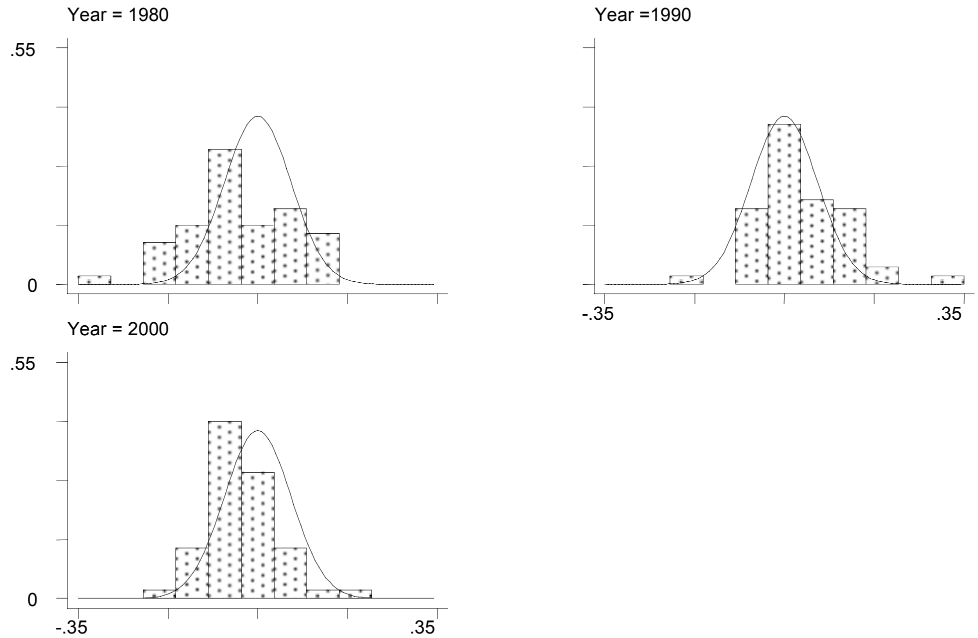
Figure B2. Errors - Regional Equilibrium Model Without Road Stock



Histograms by year

We produce one final set of state-level projections for comparison purposes using a slight simplification of the extrapolation method used for BEBR's sub-state projections. Specifically, we produce four simple extrapolations of population using a 10-year base period and average them. Smith and Nogle (2000) discuss the four extrapolative methods used. BEBR actually produces these four, and also repeats two of the methods for two additional base period lengths, throws out the high and low, and averages the remaining six. (We found our slightly simpler approximation was a bit more accurate for our MSA data, so we focus on it). We convert this population forecast to a growth rate forecast. The root mean square errors for 1980, 1990, and 2000 are 0.106, 0.086, and 0.071—the results are slightly less accurate than the method based on Equation A3. The correlation between this forecast growth rate and the growth rate forecast based on Equation A3 without RCS growth is 0.77. Figure B3 presents histograms for these errors. It is apparent that the errors from the model based on A3 are slightly more closely approximated by the normal distribution with mean 0 than those from the purely extrapolative method depicted in Figure B3 (the skew is uniformly closer to 0 and the kurtosis is uniformly closer to 3).

Figure B3. Errors – Extrapolative Technique



Histograms by year

Together, these findings suggest that projections produced ignoring RCS growth can be adjusted for non-trend RCS growth using an RCS Elasticity of Population of 0.4 to approximate what the forecast would have been with RCS growth. Because the standard errors are quite similar across all three techniques, and since they are all normally distributed, adding and subtracting 1.282 times the 2000 root mean square error will give a rough 80% confidence interval.

We now turn to MSA-level forecasts to see if these results hold up at the sub-state level. Since we do not have MSA-level data on RCS, we exclude it from our model. The only other modification to the specification used for the state-level forecasts was to use the log of relative density in place of relative density and to drop relative land per person. This is because, at the MSA level, the difference between the highest and lowest relative densities is tremendous. Transforming by taking the log moderates these extreme values. However, the log of relative density equals the negative of the log of relative land per person, thus only one can be included. Table B1 presents the root mean square errors for forecasts based on the regional equilibrium model and on the purely extrapolative technique for 1960-2000.

Table B1. MSA Level Root Mean Square Forecast Errors

Year	Extrapolative Technique	Regional Equilibrium Model
1960	0.161	0.178
1970	0.118	0.131
1980	0.129	0.126
1990	0.092	0.091
2000	0.082	0.086

Table B2. Share of Actual Growth Rates Outside Forecast Confidence Intervals, all U.S. MSAs (1960-2000)

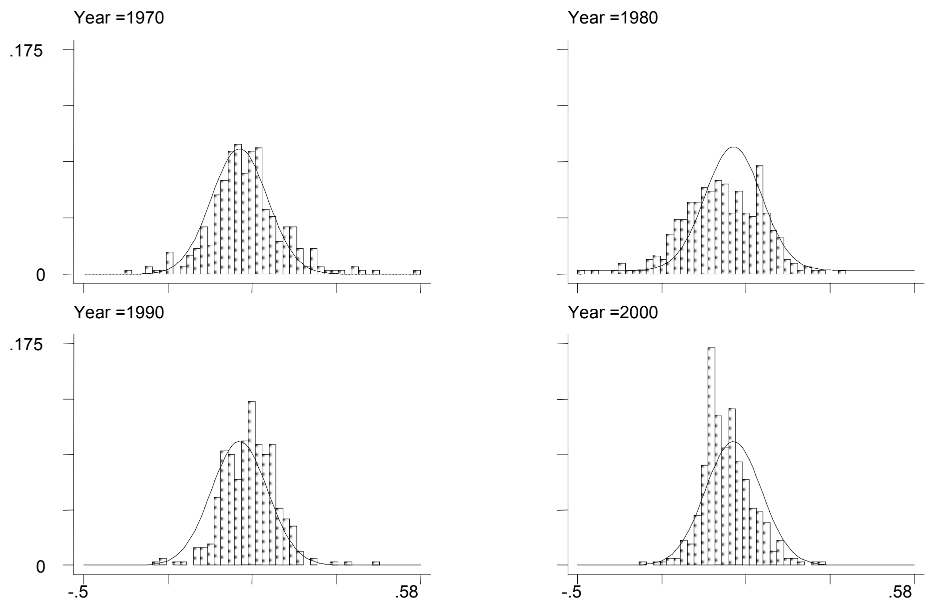
Type of Error	Extrapolative Technique	Regional Equilibrium Model
High	0.072	0.062
Low	0.051	0.048
Total	0.123	0.110

Table B3. Share of Actual Growth Rates Outside Forecast Confidence Intervals, Florida's MSAs (1960-2000)

Type of Error	Extrapolative Technique	Regional Equilibrium Model
High	0.167	0.143
Low	0.155	0.071
Total	0.321	0.214

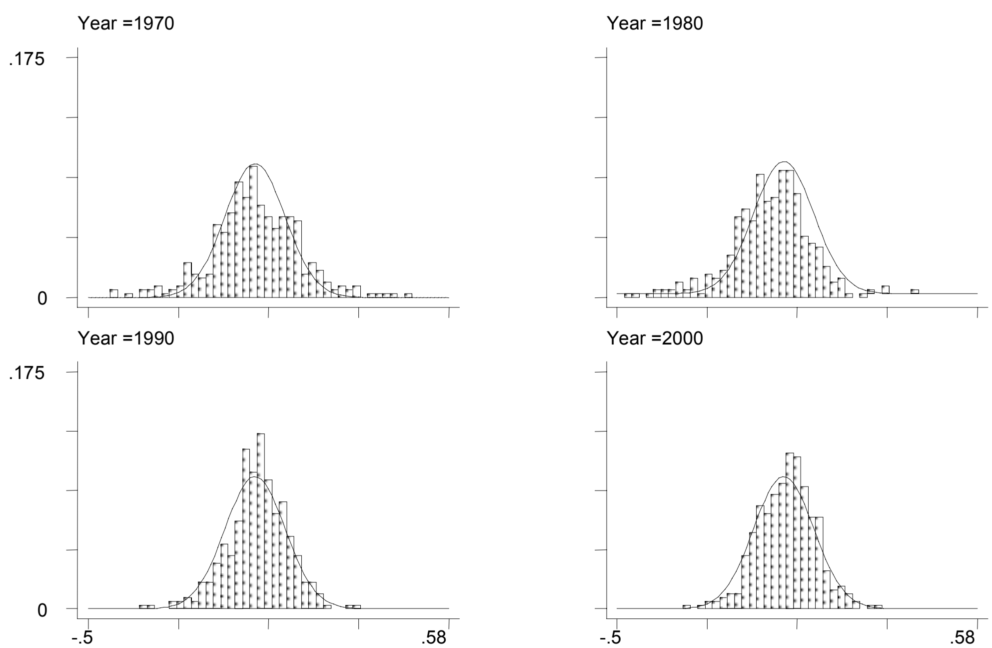
From the table, it is apparent that neither method is consistently more accurate than the other, and both exhibit a strong downward trend. The correlation between the two sets of forecasts is 0.68. Figure B4 depicts the histogram for the extrapolative technique, and Figure 5 depicts the histogram for the regional equilibrium model (in both the overlaid normal distribution has mean 0 and standard deviation 0.09). From the figures, it is clear that both are well approximated by the normal distribution.

Figure B4. Errors – Extrapolative Technique



Histograms by year

Figure B5. Errors - Regional Equilibrium Model Without Road Stock



Histograms by year

We perform one last comparison by constructing 80% confidence intervals for each technique, using the standard deviation of forecast errors from the previous year's forecast. Table B2 summarizes the national results and Table B3 summarizes the results for Florida alone. Based upon these tables, we see that forecasts fall within the 80% confidence intervals slightly more often for the model based on Equation A3 than for the simple extrapolative technique. For Florida, the extrapolative technique produces estimates that fall outside the 80% confidence interval 32% of the time, compared to 21% for the regional equilibrium model. Since the root mean square errors are similar between the two methods, we conclude that the regional equilibrium model is better suited to incorporating the impact of RCS growth, but also at least as accurate and perhaps better at dealing with uncertainty.

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