PRIVATE DEMAND FOR PUBLICLY PROVIDED GOODS: A CASE STUDY OF RURAL ROADS IN TEXAS

Laurence M. Crane
Nat Pinnoi
Stephen W. Fuller*

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* Crane is Farm Financial Specialist, North Dakota State University and formerly Research Associate, Texas Transportation Institute, Texas A&M University. Pinnoi is Research Associate, Texas Transportation Institute, Texas A&M University. Fuller is Professor, Department of Agricultural Economics at Texas A&M University.

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ABSTRACT: Private demand functions for publicly provided rural roads in Texas are estimated at the county level. Results show that changes in income and tax rates (price) have the expected effect and that the demand for rural roads has changed over time. In particular, demand has become more inelastic and the influence of income on demand has moderated.

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INTRODUCTION

Many rural economies have undergone a major restructuring in recent years resulting from an accelerated exodus from farming, increased unemployment, and the subsequent declines in tax base and population. The economic down-turn has been further compounded in oil producing states where the value of oil production has declined significantly. There is concern about the ability of rural governments to provide roads and bridges as well as other essential public services and infrastructure (U.S. Department of Agriculture, 1991; Johnson, Deaton, and Segarra, 1988; Chicoine and Walzer, 1986).

Rural transportation arteries are an important link between farmers, markets, and rural employment centers. Agriculture depends on the timely marketing of commodities and products and on purchased inputs, both of which move over the rural road system. Yet the condition of this transportation infrastructure is cause for concern (Chicoine, Walzer, and Deller, 1989; U.S. Department of Transportation, 1985). Recent studies have analyzed the growing disinvestment in rural low-volume roads and bridges (Nyamaah and Hitzhusen, 1985; Hartwig, 1979; Baumel, Schornhorst, and Smith, 1989). The costs of improving and upgrading major parts of the system exceed resources available to rural local governments (Baumel and Schornhorst, 1983; Chicoine, 1987). Expenditures for public highways are the third largest component of state and local governments budgets. Expenditures for education and welfare are first and second, respectively (Anderson, Murray, and Farley, 1984).

In recognition of the transportation problems in rural America, the U.S. Secretary of Transportation Skinner recently designated "Rural America Transportation Systems and Services" as one of the critical problem areas in U.S. transportation. He recently authorized the development of a national transportation policy to establish guidelines for meeting the nation's transportation needs over the next decade and into the 21st century (Federal Register, 1989). An analysis of the economic forces which have shaped the demand for rural transportation infrastructure is needed so that rational policies might be developed and forwarded.

The deteriorated physical and financial condition of the public rural road system has been exacerbated by the increasing numbers of rail line abandonments by private railroads (Casavant and Lenzi, 1989). Furthermore, structural shifts in rural America have dramatically changed the types of traffic on the rural road system. Increased farm size has resulted in a dramatic reduction in the number of farms and people living on farms. This has been accompanied by an increase in the size and weight of vehicles and equipment on the rural road system. These heavy and often over-weight vehicles break-up road surfaces while the frequent lack of paved surfaces creates dust, and safety problems.

Narrow lanes and other design characteristics on many of these roads are inadequate for today's large trucks thus creating safety hazards. Similarly, deficient rural bridges pose serious safety and traffic constraints. Some states that have not been able to generate sufficient revenues have downgraded the size of their rural system through road abandonment and private provision (Hamlett and Baumel, 1990; Baumel, Schornhorst, and Smith, 1989; Hartwig, 1979).

Earlier studies have investigated means of reducing the supply of rural road infrastructure (e.g., road abandonment). This study in contrast, examines factors that effect the demand for publicly provided rural roads. The objective of this paper is to develop an appropriate methodology to determine the demand for rural road infrastructure and to subsequently estimate the demand for rural roads in Texas. The results will provide policy makers with valuable information on economic forces such as income and price that influence the demand for rural roads as input to the development of better policies to address the problem of supplying privately-demanded, but publicly-supplied rural roads.

In Texas there are approximately 134,000 miles of rural roadway and 17,000 rural bridges, the largest rural road network in the U.S. (Texas Almanac, 1988; U.S. Department of Transportation, 1985). Maintaining these roads, many of which are very low-volume, is a major expense of local highway budgets (U.S. Department of Commerce, 1982). The Texas state government supplies about 17 percent of the funds for rural roads through motor fuel taxes (U.S. Department of Transportation, 1985).

METHODOLOGY

Traditional demand theory is oriented to an individual consumer's behavior. The market demand relation is simply a gross aggregation of the demands of all individual consumers. In this framework, the individual's utility function is assumed to be strictly increasing in all arguments, smooth, quasi-concave, and twice-continuously differentiable. This utility function is maximized subject to a linear budget constraint. The ratio of the partial derivatives from the first order conditions are the marginal rates of substitution between the goods in an individual's utility function. The solution to this problem yields the Marshallian demand function that relates quantities demanded to given levels of prices and income.

Goods and services which are publicly supplied generally share two characteristics that distinguish them from private goods. First, consumption by any one person need not diminish the quantity consumed by anyone else. Second, it is impossible to confine the benefits of the good to selected persons (Buchanan, 1968); Browning and Browning, 1983). Because of these characteristics, aggregate consumption patterns are consistent with utility maximization only when restrictions are placed on the shapes of individual preferences. However, the results from public sector studies based on the utility maximization paradigm have verified that most of the classical conditions hold.

Rather than viewing expenditures as responses to collectively exercised demands, Deacon (1978) incorporates the possibility of substitution among public services in response to changes in relative costs by directly modeling and estimating the substitution effects in collective consumption. Deacon carrys out the analysis using the classical consumer choice model which assumes a separable maximization of a utility function subject to a linear budget constraint. Deacon found the negativity and homogeneity properties of utility maximization held, thus suggesting classical demand theory is appropriate for analyzing public sector expenditures. That is, public budgets are allocated among public goods and services in the same theoretical manner by which individuals allocate income to private sector goods.

Since a public good simultaneously benefits all members of the community, each of these individual's marginal valuations must be accounted for when the resource allocation decision is made. Samuelson (1954, 1955) has shown the Pareto optimal condition for a public good requires the following first order condition be satisfied:

$$\sum_{i=1}^{n} MRS_{xy}^{i} = MRT_{xy} ,$$

where, n is the number of community members, y is a private sector good, and x is the public good. This condition, referred to as the Samuelsonian condition, is derived by maximizing the utility of any individual, while the utility levels of the remaining community are held constant (Cornes and Sandler, 1986; Starrett, 1988; Boadway and Wildasin, 1984).

As the cost of publicly provided goods and services increase, demand theory suggests private goods and services will substitute for public sector goods and services. To test this notion, Ehrenberg (1973) estimates wage elasticities of demand for different categories of state and local government employees and finds that an increase in the relative price of a public service leads to a substitution against that service. The substitution of capital for labor is easier to measure than the substitution between transportation modes. This is because there are no viable alternatives to the public rural road system. Currently the only alternative to the rural road system is the railroad. As Casavant and Lenzi

(1989) have documented, users of these systems are forced to substitute the rural road system for abandoned rural rail lines.

Variations in per capita expenditures on public services such as highways, health and education are often explained by population densities, urban-rural distinctions, average income levels, and age distributions. Ohls and Wales (1972) noted that theory is not clear on whether these demographic variables enter on the demand or supply side of the market. Borcherding and Deacon (1972) used the theory of collective decision-making to posit a model of public spending and to test the significance of the variables assumed by collective decision theory to be important determinants of state and local government expenditures. The effects of income, price, city size, and other social variables on the demand for municipal services were estimated by Bergstrom and Goodman (1973).

In principle, the choices that individuals of particular demographic groups make, under alternative price and income situations for privately produced commodities may be directly observed. For obvious reasons this is generally not the case with publicly supplied commodities. Bergstrom and Goodman made inferences about the effect of price, income, and other relevant variables on individual demands for municipal services by making strong assumptions about the political process of municipalities.

Rubinfeld (1987) pointed out that aggregation of preferences, measurement of output, and determination of price are conceptual problems in estimating public demands. Assumptions of the Bergstrom and Goodman model overcome the major conceptual problem of preference aggregation outlined by Rubinfeld.

Estimation Technique

In this paper, a variation of the Bergstrom and Goodman (1973) model is estimated using the sample of 254 counties in the state of Texas for 1972 and 1986. The usefulness of the publicly provided goods (rural roads in this case) to an individual is a function of the total number of users and the quantity of such goods. Mathematically this can be stated as:

$$Q^{*} = n^{-\nu} Q \ , \tag{1}$$

where,

Q^{*} is the usefulness of rural roads to a user,

n is the total number of road users,

Q is the total quantity of rural roads,

ν is a crowding parameter (i.e. if Q is a pure public good then $\nu = 0$ and if $\nu = 1$ then every user shares the same amount of the facility).

The individual is assumed to maximize their utility function, consisting of both private and public goods, subject to their budget constraint. Mathematically this maximization problem is formulated as:

$$\underset{X_i \, , \, Q^{*}}{Max} \; U_i \, (X_i \, , Q^{*}) \ , \tag{2}$$

Subject to: $$X_i + \tau_i \, q \, Q \leq Y_i \ , \tag{3}$$

or equivalently by substituting in (1), the budget constraint becomes

$$X_i + \tau_i \, q \, n^{-\nu} \, Q^{*} \leq Y_i \ , \tag{4}$$

where q is a unit cost of the rural roads (assuming that the unit cost of private goods is unity), τ_i is a tax share, X_i is private goods, and Y_i is the budget of individual i. If we assume further that income and price elasticities, η_Y and η_P, for Q^{*} are constant, then the derived demand for Q^{*} can be written as a Cobb-Douglas function:

$$A \left(\tau_i \, q \, n^{-\nu} \right)^{\eta_P} Y_i^{\eta_Y} \ . \tag{5}$$

Therefore, the demand function (after taking a natural logarithm) for rural roads is:

$$a + \alpha \ln n + \eta_P \ln \tau + \eta_Y \ln Y \ , \text{ where } \alpha = \nu(1+\eta_P).$$

Under the assumption that τ_i and q_i are constant, the county's expenditure on rural roads and streets can be considered as the quantity of rural roads demanded. Finally, the estimated demand for rural roads is described below as:

$$\ln REXP = a + \alpha \ln n + \eta_P \ln \tau + \eta_Y \ln Y + \sum_{j-1}^{G} \theta_j Z_j \ , \qquad (6)$$

where,

Z_j's are variables representing specific characteristics for Texas counties,

a, θ_j are parameters to be estimated,

REXP is the total annual expenditure on roads and streets by a county.

Let X be a matrix of all the independent variables with its corresponding vector of parameters β, and *rexp* a column vector of ln(*REXP*). Then in matrix form:

$rexp = X\beta + u$, where $u \sim (0, \sigma^2)$.

Demands are estimated by ordinary least squares (OLS) for 1972 and 1986 samples and the pooled sample.

Empirical Model and Data

The empirical model (6) can be rewritten with the selected auxiliary variables for the rural road system in Texas, including the county characteristics as:

$$\ln REXP = a + \alpha \ln n + \eta_P \ln \tau + \eta_Y \ln Y + \sum_{j-1}^{5} \theta_j Z_j \ , \qquad (6a)$$

where n is a measure of the number of road users. In the empirical model, the average annual daily traffic on the rural farm to market system in the county is a proxy for n, while Y is nonfarm per capita income in the county[1], and τ is per capita tax value upon which the tax rate is levied in each county. The five auxiliary variables (Z_j) are total county road mileage, county area, population density, and dummy variables for agricultural and metropolitan counties. Inclusion of the dummy variables controls for county-specific variables. The demand for publicly provided roads is hypothesized to be greater for metropolitan counties than agricultural counties. Economic and social activities in the

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[1] Per capita farm income as well as total per capita income were also used as a measure of average county income. When these variables were included however the results were not satisfactory (e.g., explanation declined and the expected signs on several of the key variables were not obtained).

metropolitan counties likely require more frequent use of the roads than those in the non-metropolitan counties.

Similar to any consumer demand analysis, price (represented by τ) is expected to have a negative effect on quantity demanded whereas the demand for roadways is expected to increase as income and county population increase (except in the case of a rare Giffen good). Likewise, population density, county area, and road mileage are expected to have positive impacts on road demand.

The data set consists of annual observations for the 254 counties of Texas for the years 1972 and 1986. The 1972 sample was selected because it was the last year before the oil crises. The 1986 sample was selected because it was the most current year for which complete data were available on all of the variables at the county level. Following Bergstrom and Goodman (1973), the county expenditures on road maintenance and construction (*REXP*) were used to represent the demand for rural roads. These highway maintenance and construction expenditures are reported by the Texas Department of Transportation in their biennial reports. Data on personal income and population were taken from *Regional Economic Information System* (U.S. Department of Commerce). The per capita tax (τ) was calculated using county data from the Texas State Property Tax Board. Data on miles of rural roads and the average annual daily traffic were obtained from the Texas Department of Transportation. Data on county size were taken from the *Texas Almanac* (Bello). The topology of counties used in this study are the classifications used by Ross and Green.

To exclude the effects of inflation, the nominal dollar values were deflated into real dollars using the GNP implicit price deflators (1982=100) in the Economic Report of The President. The descriptive statistics for these variables for 1972 and 1986, as well as the pooled data are shown in Table 1. Because cross-sectional data were used, a series of misspecification tests were conducted to test and correct for heteroskedasticity and structural changes over time. Specifically, White's general test for heteroskedasticity and a Wald test were performed to test and correct for the stabilization of the estimated coefficients over time. The details of these tests are outlined in the Appendix.

RESULTS

White's general test for heteroskedasticity shows the empirical model suffers from unequal error variances (Table 2). In the absence of a priori information on the known structure of the heteroskedasticity, a Feasible Generalized Least Squares is precluded. A Chow test for structural change is invalid when heteroskedasticity occurs. Alternatively, a Wald statistic was used which is unaffected by the inequality of the variances, given a large sample. The null hypothesis of equality between the two sets of regressions (1972 and 1986 samples) was rejected at the 1% confidence level as a Type I error (Table 2). Therefore, the results of the two cross-section sub-samples should be more precise than the pooled regression. Thus, attention focused on the separate models rather than the pooled model in this study.

Approximately 60% of the variation in demand for county roads in Texas was explained by the selected set of regressors (Table 2). The explanatory power of the equations estimated by Bergstrom and Goodman (1973) ranged from 35 to 96 percent. Based on White's general test for heteroskedasticity-consistent estimates of the covariances, most coefficients are statistically significant at the 5% level or higher except for the coefficients on income (significant at 15%) from the 1986 sample. Furthermore, the point estimates of all parameters possess the expected sign (except for the coefficient on the per capita tax variable in the pooled sample but it is statistically insignificant).

The results indicate that as nonfarm per capita income increases by 1 percent, the demand or expenditure for rural roads is estimated to increase by 0.48 and 0.21 percent, based upon the 1972 and 1986 data, respectively. The estimated income elasticities suggest rural road demand was less sensitive to the changes in income in 1986 than in 1972. Real per capita income was increasing in 93 percent of the counties in 1972, but was increasing in only 51 percent of the counties in 1986. Further, as the "price" of rural roads increases by 1 percent, the expenditure or demand for rural roads decreases by 0.25 percent based on the 1972 sample and by 0.19 percent based on the 1986 data. This suggests tax payers were slightly more responsive to price changes in 1972 than 1986. This may be due to an increase in the level of traffic congestion experienced by road users in some rural counties, as well as a deterioration in the quality of the rural system.

Consumption of public goods by one person diminishes the quantity consumed by another. Consequently a crowding parameter was estimated to measure this effect. A zero crowding parameter would indicate a pure public good, whereas a parameter value of one would indicate a pure private good. A crowding parameter of less than one, but greater than zero, suggests the public investment is not a pure public commodity. In this study the crowding parameter is estimated to be 0.37 in 1986 and 0.2 in 1972 indicating that the rural road system in Texas is more crowded in 1986. Thus an additional road user would decrease the availability of the roads to others, but would not completely prevent other motorists from using the roads. Bergstrom and Goodman (1973) found the estimates of crowding parameters for municipal, police, and parks and recreation expenditures were generally equal to one or greater. Their results imply that "*... as the size of municipalities increase, the advantages of sharing the cost of public services among more person are countervailed by the cost of sharing the services among more persons.*" In summary, income elasticity is decreasing over time while the price elasticity and the crowding parameter are increasing over time (Figure 1).

A series of dummy variables were used to determine if the social and economic characteristics of the county affected the demand for rural roads. Counties were classified as either metropolitan or as non-metropolitan. The non-metropolitan counties were then sorted according to a sub-classification, depending upon the dominant characteristic of that county. The possible sub-classifications for the non-metropolitan counties were agricultural, manufacturing, mining, federal lands, government, poverty, or retirement. The demand for rural roads in metropolitan counties and in agricultural counties were found to be the only statistically significant dummy variables. The negative parameter estimates for the agricultural county dummy variable and the positive value for the metropolitan county indicate that, on average, the demand for rural roads in agricultural counties is less than that of users in metropolitan counties.

SUMMARY AND CONCLUSIONS

The demand for rural roads in Texas, using county data from 1972 and 1986, is estimated following a procedure developed by Bergstrom and Goodman. The analysis shows the per capita income of a county's population, price as measured by tax rate, and selected economic characteristics of the county have shaped investment in Texas rural road infrastructure. These economic forces should be given consideration by state and local governments as they attempt to modify this system. The estimated demand relationships are consistent with consumer theory and are generally comparable with earlier results. The sign and magnitude of the coefficients are reasonable. The effect of income on rural road demand was found to vary from 0.48 in 1972 to 0.21 in 1986 while the influence of tax rate on demand varied from -0.25 in 1972 to -0.19 in 1986. This outcome suggests some change in the effect of income and tax rate (price) on the demand for rural roads over time. In particular, demand has become more inelastic and the influence of income on demand has moderated. A less favorable economic climate in 1986 relative to 1972 may offer some explanation. Further, the fact that rural roads in Texas are increasingly more crowded may partially explain the observed changes.

Finally, there have been few efforts to measure the demand for rural road infrastructure in the United States. This study shows the feasibility of estimating these demands and suggests this type of information is necessary input to development of a meaningful and comprehensive rural transportation policy.

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Table 1. Descriptive Statistics for the Variables in 1972, 1986, and Pooled.

Pooled Data (N=508)	Minimum	Maximum	Mean	Std. Dev.
Log (Nonfarm per Capita Income)	5.21	8.07	6.15	0.38
Log (Tax per Capita)	1.78	12.53	7.48	1.39
Log (AADT)	19.75	26.25	23.46	0.99
Rural Road Mileage	8.53	388.79	154.46	66.98
County Area	128.00	6169.00	1029.22	647.24
Population Density	1.49	20830.68	588.33	1761.32
Log (County Expenditures on Roads)	10.59	19.42	14.79	1.175
1972 Data (N=254)				
Log (Nonfarm per Capita Income)	19.75	7.06	6.06	0.36
Log (Tax per Capita)	8.53	9.90	6.40	0.77
Log (AADT)	128.00	26.25	23.66	1.01
Rural Road Mileage	1.49	381.84	150.03	647.87
County Area	10.59	6169.00	1029.22	647.24
Population Density	1.49	15378.41	488.06	1432.84
Log (County Expenditures on Roads)	10.59	18.61	14.59	1.14
1986 Data (N=254)				
Log (Nonfarm per Capita Income)	5.21	8.07	6.24	0.38
Log (Tax per Capita)	1.78	12.53	8.57	0.98
Log (AADT)	19.75	26.05	23.26	0.93
Rural Road Mileage	8.53	388.79	158.89	68.83
County Area	128.00	6169.00	1029.22	647.87
Population Density	1.49	20830.68	688.61	2035.57
Log (County Expenditures on Roads)	11.33	19.42	14.99	1.18

Table 2. Parameter Estimates When ln (Country Expenditures on Roads) is the Dependent Variable.

Independent Variables	First Subsample 1972	Second Subsample 1986	Pooled 1972 and 1986
Constant	9.05* (2.00)	7.62* (2.30)	8.33* (1.54)
ln(Nonfarm per Capita Income)	0.48* (0.17)	0.21*** (0.15)	0.35* (0.13)
ln(Tax per Capita)	-0.25* (0.10)	-0.19* (0.07)	0.02 (0.03)
ln(AADT)	0.15** (0.07)	0.30* (0.09)	0.14* (0.057)
Crowding Parameter	0.2* (0.09592)	0.37* (0.1621)	0.14* (0.05468)
Rural Roads Mileage	0.003* (0.001)	0.003* (0.001)	0.004* (0.0007)
County Area	0.00024* (0.0001)	0.00017** (0.00009)	0.00016* (0.00006)
Agricultural County	-0.45* (0.13)	-0.30* (0.12)	-0.43* (0.09)
Metropolitan County	0.50* (0.13)	0.54* (0.14)	0.70* (0.11)
Population Density	0.0003* (0.00006)	0.0002* (0.00005)	0.0002* (0.00005)
R^2 adjusted	0.59	0.62	0.57
White's Test	1,466,092	599,546	239,001
Wald Test		39.09	
Chow Test		11.13	

Standard errors computed from White's heteroskedasticity consistent covariance matrix are given in parentheses.
* denotes statistically significant at 1%.
** denotes statistically significant at 5%.
*** denotes statistically significant at 15%.

APPENDIX: MISSPECIFICATION TESTS

This appendix explains the tests for heteroskedasticity and structural change.

Heteroskedasticity

Given the cross-sectional nature of the data used, heteroskedasticity would be expected. White's general test for heteroskedasticity without any prior knowledge of its structure is, therefore, a recommended required test. Although, OLS estimates will be consistent under heteroskedasticity, the estimated covariance matrix of the estimated parameters will depart from its true value even in the case of a large sample. Consequently, any statistical inference about the estimated coefficients based on its covariance (e.g., t-test for statistical significance of the parameters estimated by OLS) will be inaccurate. However, White (1980) showed that a heteroskedasticity consistent estimate of the covariance can be obtained from OLS residual as follows:

$$\mathrm{Var}[\hat{\beta}] = n(X'X)^{-1}S(X'X)^{-1} \ ,$$

where

$$S = \frac{1}{n}\sum_{i-1}^{n} e_i^2\, x_i\, x_i' \quad \text{, and } e_i \text{ is OLS residual; } i = 1, \ldots, n.$$

Structural Change

A Wald test is performed instead of a simple Chow's test in order to test the stabilization (over time) of the estimated coefficients (i.e., to test whether two sets of OLS estimators are the same). It is well known that the Chow's test will be invalid in the case where the two models have unequal variances (i.e. when heteroskedasticity is present). The result of the Chow's test will reject the null hypothesis of no structural change "too" often, (Type I Error). Because the sample used is reasonably large, the Wald asymptotic tests were calculated under the assumption that the disturbance terms from the two separate regressions are independently and normally distributed. This condition is plausible because the two sample periods are fifteen years apart. Consequently, it is reasonable to believe that the errors are unlikely to be correlated. The result of the Wald test will be valid whether the two error variances are equal or not:

$$W = (\hat{\beta}_1 - \hat{\beta}_2)'(V_1 + V_2)^{-1} (\hat{\beta}_1 - \hat{\beta}_2) \underset{H_0}{\overset{a}{\sim}} \chi_K^2 ,$$

where

$\hat{\beta}_i$, $i = 1$ and 2, is the vector of OLS estimators from two separate regressions,

V_i , $i = 1$ and 2, is the estimated covariance matrix of the OLS estimates,

K , is the number of parameters estimated (i.e., dimension of β).

The Wald statistic, W, is asymptotically distributed as a Chi-Square with K degree of freedom under the null hypothesis.