1.201 / 11.545 / ESD.210
Introduction to Transportation Systems
Fall 2007

Final Exam

Monday, December 17, 2007

- You have 3 hours to complete this exam.
- Show all your work to get partial credit.
- You are allowed to use your notes from class, as well as any other notes or textbooks.
- You can use a calculator. However, laptop computers, mobile phones, and other electronic devices are not allowed.
- There are nine questions in this exam.

Good luck!

Question 1 (14 points)

Cost Functions for Public Transit Systems

Karlaftis and McCarthy (2002) estimated a translog cost function for US public transit operators. Following is the first-order approximation of that function (*Note: A 'first-order approximation' does not include interaction terms)*:

$$\ln CV = \alpha_0 + \alpha_Y \ln Y + \alpha_N \ln N + \alpha_K \ln K + \alpha_L \ln P_L + \alpha_F \ln P_F + \alpha_M \ln P_M$$

where

CV represents the total short-run variable costs (in $ millions),

Y is the number of vehicle-miles (units of 10^5), which is a measure of output,

N is the number of route miles, which is a measure of network size,

K is the number of buses in the operator's fleet,

P_L is the price of labor (in $ per hour),

P_F is the price of fuel (in $ per gallon),

P_M is the price of materials (in $ per vehicle hour – material costs were calculated by subtracting labor and fuel costs from total costs and then dividing the difference by peak-hour requirements to obtain costs per vehicle hour)

The function was estimated using data from 256 US transit systems over the period 1986-1994. The estimation results are shown in Table 1:

TABLE 1: Estimation results

Coefficient	**Estimated value**
α_0	9.27
α_Y	0.78
α_N	-0.03
α_K	0.29
α_L	0.71
α_F	0.14
α_M	0.15

<u>Answer the following questions:</u>

a. What is the point elasticity of total short-run variable costs with respect to:
   i. the price of labor (1 point)
   ii. the price of fuel (1 point)

b. Use your answer in (a) to calculate the effect of each of the following on total short-run variable costs:
   i. a 2% increase in wage rates (1.5 points)
   ii. a 10% decrease in the price of fuel (1.5 points)

c. Compute the economies of density (defined by varying the amount of output over a fixed system) for the transit agencies studied. (3 points)

d. Using the same data on which the cost function was estimated, the authors calculated a short-run average cost of $2.96 (per vehicle-mile) and a short-run marginal cost of $2.31 (per vehicle-mile) for

US transit operators. Is the relationship between these two values consistent with your answer in (c)? Briefly explain your response. (1.5 points)

e. Does your answer in (c) imply that most transit agencies are natural monopolies and that public transit (without proper regulation) is a market that lacks competition? Briefly explain your response. (1.5 points)
f. Compute the economies of system size (defined by varying output and network size) for the transit agencies studied. (3 points)

Question 2 (18 points)

Modeling Public Transit Use in a Metropolitan Area

Consider a major metropolitan area which has extensive metro and bus networks. The focus of this question is the analysis of travel demand by transit in this city and specifically the choice of mode to travel within the city. For the purposes of this question you may assume that there is a fixed demand matrix (i.e. that demand between origin-destination pairs is not a function of the level-of-service, and so can be assumed to be constant) representing travel by transit between all origin-destination pairs and that the only modes of interest are metro and bus.

<u>Answer the following questions:</u>

a. What data would you need to estimate a discrete choice binary logit model reflecting an individual's choices between metro and bus in this city? You may assume that the attributes which affect choice are the in-vehicle time, walk access time, wait time and monetary cost for the best paths between an origin-destination pair by bus and metro. (4 points)
b. List any other mode-specific attributes or individual-specific characteristics that you would include in your model. (2 points)
c. Based on your responses in (a) and (b), write two utility functions (one for bus and another for metro) that would capture an individual's well-being from choosing the corresponding mode. (5 points)
d. What is the expected sign of each coefficient you included in your model specification in (c)? (2 points)
e. Many studies have shown that a minute of in-vehicle travel time on a bus is more onerous than a minute of travel time on metro. Assume you have a mode choice model that incorrectly assumes that these two travel times are equivalent (i.e. it assumes that a minute of travel time on the bus causes the same disutility as a minute of travel time on metro). What are the implications of using such a model to evaluate alternative investments in the public transit system? (5 points)

Question 3 (12 points)

Path-Based Congestion Pricing

In the simple network represented in Figure 1, there are two OD pairs:

- **A-C**: There is only one path connecting this pair (which is the direct path).
- **B-C**: There are two paths connecting this pair (the direct path and the one passing through A).

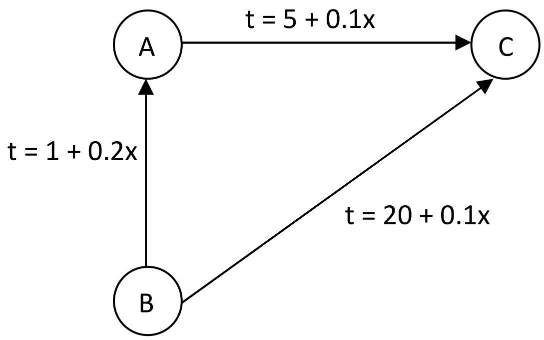

FIGURE 1: Simple network with two OD pairs

The travel times on each link are represented by the functions shown in Figure 1. In each function, *t* represents the travel time on the corresponding link (in minutes) and *x* represents the number of vehicles traveling on that link.

Demand on each OD pair is fixed (inelastic) within the study period:

- A-C demand = 100 vehicles
- B-C demand = 250 vehicles

Assume that travel on the A-C OD pair is priced at marginal cost. In other words, the 100 vehicles going from A to C are already paying a toll that makes their 'perceived' cost of using the direct link between these two nodes equal to marginal cost. Also assume that people traveling on the A-C OD pair have no other choice than to use the direct link (i.e. they will use that link regardless of the level of flow). Your task here is to find tolls that you could charge on the two paths connecting B and C.

Under path-based congestion pricing, each vehicle is charged based on its OD pair. This means that there can be two vehicles traveling on the link connecting A and C and paying different tolls because one originated at A, while the other originated at B.

Answer the following questions:

a. Write an expression for the optimal toll to be charged on each path connecting the B-C OD pair. Keep in mind the flow on the first OD pair (A-C). (3 points)
b. In order to find the value of the two tolls, you will need to calculate equilibrium levels of flow on each of the two paths. Assume this equilibrium is reached when the perceived cost of travel (i.e. travel time + toll) on both paths are equal. What is the value of the toll on each path if the value of time is $9 per hour? (6 points)
c. Tolls are usually charged either to make road users choose a different path (route) or to make them switch modes and use public transportation. Sketch a nested model structure that could be used to

predict people's choices for travel between B and C. The alternative modes available are (1) bus and (2) car, and the alternative paths for 'car' users are (1) B to C and (2) B to A to C. (3 points)

Question 4 (8 points)

Evaluation of Road Pricing Scenarios

A report published earlier this month in the UK analyzed the impacts of a national road pricing scheme accompanying various levels of additional road capacity. Table 2 shows some of the results presented in the report. The table compares the 'base' scenario, in which no pricing schemes are implemented, with several other scenarios that involve building additional road capacity, implementing an efficient road pricing scheme, or both.

TABLE 2: Costs and benefits of road building and efficient pricing (figures in billions of British Pounds)

	Change in capacity (Lkmpa → lane kilometers per year)				
	No extra capacity	**+200 Lkmpa**	**+400 Lkmpa**	**+600 Lkmpa**	**+800 Lkmpa**
No road pricing					
Gross benefit to society	Base	7.5	12.8	16.4	19.6
Cost of additional capacity	Base	1.5	3.0	4.4	5.6
Marginal benefit of additional capacity	-	5.0	3.5	2.6	2.7
Efficient road pricing					
Gross benefit to society	22.3	28.3	32.7	36.1	38.4
Cost of additional capacity	0	1.5	3.0	4.4	5.6
Cost of charge collection	4.5	4.5	4.5	4.5	4.5
Marginal benefit of additional capacity	5.0	4.0	2.9	2.4	1.9

<u>Answer the following questions:</u>

a. Calculate the benefit-cost ratio of each of the nine scenarios presented in Table 2. (2 points)
b. Based on your results in (a), should road pricing be implemented if road capacity is to be increased at 600 lane kilometers per year? Should pricing be implemented if capacity is to be increased at only 200 lane kilometers per year? (3 points)
c. In each of the four rightmost columns in Table 2, the marginal benefit of additional capacity is smaller under efficient road pricing compared to having no road pricing. Explain this difference. (3 points)

Question 5 (12 points)

Project Evaluation with Multi-Criteria Analysis

The selection of a project among several alternatives often involves considering multiple objectives and multiple attributes. Traditional cost-benefit analysis cannot easily accommodate such complexities, mainly because (1) there is often concern with the incidence of benefits and costs, rather than the overall value of benefits and costs to whomever they may accrue, and also because (2) not all attributes can be monetized and included in a single net benefit estimate.

Answer the following questions:

a. List two groups whose benefits and costs might be of specific interest in a project involving building a new subway line in an urban corridor. (1 point)

b. Table 3 compares the net benefits, travel time savings, and air pollution reductions associated with each of six alternative transportation projects. Travel time savings and air pollution reductions were considered separately because it was unclear how these two attributes would be monetized.

    i. What alternatives are dominated and, thus, can be eliminated from the analysis? (3 points)

    ii. Travel time savings were not included in net benefits because the analyst comparing these alternatives was not sure about the value of time in the study area. She knew, however, that the value of time was between \$6 and \$8 per hour. Compare the net benefits *(including* travel time savings) of the *five remaining alternatives* assuming values of time of \$6, \$7, and \$8 per hour. From this comparison, can you eliminate any other inferior projects? (5 points)

    iii. Assume that after further study, the analyst concludes that the value of time is \$8 per hour. Under this assumption, is there a clear 'winner' among the remaining alternatives (i.e. one that surpasses all the others in both net benefits and air pollution reductions)? If there is, which one is it? If there isn't, what trade-offs need to be made in order to choose the best project? (3 points)

TABLE 3: Multi-attribute comparison among six project alternatives

Project Alternative	**Attribute (criterion)**		
	Net Benefits (in thousands, excluding travel time savings and air pollution reduction)	**Travel time savings (thousands of hours)**	**Air pollution reductions (kg/day)**
A	\$200	10	4
B	\$155	30	5
C	\$120	35	4
D	\$50	40	3
E	\$15	8	1
F	\$20	42	2

Question 6 (6 points)

Public-Private Partnerships in Transportation Projects

Consider a project to build a new highway on which vehicles will be tolled.

<u>Answer the following question:</u>
What are the advantages or disadvantages of developing this project within a public-private partnership (PPP) in terms of the following:

a. Implementation time (1.5 points)
b. Financing and budgeting (1.5 points)
c. Operating the toll facility (1.5 points)
d. Maintenance. (1.5 points)

Question 7 (10 points)

Public Transit Contract Structures

In public transit operations contracting, there are two main types of risks that must be allocated between the concessionaire (operator) and the public agency:

- Revenue risks (related to uncertainties in the level of demand given specified fares and service levels)
- Operational cost risks (related to operating technologies and cost efficiency)

Consider the following contract structures:

I. *Gross-cost structure:* The concessionaire bears only the operational cost risks, while revenue risks are allocated to the public agency. Under this structure, all revenues (from fares and other sources) are transferred to the public agency.
II. *Net-cost structure:* The concessionaire bears both the operational cost and the revenue risks. Under this structure, all revenues (from fares and other sources) are retained by the concessionaire.

<u>Answer the following question:</u>

a. How does each contract structure affect the operator's incentives to maintain (1) level-of-service and (2) cost efficiency? (4 points)
b. What are the other advantages and disadvantages of the gross-cost contract structure from the public agency's point of view? (3 points)
c. How would you remedy the disadvantages that you mentioned in part (b)? (3 points)

Question 8 (10 points)

Freight Demand Modeling

Following is the specification for a freight mode choice model in which there are three alternatives: (1) rail, (2) road, and (3) combined rail-road:

$$V_{Rail} = \beta_{Rail} + \beta_{T_t}T_t + \beta_{Mc}Mc_t + \beta_{p>30}(p > 30) + \beta_{HVG}HVG$$
$$V_{Road} = \beta_{T_r}T_r + \beta_{Mc}Mc_r + \beta_{PSH}PSH$$
$$V_{Combined} = \beta_{Combined} + \beta_{T_c}T_c + \beta_{Mc}Mc_c$$

where
T_t is the travel time for the 'rail' alternative
T_r is the travel time for the 'road' alternative
T_c is the travel time for the 'combined rail-road' alternative
Mc_t is the monetary cost for the 'rail' alternative
Mc_r is the monetary cost for the 'road' alternative
Mc_c is the monetary cost for the 'combined rail-road' alternative
p>30 is a dummy variable equal to 1 if the shipment weighs more than 30 tons and 0 otherwise
PSH is a dummy variable equal to 1 if the goods carried are perishable and 0 otherwise
HVG is a dummy variable equal to 1 for high value goods and 0 otherwise

The model was estimated on national data from Italy, in which each row represented a shipment moving from a point of production to a point of consumption. The results are shown in Table 4.

TABLE 4: Estimation results for freight mode choice model

	β_{Rail}	$\beta_{Combined}$	β_{T_t}	β_{T_r}	β_{T_c}	β_{Mc}	$\beta_{p>30}$	β_{PSH}	β_{HVG}
Estimate	0.29	-3.34	-0.06	-0.15	-0.12	-1.47	1.20	0.86	-0.64
t-statistic	0.5	-2.5	-1.7	-2.2	-2.0	-3.2	0.6	1.1	-1.2

<u>Answer the following questions:</u>

a. Interpret the signs of the estimated values for $\beta_{p>30}$ and β_{HVG}. (2 points)

b. Briefly explain the differences among the estimated values for β_{T_t}, β_{T_r}, and β_{T_c}. (3 points)

c. To obtain the data needed to estimate the model above, another model was applied to predict the shipment weight (which is a measure of shipment size) for each of the shipments used in the mode choice model. Shipment weight was needed in order to assign a value for the dummy variable 'p>30' listed above.
   i. What is the trade-off that needs to be captured in a model that predicts shipment sizes? (2 points)
   ii. How does the nature of this trade-off change if the goods being shipped are perishable? In general, do you expect the predicted shipment size for perishable goods to be smaller or larger than the shipment size for other goods? (3 points)

Question 9 (10 points)

Airline Revenue Management

Consider a flight from Boston, MA to Minneapolis, MN. Table 5 describes the different booking classes on the flight and the predicted demand on each class.

TABLE 5: Booking class for BOS-MSP flight leg

Booking class	Mean Predicted demand	Fare
A	15	1000
B	30	650
C	50	350

The demand for booking classes A and B are characterized by the discrete distributions shown in Table 6. The total number of available seats on the aircraft is 100.

TABLE 6: Distributions of demand for booking classes A and B

Booking Class A			**Booking Class B**	
Demand	**Probability**		**Demand**	**Probability**
7	0.11		10	0.2
9	0.11		20	0.2
11	0.11		30	0.2
13	0.11		40	0.2
15	0.11		50	0.2
17	0.11			
19	0.11			
21	0.11			
23	0.11			

Note: These are discrete distributions, so demand on booking classes A and B can only take on the values shown in the table. For example, the probability that demand for booking class B is 23 or 44 is zero.

<u>Answer the following question:</u>

Apply the EMSRb model to calculate the number of seats that should be protected in each booking class. (10 points)

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