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PRICE ELASTICITIES OF INTERCITY PASSENGER TRAVEL DEMAND

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1. INTRODUCTION[1]

It is readily understood that the demand for air travel between Montreal and Toronto depends on the price of such a trip by airplane and on the prices of other modes of transport. It also depends on personal income, on the populations of Montreal and Toronto and on a host of other factors. When these factors are taken individually, it is easy to demonstrate that each one affects the number of air passengers. Graphs or simple correlations could show that changes in the number of travellers and income go hand in hand, or that there is a negative correlation between the number of passengers and the price of airline tickets.

Since the goal of this analysis is to isolate the influence of price on the number of trips taken, a method that considers all the other factors that also affect air travel must be used. For this reason, of the various ways of studying the reaction of travel demand to prices, only econometric models that measure the influence of different explanatory factors on the use of modes of transport are used in this study.

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This multidimensional approach makes it possible to ask the following question: *Ceteris paribus*, what is the effect of a price increase on travel demand? Because it isolates each explanatory factor, a multivariate mathematical analysis will answer the question.

The review of various econometric models of intercity travel demand deals primarily with the sensitivity of modal demand for passenger travel in relation to price. The reader should keep in mind that these models, as indicated in Section 2, incorporate considerations other than price.

Price elasticity, which can be defined as the percentage change in demand resulting from a 1 percent change in price, is a useful measure of demand sensitivity to price. Travel demand usually has a negative price elasticity: a 1 percent price increase reduces demand by *x* percent. In this study, however, the negative or positive sign is set aside and the absolute value of elasticity is used. Thus, a price elasticity of –3 is greater than a price elasticity of –1.

In this study, different estimates of the effect of prices on intercity travel are compared for the first time. More precisely, demand sensitivity of each mode of transportation (auto, air, rail, bus) are evaluated in relation to the price of each mode. Several intercity passenger travel demand models have been calibrated in the past, resulting in estimates of price elasticities specific to each of those models. These price elasticity estimates are difficult to compare because they are based on different prices and demands.

This review of price elasticities of passenger travel demand makes it possible to answer several questions: Do models calibrated more than 10 years ago still permit the evaluation of current travel demand sensitivity? Which models are applicable to any given market type? Are the price elasticities derived from models sufficiently homogeneous to suggest a "consensus"? Which modes have an elastic travel demand? Which travel demand modes are sensitive to prices of other modes?

The answers can be found in Section 3, which contains an analysis of price elasticities for four Canadian markets. These elasticities are calculated with nine econometric models of intercity passenger travel demand. The method used to compare these demand models is set out in Section 2. It is based on hypotheses whose validity is confirmed in Section 4. The detailed formulas for the nine demand models can be found in Section 5.

2. COMPARISON OF MODELS AND MARKET DESCRIPTIONS

As mentioned above, price elasticity of demand for travel usually varies from one market to another. It is expected that price elasticities for the Montreal–Toronto market differ from those for the Toronto–Vancouver market, because the modes of transport have different prices, the level of travel is not the same, etc.

In the empirical literature on travel demand, it is common practice to present price elasticities which have been calculated using the same data as those used to calibrate the econometric model. Price elasticities calculated in this way cannot be compared with the price elasticities of other studies if they are based on different data.

2.1 FOUR REPRESENTATIVE MARKETS

To avoid these difficulties, this study presents on a common basis, price elasticities obtained from different mathematical models. This comparative analysis of price elasticities is conducted for four Canadian markets: a representative Canadian market, Montreal–Ottawa, Montreal–Toronto and Toronto–Vancouver. Table 2.1 reports the number of trips per mode (T_m), modal shares (S_m), the cost of using each mode (C_m), the distance (DIST) and the per capita income in the zone of origin (Y) in 1976 for each of the four markets. The representative market corresponds to the mean values of the Transport Canada data base which covers trips taken between 155 pairs of Canadian cities in 1976.

The travel demand models examined in this study can be grouped into three large categories: probability models, modal-split or market-share models, and generation-distribution models. A probability model yields the probability that an individual will opt for a mode of transport for an intercity trip. A modal-split model gives the proportion of trips per mode. A generation-distribution model deals with the total number of trips within a market.

When elasticities for a particular market are obtained from aggregate information such as that presented in Table 2.1, no specific methodological difficulties are encountered with the modal-split and generation-distribution models. This is not so for probability models. To understand the method used to calculate elasticities in this study, a brief review of the derivation of elasticities in probability models is necessary.

Table 2.1
INFORMATION BY MARKET (1976)

	Representative market	Montreal–Ottawa	Montreal–Toronto	Toronto–Vancouver
Trips per mode:				
T_{auto}	106,650	1,710,000	899,630	1,366
T_{air}	12,812	26,224	343,800	110,420
T_{train}	6,257	83,561	219,530	9,271
T_{bus}	5,633	307,740	58,500	1,144
Modal shares:				
S_{auto}	0.81	0.80	0.59	0.01
S_{air}	0.10	0.01	0.23	0.90
S_{train}	0.05	0.04	0.14	0.08
S_{bus}	0.04	0.15	0.04	0.01
Cost of a trip per mode ($1/100 Canadian, 1976):				
C_{auto}	5,115.5	605.0	1,662.0	14,998.0
C_{air}	8,335.6	3,027.0	5,133.0	16,475.0
C_{train}	4,233.5	942.0	2,366.0	10,419.0
C_{bus}	4,042.6	867.0	2,000.0	8,983.0
Distance (miles):				
DIST	930.2	110.0	302.0	2,727.0
Cost of a trip per mile travelled (cents/mile):				
C_{auto}/DIST	5.50	5.50	5.50	5.50
C_{train}/DIST	8.96	27.52	17.00	6.04
C_{bus}/DIST	4.55	8.56	7.83	3.82
C_{auto}/DIST	4.35	7.88	6.62	3.29
Per capita income in the city of origin (Canadian $ 1976):				
Y	4,241.0	4,270.4	4,270.4	4,508.8

2.2 PROBABILITY MODELS: PRECISE AND APPROXIMATE ELASTICITY MEASUREMENTS

To begin with, a sample consisting of information on modal choices for a group of individuals is required to calibrate or estimate a probability model. Thus, the selected mode, the transportation prices and times for the available modes, various socio-economic characteristics (for example, sex, occupation, age, income, etc.) are known for each individual.

Once the model has been estimated, the elasticity of the demand for mode of transport m in relation to its price (C_m) can be calculated for each individual k in the sample ($\eta^{m}_{C_m}(k)$).

It is then easy to determine the price elasticity of a specific market ($\eta^{m}_{C_m}$ (market)), Montreal–Toronto for example, using the individual elasticities and the weight (f_k) of the individuals in the sample:

$$\eta^{m}_{C_m}(\text{market}) = \Sigma_k \eta^{m}_{C_m}(k) \cdot f_k \tag{2.1}$$

Three pieces of information are usually required to calculate price elasticity for individual k: a parameter (β), the price of the travel by mode m for individual ($C_m(k)$), and the probability that individual k will not choose mode m ($1 - \text{prob}_m(k)$). More precisely:[2]

$$\eta^{m}_{C_m}(k) \;=\; \beta \cdot C_m(k) \cdot (1 - \text{prob}_m(k)) \tag{2.2}$$

Therefore, aggregate elasticity is derived as a weighted sum of individual elasticities. This "enumeration method" for calculating aggregate elasticities requires the sample that was used to calibrate the model. A comparison of the elasticities from models that use different samples becomes very tedious and prevents the type of analysis envisaged here. Another solution must be considered.

For example, to obtain aggregate elasticities for the Montreal–Toronto market, without the sample that was used for calibration, it is suggested that an approximation of aggregate price elasticity be used ($\eta^{m}_{C_m}$ (approx.)). Equation (2.2) for an individual's price elasticity is used, replacing the price ($C_m(k)$) of individual k with a representative market price ($\overline{C_m}$). The market share of the other modes, $1 - S_m$, is substituted for $1 - \text{prob}_m(k)$, the probability that mode m will not be chosen:

$$\eta_{C_m}^{m}(\text{approx.}) = \beta \cdot \overline{C_m} \cdot (1 - S_m) \tag{2.3}$$

When (2.3) is compared with the two preceding equations, it becomes obvious that this approximation greatly simplifies the calculation of price elasticities because:

- Price elasticity with equation (2.3) only requires a single value for the price of each mode ($\overline{C_m}$);
- The approximation of aggregate price elasticity ($\eta_{C_m}^{m}$ (approx.)) is based on the observed market share (S_m) rather than on the calculated share ($\text{prob}_m(k)$).

Instead of first calculating elasticities for each individual in the sample and then taking a measured average of those elasticities, approximation involves directly calculating one aggregate elasticity with a mean price and the observed market share. Section 4 contains two examples that show that the difference between precise aggregate elasticities ($\eta_{C_m}^{m}$ (market)) and those obtained from the approximation ($\eta_{C_m}^{m}$ (approx.)) is small. For this reason, and because approximation simplifies the calculations, it is felt that such an approximation is useful. Otherwise it would not be possible to compare the elasticities obtained from aggregate and disaggregate models. It would not even be possible to compare elasticities obtained from two disaggregate models!

3. Price Elasticities of Passenger Travel Demand

In this section, price elasticities are calculated for four Canadian markets, using nine demand models. The market situation corresponds to that in 1976. This year was selected because it is the latest year for which information on intercity travel by all modes of transport in Canada is available.

The demand models to be examined are:

Probability models:

- Grayson (1981)

- HORIZONS (1989)
- Peat-Marwick (1990)
- Ridout-Miller (1989)
- Wilson et al. (1990)
- Stopher-Prashker (1976)

Modal-split models:

- PERAM
- SLAG (1977)
- Gaudry-Wills (1978)

Generation-distribution models:

- HORIZONS (1989)
- Peat-Marwick (1990)
- PERAM
- SLAG (1977)
- Gaudry-Wills (1978)

The parameters of all models other than those of Grayson and Stopher-Prashker have been estimated using Canadian data obtained from three different sources: Transport Canada, Canadian Travel Survey (CTS) and VIA Rail. The data from Transport Canada date back to 1972 and were used to calibrate the SLAG and Gaudry-Wills models. The PERAM model is based on a 1976 Transport Canada data base. The Ridout-Miller and Wilson et al. models are estimated using CTS data for the years 1968 and 1982, respectively. Finally, the Peat-Marwick and HORIZONS models are based on 1987 VIA Rail data.

3.1 PROPERTIES OF THE MODELS

Before proceeding with a market-by-market analysis of price elasticities, it is useful to discuss some properties of the econometric models used in this study. Section 5 contains a more formal presentation of the models.

3.1.1 The Influence of Prices and Market Shares on Price Elasticities

The number of trips per mode of transport can be expressed as the product of the total number of trips by all modes of transport and the share of each mode in total trips. It follows that the price elasticity of the demand for trips by mode *m* (η^m (mode)) is necessarily equal to the sum of the price elasticity of total demand (η (total)) and the price elasticity of the share of mode *m* in total trips (η^m (share)),[3]

$$\eta^m(\text{mode}) = \eta(\text{total}) + \eta^m(\text{share}) \tag{3.1}$$

Price elasticities of the modal share (η^m (share)) are evaluated using probability or modal-split models, while price elasticities of total demand (η (total)) are obtained from generation-distribution models. In this section, certain properties of price elasticities of the modal share (η^m (share)) and total demand (η (total)) are examined.

As a rule, price elasticities of the shares are calculated using three elements: parameter β, market share (S_m) and the cost (C_m). The price elasticity of the linear logit model (see equation (2.3) is an example of expression (3.2).

$$(\beta, S_m, C_m) \rightarrow \eta^m(\text{share}) \tag{3.2}$$

It is also true (as shown in Section 5) that total elasticities also depend on parameter γ, shares and price levels.

$$(\gamma, S_m, C_m) \rightarrow \eta(\text{total}) \tag{3.3}$$

It follows that price elasticities of a particular mode (η^m (mode)) vary from one market to another because prices and market shares differ. The separate effect of market share (share effect) and of the mode's cost (price effect) on price elasticities is discussed below.[4]

A. Share Effect on Price Elasticities of the Modal Share

Own Elasticities: As far as the relationship between price elasticities and modal shares is concerned, all models mentioned above imply that direct price elasticity ($\eta^{m}_{C_m}$ (share)) of the modal share decreases as the share of mode *m* increases (S_m). *Ceteris paribus* the greater the modal share, the less sensitive the modal share is to that mode's cost (C_m). This first property is termed P.1.

$$\boxed{\Delta^{+}S_m \quad \rightarrow \quad \Delta^{-}\eta^{m}_{C_m}(\text{share})} \qquad \text{P.1}$$

Cross Elasticities: Cross price elasticities ($\eta^{m}_{C_l}$ (share)) are directly proportional to the share of the mode (S_l) whose price (C_l) is changing. That is, the price elasticity of mode *m* with respect to the price of mode *l* increases as the share of mode *l* increases. If mode *l* has a large share, then, according to property P.1, it will not adjust by much in response to a change in its own price; the other modes of transport will adjust more. This implies another property:

$$\boxed{\Delta^{+}S_l \quad \rightarrow \quad \Delta^{+}\eta^{m}_{C_l}(\text{share})} \qquad \text{P.2}$$

B. Share Effect on the Price Elasticity of Total Demand

Total travel demand elasticities (η(total)), with respect to the cost of the modes of transport, are directly proportional to modal shares. The larger the market share, the higher the sensitivity of total demand to changes in the price of the mode in question. At the limit, total demand will not be affected at all by changes in the price of a mode whose market share is zero.

$$\boxed{\Delta^{+}S_m \quad \rightarrow \quad \Delta^{+}\eta_{C_m}(\text{total})} \qquad \text{P.3}$$

C. Price Effect on Price Elasticities of the Modal Share

It has been shown that the share effect on price elasticities is the same for all the models examined: cross elasticity of the modal share and elasticity of total demand increase, and direct elasticity of the modal share decreases as modal share increases. The same does not hold true for changes in a mode's price. In fact, as a mode's price increases, price elasticities may increase, decrease or remain unchanged depending on the model examined.

A priori, it is expected that the price elasticity of the modal share increases as the price increases. The Peat-Marwick, Ridout-Miller, HORIZONS, Grayson and Stopher-Prashker models conform to this rule for direct and cross elasticities.

$$\boxed{\Delta^{+}C_m \rightarrow \Delta^{+}\eta^{m}_{C_m}(\text{share}), \quad \Delta^{+}\eta^{l}_{C_m}(\text{share})} \qquad \text{P.4}$$

Price elasticities of modal shares for the PERAM and SLAG models are invariant with the price of modes. Since these elasticities reflect the sample's estimation conditions, comparing them with other models can reveal surprises for prices that differ too much from the sample averages.

$$\boxed{\Delta^{+}C_m \rightarrow \eta^{m}_{C_m}(\text{share}) \text{ constant}, \ \eta^{l}_{C_m}(\text{share}) \text{ constant}} \qquad \text{P.5}$$

Price elasticities of the Gaudry-Wills and Wilson et al. models decrease as the price increases. The cost of a mode in the Wilson et al. model corresponds to the cost of a trip divided by the distance travelled. (It is interesting to note that Wilson et al. (1990) refer to this variable as the unit cost of travel.) The result follows if, as is the case for the markets studied, the cost of use per unit of distance decreases as the distance increases (see Table 2.1). The Gaudry-Wills model specifies the mode's cost as an explanatory variable, but the Box-Cox transformation applied to it implies the same result.[5]

$$\boxed{\Delta^{+}C_m \rightarrow \Delta^{-}\eta^{m}_{C_m}(\text{share}), \quad \Delta^{-}\eta^{l}_{C_m}(\text{share})} \qquad \text{P.6}$$

Discussion: It is reasonable that the share price elasticity increases as the price increases. Knowing that price must represent the cost per unit of obtaining a good, the question is whether the price should be defined per unit of distance or by market. The answer depends on how one defines a consumer good: Is the demanded good a quantity of distance or a number of trips in a given market? It seems that this issue, which deals with the very formulation of intercity demand models, has not been given the attention it deserves.

Due to the difficulty of this issue, it is felt that an in-depth discussion is beyond the scope of this study. Some answers, however, can be found in Dagenais and Gaudry (1986). It is interesting to note that the Box-Cox transformation approach of the Gaudry-Wills model avoids the question somewhat by letting the data decide the formulation.

D. Price Effect on Price Elasticity of Total Demand

The price effect on the price elasticity of total demand is similar to the price effect on the price elasticity of the modal share. Thus, price elasticities of total demand for the Peat-Marwick and HORIZONS generation-distribution models increase as the mode's cost increases (in a manner similar to P.4). The PERAM and SLAG generation-distribution models generate total demand price elasticities that are not affected by price (in a manner similar to P.5). Total demand price elasticities of the Gaudry-Wills generation-distribution model decrease as the mode's price increases (in a manner similar to P.6). This result can be explained by the fact that equations that involve the costs of modes are similar in the generation-distribution and modal-split models.

Properties P.4, P.5 and P.6 can therefore be rewritten by substituting the term "total" for the term "share," calling the formulas P.4*, P.5* and P.6* and associating them with the same sub-groups of models.

3.1.2 Cross Elasticities

The preceding section dealt with the causes of variations in price elasticities from one market to another. Attention is now focussed on the properties of cross elasticities for the models examined, irrespective of the market studied.

Except for the HORIZONS model, one of the special features of the demand models considered in this study is the equality of cross price elasticities of modal shares.

$$\boxed{\begin{aligned}
\eta^{air}_{C_{auto}}(\text{share}) &= \eta^{rail}_{C_{auto}}(\text{share}) = \eta^{bus}_{C_{auto}}(\text{share})\\
\eta^{auto}_{C_{air}}(\text{share}) &= \eta^{rail}_{C_{air}}(\text{share}) = \eta^{bus}_{C_{air}}(\text{share})\\
\eta^{auto}_{C_{rail}}(\text{share}) &= \eta^{air}_{C_{rail}}(\text{share}) = \eta^{bus}_{C_{rail}}(\text{share})\\
\eta^{auto}_{C_{bus}}(\text{share}) &= \eta^{air}_{C_{bus}}(\text{share}) = \eta^{rail}_{C_{bus}}(\text{share})
\end{aligned}} \tag{P.7}$$

3.1.3 Modal Substitution Index

Cross price elasticities of modes of transport are used to address the issue of substitutability between modes of transport. However, it can be somewhat difficult to interpret these price elasticities. When there is substitution between modes, the cross price elasticity reveals, for example, that an increase in the cost of the bus mode will increase the demand for other modes of transport by a certain percentage. However, the cumulative significance of these diversions in relation to a change in demand for the bus mode is not clear. A modal substitution index has been developed to facilitate discussion of the subject.

There are two components to the change in demand for a mode: on the one hand, there is a diversion or modal substitution effect; on the other, there is an induced demand or an adjustment in the total travel demand. The modal substitution index indicates the percentage of the change in demand for the mode that is associated with the substitution effect. For example, a modal substitution index of 0.75 for travel by bus implies that if the cost of the bus mode decreases, 75 percent of the increase in the number of bus travellers results from a diversion or a decrease in demand for other modes of transport, and 25 percent of the increase in demand for the bus mode is induced (total) demand.

Formally, the modal substitution index for mode m (θ^S_m) is calculated using the market share of mode m, the elasticities of total demand and demand for mode m with respect to the cost of mode m.

$$\theta^S_m = 1 - \frac{\eta_{C_m}(\text{total})}{\eta^m_{C_m}(\text{mode})\, S_m} \qquad (3.4)$$

Subsection 5.2 shows the derivation of the modal substitution index. After a few transformations, the modal substitution index may also be written as follows:

$$\theta^S_m = \frac{1 - S_m}{1 + (\alpha - 1) S_m} \qquad (3.5)$$

where parameter α refers to total demand elasticity with respect to the level of aggregate service of all modes. As mentioned in subsection 2.2, the calculation of elasticities is based on observed market shares (S_m) rather than calculated shares. Equation (3.5) shows that the modal substitution index varies from one model to another only if the parameter α changes.

It is possible to estimate the parameter α from the PERAM, SLAG, Gaudry-Wills, HORIZONS and Peat-Marwick models. To calculate the price elasticities of total demand and the modal substitution indices using the probability models, a value must be assumed for the parameter α. For reasons discussed in subsection 3.3, the value assigned to the parameter α for the Ridout-Miller and Grayson models is the same as the value estimated by the Peat-Marwick model. The Wilson et al. and Stopher-Prashker models use the same value of α as the PERAM model. Therefore, the following property is obtained:

$$\begin{aligned} \theta^{s}_{m}(\text{Peat-Marwick}) &= \theta^{s}_{m}(\text{Ridout-Miller}) = \theta^{s}_{m}(\text{Grayson}) \\ \theta^{s}_{m}(\text{PERAM}) &= \theta^{s}_{m}(\text{Wilson et al.}) = \theta^{s}_{m}(\text{Stopher-Prashker}) \end{aligned} \qquad \text{P.8}$$

3.2 PRESENTATION OF RESULTS

For each of the markets studied, a three-part table provides the price elasticities associated with each demand model. The first part of the table, part **a**, contains direct price elasticities, that is, the demand sensitivity of a particular mode with respect to its price. The second part of the table, part **b**, reports cross price elasticities, that is, the demand sensitivity of a particular mode with respect to the price of another mode. The third and final part of the table, part **c**, contains price elasticities of the total demand for travel (all modes combined) with respect to the price of each mode, as well as the modal substitution indices.

More specifically, price elasticities for the level of modal demand (η^{m}(mode)) are reported in columns 1, 2, 3 and 4 in part **a**. Thus, according to the Peat-Marwick model, the demand elasticity for travel by car, with respect to the cost of a trip by car for the representative market (see Table 3.1 **a**), is –1.37; the demand elasticity of air travel, with respect to the cost of a trip by air, is –5.44, etc. Columns 5, 6, 7 and 8 contain the price elasticities of the modal share (η^{m} (share)). According to the Peat-Marwick model, the price elasticity of the share of trips by auto, with respect to the cost of a trip by auto, is –0.68; the elasticity of the share of trips by air, with respect to the price of a trip by air, is –5.31, etc.

One of the distinctive characteristics of the demand models examined in this study, with the exception of the HORIZONS model, is that cross price elasticities of modal demands are all equal (see property P.7). Thus, the Peat-Marwick model estimates the demand elasticity of travel by air, rail or bus with respect to the cost of a trip by auto to be 2.24 (see Table 3.1 **b**).

Also, according to this model, the demand elasticity of travel by auto, rail or bus with respect to the cost of a trip by air is 0.44. Cross elasticities of the HORIZONS model (in part **b**) are averages. Appendix 1 reports all the direct and cross elasticities for the HORIZONS model.

Modal demand price elasticities (η^m (mode)) are equal to the sum of the price elasticities of the modal share (η^m (share)) and total demand (η (total)). Thus, for the Peat-Marwick model, direct and cross elasticities with respect to the cost of a trip by auto, –1.37 and 2.24 (Table 3.1 **a** and **b**, column 1), are equal to the sum of the direct or cross elasticities of modal share with respect to the cost of a trip by auto, –0.68 and 2.93 (Table 3.1 **a** and **b**, column 5), and the total demand elasticities in relation to the price of a trip by auto, –0.70 (Table 3.1 **c**, column 1).

Modal substitution indices for the representative market are shown in columns 5 to 8 of Table 3.1 **c**. Thus, for the Peat-Marwick model, the modal substitution index for buses is 0.75. In response to a drop in the cost of the bus mode, 75 percent of the increase in travellers taking the bus comes from a diversion or a reduction in demand for other modes of transport, and 25 percent of the increase in demand for the bus mode is induced demand.

Table 3.1
Representative Market (1976)

(a) Direct Price Elasticities

	Direct price elasticities of modes				Direct price elasticities of modal shares			
Models	**1. auto**	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
Peat-Marwick	–1.37	–5.44	–2.88	–2.76	–0.68	–5.31	–2.85	–2.73
Ridout-Miller	–1.06	–4.13	–2.18	–2.09	–0.52	–4.02	–2.16	–2.07
Gaudry-Wills	–0.55	–1.34	–1.64	–1.66	–0.31	–1.32	–1.63	–1.65
PERAM	–0.40	–1.49	–1.45	–1.46	–0.17	–1.44	–1.43	–1.44
SLAG	–1.26	–2.55	–2.63	–2.64	–0.51	–2.46	–2.59	–2.60
Wilson et al.	–0.46	–1.57	–0.83	–0.79	–0.19	–1.52	–0.81	–0.78
HORIZONS	–1.90	–1.98	–0.97	–0.73	–0.50	–1.86	–0.93	–0.71
Grayson	–0.66	–2.56	–1.35	–1.30	–0.32	–2.49	–1.34	–1.28
Stopher-Prashker	–1.77	–3.69	–3.83	–3.84	–0.74	–3.57	–3.77	–3.79

Table 3.1 (cont'd)
REPRESENTATIVE MARKET (1976)

(b) Cross Price Elasticities

Models	Cross price elasticities of modes				Cross price elasticities of modal shares			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Peat-Marwick	2.24	0.44	0.11	0.09	2.93	0.57	0.14	0.12
Ridout-Miller	1.67	0.32	0.08	0.07	2.22	0.44	0.11	0.09
Gaudry-Wills	1.08	0.12	0.07	0.06	1.33	0.14	0.08	0.07
PERAM	0.50	0.11	0.05	0.04	0.73	0.16	0.07	0.06
SLAG	1.46	0.18	0.09	0.08	2.21	0.27	0.13	0.12
Wilson et al.	0.57	0.11	0.03	0.02	0.84	0.16	0.04	0.04
HORIZONS	0.77	0.15	−0.02	−0.02	2.17	0.27	0.01	0.01
Grayson	1.04	0.20	0.05	0.04	1.38	0.27	0.07	0.06
Stopher-Prashker	2.18	0.26	0.13	0.12	3.21	0.39	0.19	0.17

(c) Price Elasticities of Total Demand and Modal Substitution Indices

Models	Price elasticities of total demand				Modal substitution indices (θ^S_m)			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Peat-Marwick	−0.72	−0.14	−0.04	−0.03	0.36	0.73	0.74	0.75
Ridout-Miller	−0.55	−0.11	−0.03	−0.02	0.36	0.73	0.74	0.75
Gaudry-Wills	−0.25	−0.03	−0.02	−0.01	0.45	0.80	0.81	0.81
PERAM	−0.23	−0.05	−0.02	−0.02	0.29	0.66	0.67	0.67
SLAG	−0.75	−0.09	−0.04	−0.04	0.27	0.64	0.65	0.65
Wilson et al.	−0.27	−0.05	−0.01	−0.01	0.29	0.66	0.67	0.67
HORIZONS	−1.40	−0.12	−0.03	−0.02	0.09	0.37	0.29	0.28
Grayson	−0.34	−0.07	−0.02	−0.01	0.36	0.73	0.74	0.75
Stopher-Prashker	−1.03	−0.12	−0.06	−0.05	0.29	0.66	0.67	0.67

3.3 REPRESENTATIVE MARKET

This elasticity analysis starts with a representative intercity travel market defined by the mean values of the Transport Canada sample for 1976, found in Table 2.1. After an analysis of the price elasticities of the nine econometric models, price elasticities are suggested for the representative market. A discussion on modal substitution completes this section.

Analysis: The following analysis is based on the price elasticities of modal shares and total demand. The first six comments (C.1 to C.6) deal with the price elasticities of modal shares in columns 5, 6, 7 and 8 of Table 3.1 **a** and **b**. These comments also apply to the price elasticities of modal demand.

C.1: Except for the auto mode, the share of a mode is more sensitive to variations in its own price than to variations in the prices of the other modes. In other words, direct elasticities are greater than cross elasticities (columns 6, 7 and 8 of Table 3.1 **a** and **b**).

C.2: The relative size of cross price elasticities is similar to the relative shares of the modes. Thus, the price of the auto mode, which has the largest market share (81 percent), influences the other modes of transport the most. The effect of the cost of the air, rail and bus modes decreases as their market shares decrease (columns 5 to 8 in Table 3.1 **b**).

The first two comments can be explained by the fact that the share of the auto mode is 81 percent, which results in a low direct elasticity of that mode (property P.1) and high cross elasticities with respect to the cost of the auto mode (property P.2). In fact, it is known that demand models are such that the dominant mode has a relatively low direct elasticity and fairly high cross elasticities with respect to the cost of the dominant mode. The opposite is true for modes with small market shares (high direct elasticities and low cross elasticities).

C.3: The elasticities of the SLAG model do not differ very much from those of the Peat-Marwick, Ridout-Miller and Stopher-Prashker models.

As becomes evident from the discussion of other markets, price elasticities of the Peat-Marwick, Ridout-Miller and Stopher-Prashker models are very similar. Interestingly enough, the two probability models (Ridout-Miller and Peat-Marwick) were both estimated using the multinomial logit model based on travel within the Windsor–Quebec City corridor. However, the data base for the Peat-Marwick model dates back to 1989 and that of the Ridout-Miller model to 1969. Twenty years later, travellers' sensitivity to price has not changed! This answers one of the questions raised in the introduction: Can models calibrated at different periods be compared? The results do seem transferable over time.

The Stopher-Prashker model is also a multinomial logit model and was estimated using a sample of trips between 22 pairs of U.S. cities in 1972. The similarities between this model and the other two are also interesting in that they confirm the transferability of results over time and even suggest that the results can be transferred over space.

C.4: The structure of the elasticities of the HORIZONS model differs from those obtained from other models.

Like the Peat-Marwick model, the HORIZONS model is calibrated using the 1989 VIA Rail data base. The Peat-Marwick model retains the general formulation of the multinomial logit model and presumes that a traveller selects a mode of transport on the basis of a simultaneous comparison of levels of service. The HORIZONS model, however, uses the nested logit and assumes that the selection process is sequential. A choice is first made between private and public modes of transport and then, if necessary, between air or ground travel. Finally, a traveller decides on the rail or bus mode. Since the samples used to calibrate the Peat-Marwick and HORIZONS models are more or less the same, any differences between the price elasticities of the HORIZONS model and those of the Peat-Marwick model may be attributed to the sequential choice hypothesis.

C.5 The PERAM, Gaudry-Wills, Wilson et al. and Grayson models yield similar results.

The Gaudry-Wills and PERAM aggregate demand models yield more or less the same elasticities. As before, the hypothesis of transferability of results over time is supported because the two models use different calibration periods, 1972 and 1976, respectively. Similarities between the results of these two models hold for the other markets studied. This is not surprising because both models use a similar data base and the same explanatory variables. The Gaudry-Wills model generalizes the PERAM model by applying the Box-Cox and Box-Tukey transformations to the explanatory variables.

C.6: Despite the similarities mentioned above, there are some significant differences in price elasticities. Direct price elasticities of the share of the air mode vary from –5.3 to –1.3; those of the rail and bus modes, from –2.8 to –0.8. The higher values were obtained from the Peat-Marwick, Ridout-Miller and SLAG models. Unlike direct elasticities, cross elasticities differ more for the auto mode than for the public modes.

The last comment can be explained by properties P.1 and P.2. The three determinants of price elasticities are: parameters, market share and price. Since the same data base is used, these elasticity variations from one model to another are attributable solely to the fact that each model has distinctive parameters. The effect of these parameters is more noticeable when the share effect is significant. This is the case for the air, rail and bus direct elasticities (Table 3.1 **a**, columns 6–9), and the cross elasticities with respect to the price of the auto mode (Table 3.1 **b**, column 6).

Surprisingly, the SLAG model has higher elasticities than the other two aggregate models. This cannot be due to the formulation of the SLAG model because it is similar to the formulation of the PERAM model. Therefore, the sample used to calibrate the model must be examined. The Gaudry-Wills and SLAG models are both estimated using a sample for 1972. However, the Gaudry-Wills model has 92 city-pairs, while the SLAG model has 94. Since the exact list of city-pairs in each sample is not available, it can only be conjectured that the additional two city-pairs are responsible for the higher elasticities. Therefore, the SLAG model is excluded in the discussion of other markets.

It is obvious that the capacity of a model to produce reliable estimates is reduced when it is applied to markets that differ too much from the markets used to calibrate the model. The Peat-Marwick, Ridout-Miller, HORIZONS, Grayson and Stopher-Prashker probability models, which have been calibrated with markets whose distances and prices are less than those of the representative market, yield elasticities that do not seem credible. In fact, since the price elasticities of these models are directly proportional to prices (see property P.4), these models are not applicable when the prices are "relatively high." In proposing elasticities for the representative market, we have excluded the Peat-Marwick, Ridout-Miller, HORIZONS, Grayson and Stopher-Prashker models.

C.7: There are two sets of total demand elasticities with respect to the prices of the modes of transport. The first set (Peat-Marwick, Ridout-Miller, SLAG, HORIZONS and Stopher-Prashker models) implies demands that are more elastic than the second set (Gaudry-Wills, PERAM, Wilson et al. and Grayson models). (See Table 3.1 **c**.)

C.8: All models indicate that total demand is influenced the most by the price of the auto mode. The next in order of importance is the price of the air mode, followed by the price of the rail mode. Total demand hardly varies in relation to the price of the bus mode (Table 3.1 **c**).

Since the Peat-Marwick and HORIZONS models are calibrated with a travel sample from the Windsor–Quebec City corridor, it is not surprising that the total travel demand obtained is more elastic than the total travel demand throughout Canada. Comment C.8 is a direct consequence of the share effect explained in subsection 3.1 (see property P.3).

Values Selected: Because the price elasticities of the Gaudry-Wills, PERAM, Wilson et al. and Grayson models are sufficiently homogeneous, elasticities based on the PERAM model shown in Table 3.2 constitute the "best judgement" values.

Table 3.2
Price Elasticities and Substitution Indices Selected, Representative Market (1976)

(a) Direct and Cross Price Elasticities

	Price elasticities of modes of transport				Price elasticities of modal shares			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Direct elasticities	−0.40	−1.49	−1.45	−1.46	−0.17	−1.44	−1.43	−1.44
Cross elasticities	0.50	0.11	0.05	0.04	0.73	0.16	0.07	0.06

(b) Price Elasticities of Total Demand and Modal Substitution Indices

	Price elasticities of total demand				Modal substitution indices (θ^s_m)			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
	−0.23	−0.05	−0.02	−0.02	0.29	0.66	0.67	0.67

An examination of own elasticities reveals that the demand for travel by auto is clearly inelastic: the demand for travel by auto reacts less than proportionally to a price increase. Conversely, the demand for the air mode is moderately elastic. Since the rail and bus modes have small market shares — 5 and 4 percent, respectively — there is a greater spread in the estimates for the direct elasticities of these modes. Demand sensitivity of the rail and bus modes seems to lie between that of the two other modes but is more similar to the elasticity of the air mode than the elasticity of the auto mode.

Substitution among Modes: Cross elasticities with respect to the cost of the rail (0.05) and bus (0.04) modes are low. At first sight, these elasticities seem negligible and could suggest that there is no substitution among modes. However, it can be shown quite easily that this is not the case and that there is significant modal substitution. For example, consider the impact of a 50 percent increase in the cost of the rail mode on the demand for other modes of transport. Given that the direct elasticity of the demand for the rail mode is –1.45, the demand for travel by rail drops 72.5 percent (–1.45 × 50 percent), or a reduction of 4536 (6257 × 0.725) trips. Since the substitution index for the rail mode is 67 percent, this means that of these 4,536 trips, 1497 trips (4536 × 0.33) represent a reduction in total demand and 3039 trips (4536 × 0.67) use the other modes of transport. Thus, modal substitution is responsible for 67 percent of the adjustment in demand for the rail and 33 percent of the adjustment results from a decrease in the total number of trips.

A study of the air and bus modes leads to the same conclusion: following a change in price of a public mode of transport, 66 percent of the changes in demand for that public mode are offset by changes in the other modes (public or private).

If the price of the auto mode increases, then 29 percent of the decrease in the demand for the auto mode is offset by an increase in the number of travellers using public modes of transport. Even though the substitution effect is significant, it remains less than the substitution effects brought about by changes in the prices of public modes.

3.4 INDIVIDUAL MARKETS

Having made various observations on the representative market, the price elasticities for three specific markets are examined: Montreal–Ottawa, Montreal–Toronto and Toronto–Vancouver.

3.4.1 The Montreal–Ottawa Market

Analysis: The discussion on the effect of price on price elasticity of modal shares in section 3.1 is very relevant to the Montreal–Ottawa market. According to Table 3.3 **a, b** and **c**, the three categories of models, identified by properties P.4, P.5 and P.6, result in fairly different elasticities. Models whose price elasticity is directly proportional to the price (Peat-Marwick, Ridout-Miller, HORIZONS, Grayson, Stopher-Prashker) yield fairly low elasticities; models whose price elasticity is inversely proportional to the price (Gaudry-Wills, Wilson et al.) result in fairly high price elasticities. The PERAM model yields elasticities that lie between the first two because price elasticity does not change as the price changes.

It is known that, on average, the prices used to calibrate the Gaudry-Wills model correspond to the prices of the representative market. The prices of the Montreal–Ottawa market are therefore "extreme" values for the Gaudry-Wills model, because they are lower than those of the representative market. Since the Gaudry-Wills model generates elasticities that are inversely proportional to prices (see property P.6), it is not surprising that this model yields elasticities that are large in magnitude. The same reasoning applies to the PERAM and Wilson et al. models. Consequently, the Gaudry-Wills, PERAM and Wilson et al. models seem ill-equipped to assist in the analysis of the Montreal–Ottawa market, and the estimates from these models are not used in choosing proposed values.

Values selected: The Peat-Marwick, Ridout-Miller, HORIZONS, Grayson and Stopher-Prashker models yield fairly homogeneous direct price elasticities. As was the case with the representative market, differences in elasticities across models are larger for the mode with the smallest market share — the air mode. The estimates are, however, similar enough to permit the use of the Peat-Marwick model as the representative model. Elasticities from this model are reported in Table 3.4.

Table 3.3
MONTREAL-OTTAWA MARKET (1976)

(a) Direct Price Estimates

Models	Direct price elasticities of modes				Direct price elasticities of modal shares			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Peat-Marwick	−0.17	−2.12	−0.65	−0.54	−0.08	−2.11	−0.64	−0.52
Ridout-Miller	−0.13	−1.59	−0.47	−0.41	−0.06	−1.59	−0.48	−0.39
Gaudry-Wills	−0.79	−1.82	−2.28	−2.10	−0.50	−1.82	−2.27	−2.05
PERAM	−0.41	−1.59	−1.46	−1.35	−0.18	−1.58	−1.44	−1.28
Wilson et al.	−0.47	−5.12	−1.57	−1.33	−0.20	−5.10	−1.55	−1.27
HORIZONS	−0.23	−0.78	−0.19	−0.16	−0.06	−0.77	−0.19	−0.14
Grayson	−0.08	−0.99	−0.30	−0.26	−0.04	−0.99	−0.30	−0.25
Stopher-Prashker	−0.21	−1.43	−0.86	−0.77	−0.09	−1.42	−0.85	−0.73

(b) Cross Price Elasticities

Models	Cross price elasticities of modes				Cross price elasticities of modal shares			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Peat-Marwick	0.26	0.02	0.02	0.07	0.34	0.03	0.03	0.09
Ridout-Miller	0.20	0.02	0.02	0.05	0.26	0.02	0.02	0.07
Gaudry-Wills	1.78	0.02	0.08	0.30	2.06	0.02	0.09	0.35
PERAM	0.49	0.01	0.04	0.15	0.72	0.02	0.06	0.22
Wilson et al.	0.56	0.04	0.04	0.15	0.83	0.06	0.06	0.21
HORIZONS	0.09	0.01	0.00	0.00	0.25	0.01	0.01	0.02
Grayson	0.12	0.01	0.01	0.03	0.16	0.01	0.01	0.04
Stopher-Prashker	0.26	0.01	0.02	0.08	0.38	0.02	0.04	0.12

(c) Price Elasticities of Total Demand and Modal Substitution Indices

Models	Elasticities of travel demand				Modal substitution indices (θ^s_m)			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Peat-Marwick	−0.09	−0.01	−0.01	−0.02	0.37	0.75	0.75	0.72
Ridout-Miller	−0.06	−0.01	−0.01	−0.02	0.37	0.75	0.75	0.72
Gaudry-Wills	−0.28	0.00	−0.01	−0.05	0.55	0.86	0.86	0.84
PERAM	−0.23	−0.01	−0.02	−0.07	0.29	0.68	0.67	0.65
Wilson et al.	−0.27	−0.02	−0.02	−0.07	0.29	0.68	0.67	0.65
HORIZONS	−0.16	−0.01	−0.01	−0.02	0.10	0.42	0.20	0.29
Grayson	−0.04	0.00	0.00	−0.01	0.37	0.75	0.75	0.72
Stopher-Prashker	−0.12	−0.01	−0.01	−0.04	0.29	0.68	0.67	0.65

Table 3.4

PRICE ELASTICITIES AND SUBSTITUTION INDICES SELECTED, MONTREAL–OTTAWA MARKET (1976)

(a) Direct and Cross Price Elasticities

	Price elasticities of modes of transport				Price elasticities of modal shares			
	1. auto	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
Direct elasticities	–0.17	–2.12	–0.65	–0.54	–0.08	–2.11	–0.64	–0.52
Cross elasticities	0.26	0.02	0.02	0.07	0.34	0.03	0.03	0.09

(b) Price Elasticities of Total Demand and Modal Substitution Indices

	Price elasticities of total demand				Modal substitution indices (θ^s_m)			
	1. auto	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
	–0.09	–0.01	–0.01	–0.02	0.37	0.75	0.75	0.72

Unlike the representative market, the price elasticities of the rail and bus modes are inelastic for the Montreal–Ottawa market. All the ground modes have inelastic demand (less than or equal to –0.65). Only the air mode has an elastic demand.

Substitution among Modes: The substitution index for the auto mode (0.37) implies that 37 percent of the decrease in demand for the auto mode, due to an increase in the price of that mode, is added to the demand for the public modes. However, 63 percent of the decrease in demand for the auto mode is reflected in a decrease in total demand. Even if the effect of substituting public modes for the private mode is small, it nevertheless has a considerable influence on the modal shares of the public modes. In fact, the cross elasticity of the public modes compared to the cost of the auto mode is fairly high (0.26).

A change in the price of a public mode primarily affects market shares while having little effect on total demand. The modal substitution effect is 75 percent for the air and rail modes and 72 percent for the bus mode.

3.4.2 The Montreal-Toronto Market

Analysis: The elasticities of the Montreal–Toronto market are reported in Table 3.6 **a**, **b** and **c**. Of the four markets examined, this market has the most homogeneous elasticities across models. The only systematic difference comes from the HORIZONS and Grayson models, which yield considerably lower estimates of the own elasticities of the rail and bus modes. Perhaps the hypothesized sequential selection process of the HORIZONS model is responsible for the low elasticities associated with the public modes of ground transportation.

Values Selected: The price elasticities in Table 3.5 correspond to those of the Ridout-Miller model. The price elasticities of the Montreal–Toronto market do not differ very much from those of the representative market: demand for the auto mode is inelastic (–0.49) and demand for the public modes is elastic.

Table 3.5
Price Elasticities Selected, Montreal–Toronto Market (1976)

(a) Direct and Cross Elasticities

	Price elasticities of modes of transport				Price elasticities of modal shares			
	1. auto	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
Direct elasticities	–0.49	–2.26	–1.12	–1.03	–0.35	–2.07	–1.06	–1.00
Cross elasticities	0.39	0.46	0.14	0.03	0.51	0.61	0.18	0.04

(b) Price Elasticities of Total Demand and Modal Substitution Indices

	Price elasticities of total demand				Modal substitution indices (θ^{s}_{m})			
	1. auto	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
	–0.13	–0.15	–0.05	–0.01	0.56	0.70	0.72	0.75

Substitution among Modes: The hypothesis of no modal substitution can be rejected. A change in the price of one mode will definitely lead to adjustments to the distribution of travel. The proportions of the adjustments resulting from a modal substitution are: 56 percent for the auto mode, 70 percent for the air mode, 72 percent for the rail mode and 75 percent for the bus mode.

Table 3.6

Montreal–Toronto Market (1976)

(a) Direct Price Elasticities

	Direct price elasticities of modes				Direct price elasticities of modal shares			
Models	**1. auto**	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
Peat-Marwick	−0.64	−3.00	−1.49	−1.37	−0.48	−2.80	−1.43	−1.36
Ridout-Miller	−0.49	−2.26	−1.12	−1.03	−0.35	−2.07	−1.06	−1.00
Gaudry-Wills	−1.02	−1.31	−1.70	−1.95	−0.86	−1.26	−1.67	−1.94
PERAM	−0.54	−1.35	−1.35	−1.46	−0.37	−1.24	−1.28	−1.44
Wilson et al.	−0.62	−2.70	−1.33	−1.21	−0.42	−2.47	−1.26	−1.20
HORIZONS	−0.69	−1.16	−0.56	−0.33	−0.35	−0.99	−0.51	−0.32
Grayson	−0.31	−1.41	−0.70	−0.64	−0.23	−1.32	−0.67	−0.64
Stopher-Prashker	−0.77	−2.06	−1.99	−1.91	−0.53	−1.89	−1.89	−1.88

(b) Cross Price Elasticities

	Cross price elasticities of modes				Cross price elasticities of modal shares			
Models	**1. auto**	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
Peat-Marwick	0.53	0.63	0.18	0.04	0.69	0.82	0.24	0.05
Ridout-Miller	0.39	0.46	0.14	0.03	0.51	0.61	0.18	0.04
Gaudry-Wills	1.08	0.32	0.24	0.07	1.24	0.37	0.28	0.08
PERAM	0.36	0.25	0.15	0.04	0.53	0.36	0.22	0.06
Wilson et al.	0.42	0.49	0.14	0.03	0.61	0.72	0.21	0.05
HORIZONS	0.18	0.15	-0.01	0.00	0.51	0.32	0.05	0.01
Grayson	0.25	0.29	0.09	0.02	0.33	0.38	0.11	0.03
Stopher-Prashker	0.52	0.37	0.22	0.05	0.76	0.55	0.32	0.08

(c) Price Elasticities of Total Demand and Modal Substitution Indices

	Price elasticities of total demand				Modal substitution indices (θ^S_m)			
Models	**1. auto**	**2. air**	**3. rail**	**4. bus**	**5. auto**	**6. air**	**7. rail**	**8. bus**
Peat-Marwick	−0.17	−0.20	−0.06	−0.01	0.56	0.70	0.72	0.75
Ridout-Miller	−0.13	−0.15	−0.05	−0.01	0.56	0.70	0.72	0.75
Gaudry-Wills	−0.17	−0.05	−0.04	−0.01	0.73	0.84	0.85	0.86
PERAM	−0.17	−0.12	−0.07	−0.02	0.47	0.62	0.65	0.67
Wilson et al.	−0.20	−0.23	−0.07	−0.02	0.47	0.62	0.65	0.67
HORIZONS	−0.33	−0.17	−0.06	−0.01	0.18	0.34	0.32	0.22
Grayson	−0.08	−0.10	−0.03	−0.01	0.56	0.70	0.72	0.75
Stopher-Prashker	−0.24	−0.18	−0.10	−0.02	0.47	0.62	0.65	0.67

3.4.3 The Toronto–Vancouver Market

Values Selected: For the same reasons as those discussed in the analysis of the representative market, only the Gaudry-Wills, PERAM and Wilson et al. models can be applied to the analysis of the Toronto–Vancouver market. The elasticities of these models for the Toronto–Vancouver market are reported in Table 3.8 **a, b** and **c.** Table 3.7 summarizes the various estimates of price elasticities.

Analysis: Apart from the dominant mode (air mode), demand elasticities for travel are unitary or elastic. It is interesting to note that the direct elasticity of the air mode is –0.62 and closely resembles the direct elasticity of the auto mode in the other markets.

Substitution among Modes: Total demand for the Toronto–Vancouver market is more sensitive to the price of the air mode than to the price of the ground transportation modes. Given an increase in the price of the auto mode, 68 percent of the decrease in travel by that mode is transferred to increases in travellers using the other modes. An increase in the price of the air mode, however, implies that 83 percent of the decrease in demand for the air mode leads to a decrease in total demand. The market shares of the auto, bus and rail modes are affected by a change in the price of the air mode as shown by the cross elasticity of 1.45.

Table 3.7
PRICE ELASTICITIES SELECTED, TORONTO–VANCOUVER MARKET (1976)

(a) Direct and Cross Price Elasticities

	Price elasticities of modes of transport				Price elasticities of modal shares			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Direct elasticities	–0.89	–0.62	–1.42	–1.49	–0.89	–0.15	–1.39	–1.49
Cross elasticities	0.01	0.98	0.08	0.01	0.01	1.45	0.11	0.01

(b) Price Elasticities of Total Demand and Modal Substitution Indices

	Price elasticities of total demand				Modal substitution indices (θ^s_m)			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
	–0.00	–0.46	–0.04	–0.00	0.68	0.17	0.66	0.68

Table 3.8
TORONTO–VANCOUVER MARKET (1976)

(a) Direct Price Elasticities

Models	Direct price elasticities of modes				Direct price elasticities of modal shares			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Gaudry-Wills	−1.26	−0.32	−1.30	−1.42	−1.26	−0.12	−1.28	−1.42
PERAM	−0.89	−0.62	−1.42	−1.49	−0.89	−0.15	−1.39	−1.49
Wilson et al.	−1.02	−0.44	−0.68	−0.62	−1.02	−0.11	−0.66	−0.61

(b) Cross Price Elasticities

Models	Cross price elasticities of modes				Cross price elasticities of modal shares			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Gaudry-Wills	0.01	0.92	0.09	0.01	0.01	1.12	0.11	0.01
PERAM	0.01	0.98	0.08	0.01	0.01	1.45	0.11	0.01
Wilson et al.	0.01	0.56	0.02	0.00	0.01	1.03	0.05	0.01

(c) Price Elasticities of Total Demand and Modal Substitution Indices

Models	Price elasticities of total demand				Modal substitution indices (θ^S_m)			
	1. auto	2. air	3. rail	4. bus	5. auto	6. air	7. rail	8. bus
Gaudry-Wills	−0.00	−0.20	−0.02	−0.00	0.82	0.31	0.81	0.82
PERAM	−0.00	−0.46	−0.04	−0.00	0.68	0.17	0.66	0.68
Wilson et al.	−0.00	−0.33	−0.02	−0.00	0.68	0.17	0.66	0.68

4. THE EFFECTS OF AGGREGATION ON THE CALCULATION OF ELASTICITIES AND ON ESTIMATES

This section deals primarily with the quality of the method of approximation described in Section 2. The subject is dealt with by examining two elements separately: the use of a representative individual and the use of observed market shares.

Section 2 showed that the aggregate direct price elasticity of the share of mode *m* associated with a probability model is represented by equations (4.1), (4.2) and (4.3).

$$\eta^{m}_{C_m}(\text{market}) = \Sigma_k \eta^{m}_{C_m}(k) \cdot f_k \qquad (4.1)$$

$$\eta^{m}_{C_m}(k) = \beta \cdot C_m(k) \cdot [1 - \text{prob}_m(k)] \qquad (4.2)$$

$$\text{prob}_m(k) = \frac{\exp [\beta \cdot C_m(k) + A_m(k)]}{\Sigma_l \exp [\beta \cdot C_l(k) + A_l(k)]} \qquad (4.3)$$

where

$\text{prob}_m(k)$ = the probability that individual k will choose mode m;

$\eta^{m}_{C_m}(k)$ = the elasticity of the probability that individual k will choose mode m with respect to the price of that mode;

$\eta^{m}_{C_m}$ (market) = the aggregate own price elasticity with the enumeration method;

f_k = individual k's weight in the population;

$C_{ijm}(k)$ = the price of mode m for individual k;

$A_{ijm}(k)$ = the level of service of mode m for individual k, level of service associated with factors other than price.

Aggregate elasticity is derived as a result of a weighted sum of the elasticities of individuals. Since sample data are not available, this method cannot be used. In this study, aggregate own price elasticity obtained for a probability model is calculated using the equation:

$$\eta^{m}_{C_m}(\text{approx.}) = \beta \cdot \overline{C_m} \cdot (1 - S_m) \qquad (4.4)$$

A comparison of equations (4.1) to (4.3) with equation (4.4) shows the two methods differ in two ways:

- the aggregate value of price elasticity with equation (4.4) requires a single price value ($\overline{C_m}$), while the aggregate price elasticity obtained with equation (4.1) requires all the prices in the sample;

- the $\eta^{m}_{\mathcal{C}_m}$ (market) price elasticity is obtained from the calculated probability for each individual, while $\eta^{m}_{\mathcal{C}_m}$ (approx.) is obtained from the market share (S_m).

The similarity between the elasticities obtained with the enumeration method (4.1) to (4.3) and the elasticities calculated with equation (4.4) is illustrated by the following empirical examples.

Santiago: The first example comes from a logit model applied to urban data for Santiago, Chile.[6] The first column in Table 4.1 shows the direct price elasticities associated with this model, using the aggregation method for individual elasticities ($\eta^{m}_{\mathcal{C}_m}$ (market)). The second column contains direct price elasticities ($\eta^{m}_{\mathcal{C}_m}$ (approx.)) for a representative individual based on equation (4.4). The third column contains the price elasticity calculated for a representative individual, but the share calculated for a representative individual replaces the observed share in equation (4.4), as follows:

$$\eta^{m}_{\mathcal{C}_m}(\text{repres.}) = \beta \cdot \overline{C}_m \cdot \left[1 - \frac{\exp(\beta \cdot \overline{C_m} + \overline{A_m})}{\sum_l \exp(\beta \cdot \overline{C_l} + \overline{A_l})} \right] \qquad (4.5)$$

An examination of Table 4.1 shows that the three methods yield very similar estimates. Furthermore, a comparison of columns 2 and 3 indicates that the use of market shares yields more precise estimates than the use of the calculated share of the representative individual according to equation (4.5). Although this is not a scientific justification, this example confirms that the approximation of aggregate elasticities ($\eta^{m}_{\mathcal{C}_m}$ (approx.)) yields reasonable estimates.

Table 4.1

Direct Price Elasticities with Three Different Methods, Santiago, Chile

	1. Weighted sum of individual elasticities ($\eta^{m}_{\mathcal{C}_m}$(market))	2. Elasticities of a representative individual, market share ($\eta^{m}_{\mathcal{C}_m}$(approx.))	3. Elasticities of a representative individual, calculated probability ($\eta^{m}_{\mathcal{C}_m}$(repres.))
Mode 1	–0.251	–0.340	–0.370
Mode 2	–0.064	–0.087	–0.075
Mode 3	–0.213	–0.233	–0.240
Mode 4	–0.015	–0.047	–0.015
Mode 5	–0.049	–0.069	–0.095
Mode 6	–0.154	–0.184	–0.193
Mode 7	–0.070	–0.075	–0.077
Mode 8	–0.169	–0.182	–0.189
Mode 9	–0.141	–0.153	–0.160

Montreal–Toronto: The second example comes from the Peat-Marwick model (1990). The first row in Table 4.2 presents the direct price elasticities of the probability that a low-income individual will choose a mode of transport for "business purposes" in the Montreal–Toronto market. The second row reports the same elasticity for high-income individuals. Rows 4 and 5 report the same information for non-business travellers. These elasticities apply to an individual with the same characteristics as those presented in Table II-11 of the Peat-Marwick study (1990).[7] Equation 4.2 is used to calculate direct price elasticities.

Row 3 in Table 4.2 presents price elasticities calculated using the approximation of aggregate elasticity ($\eta^{m}_{C_m}$ (approx.)). The elasticities in row 3 differ from those in the first two rows because the calculated probabilities are replaced with market shares.

A comparison of row 3 with rows 1 and 2 in Table 4.2 shows that use of the approximation approach yields reasonable elasticities that lie between the elasticities for high- and low-income individuals.

Similar to row 3, row 6 reports price elasticities calculated using the approximation of the aggregate elasticity ($\eta^{m}_{C_m}$ (approx.)). The only difference is that the prices are not those for business trips, but rather, average prices of the modes for "business and other" purposes. The aggregate price elasticities of the Peat-Marwick model for the Montreal–Toronto market are not known, but they must correspond to the mean of the values in rows 1, 2, 4 and 5. This is precisely what is found in line 6 — an approximation of aggregate price elasticities for the Montreal–Toronto market.

Table 4.2

PRICE ELASTICITIES FOR THE MONTREAL–TORONTO MARKET (1987) WITH THE PEAT-MARWICK MODEL (1990)

	Direct elasticities				Cross elasticities			
	auto	**air**	**rail**	**bus**	**auto**	**air**	**rail**	**bus**
Business purposes:								
1. low-inc. calculated prob.	−2.69	−2.28	−1.79	−1.04	0.53	3.84	0.41	0.02
2. high-inc. calculated prob.	−3.09	−0.49	−2.12	−1.06	0.13	5.63	0.08	0.00
3. market share	−2.90	−0.98	−2.05	−1.06	0.29	5.11	0.15	0.00
Other motives, non-group:								
4. low-inc. calculated prob.	−0.69	−4.14	−1.43	−1.04	0.64	0.47	0.32	0.31
5. high-inc. calculated prob.	−0.74	−3.24	−1.50	−1.20	0.59	1.37	0.26	0.15
All motives:								
6. market share, bus. motives parameters	−1.42	−2.69	−1.46	−0.99	0.70	2.11	0.32	0.05

Note: **Equation (4.2) is used for rows 1, 2, 4 and 5, while the approximation equation (4.4) is used for rows 3 and 6.**

5. FORMULATING PRICE ELASTICITIES AND THE MODAL SUBSTITUTION INDEX

The formulas used to calculate the modal substitution index and price elasticities are presented here.

5.1 DESCRIPTION OF DEMAND MODELS

Details on the derivation of the information in Tables 3.3 to 3.8 are discussed in this section. Since the interest is in the demand sensitivity to the cost of the modes of transport, only the specification of the price variable is explained using the probability or modal-split model. All other variables in the modal-split or probability model are grouped together in the A_{ijm} variable.

The calibrated parameters of some of the models have to be adjusted in order to compare the price elasticities given in Section 3. This adjustment consists of changing the monetary units of the coefficients in order to obtain the "Canadian cent of 1976" unit. The probability and modal-split models define the level of utility (V_m) of mode m as:

$$V_m = \beta C_m + A_m \tag{5.1}$$

Coefficient β is interpreted as utility per monetary unit of variable C_m; if the calibration period is 1972, the following transformation is necessary:

$$\beta_{1976} = \beta_{1972} \cdot IPC_{1972}/IPC_{1976} \tag{5.2}$$

where IPC_{1972} and IPC_{1976} refer to the 1972 and 1976 consumer price indices, respectively. Table 5.1 provides the values of price indices and exchange rates used in the calculations.

Table 5.1
PRICE INDICES AND EXCHANGE RATES

	1969	1972	1976	1977	1984
Consumer price indices	39.2	42.6	60.6	65.1	120.7
Exchange rate ($ CAN./$ U.S.)	1.077	0.991	0.986	1.063	1.295

The following notation is used:

S_{ijm} = modal share of mode m in market ij

T_{ij} = total number of trips in market ij

C_{ijm} = price of mode m in market ij

IPC_y = consumer price index for the year y

TDC_y = U.S.$ exchange rate for the year y

η_{C_m} (total) = total demand elasticity with respect to the price of mode m

$\eta^m_{C_m}$ (share) = elasticity of the share of mode m (S_{ijm}) with respect to the price of mode m (C_{ijm}).

5.1.1 The Gaudry-Wills Model (1978)

The 1972 Transport Canada data base was used to calibrate the Gaudry-Wills model. The generation-distribution model is formulated using equation (5.3) and the modal-split model is given in equation (5.4).

$$T_{ij} = \Big[24.46 + 0.8P_{ij}^{(\lambda_1)} + 0.0014L_{ij}^{(\lambda_2)} + 2.5\left\{\Sigma_l \exp\left[-1.82(C_{ijl} + 35.7)^{(\lambda_3)} + A_{ijl}\right]\right\}^{(\lambda_4)}\Big]^{-1} \quad (5.3)$$

$$S_{ijm} = \frac{\exp\left[-1.82(C_{ijm} + 35.7)^{(\lambda_3)} + A_{ijm}\right]}{\Sigma_l \exp\left[-1.82(C_{ijl} + 3.57)^{(\lambda_3)} + A_{ijl}\right]} \quad (5.4)$$

where:

P_iS= the product of the population of city *i* and the population of city *j*;

L_{ij} = similarity of the linguistic composition of city *i* and city *j*;

A_{ijm} = travel time, number of departures.

Equations (5.5), (5.6) and (5.7) were used to calculate the price elasticities of the Gaudry-Wills model. For $\lambda_1 = 0.2$, $\lambda_2 = 1.94$, $\lambda_3 = -0.24$, and $\lambda_4 = -0.17$,

$$\eta_{C_m}(\text{total}) = -1.82 \bullet 2.5 \bullet (C_{mk} + 35.7)^{(-0.24-1)} \bullet S_{ijm} \bullet U^{0.04} \bullet T_{ij}^{-0.17} \quad (5.5)$$

$$\eta_{C_m}^{m}(\text{share}) = -1.82 \bullet (C_{ijm} + 35.7)^{(-0.24-1)} \bullet C_{ijm} \bullet (1 - S_{ijm}) \quad (5.6)$$

$$\eta_{C_l}^{m}(\text{share}) = 1.82 \bullet (C_{ijl} + 35.7)^{(-0.24-1)} \bullet C_{ijl} \bullet S_{ijl} \quad (5.7)$$

5.1.2 The Grayson Model (1981)

The 1977 National Travel Survey data base was used to calibrate the Grayson model. The sample consisted of 1,658 trips between 46 city-pairs, including New York, San Francisco and Los Angeles. Equation (5.8) describes the probability model.

$$S_{ijm} = \frac{\exp(-0.016 C_{ijm} + A_{ijm})}{\sum_l \exp(-0.016 C_{ijl} + A_{ijl})} \tag{5.8}$$

where

A_{ijl} = time in vehicle, access time, waiting time.

Equations (5.9), (5.10) and (5.11) were used to calculate the price elasticities of the Grayson model.

$$\eta_{C_m}(\text{total}) = 0.247[-0.016\ IPC_{77}/(100\ IPC_{76}TDC_{77})] \cdot S_{ijm} \cdot C_{ijm} \tag{5.9}$$

$$\eta^{m}_{C_m}(\text{share}) = [-0.016\ IPC_{77}/(100\ IPC_{76}TDC_{77})] \cdot C_{ijm} \cdot (1 - S_{ijm}) \tag{5.10}$$

$$\eta^{m}_{C_l}(\text{share}) = [0.0161 \cdot IPC_{77}/(100\ IPC_{76}TDC_{77})] \cdot C_{ijl} \cdot S_{ijl} \tag{5.11}$$

5.1.3 The HORIZONS Model

The 1987 data base for the Windsor–Quebec City Corridor Survey was used to calibrate the HORIZONS model. Equation (5.12) shows the generation-distribution model.

$$T_{ij} = e^{-15.7-0.23 I_o + 2 I_q} \cdot U^{0.65} \cdot (Y_i E_j)^{1.04} \tag{5.12}$$

where

I_o = a trip with an origin and destination in Ontario

I_q = a trip with an origin and destination in Quebec

E_j = employment in city j

Equations (5.13) to (5.16) are for the conditional choice probability models. Thus, S_a refers to the probability that the auto mode is chosen. The alternative is to choose a public mode of transport $(1 - S_a)$. S_p refers to the probability that the public air mode is selected, provided a public mode of transport is selected. The alternative is to select a ground transportation mode $(1 - S_p)$. S_t and S_b refer to the probabilities that the train or bus mode are selected, respectively, provided a public mode of ground transportation is selected.

$$S_a = \frac{\exp(\beta_{10} + \beta_{11}GC_a)}{\exp(\beta_{01} + \beta_{11}GC_a) + \exp(\beta_{12}GC'_a)} \tag{5.13}$$

$$S_p = \frac{\exp(\beta_{20} + \beta_{21}GC_p)}{\exp(\beta_{20} + \beta_{21}GC_p) + \exp(\beta_{22}GC'_p)} \tag{5.14}$$

$$S_t = \frac{\exp(\beta_{30} + \beta_{31}GC_t)}{\exp(\beta_{30} + \beta_{31}GC_t) + \exp(\beta_{32}GC_b)} \tag{5.15}$$

$$S_b = \frac{\exp(\beta_{32}GC_b)}{\exp(\beta_{30} + \beta_{31}GC_t) + \exp(\beta_{32}GC_b)} \tag{5.16}$$

$$S_{auto} = S_a, \qquad S_{air} = (1 - S_a) \cdot S_p \tag{5.17}$$

$$S_{train} = (1 - S_a) \cdot (1 - S_p) \cdot S_t \tag{5.18}$$

$$S_{bus} = (1 - S_a) \cdot (1 - S_p) \cdot S_b \tag{5.19}$$

$$GC_b = A_b + C_b/VOT_b, \qquad GC_t = A_t + C_t/VOT_t \tag{5.20}$$

$$GC_p = A_p + C_p/VOT_p, \qquad GC_a = A_a + C_a/VOT_a \tag{5.21}$$

$$GC'_p = \ln[\exp(\beta_{30} + \beta_{31}GC_t) + \exp(\beta_{32}GC_b)] \tag{5.22}$$

$$GC'_a = \ln[\exp(\beta_{20} + \beta_{21}GC_p) + \exp(\beta_{22}GC'_p)] \tag{5.23}$$

$$VOT_a = 28, \quad VOT_p = 65.7, \quad VOT_t = 27.8, \quad VOT_b = 18.2 \tag{5.24}$$

The price elasticites of the generation-distribution model (5.11) are derived using equations (5.25) to (5.28).

$$\eta(\text{total, auto}) = \beta_{11} \cdot S_a \cdot C_a/VOT_a \tag{5.25}$$

$$\eta(\text{total, air}) = \beta_{12} \cdot \beta_{21} \cdot S_p \cdot C_p/VOT_p \tag{5.26}$$

$$\eta(\text{total, train}) = \beta_{12} \cdot \beta_{22} \cdot \beta_{31} \cdot S_t \cdot C_t/\text{VOT}_t \tag{5.27}$$

$$\eta(\text{total, bus}) = \beta_{12} \cdot \beta_{22} \cdot \beta_{32} \cdot S_b \cdot C_b/\text{VOT}_b \tag{5.28}$$

The equations from Table 5.2 were used to calculate the direct and cross elasticities of the modal shares in Appendix 1. The reader should note that the nested logit model implies a specific structure of cross elasticities: elasticities of the public modes with respect to the cost of the auto mode are equal; elasticities of the public modes of ground transportation with respect to the cost of the air mode are equal.

Table 5.2

PRICE ELASTICITIES OF MODAL SHARES IN THE HORIZONS MODEL

	Auto
Auto	$\beta_{11} \cdot (1 - S_a) \cdot C_a/\text{VOT}_a$
Air	$-\beta_{11} \cdot S_a \cdot C_a/\text{VOT}_a$
Train	$-\beta_{11} \cdot S_a \cdot C_a/VOT_a$
Bus	$-\beta_{11} \cdot S_a \cdot C_a/VOT_a$
	Air
Auto	$-\beta_{12} \cdot (1 - S_a) \cdot \beta_{21} \cdot S_p \cdot C_p/\text{VOT}_p$
Air	$[-\beta_{12} \cdot S_a \cdot \beta_{21} \cdot S_p + \beta_{21} \cdot (1 - S_p)] \cdot C_p/\text{VOT}_p$
Train	$(-\beta_{12} \cdot S_a \cdot \beta_{21} \cdot S_p - \beta_{21} \cdot S_p) \cdot C_p/\text{VOT}_p$
Bus	$(-\beta_{12} \cdot S_a \cdot \beta_{21} \cdot S_p - \beta_{21} \cdot S_p) \cdot C_p/\text{VOT}_p$
	Train
Auto	$-\beta_{12} \cdot (1 - S_a) \cdot \beta_{22} \cdot (1 - S_p) \cdot \beta_{31} \cdot S_t \cdot C_t/\text{VOT}_t$
Air	$[-\beta_{12} \cdot S_a \cdot \beta_{22} \cdot (1 - S_p) \cdot \beta_{31} \cdot S_t - \beta_{22} \cdot (1 - S_p) \cdot \beta_{31} \cdot S_t] \cdot C_t/\text{VOT}_t$
Train	$[\beta_{12} \cdot S_a \cdot \beta_{22} \cdot (1 - S_p)\beta_{31} \cdot S_t - \beta_{22} \cdot S_p \cdot S_t \cdot \beta_{31} + \beta_{31} \cdot (1 - S_t)] \cdot C_t/\text{VOT}_t$
Bus	$[\beta_{12} \cdot S_a \cdot \beta_{22} \cdot (1 - S_p)\beta_{31} \cdot S_t - \beta_{22} \cdot S_p \cdot S_t \cdot \beta_{31} - \beta_{31} \cdot S_t] \cdot C_t/\text{VOT}_t$
	Bus
Auto	$-\beta_{12} \cdot (1 - S_a) \cdot \beta_{22} \cdot (1 - S_p) \cdot \beta_{32} \cdot S_b \cdot C_b/\text{VOT}_b$
Air	$[-\beta_{12} \cdot S_a \cdot \beta_{22} \cdot (1 - S_p) \cdot \beta_{32} \cdot S_b - \beta_{22} \cdot (1 - S_p) \cdot \beta_{32} \cdot S_b] \cdot C_b/\text{VOT}_b$
Train	$[\beta_{12} \cdot S_a \cdot \beta_{22} \cdot (1 - S_p)\beta_{32} \cdot S_b + \beta_{22} \cdot S_p \cdot S_b \cdot \beta_{32} - \beta_{32} \cdot S_b] \cdot C_b/\text{VOT}_b$
Bus	$[\beta_{12} \cdot S_a \cdot \beta_{22} \cdot (1 - S_p)\beta_{32} \cdot S_b + \beta_{22} \cdot S_p \cdot S_b \cdot \beta_{32} + \beta_{32} \cdot (1 - S_b)] \cdot C_b/\text{VOT}_b$

5.1.4 The PERAM Model (1976)

The sample used to calibrate the PERAM Model consists of 16 city–pairs in the 1976 Transport Canada data base. The generation-distribution model is described by (5.29). Equation (5.30) provides the modal-split model.

$$T_{ij} = e^{4.12} P_{ij}^{0.76} Y_{ij}^{0.56} \bullet \left(\Sigma_l C_{ijl}^{\beta_{1l}} A_{ijl}\right)^{0.32} \tag{5.29}$$

$$S_{ijm} = \frac{C_{ijm}^{\beta 1m} A_{ijm}}{\Sigma_l C_{ijl}^{\beta 1m} A_{ijl}} \tag{5.30}$$

where

A_{ijm} = time spent in vehicle, frequency.

The price elasticities of the generation-distribution model (5.29) are derived using equation (5.31). The modal-split model price elasticities are derived using equations (5.32) and (5.33).

$$\eta_{C_m}(\text{total}) = \beta_{1m} \bullet 0.32 \bullet S_{ijm} \tag{5.31}$$

$$\eta_{C_m}^{m}(\text{share}) = \beta_{1m} \bullet (1 - S_{ijm}) \tag{5.32}$$

$$\eta_{C_l}^{m}(\text{share}) = -\beta_{1l} \bullet S_{ijl} \tag{5.33}$$

$\beta_{auto} = -0.9$, $\beta_{air} = -1.6$, $\beta_{train} = -1.5$, $\beta_{bus} = -1.5$

5.1.5 The Peat-Marwick Model (1990)

The data base for the 1987 Windsor–Quebec City corridor travel survey was used to calibrate the Peat-Marwick model. Equation (5.34) presents the generation-distribution model, while equation (5.35) describes the probability model for business travel purposes.

$$T_{ij} = e^{-8} P_i E_j^{0.39} \left[\Sigma_l \exp(-0.0317 C_{ijl} + A_{ijl})\right]^{.247} \tag{5.34}$$

$$S_{ijm} = \frac{\exp(-0.0317 C_{ijm} + A_{ijm})}{\Sigma_l \exp(-0.0317 C_{ijl} + A_{ijl})} \tag{5.35}$$

where

A_{ijm} = time spent in vehicle, access time, waiting time, frequency.

The price elasticities of the generation-distribution model are derived using equation (5.36), while the price elasticities of the probability model use equations (5.37) and (5.38).

$$\eta_{C_m}(\text{total}) = 0.247 \cdot -0.0317 \cdot [\text{IPC}_{87}/(\text{IPC}_{76} \cdot 100)] \cdot S_{ijm} \cdot C_{ijm} \tag{5.36}$$

$$\eta^{m}_{C_m}(\text{share}) = -0.0317 \cdot [\text{IPC}_{87}/(\text{IPC}_{76} \cdot 100)] \cdot (1 - S_{ijm}) \cdot C_{ijm} \tag{5.37}$$

$$\eta^{m}_{C_l}(\text{share}) = 0.0317 \cdot [\text{IPC}_{87}/(\text{IPC}_{76} \cdot 100)] \cdot S_{ijm} \cdot C_{ijm} \tag{5.38}$$

5.1.6 The Ridout-Miller Model (1989)

The data base for the 1969 Windsor–Quebec city corridor survey was used to calibrate the Ridout-Miller probability model. The auto mode is omitted and the parameters used are those for business purposes.

$$S_{ijm} = \frac{\exp\,(-0.035C_{ijm}/Y_i + A_{ijm})}{\Sigma_l \exp\,(-0.035C_{ijl}/Y_i + A_{ijl})} \tag{5.39}$$

where

A_{ijm} = access distance, travel time, economic sectors.

The price elasticities of the probability model are derived from equations (5.40) and (5.42).

$$\eta_{C_m}(\text{total}) = [0.32 \cdot -0.035\ \text{IPC}_{69}/(100\ \text{IPC}_{76})](C_{ijm}/Y_i)S_{ijm} \tag{5.40}$$

$$\eta^{m}_{C_m}(\text{share}) = [-0.035\ \text{IPC}_{69}/(100\ \text{IPC}_{76})](C_{ijm}/Y_i)(1 - S_{ijm}) \tag{5.41}$$

$$\eta^{m}_{C_l}(\text{share}) = [-0.035\ \text{IPC}_{69}/(100\ \text{IPC}_{76})](C_{ijl}/Y_i)(-S_{ijm}) \tag{5.42}$$

5.1.7 The SLAG Model (1975)

The 1972 Canadian Transport Commission data base was used to calibrate this model. A more detailed description of the SLAG model can be found in Rea et al. (1977). The generation-distribution model is given in (5.43), and the modal-split model is described in (5.44)

$$T_{ij} = e^{4.12} P_{ij}^{0.492} L_{ij}^{0.52} \cdot \left(\Sigma_l C_{ijl}^{-2.72} A_{ijl}\right)^{0.339} \tag{5.43}$$

$$S_{ijm} = \frac{C_{ijm}^{-2.72} A_{ijm}}{\Sigma_l C_{ijl}^{-2.72} A_{ijl}} \tag{5.44}$$

where

P_{ij} = the product of the population of city i and the population of city j

L_{ij} = similarity in the linguistic composition of cities i and j

A_{ijm} = travel time, number of departures

The price elasticities of the generation-distribution model are derived using equation (5.45) and those in the probability model are derived from equations (5.46) and (5.47).

$$\eta_{C_m}(\text{total}) = 0.339 \cdot -2.72 \cdot S_{ijm} \tag{5.45}$$

$$\eta^{m}_{\bar{C}_m}(\text{share}) = -2.72 \cdot (1 - S_{ijm}) \tag{5.46}$$

$$\eta^{m}_{\bar{C}_l}(\text{share}) = 2.72 \cdot S_{ijl} \tag{5.47}$$

5.1.8 The Stopher-Prashker Model (1976)

The 1972 National Travel Survey data base was used to calibrate the Stopher-Prashker probability model. The sample consists of 2,085 trips between 22 city-pairs. The $\overline{C_m}$ values correspond to those of the representative market.

$$S_{ijm} = \frac{\exp\,(-3.957 \cdot (C_{ijm}/\overline{C}) + A_{ijm})}{\Sigma_l \exp\,(-3.957 \cdot C_{ijl}/\overline{C} + A_{ijl})} \tag{5.48}$$

where

A_{ijm} = time spent in vehicle, access time, number of departures.

The price elasticities of the probability model are derived from equations (5.49) to (5.51).

$$\eta_{C_m}(\text{total}) = 0.247 \cdot (-3.957) \cdot S_{ijm} \cdot C_{ijm}/\overline{C} \tag{5.49}$$

$$\eta^{m}_{\bar{C}_m}(\text{share}) = -3.957 \cdot (1 - S_{ijm}) \cdot C_{ijm}/\overline{C} \tag{5.50}$$

$$\eta^{m}_{\bar{C}_l}(\text{share}) = 3.957 \cdot S_{ijl} \cdot C_{ijl}/\overline{C} \tag{5.51}$$

5.1.9 The Wilson et al. Model (1990)

The 1976 Canadian Travel Survey data base was used to calibrate the Wilson et al. model. The probability model is reported in equation (5.52).

$$S_{ijm} = \frac{\exp\left(-15.08 C_{ijm}/\mathrm{DIST}_{ij} + A_{ijm}\right)}{\Sigma_l \exp\left(-15.08 C_{ijm}/\mathrm{DIST}_{ij} + A_{ijm}\right)} \tag{5.52}$$

where

A_{ijm} = travel time, number of departures, income.

The price elasticities of the probability model are derived using equations (5.53) to (5.55).

$$\eta_{C_m}(\text{total}) = 0.32 \cdot [-15.08\ \mathrm{IPC}_{84}/(100\ \mathrm{IPC}_{76})](C_{ijm}/\mathrm{DIST}_{ijm})(1 - S_{ijm}) \tag{5.53}$$

$$\eta^m_{C_m}(\text{share}) = [-15.08\ \mathrm{IPC}_{84}/(100\ \mathrm{IPC}_{76})](C_{ijm}/\mathrm{DIST}_{ijm})(1 - S_{ijm}) \tag{5.54}$$

$$\eta^m_{C_l}(\text{share}) = (15.08\ \mathrm{IPC}_{84}/(100\ \mathrm{IPC}_{76})](C_{ijl}/\mathrm{DIST}_{ijl})S_{ijl} \tag{5.55}$$

5.2 DERIVING THE MODAL SUBSTITUTION INDEX

The modal substitution index is derived as follows for the rail mode:

$$\Delta T_{\text{train}} / \Delta C_{\text{train}} = \Delta T_{\text{total}} / \Delta C_{\text{train}} - \Delta T_{\text{auto}} / \Delta C_{\text{train}} - \Delta T_{\text{air}} / \Delta C_{\text{train}} - \Delta T_{\text{bus}} / \Delta C_{\text{train}} \tag{5.56}$$

where

T_{train} = the number of trips taken by the rail mode.

After a few transformations, the proportion that affects trips taken by the other modes (θ^S_{train}) can be determined, as can the effect on total demand for trips (θ^T_{train}),

$$\Delta T_{\text{train}} / \Delta C_{\text{train}} = \Delta T_{\text{total}} / \Delta C_{\text{train}} - \Delta T_{\text{auto}} / \Delta C_{\text{train}} - \Delta T_{\text{air}} / \Delta C_{\text{train}} - \Delta T_{\text{bus}} / \Delta C_{\text{train}}$$

$$1 = \frac{\Delta T_{\text{total}} / \Delta C_{\text{train}}}{\Delta T_{\text{train}} / \Delta C_{\text{train}}} - \frac{\Delta T_{\text{auto}} / \Delta C_{\text{train}}}{\Delta T_{\text{train}} / \Delta C_{\text{train}}} - \frac{\Delta T_{\text{air}} / \Delta C_{\text{train}}}{\Delta T_{\text{train}} / \Delta C_{\text{train}}} - \frac{\Delta T_{\text{bus}} / \Delta C_{\text{train}}}{\Delta T_{\text{train}} / \Delta C_{\text{train}}}$$

$$1 = \frac{\Delta T_{\text{total}} / \Delta C_{\text{train}}}{\Delta T_{\text{train}} / \Delta C_{\text{train}}} + \frac{\Delta T_{\text{auto}} / \Delta C_{\text{train}}}{\left|\Delta T_{\text{train}} / \Delta C_{\text{train}}\right|} + \frac{\Delta T_{\text{air}} / \Delta C_{\text{train}}}{\left|\Delta T_{\text{train}} / \Delta C_{\text{train}}\right|} + \frac{\Delta T_{\text{bus}} / \Delta C_{\text{train}}}{\left|\Delta T_{\text{train}} / \Delta C_{\text{train}}\right|}$$

$$1 = \frac{\eta_{C_{\text{train}}}^{T}}{\eta_{C_{\text{train}}}^{\text{train}} S_{\text{train}}} + \frac{\eta_{C_{\text{train}}}^{\text{auto}} S_{\text{auto}}}{\left|\eta_{C_{\text{train}}}^{\text{train}}\right| S_{\text{train}}} + \frac{\eta_{C_{\text{train}}}^{\text{air}} S_{\text{air}}}{\left|\eta_{C_{\text{train}}}^{\text{train}}\right| S_{\text{train}}} + \frac{\eta_{C_{\text{train}}}^{\text{bus}} S_{\text{bus}}}{\left|\eta_{C_{\text{train}}}^{\text{train}}\right| S_{\text{train}}}$$

$$1 = \theta_{\text{train}}^{T} + \theta_{\text{train}}^{S} \tag{5.57}$$

where

$$\theta_{\text{train}}^{S} = \frac{\eta_{C_{\text{train}}}^{T}}{\eta_{C_{\text{train}}}^{\text{train}} S_{\text{train}}}$$

and

$$\theta_{\text{train}}^{T} = 1 - \frac{\eta_{C_{\text{train}}}^{T}}{\eta_{C_{\text{train}}}^{\text{train}} S_{\text{train}}}$$

With the exception of the HORIZONS model, the general form of price elasticities of the demand models presented in the preceding section are:

$$\eta_{C_m}(\text{total}) = \alpha\beta_{1m} S_m C_m \tag{5.58}$$

$$\eta_{C_m}^{m}(\text{share}) = \beta_{1m}(1 - S_m) C_m \tag{5.59}$$

$$\eta_{C_m}^{m}(\text{mode}) = \eta_{C_m}(\text{total}) + \eta_{C_m}^{m}(\text{share}) \tag{5.60}$$

When equations (5–58) to (5-60) are substituted in the definition of θ_m^S, the following is obtained:

$$\theta_m^S = \frac{1 - S_m}{1 + (\alpha - 1) S_m}$$

6. Models Excluded from the Analysis

The nine models used in the analysis of price elasticities in this study are not exhaustive. In fact, there are a considerable number of intercity passenger travel demand models,[8] and some judgement had to be used to arrive at the list of nine models.

One of the selection criteria was the applicability of the model to Canadian markets. Some demand models estimated using Canadian data were excluded from the analysis: Gillen and Oum (1983), Andrikopoulos and Brox (1990) and Abdelawabah (1990).

6.1 DESCRIPTION OF EXCLUDED MODELS

6.1.1 The Gillen-Oum Model (1983)

Gillen and Oum (1983) developed a demand system to explain the percentage of income spent on the three modes of public intercity travel and on goods and services other than transportation. Since the model was calibrated using Canadian time series data, it is not possible to analyze specific markets like those discussed in this study. However, the price elasticities derived from the Gillen-Oum model for 1976 are comparable to those of the representative market, as can be seen in Table 6.1.

Table 6.1
PRICE ELASTICITIES OF THE REPRESENTATIVE MARKET AND THE GILLEN–OUM MODEL

	1. air	2. rail	3. bus
Direct price elasticities of modal shares with the representative market (see Table 3.2)	−1.44	−1.43	−1.44
Direct price elasticities of percentage of expenditures on modes in 1976, Gillen–Oum model	−1.15	−1.55	−1.45

6.1.2 The Andrikopoulos-Brox Model (1990)

The Andrikopoulos-Brox model (1990) is a demand system that yields the percentage of income spent on the four modes of intercity transport. The 1976 Transport Canada data base, which contains data on intercity trips between 86 city-pairs by the four modes of transport, was used to calibrate the Andrikopoulos-Brox model. This model was not excluded for methodological reasons but rather for empirical reasons. The cross elasticities of this model imply that the four modes of intercity transport are complementary. Complementarity between some modes is not unreasonable, but complementarity on an aggregate level for all markets seems to run counter to intuition and to the findings of all recognized studies.

In addition to these empirical considerations, the Gillen-Oum and Andrikopoulos-Brox models both have, in our opinion, a methodological difficulty. They both produce price elasticity estimates for modal expenditures that are obtained from a calibration based on expenditure percentages. With the chain derivative technique, as in equation (6.1), the price elasticity of mode m ($\eta^{m}_{\mathcal{E}_m}$ (mode)) can be obtained by using the share of mode m in total expenditures (d_m).

$$\eta^{m}_{C_m}(\text{mode}) = \frac{\partial T_m}{\partial C_m} \cdot \frac{C_m}{T_m}$$

$$= \frac{\partial T_m}{\partial d_m} \cdot \frac{\partial d_m}{\partial C_m} \cdot \frac{C_m}{T_m} \tag{6.1}$$

where

d_m = expenditure share of mode *m*.

$$d_m = \frac{C_m \cdot T_m}{\Sigma_l C_l \cdot T_l} \tag{6.2}$$

since the number of trips taken by mode *m* is equal to the product of the total number of trips and the percentage of trips taken by mode *m*, when $\eta^{m}_{C_m}$ (mode) is calculated using (6.1), a price elasticity estimate of total demand is implicitly hidden. It is felt that the price elasticity of total demand should be obtained from a model that deals directly with total demand and not from a model that explains expenditure shares.

6.1.3 The Abdelawabah Model (1990)

The Abdelawabah model was omitted due to specification problems. In fact, this model does not include a price variable for business travel, because it did not have the "right" sign, that is, an increase in the price of a mode causes an increase in the probability that the mode is chosen.

7. Conclusion

Several intercity passenger travel demand models have been calibrated in the past. Price elasticities of travel demand obtained from these models are difficult to compare because they are usually calculated using different prices and different trips. This study compared, for the first time, price elasticities from different models.

Price elasticities (direct and cross) of demand for modes of transport within four Canadian markets were compared using the parameters from nine econometric models. The four Canadian markets are Montreal–Ottawa, Montreal–Toronto, Toronto–Vancouver and a representative market made up of 155 Canadian markets.

For each of the four markets analyzed, it was possible to propose price elasticities based on certain econometric models. Depending on the market studied, some models had to be disregarded. For example, the models estimated using information from the Windsor–Quebec City corridor cannot be applied to the study of travel in the Toronto–Vancouver market.

Direct elasticities for the rail and bus modes are practically identical for all markets. They are both inelastic (about –0.6) for the Montreal–Ottawa market and elastic (about –1.3) for the other markets. The demand for the auto mode almost has unit elasticity (about –0.9) for the "long distance" Toronto–Vancouver market and is inelastic (about –0.3) for the other markets. Unlike the auto mode, the demand for the air mode is inelastic for the Toronto–Vancouver market (about –0.6) and elastic for the other markets.

It was noted that, in general, modal substitution is very important. In fact, a change in the price of one mode of transport leads to substitution among the modes that is greater than the change in the total travel demand.

Appendix 1. Modal Shares/Elasticities for the HORIZONS Model

Table A1
Price Elasticities of the HORIZONS Model

Representative Market								
	Modal demand elasticities				Modal share elasticities			
	Auto	Air	Rail	Bus	Auto	Air	Rail	Bus
Auto share	−1.90	0.07	0.02	0.01	−0.50	0.19	0.05	0.04
Air share	0.77	−1.98	0.05	0.04	2.17	−1.86	0.08	0.06
Rail share	0.77	0.19	−0.97	−0.10	2.17	0.31	−0.93	−0.08
Bus share	0.77	0.19	−0.14	−0.73	2.17	0.31	−0.11	−0.71
Total demand	−1.40	−0.12	−0.03	−0.02	—	—	—	—
Montreal–Ottawa Market								
	Modal demand elasticities				Modal share elasticities			
	Auto	Air	Rail	Bus	Auto	Air	Rail	Bus
Auto share	−0.23	0.00	0.00	0.01	−0.06	0.01	0.01	0.03
Air share	0.09	−0.78	0.01	0.02	0.25	−0.77	0.02	0.04
Rail share	0.09	0.01	−0.19	−0.02	0.25	0.01	−0.19	−0.01
Bus share	0.09	0.01	−0.01	−0.16	0.25	0.01	0.00	−0.14
Total demand	−0.16	−0.01	−0.01	−0.02	—	—	—	—
Montreal–Toronto Market								
	Modal demand elasticities				Modal share elasticities			
	Auto	Air	Rail	Bus	Auto	Air	Rail	Bus
Auto share	−0.69	0.10	0.03	0.01	−0.35	0.27	0.09	0.02
Air share	0.18	−1.16	0.06	0.01	0.51	−0.99	0.11	0.02
Rail share	0.18	0.17	−0.56	−0.02	0.51	0.35	−0.51	−0.01
Bus share	0.18	0.17	−0.11	−0.33	0.51	0.35	−0.05	−0.32
Total demand	−0.33	−0.17	−0.06	−0.01	—	—	—	—
Toronto–Vancouver Market								
	Modal demand elasticities				Modal share elasticities			
	Auto	Air	Rail	Bus	Auto	Air	Rail	Bus
Auto share	−7.79	1.22	0.07	0.01	−7.73	3.46	0.20	0.02
Air share	0.03	−2.65	−0.09	0.01	0.09	−0.41	0.22	0.02
Rail share	0.03	1.64	−2.73	−0.06	−0.09	3.88	−2.60	−0.05
Bus share	0.03	1.64	−0.70	−1.47	0.09	3.88	−0.57	−1.46
Total demand	−0.06	−2.24	−0.13	−0.01	—	—	—	—

ENDNOTES

1. The author would like to thank Marc Gaudry, Sophie Mahseredjian and John Sargent for their comments.

2. Equation (2.2) is the elasticity equation from the logit model with a linear utility function. This equation is only given as an example to explain the three pieces of information required. The elasticities of the models examined in the next section were not necessarily obtained from equation (2.2).

3. Since it is clear that all the price elasticities discussed in Section 3 are obtained from an approximation of the aggregate price elasticity, the adjective "approx." has been omitted to facilitate reading.

4. The discussion is not particular to the approximation of aggregate price elasticity described in Section 2. It also holds for the "true" aggregate price elasticity (equation (2.1)).

5. More precisely, price elasticities decrease in relation to price if the price is greater than $1.40.

6. This model was derived by modifying the model in column 0^1 of Table 5 in Gaudry et al. (1992).

7. The elasticities in rows 1, 2, 4 and 5 are also calculated by Miller and Fan (1992) (see Table 4(b)). The reasons for differences in the elasticities reported by Miller and Fan and those reported here are not known.

8. Miller and Fan (1992) describe and discuss intercity passenger transportation demand models.

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DIFFERENTIAL TAXATION OF CANADIAN AND U.S. PASSENGER TRANSPORTATION

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1. Introduction

The inter-modal and international competitiveness of the Canadian passenger transportation sector has become a topical, yet somewhat contentious, issue. Of particular interest is the effect of the Canadian tax system on this competitiveness, or lack thereof. The purpose of this study is to examine and compare quantitatively the impact of taxes on the inter-modal competitiveness of Canadian intercity passenger transportation (air, bus and rail) and the competitiveness with U.S. carriers.

To determine the impact of taxes on competitiveness, it is important to clarify exactly what is meant by the term "competitive." This study is specifically interested in cost competitiveness. Taxes may affect the ability of firms in the transportation sector to compete, both against alternative modes and with U.S. competitors, by altering the cost of providing transportation services. To the extent that taxes affect costs differentially among modes, or impose a greater cost burden on Canadian companies vis-à-vis their American counterparts, taxes affect cost competitiveness. This study uses a new methodology which enables it to quantify the impact of taxation on the cost of providing transportation services and to compare this impact across modes.

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Many taxes potentially affect the cost competitiveness of transportation companies, either directly or indirectly. Unfortunately, data limitations preclude the analysis of all of them.[1] This study includes the following federal and provincial taxes in the analysis: fuel taxes, business taxes (for example, federal and provincial corporate income taxes and provincial capital taxes) and payroll taxes (including UIC, CPP/QPP and various provincial health taxes). Note that the introduction of the GST has largely removed any federal taxes on business inputs that existed under the old Federal Sales Tax. Although provincial retail sales taxes still result in the taxation of some business inputs, these are ignored in this analysis due to lack of data.

The remainder of the study is organized as follows. Section 2 gives a heuristic description of the methodology. Sections 3 and 4 present and discuss the results of the quantitative analysis. This includes a comparison of the impact of taxes on costs across modes as well as a Canada–United States comparison. The study also includes three fairly extensive appendices. Appendix A presents the methodology in a more rigorous fashion than Section 2, while Appendices B and C present the Canadian and United States data used in the computations.

2. Methodology

A popular approach to the comparative analysis of the impact of taxation on business operations is to undertake a cash flow analysis of the following sort: specify an "average" or "standard" enterprise for each mode of transportation, compute the total taxes paid by the standard firm and express these as a percentage of total costs, gross revenues or perhaps some definition of profits. While this commonly used "accounting" approach is useful in identifying important differences in the tax treatment of various modes, it lacks strong economic underpinnings and does not address the key questions addressed in this study: How do taxes affect the cost of providing a unit of transportation services? How does this impact vary across transportation modes?

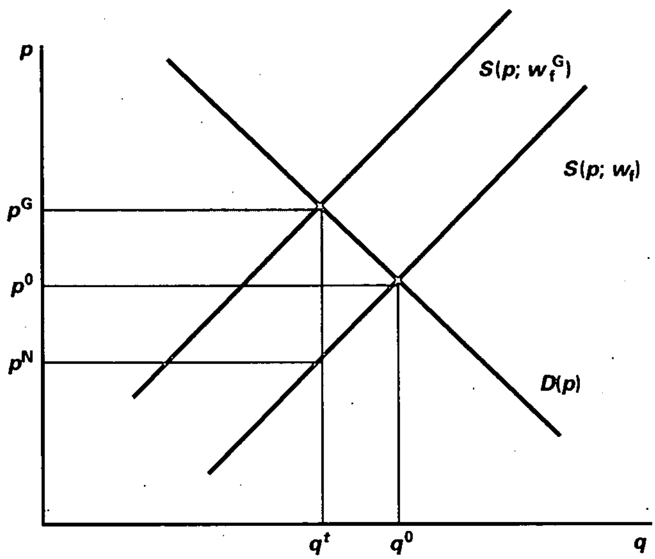
To answer these questions, a new methodology grounded more firmly in the fundamentals of elementary economic analysis than the more traditional cash flow or project analysis approach has been developed. Although the concepts are simple and straightforward, to the authors' knowledge the approach has not been used in other studies of the transportation sector or otherwise. An intuitive explanation of the methodology is also provided, relying on concepts from elementary price theory. A more rigorous representation is contained in Appendix A.

The idea is very simple. The study considers three broad inputs used in the production of transportation services: capital (buildings, land, machinery and equipment, and the "planes, trains and automobiles" themselves), labour and fuel. The cost of providing a unit of transportation services reflects the cost of purchasing these three inputs, which in turn may reflect various taxes levied on them, either directly or indirectly. Thus, although a tax is not levied directly on the cost of providing transportation services, the cost nevertheless reflects the imposition of taxes on the inputs used to produce the services. This study seeks to measure the "effective" rate of tax on the cost of providing the last, or marginal, unit of transportation services. This effective tax rate is simply the rate of tax which would have to be levied (hypothetically) directly on the marginal cost of providing transportation service to end up with the same gross-of-tax marginal cost which results from the various taxes actually levied on the firm's inputs. To the extent that the effective tax rate on the marginal cost of providing transportation differs across the three modes, the tax system affects the ability of these modes to compete both with each other and with their counterparts in the United States.

The methodology can best be illustrated by considering the example in Figure 1. As indicated above, the inputs used to produce transportation services are aggregated into three classes called capital, labour and fuel. The cost of purchasing a unit of each of these inputs is determined by the supply and demand conditions in the appropriate input market. Consider, for example, the cost of fuel. This study assumes that the producer price of fuel is fixed. This is equivalent to assuming that the supply curve for fuel is perfectly elastic. In the absence of taxes, the cost of a unit of fuel to the transportation sector is then simply equal to its fixed producer price, which is denoted by w_f.

Now consider the output market for transportation services provided by the bus industry, for example. The price of a unit of bus services is determined by the demand and supply conditions in that market. For the sake of expositional simplicity, it is assumed that the output market for bus services is characterized by perfect competition.[2] The price of a unit of bus transportation in the absence of any taxes is illustrated in Figure 1, where p is the

Figure 1
The Output Market for Transportation Services



price, $D(p)$ is the aggregate demand curve for bus services and $(p;\ w_f)$ is the aggregate supply curve. (The reason for including w_f in the supply function will be explained shortly.) The equilibrium price in the absence of any taxes is determined by the intersection of $D(p)$ and $S(p;\ w_f)$, and is denoted by p^0. (Ignore the rest of the diagram for the moment.)

How are the input and output markets connected? According to standard price theory, the aggregate supply curve for the output is simply the (horizontal) sum of the marginal cost curves for the individual suppliers. The marginal cost curves for these individual suppliers indicate the cost of providing an incremental unit of output at all output levels. Marginal costs are increasing over the relevant range of output (that is, the incremental cost of providing the tenth unit of output is greater than the cost of providing the first), thus the aggregate supply curve is upward sloping — more output is supplied at higher prices. The marginal cost of providing an additional unit of output for the individual suppliers obviously reflects the cost of the inputs used in production. This is why the aggregate supply function for transportation services is written as $(p;\ w_f)$ — to stress the fact that the function tells how much supply is forthcoming at various output prices given the price of the fuel input w_f. (Only the price of fuel is included in the function for simplicity. Obviously the prices of capital and labour could also be affected.) If input prices rise, the marginal cost of producing an additional unit of output will increase, and the aggregate supply curve will shift upward. This is the key link between the input and output markets which allows the determination of how taxes on business inputs affect the marginal cost of providing transportation services. If taxes cause the user cost of an input such as fuel to rise, the marginal cost to the firm of providing an additional unit of output will increase as well; by how much depends on the substitutability between inputs and the technology of how they are combined.

Given the expositional assumption that the output market is perfectly competitive, the equilibrium price of a unit of transportation services provided by bus companies is equal to the marginal cost of providing the last unit. Thus, $p^0 = \mathrm{MC}(q^0; w_f)$, where $\mathrm{MC}(q^0; w_f)$ is the marginal cost of providing the last unit of transportation services given that the price of fuel is w_f and the total output produced is q^0.

Suppose a tax at the rate of t percent is levied on the purchase of fuel. The impact of this tax on the cost of providing bus services can be illustrated in Figure 1. Given the assumption that the producer price of fuel is fixed at w_f, the user price increases from w_f to w_f^G where $w_f^G = w_f(1 + t)$. But the real interest is in the impact of the fuel tax on the cost of providing an incremental unit of bus transportation, rather than on the user cost of the fuel itself. This is where the relationship between the input and output markets discussed above is exploited.

As indicated earlier, the imposition of the fuel tax increases the user price of fuel to the bus industry from w_f to w_f^G. This in turn increases the marginal cost of providing a unit of bus transportation. Thus, the marginal cost curves for the individual firms shift upward due to the fuel tax, which in turn causes the aggregate supply curve in Figure 1 to shift to $S(p; w_f^G)$, which is the supply curve for bus services given the now higher gross-of-tax input price for fuel, w_f^G. The increase in marginal costs, and therefore the upward shift in the aggregate output supply curve, leads to an increase in the equilibrium price of bus services from p^0 to p^G, where p^G is the gross-of-fuel-tax price of a unit of bus transportation. Industry output falls to q^t.

Recall that given the expositional assumption of perfect competition in the output market, the output price is equal to the marginal cost of the last unit produced; therefore, $p^G = MC(q^t; w_f^G)$, where $MC(q^t; w_f^G)$ is the gross-of-fuel-tax marginal cost of providing the last unit of output expressed as a function of the user price of fuel w_f^G. Associated with the gross-of-tax marginal cost of a unit of transportation services is a net-of-tax marginal cost, defined as $p^N = MC(q^t; w_f^G)$, where w_f is the fixed supply price of a unit of fuel, as discussed above.

The effective tax rate on the marginal cost of providing bus services is defined as the rate of tax T which if (hypothetically) directly applied to the marginal cost of bus transportation would yield the same gross-of-tax marginal cost that results under the fuel tax. Thus, T solves the equation $(1 + T)MC(q^t; w_f) = MC(q^t; w_f^G)$, which gives $T = [MC(q^t; w_f^G) - MC(q^t; w_f)]/MC(q^t; w_f)$.

The effective tax rate on the marginal cost of production gives the rate of tax on marginal costs implied by the various taxes levied on business inputs. For illustrative purposes, the study focussed on a simple fuel tax and its impact on the marginal cost of providing bus services; obviously other taxes apply both to fuel and to the other business inputs used in the bus, air and rail sectors. All of these taxes impinge on the marginal cost of transportation because they increase the user cost of the inputs. An effective tax rate on marginal costs, which reflects the aggregate imposition of all these taxes for each of the three modes, may be determined. In Section 3, estimates of T for bus, air and rail for both Canada and the United States are presented.

The simplicity of the above discussion illustrates how straightforward the approach is, but it also masks a number of important empirical difficulties in actually measuring the effective tax rate on marginal costs. A few of the complications are mentioned here. A more extensive discussion is delegated to the data and methodological appendices.

The first complication concerns the marginal cost function. In order to estimate T, a specific functional form for the cost function must be selected. A number of choices are possible, including generalized functional forms, constant elasticity of substitution (CES), and Cobb-Douglas (C-D), which is a special case of the CES. In Section 3 estimates of T using a constant returns to scale C-D cost function are presented. This has been used widely in other empirical work. For this parameterization, it turns out that T is a simple function of the factor shares for capital, labour and fuel, and the effective rates of tax on those business inputs implied by the tax system. In Appendix A it is shown that for this functional form T is determined as follows:

$$T = (1 + t_k)^{\alpha_k}(1 + t_f)^{\alpha_f}(1 + t_l)^{\alpha_l} - 1 \qquad (1)$$

where t_i is the effective tax rate on business input i, where i = k,f,l for capital, labour and fuel respectively; α_k is the input share of capital, α_f is the share of fuel, and α_l is the share of labour, where $\Sigma_i \alpha_i = 1$ under the constant returns-to-scale assumption. T is computed for each of bus, rail and air, where, of course, the input shares and the effective tax rates on the business inputs may vary by sector.

The simplicity of the expression for T in the C-D case is misleading, as there are a number of empirical difficulties. The first concerns the determination of the effective tax rates on the business inputs themselves — the t in the above expression. A number of issues arise. For example, a simple *ad valorem* fuel tax, such as discussed above, is straightforward; however, many provincial fuel taxes are levied on a specific, or per litre basis. Thus, it is necessary to convert these per litre taxes into *ad valorem* rates using data on average selling prices for fuel. This is a relatively simple problem to overcome; the other two inputs, labour and capital, give rise to more onerous difficulties.

In the case of capital, the federal and provincial income tax systems treat the capital used in the three sectors differently. For example, different capital cost allowance (CCA) rates apply to buses, planes and trains, and the allocation rules used to allocate taxable income among the provinces varies considerably for the three modes. Moreover, the "economic rate of depreciation" on the assets used in the three sectors differs. The effective tax rate on capital t_c reflects all these differences, and others not mentioned here. There is also an aggregation problem which involves exactly what is meant by "capital." Different assets (machinery and equipment, buildings, land, etc.) bear different effective tax rates, and some degree of aggregation is required to determine the effective tax rate on the broad input called "capital."

In the case of labour, there are also difficulties in estimating t_l. Many of the payroll taxes levied on labour, for example, CPP/QPP and UIC, are imposed at a flat rate subject to an income threshold. Thus, the average payroll tax rate varies by the income of the workers. Moreover, payroll tax rates can vary according to the marital status of the individual. Since the interest in this study is on the impact of taxes on marginal costs — which is the cost of providing one more unit of output — the impact of taxes on the user cost of hiring the marginal worker must also be determined. But the effective tax rate on the marginal worker cannot be determined without knowing what the worker's income is! Thus, employment data for each mode are used to construct a profile of an "average" worker in each sector. See Appendix B for details.

Another concern is the treatment and interpretation of certain taxes that are related to government expenditures. Payroll taxes, property and fuel taxes can be considered "benefit taxes" in the sense that the payments are used to directly fund specific benefits, such as the provision of health care, municipal services and transportation infrastructures that are beneficial to the company.

A question arises regarding whether levies of this sort should be compared to other taxes less directly tied to the provision of benefits, such as general income taxes or sales taxes. There are two issues in this regard. First, although these benefit taxes certainly increase the marginal cost of providing transportation just as any other taxes do, it may be considered inappropriate to account for the costs associated with these taxes without at the same time somehow accounting for the benefits — for example, the availability of a healthier work force due to the provision of universal access to medical services — which may well lower costs. Second, in the absence of these benefit taxes, employers may fund things such as health insurance plans, sewage treatment and transportation infrastructures on their own, or in the case of payroll taxes, workers would have to bear some of the costs themselves which could lead to higher wages. In either case, the elimination of government services, and the taxes which fund them, may cause costs to actually increase. It is thus questionable that these benefit taxes actually impinge on the costs of providing output. On the other hand, the taxes may not be directly related to expenditure. For example, if a company hires one more worker and pays the payroll tax, services from the government are available irrespective of "insurance risks" of the worker (for example, there is no "experience related" social insurance).

A similar argument can be made with regard to fuel taxes that bear little relationship to the provision of road services. On the other hand, property taxes are directly related to the provision of municipal services to companies, especially development charges. Thus, effective tax rates on marginal costs for the case where payroll and fuel taxes impinge on costs are computed like any other tax. As well, given the data limitations discussed above and the difficulty in separating out the benefit portion of property taxes, they are not included in the calculations.

Finally, a comment should be made regarding the limitations of the approach adopted in this study. Although it goes considerably further than most studies of the impact of taxation on cost competitiveness by explicitly taking account of the linkages between the input and output markets and the technology which underlies it, this analysis is still partial equilibrium in nature. For example, producer prices are held at a fixed rate when determining the impact of taxes on the user costs of the inputs. Although this may be justifiable in a small open economy such as Canada, for some inputs, such as capital, for other inputs, in particular labour, this may be questionable. More generally, how taxes affect producer prices should be accounted for as well. This clearly would require a full general equilibrium analysis, which is beyond the scope of this study.

3. Principal Results of the Comparison of Canadian Modes

The principal results of the analysis are shown in Tables 1 to 6, which contain estimates of the various effective tax rates (t_k, t_l, t_f, and T) for Canadian transportation companies.

Table 1 contains estimates of the effective tax rate on capital assets, t_k, both by category of asset and in aggregate. Capital assets in each mode are broken into five main categories: building construction, engineering construction, machinery and equipment, buses and capital items charged to expense accounts.[3] The calculations indicate that overall, capital investments in the rail industry are taxed at a slightly higher effective rate than bus and air (33.0%, 30.9% and 22.6% respectively). In aggregate, the Canadian tax system appears to favour capital investments in the air sector relative to bus and rail.

The differentials in marginal effective tax rates on capital primarily reflect differences in capital cost allowance (CCA) rates (unindexed for inflation) relative to "economic" rates of depreciation. For example, the CCA rate for air in the machinery and equipment category is 25%, two and a half times the estimate of 10% for the economic rate of depreciation for that category. The CCA rate in the same category for rail is 10%, almost equal to an economic depreciation rate of 8%, and the bus industry is allowed a CCA rate of 30%, only one and a half times the economic depreciation rate of 20%.[4] This can result in preferential treatment for air compared to rail and bus: as shown in Table 1, bus and rail face higher marginal effective tax rates on machinery and equipment.

Table 1

Canadian Marginal Effective Tax Rates on Capital

	Rail	Bus	Air
	(%)		
Parameterization			
Percentage of debt in one dollar's worth of financing	43	43	43
Percentage of equity in one dollar's worth of financing	57	57	57
Nominal return on debt	12	12	12
Nominal return on equity	20	20	20
Inflation rate	5	5	5
Effective tax rate on capital			
Building construction	44.3	44.3	49.1
Engineering construction	29.6	44.3	29.8
Machinery and equipment	37.8	na	16.3
Buses	na	27.7	na
Capital items charged to operating expenses	2.3	2.3	2.3
Overall (t_k)	33.0	30.9	22.6

The aggregate effective tax rate on capital for each mode is the weighted average of the effective tax rates for the individual asset categories. If a mode exhibits a high marginal effective tax rate in a particular asset category, but the weight attached to that category is relatively low, the high marginal effective tax rate may be neutralized by the low capital expenditure weight. This point is illustrated in Table 1 where bus has the highest marginal effective tax rate in engineering construction (44.3% compared to 29.6% and 29.8% for rail and air respectively). However, the weight attached to engineering construction is only 1.1%, compared to 62.3% for rail.[5] Thus, the relative tax disadvantage for the bus industry in engineering construction is partially offset by the low expenditure weight in that category; the overall effective rate of tax on capital in the bus industry is still lower than the effective tax rate in the engineering construction category.

Tables 2 and 3 contain estimates of the marginal effective tax rate on labour, t_l, across modes. Table 2 gives the effective payroll tax rates for workers by income class. These rates are identical across modes since payroll taxes are uniform for all production sectors. In contrast, Table 3 presents effective payroll tax rates for an average worker in each sector, using a weighted average based on employment statistics to arrive at t_l across modes. It turns out that the effective tax rates are very similar across modes (5.4%, 4.2% and 5.6% for rail, air and bus respectively). The differences are due solely to variations in the composition of the labour force across the modes.

Table 2

CANADIAN MARGINAL EFFECTIVE TAX RATES ON LABOUR BY INCOME CLASS (ALL MODES)

Income (CAN$)	(%)
0–30,500	3.8
30,501–35,000	6.6
35,001–40,000	5.9
40,001–45,000	5.3
45,001–50,000	4.9
50,001–55,000	4.5
55,001–60,000	4.2
60,001–65,000	4.0
65,001–70,000	3.8
70,001–75,000	3.6
75,001–80,000	3.4
80,001–	2.9

Table 3

CANADIAN MARGINAL EFFECTIVE TAX RATES ON LABOUR (%) (WEIGHTED AVERAGE)

Rail	Bus	Air
5.41	4.18	5.61

Table 4 presents marginal effective tax rates on fuel, t_f, across modes for commercial and industrial fuel. The bus industry faces the largest t_f for fuel: 63.6% versus 38.3% for rail and 32% for domestic air.[6] Since a lot of the flights that leave from Canadian airports have arrived from a different country, or are destined for a different country, Canadian planes load up with fuel in the country with the lower gross fuel costs. Since the United States is Canada's closest neighbour and since they also have very low fuel taxes relative to Canada, a combined weighted effective fuel tax rate that takes into account both the domestic and international aspects of Canadian airlines was calculated. Domestic rates are presumed to be the Canadian rates listed below. The United States effective tax rates on fuel were used to indicate rates faced by domestic airlines engaged in international flights. These effective rates were weighted by the proportion of aviation fuel consumed in Canada for domestic flights to aviation fuel consumed for international flights. For comparison, the effective fuel tax rate faced by Canadian airplanes that load up in the United States is also shown. Findings indicate that the combined Canadian and U.S. effective tax rate on fuel is 25.7%. This is lower than the rate given above for domestic flights only, but much higher than the U.S. counterpart (5.6%).

Table 4
Canadian Marginal Effective Tax Rates on Fuel (%)

	Rail	Bus	Air		
			Domestic	U.S.	Combined
Commercial and industrial	38.3	63.3	32.0	5.6	25.7

While a comparison of the effective tax rates on each of the inputs used in the production of transportation services is certainly of some interest, an intermodal comparison of the impact of taxes on cost competitiveness requires going beyond a single dimensional analysis and examining how the various taxes on business inputs interact to affect the cost of providing an additional unit of output in the three sectors.

As discussed in the previous section, this is determined by calculating the effective rate of tax on the cost of providing an additional unit of transportation implied by the various taxes on the business input. Tables 5 and 6 present estimates of the effective tax rate on the marginal cost of production, T, across modes. The calculations are based on a constant returns to scale Cobb-Douglas (C-D) specification of costs which allows for the calculation of T by weighting t_i', i = k,l,f, by each input's share of total costs. The shares are denoted as α_i, for i = k,l,f.

In Table 5 the effective tax rate on marginal costs reflects the following input shares for labour, fuel and capital: 41.1%, 8.6%, 50.3% in the rail industry; 27.4%, 18.1%, and 54.5% in the air industry; 42.5%, 8.4%, and 49.1% in the bus industry. (The shares are based on transportation statistics of the Royal Commission on National Passenger Transportation.)[7] For these input shares, the rail industry faces the highest effective tax rate on marginal costs at 21.3%, followed closely by both bus (21%) and air (19.3%). The effective tax rates are similar for all three modes, indicating that, on balance, the Canadian tax system does not appear to inhibit significantly cost competitiveness across modes. The relative tax disadvantages faced by the bus industry in terms of fuel are largely offset by low effective tax rates on labour and, to a lesser extent, capital.[8]

Table 5

Canada — Effective Tax Rates on Marginal Cost and Marginal Effective Tax Rates on Inputs (Reference Input Shares)

		Rail	Bus	Air
			(%)	
Parameterization				
Percentage of debt in one dollar's worth of financing	(β)	43	43	43
Percentage of equity in one dollar's worth of financing	($1-\beta$)	57	57	57
Nominal return on debt	(i)	12	12	12
Nominal return on equity	(ρ)	20	20	20
Inflation rate	(π)	5	5	5
Input share				
Labour	(α_l)	41.1	42.5	27.4
Fuel	(α_f)	8.6	8.4	18.1
Capital	(α_k)	50.3	49.1	54.5
Marginal effective tax rate				
Labour	(t_l)	5.4	4.2	5.6
Fuel	(t_f)	38.3	63.3	32.0
Capital	(t_k)	33.0	30.9	22.6
Effective tax rate on marginal cost	(T)	21.3	21.0	19.3

To isolate the implications of different share structures across modes for the impact of taxation on cost competitiveness, an alternative experiment was conducted where all of the other parameters were held constant and the input shares adjusted as follows. Gillen, Oum and Tretheway were used for air. They estimate that Air Canada's input share structure in 1980 was 30.2% for labour and 21.7% and 48.1% for fuel and capital respectively. Statistics Canada is used for rail. Their estimates of Canadian National's input shares for 1984 are 56%, 10% and 34% for labour, fuel and capital.

For the bus industry approximately the same shares are maintained (the largest change is in the share of fuel) as used above. The results of this experiment are summarized in Table 6.

Table 6
CANADA — EFFECTIVE TAX RATES ON MARGINAL COST AND MARGINAL EFFECTIVE TAX RATES ON INPUTS (MODIFIED INPUT SHARES)

		Rail	Bus	Air
			(%)	
Parameterization				
Percentage of debt in one dollar's worth of financing	(β)	43	43	43
Percentage of equity in one dollar's worth of financing	($1-\beta$)	57	57	57
Nominal return on debt	(i)	12	12	12
Nominal return on equity	(ρ)	20	20	20
Inflation rate	(π)	5	5	5
Input share				
Labour	(α_l)	56	40	30
Fuel	(α_f)	10	16	22
Capital	(α_k)	34	44	48
Marginal effective tax rate				
Labour	(t_l)	5.4	4.2	5.6
Fuel	(t_f)	38.3	63.3	32.0
Capital	(t_k)	33.0	30.9	22.6
Effective tax rate on marginal cost	(T)	17.2	23.8	19.2

From these figures it is clear that, under the modified share structure, the share of fuel input for the bus industry almost doubles (at the expense of both labour and capital). Given the high marginal effective tax rate on bus fuel, it is not unexpected that the bus industry assumes the position of the highest taxed mode. For the rail mode, the share of fuel is only marginally affected under the modified share structure. The share of labour (input with the lowest marginal effective tax rate) increases at the expense of capital (input with the highest marginal effective tax rate), resulting in rail being the least taxed mode. Under the modified share structure, the tax system seems to grant a competitive advantage to rail (17.2%) relative to bus (23.8%). The effective tax on marginal cost for the air mode remains at approximately 19%.

Finally, a second set of experiments uses U.S. and combined U.S.–Canadian effective tax rates on fuel in the air industry. These results are presented in Table 7. As is shown, the results suggest that employing a combined fuel tax rate of 25.7% in the air industry further adds to the tax advantage in that mode. Air now faces effective tax rates on marginal costs of 18.2% and 17.9% for the respective share structures. Furthermore, if Canadian planes are able always to load in the United States, the effective tax rate on marginal costs is even lower (14.6% and 13.5% for the respective share structures).

Table 7

CANADIAN AIR EFFECTIVE TAX RATES ON MARGINAL COST FOR THE SPECIFIED EFFECTIVE FUEL TAX RATES

Reference input shares		**(%)**
Labour	(α_l)	27.4
Fuel	(α_f)	18.1
Capital	(α_k)	54.5
Marginal effective tax rate		
Labour	(t_l)	5.6
Fuel (domestic)	(t_f)	32.0
Fuel (U.S.)	(t_f)	5.6
Fuel (combined)	(t_f)	25.7
Capital	(t_k)	22.6
Effective tax rate on marginal cost (domestic)	(T)	19.3
Effective tax rate on marginal cost (U.S.)	(T)	14.6
Effective tax rate on marginal cost (combined)	(T)	18.2
Modified input share		
Labour	(α_l)	30
Fuel	(α_f)	22
Capital	(α_k)	48
Effective tax rate on marginal cost (domestic)	(T)	19.2
Effective tax rate on marginal cost (U.S.)	(T)	13.5
Effective tax rate on marginal cost (combined)	(T)	17.9

These calculations do not take into account the fact that some of the transportation companies may not be paying taxes in a particular year. As is well known, a company that experiences tax losses may be more or less highly taxed than full taxpaying companies. When a company is in a tax loss position, it is only able to carry back losses for three years or carry forward losses (at no interest) for seven years.[9] Thus, the time value of loss deductions, when carried forward, falls as it takes longer for the firm to use up losses.

The implication of tax losses is twofold. Companies with economic losses or fast write-offs for new investments cannot use the deductions immediately compared to companies that never carry forward losses. Thus, these companies, often facing risk, are more highly taxed than the taxpaying companies. On the other hand, profitable companies that are carrying forward prior years' losses, can shelter income earned from new investments until the company begins to pay taxes. In this case, the company can face a lower effective tax rate on investments compared to taxpaying companies. On balance, the degree to which losses affect the effective tax rate on capital cannot be judged unless more information is available on the time profile of taxable income and losses in the transportation industry.[10]

It is also important to emphasize the sensitivity of the results to changes in the parameters, particularly the input share structure. Though use of the reference input share structure indicates that the tax treatment across modes is equitable, the modified input shares place the bus industry at a competitive disadvantage relative to air and rail.

4. Principal Results of Canada–United States Comparisons

In this section a similar analysis based on the American tax system is undertaken and the results are compared to the Canadian case. The principal results are contained in Tables 8 to 12.

Table 8 contains estimates of marginal effective tax rates on capital, t_k, both by category of asset and in aggregate. The results indicate that, in the United States, the rail industry faces the highest effective tax rate on capital (28.5%), followed by bus (25.1%) and air (19.5%). Like the Canadian case, the differences in effective tax rates on capital between modes are small and of the same ranking between modes. Capital investments in the rail industry are taxed at a relatively higher rate, while investments in airlines are taxed less overall by the American tax system because of generous tax depreciation rates for the air industry relative to the economic rate of depreciation. On balance, the American tax system favours capital investments in the air sector, followed by bus and then rail.

Overall, United States' carriers face slightly lower effective tax rates on capital than their Canadian counterparts. This is due in part to the capital cost recovery system in the United States. The write-offs for machinery and equipment in the United States are generally faster than those available to Canadian firms.[11] Another contributing factor is the lower statutory tax rate in the United States (on average across all states, 40.4% in the United States as opposed to a 42% to 43% federal and provincial combined rate in Canada).

Table 8
U.S. Marginal Effective Tax Rates on Capital

	Rail	Bus	Air
		(%)	
Parameterization			
Percentage of debt in one dollar's worth of financing	43	43	43
Percentage of equity in one dollar's worth of financing	57	57	57
Nominal return on debt	12	12	12
Nominal return on equity	20	20	20
Inflation rate	5	5	5
Effective tax rate on capital			
Building construction	37.5	37.5	41.6
Engineering construction	37.5	37.5	37.5
Machinery and equipment	9.2	na	14.2
Buses	na	22.1	na
Capital items charged to operating expenses	–0.9	–0.9	–0.9
Overall (t_k)	28.5	25.1	19.5

Table 9 shows the estimates of the marginal effective tax rate on labour, t_l, for an average worker in each mode. As before, t_l represents a weighted average based on labour statistics for each industry. The rates are very similar across modes (9.5%, 9.5% and 9.2% for rail, bus and air respectively). As in the Canadian case, the differences are due solely to variations in the composition of the labour force across modes. Overall, U.S. payroll tax rates are about 5 percentage points above the Canadian rates, so along this dimension, Canadian firms are at an advantage.

Table 9
U.S. Marginal Effective Tax Rates on Labour (%) (Weighted Average)

Rail	Bus	Air
9.5	9.5	9.2

Table 10 presents marginal effective tax rates on fuel, t_f, across modes for retail fuel consumption. The bus industry has the highest effective tax rate on fuel: 44.7% versus 8.6% for rail and 5.6% for air. In comparison to Canada, the U.S. has a large fuel tax advantage in all three modes.[12] It should be noted that this comparison may be misleading since the differences in load factors and distances travelled by Canadian companies have not been taken into account. U.S firms face a denser and more multidimensional market when compared to their Canadian counterparts.

Table 10
U.S. Marginal Effective Tax Rates on Fuel (%) (Weighted)

Rail	Bus	Air
8.6	44.7	5.6

Tables 11 and 12 show estimates of the effective tax rate on the marginal cost of production, *T*, across modes for the United States. As in the Canadian case, *T* is calculated for a constant returns to scale Cobb-Douglas (C-D) specification of costs which allows *T* to be derived by weighting t_i, i = k,l,f, by each input's share in total costs. The same input shares employed in the calculations for Canada were used. As the figures indicate, the air sector has a competitive advantage relative to bus and rail, while rail has a competitive advantage relative to bus. This reflects the preferential treatment of capital and fuel used in the air industry in the United States as well as the preferential treatment of fuel in the U.S. rail industry relative to bus.

In a mode-to-mode comparison with Canada, the calculations indicate that the effective rate of tax on marginal costs in the United States is lower for all modes. In the air industry, the U.S. rates are lower than those in Canada by approximately five percentage points (14.0% U.S. vs. 19.3% Canadian). This is due to a substantially lower fuel tax rate and a lower capital tax rate in the United States. Despite the significantly higher fuel tax rates in Canada for the rail and bus industry, the effective tax rates on marginal cost are quite competitive across countries. Due to the low share of fuel input in the rail and bus industries, large differences in the fuel taxes across countries have a small impact on the effective tax rates on marginal costs. Compared to their U.S. counterparts, Canadian modes have a tax advantage only in labour input.

As in the previous section, in order to isolate the implications of different input share structures across modes for the impact of U.S. taxation on the marginal cost of production, a sensitivity test is conducted with all the other parameters held constant. The input shares are adjusted accordingly. These alternative calculations are summarized in Table 12. Unlike the Canadian case, the ranking of the modes by their effective tax rates on marginal costs is not sensitive to the specified change in input share structures: under both share structure scenarios bus has the highest *T*, followed by rail and air.

Under the modified input share structure, the difference across countries in the effective tax rates on marginal costs lies within 2 percentage points for the rail and bus industries. For the air mode, the competitive edge of the United States has increased by 1 percentage point.

Table 11

U.S. EFFECTIVE TAX RATES ON MARGINAL COST AND MARGINAL EFFECTIVE TAX RATES ON INPUTS (REFERENCE INPUT SHARES)

		Rail	Bus	Air
			(%)	
Parameterization				
Percentage of debt in one dollar's worth of financing	(β)	43	43	43
Percentage of equity in one dollar's worth of financing	($1 - \beta$)	57	57	57
Nominal return on debt	(i)	12	12	12
Nominal return on equity	(ρ)	20	20	20
Inflation rate	(π)	5	5	5
Input share				
Labour	(α_l)	41.1	42.5	27.4
Fuel	(α_f)	8.6	8.4	18.1
Capital	(α_k)	50.3	49.1	54.5
Marginal effective tax rate				
Labour	(t_l)	9.5	9.5	9.2
Fuel	(t_f)	8.6	44.7	5.6
Capital	(t_k)	28.5	25.1	19.5
Effective tax rate on marginal cost	(T)	18.6	19.7	14.0

Overall, on balance (irrespective of the input share structure used) the Canadian tax system places transportation companies at a competitive disadvantage relative to their American counterparts, particularly for the air mode. Although the effective payroll tax rate is significantly lower in Canada, the effective rate of tax on fuel is substantially lower for all modes in the United States. The effective tax rates on capital are slightly lower for all U.S. modes.

Table 12

U.S. Effective Tax Rates on Marginal Cost and Marginal Effective Tax Rates on Inputs (Modified Input Shares)

		Rail	Bus	Air
			(%)	
Parameterization				
Percentage of debt in one dollar's worth of financing	(β)	43	43	43
Percentage of equity in one dollar's worth of financing	($1-\beta$)	57	57	57
Nominal return on debt	(i)	12	12	12
Nominal return on equity	(ρ)	20	20	20
Inflation rate	(π)	5	5	5
Input share				
Labour	(α_l)	56	40	30
Fuel	(α_f)	10	16	22
Capital	(α_k)	34	44	48
Marginal effective tax rate				
Labour	(t_l)	9.5	9.5	9.2
Fuel	(t_f)	8.6	44.7	5.6
Capital	(t_k)	28.5	25.1	19.5
Effective tax rate on marginal cost	(T)	15.5	21.4	13.2

APPENDIX A: DERIVATION OF EFFECTIVE TAX RATES

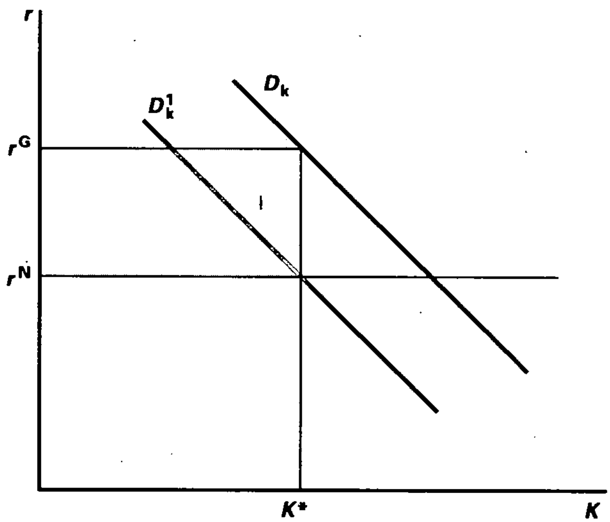
This appendix provides a more formal statement of the methodology discussed in Section 2. First, the formulae are presented for marginal effective tax rates for three inputs in the production process: capital, labour and fuel (t_k, t_l and t_f respectively). Subsequently an expression for the effective tax rate on the marginal cost of production (T) is discussed.

A.1 THE MARGINAL EFFECTIVE TAX RATE ON CAPITAL

The methodology closely follows Boadway, Bruce and Mintz (1987). It is assumed that the interest rate is invariant to changes in domestic fiscal policy. This is consistent with a small open economy assumption whereby the net-of-tax rate of return required by investors is determined by the world capital market. Figure 2 illustrates this situation diagrammatically. Domestic suppliers of capital must receive r^N, the net-of-tax world rate of interest, or else they would invest elsewhere. D_k represents the demand for capital schedule, showing the relationship between the gross-of-tax rate of return and the quantity of capital demanded, K, while D_k^1 depicts the relationship between the net-of-tax rate of return to capital and the quantity of capital demanded. The intersection of D_k^1 and r^N allows us to determine the equilibrium quantity of capital, K^*. Suppliers of capital will receive the net-of-tax real rate of return, r^N, while capital users will have to pay an amount equal to r^G. In turn, this will have to be equal to the marginal return to investment by a firm. The difference between r^G and r^N is a tax wedge created by tax instruments which affect the user cost of capital. This wedge, assumed to be net-of-depreciation and in real terms, may be converted to a rate by dividing it by the net-of-tax real rate of return paid to the supplier of capital. This rate is defined as t_k, the marginal effective tax rate on capital. In the following discussion expressions are determined for r^N and r^G, and use d to find $t_k = (r^G - r^N)/r^N$.

Before proceeding with the discussion, it is necessary to emphasize an important distinction concerning the economic nature of capital. Capital provides services over time and it depreciates, or physically wears out over time: capital services flow from the stock of capital while the stock itself depreciates. This distinction is crucial for the analysis of the effects of taxes on the user cost of capital since the tax code has an impact on the cost of capital services and the cost of depreciation through different channels:

Figure 2
THE MARKET FOR CAPITAL



capital services are affected by interest deductibility provisions in corporate income tax (CIT) rates at the federal and provincial level, while depreciation is affected by capital cost allowance (CCA) provisions.

When a cost-minimizing firm decides to make a marginal investment, neoclassical theory stipulates that the gross-of-tax return to that investment must be equal to what is termed the user cost of the investment in capital, which consists of two components: the user cost of financing capital services and the user cost of depreciation. Thus, the user cost of capital is affected both by taxes which directly affect the cost of financing and by tax provisions for depreciation. In the following the user cost of financing capital services and the user cost of depreciation are determined and then combined to arrive at an expression for the user cost of capital, r^G.

The user cost of financing capital services depends on the financial structure of the firm. A firm can choose to finance one dollar's worth of capital through debt financing — issuing bonds or borrowing funds — or through equity financing — retaining earnings or issuing new shares. The real cost of one dollar's worth of debt financing is the nominal interest rate adjusted for inflation, while the real cost of financing through equity is the nominal yield on equity adjusted for inflation and risk.

Corporate income taxes directly affect the real cost of debt financing through interest deductibility provisions, whereas the cost of equity is not deductible. In a small open economy the differential taxation of debt and equity at the personal level does not affect the cost of funds to the firm, and personal taxes may be ignored in what follows.

By defining the following terms:

r^F	=	real gross-of-tax user cost of financing to the firm
r^D	=	real gross-of-tax user cost of debt financing to the firm
r^E	=	real gross-of-tax user cost of equity financing to the firm
β	=	share of debt in one dollar's worth of financing capital services
$(1-\beta)$	=	share of equity in one dollar's worth of financing capital services
i	=	nominal interest rate
U^c	=	corporate income tax rates
ρ	=	nominal return to equity
π	=	inflation rate

the real gross-of-tax user cost of finance to the firm can be expressed as:

$$r^F = \beta r^D + (1-\beta) r^E \tag{2}$$

where

$$r^D = i(1 - U^c) - \pi \tag{3}$$

and

$$r^E = \rho - \pi \tag{4}$$

Thus:

$$r^F = \beta i(1 - U^c) + (1-\beta)\rho - \pi \tag{5}$$

As a corollary, note that the real rate of return required by the suppliers of capital, r^N, is simply $r^N = \beta i + (1-\beta)\rho - \pi$. This expression provides the first term needed in order to calculate t_k.

The second component of the user cost of capital to the firm is the user cost of depreciation. As noted previously, capital stocks physically depreciate over time as they wear out. They may also appreciate or depreciate in value over time as a result of changes in the relative price of investment goods which differ from the inflation rate. The combination of these two characteristics of the capital stock is known as the economic rate of depreciation. Let $\dot{q}$ denote the real change in value of the capital stock and δ the physical rate of depreciation. The economic rate of depreciation is then $\delta^e = \delta - \dot{q}$ (the calculations in the text assume that $\dot{q} = 0$). Now suppose that CCAs are allowed at a constant declining-balance rate equal to d, ignoring for the moment the half-year rule in the Canadian tax code. The present value to the firm of capital cost allowances is then:

$$Z = \frac{U^c d}{r^F + \pi + d} \tag{6}$$

In each period the CCA rate times the CIT rate is allowed as a deduction. If the fact that the value of the capital stock is reduced in each period by the CCA rate is taken into account and the fact that tax authorities base depreciation allowances on an historical cost basis, with no adjustment for inflation assumed, and if the CCA rates are discounted by the real cost of finance to the firm,[13] then the total gross-of-tax real cost of holding one dollar's worth of capital services may be defined as $(r^F + \delta^e)(1 - Z)$. At the margin, this real cost must equal the net-of-tax price the asset could be rented for in its next best use, and must be sufficient to cover economic depreciation as well as taxes. If $R^G(1 - U^c)$ is defined as the marginal net-of-tax return to capital, then the gross-of-tax return to capital is $R^G = (r^F + \delta^e)(1 - Z)/(1 - U^c)$. Since R^G is gross-of-depreciation and the required net-of-depreciation return to the marginal investment is the desired calculation, the economic rate of depreciation must be subtracted from R^G to arrive at r^G. The expression for r^G may be summarized as follows:

$$r^G = (r^F + \delta^e)(1 - Z)/(1 - U^c) - \delta^e \tag{7}$$

Now all the necessary information is in place to provide an expression for the marginal effective tax rate on capital, t_k. This rate may be formally expressed as follows:

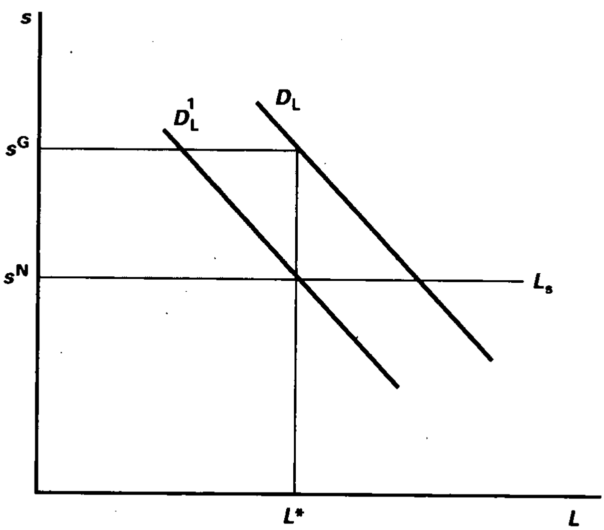
$$t_k = \frac{(r^F + \delta^e)(1 - Z)/(1 - U^c) - \delta^e - r^N}{r^N} \qquad (8)$$

A.2 THE MARGINAL EFFECTIVE TAX RATE ON LABOUR

To calculate t_l it must be assumed that for a particular sector, the elasticity of labour supply is infinite, that is, the supply curve, L_s, in Figure 3 is perfectly horizontal.[14] The gross-of-tax demand for labour curve in the transportation sector is downward sloping and is denoted as D_L in Figure 3. D_L depicts the relationship between labour demand and gross-of-tax wages, s^G. Since payroll taxes differ by type of worker (income level), the tax bill depends on the composition of the work force. For this analysis, this composition is assumed to be constant.

D_L^1 shows the relationship between net-of-tax wages, s^N, and labour demand. The difference between s^G and s^N is the tax wedge imposed on labour. Given the assumption of a perfectly elastic labour supply curve for a particular sector, and the inability to account properly for the possibility that payroll taxes may be interpreted as benefit taxes, the firm bears the entire burden of any taxes levied on their payroll.

Figure 3
THE MARKET FOR LABOUR



Given this interpretation, the marginal effective tax rate on labour is simply obtained as:

$$t_l = \frac{(s^G - s^N)}{s^N} \tag{9}$$

A.3 THE MARGINAL EFFECTIVE TAX RATE ON FUEL

It is assumed that the single firm faces a horizontal supply curve for fuel. The marginal effective tax rates on fuel are then simply equal to the equivalent *ad valorem* statutory tax rates.

A.4 THE EFFECTIVE TAX RATE ON MARGINAL COST

In this section the methodology to compute the effective tax rate on the marginal cost of production for given marginal effective tax rates on individual inputs is discussed, and some of the main methodological problems inherent in any cost study are mentioned.

Economic theory defines cost, $C(\boldsymbol{y}, \boldsymbol{w}')$, as the minimum value function for the following problem:

$$\min_{\boldsymbol{x}} \ \boldsymbol{w}'\boldsymbol{x} \ \ s.t. \ \ f(\boldsymbol{x}) = \boldsymbol{y} \tag{10}$$

where $\boldsymbol{y}$ is a vector of outputs, $\boldsymbol{x}$ is a vector of inputs, $f(\boldsymbol{x})$ is the representation of technology, and $\boldsymbol{w}'$ is the vector of factor input user prices. As such, $C(\boldsymbol{y}, \boldsymbol{w}')$ may be written as $C(\boldsymbol{y}, \boldsymbol{w}') = \boldsymbol{w}'\boldsymbol{x}^*$, where $\boldsymbol{x}^*$ represents optimal quantities of inputs and depends on the vector of outputs and the vector of user input prices. These user prices incorporate any opportunity costs associated with factor inputs. In general, $\boldsymbol{w}'$ will depend on market prices for inputs, $\boldsymbol{w}$, and a vector of marginal effective tax rates on inputs, $\boldsymbol{t}$.

In the absence of taxation, $\boldsymbol{w}' = \boldsymbol{w}$ and the incremental, or marginal, cost of producing an additional unit of output of type i is:

$$\mathrm{MC}_i(\boldsymbol{y}, \boldsymbol{w}) = \frac{\partial C(\boldsymbol{y}, \boldsymbol{w})}{\partial y_i} \tag{11}$$

When input taxes are introduced, $\boldsymbol{w}' = \boldsymbol{w}(1 + t)$. The marginal cost of producing an additional unit of output of type i is $MC_i[\boldsymbol{y}, \boldsymbol{w}(1 + t)]$.

The difference between $MC_i[\boldsymbol{y}, \boldsymbol{w}(1 + t)]$ and $MC_i(\boldsymbol{y}, \boldsymbol{w})$ may be thought of as the wedge between the gross-of-tax marginal cost and net-of-tax marginal cost for producing output of type *i*. The wedge depends on t and the functional form used to represent *C*. The wedge may be converted into a rate by dividing it by $MC_i(\boldsymbol{y}, \boldsymbol{w})$. This yields the marginal tax rate on marginal costs of production (T). T serves as a tool for measuring the effective rate of tax on the marginal cost of providing transportation services. Modes in which a higher tax rate relative to other modes is observed are placed at a competitive disadvantage by the tax system.

The preceding remarks provide a very general description of the methodology adopted in this study. The next step is to discuss the treatment of costs in a more detailed fashion, first specifying the nature of carrier output and then examining functional forms which may be used for estimating T across modes within a country or within modes across countries.

Carrier Output

Passenger services differ according to service characteristics such as speed of trip, quality of service, etc.; this equates to a carrier providing different services or outputs on the same trip. In effect, multiple outputs are produced, the number of which depend on service definitions. It is beyond the scope of this paper to analyze multi-output passenger services. The assumption is made that each carrier produces a single homogeneous passenger output which is defined to be comparable across modes.

Functional Forms

The analysis focusses on three types of inputs in the production process, capital, labour and fuel, and assumes that firms seek to combine these inputs in a way that will minimize the cost of attaining some level of output. The relationship between user prices and the cost of production is known as the cost function. The specific form of the cost function may be estimated econometrically using available data to recover the underlying structure of technology, and conclusions may be drawn regarding the specific parameters which describe an agent's behaviour. Since an econometric estimation is beyond the scope of this paper, the functional form to be used for representing costs is specified exogenously and parametric information is obtained from existing data and previous studies.

Informational requirements and restrictions faced in the study are discussed with three types of functional forms, the Cobb-Douglas (C-D) cost function and the constant elasticity of substitution cost function (of which the Cobb-Douglas is a special case). The informational requirements for the use of flexible functional forms are also discussed briefly.

Cobb-Douglas Cost Function (C-D)

For inputs i (i = capital (K), labour (L) and fuel (F)), the Cobb-Douglas cost function is written as:

$$C(y, \mathbf{w}') = Ay^{\frac{1}{\eta}}\prod_i (w_i')^{\alpha_i} \tag{12}$$

where $\sum_i \alpha_i = 1$, and η represents the elasticity of scale. The underlying technology is homothetic and exhibits increasing, decreasing or constant returns-to-scale respectively for $\eta > 1$, $\eta < 1$ and $\eta = 1$. Allen-Uzawa elasticities of substitution ($\sigma_{ij} = C_{ij}C/C_iC_j$) are equal to unity for all pairs of factor inputs: this implies that value shares are constant for all inputs (they are represented by the α values).

The marginal cost of an additional unit of output is:

$$\mathrm{MC} = \frac{\partial C}{\partial y} = \frac{1}{\eta} Ay^{\frac{1-\eta}{\eta}} \prod_i (w_i')^{\alpha_i} \tag{13}$$

Given $N+1$ exogenous values for conditional demands and marginal cost, all $N+1$ free parameters can be recovered.

Then, T can be obtained as follows:

$$T = \frac{\frac{1}{\eta} Ay^{\frac{1-\eta}{\eta}} \left[\prod_i (w_i')^{\alpha_i} - \prod_i (w_i)^{\alpha_i}\right]}{\frac{1}{\eta} Ay^{\frac{1-\eta}{\eta}} \prod_i (w_i)^{\alpha_i}} \tag{14}$$

This can be simplified to:

$$T = \prod_i (1 + t_i)^{\alpha_i} - 1 \tag{15}$$

Constant Elasticity of Substitution Cost Function (CES)

The CES cost function is defined as follows:

$$C(y, \boldsymbol{w}') = Ay^{\frac{1}{\eta}}\left[\sum_i \alpha_i (w_i')^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{16}$$

where , $\sum_i \alpha_i = 1$, η is the elasticity of scale, and $\sigma \neq 1$. The underlying technology is homothetic. Allen-Uzawa elasticities of substitution are equal to σ for all pairs of factor inputs.

The following expression must be defined:

$$V(\boldsymbol{w}') = \left[\sum_i \alpha_i (w_i')^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{17}$$

(Notice that this expression is also valid for the Cobb-Douglas case when $\sigma = 1$ and $V(\boldsymbol{w}') = \prod_i (w_i')^{\alpha_i}$.)

The marginal cost of an additional unit of output is:

$$\mathrm{MC} = \frac{\partial C}{\partial y} = \frac{1}{\eta} Ay^{\frac{1-\eta}{\eta}} V(\boldsymbol{w}') \tag{18}$$

Given $N + 1$ exogenous values for conditional demands and marginal cost, and an exogenous estimate for σ, the residual $N + 1$ free parameters can be recovered.

Then, T can be obtained as follows:

$$T = \frac{\frac{1}{\eta} Ay^{\frac{1-\eta}{\eta}} [V(\boldsymbol{w}') - V(\boldsymbol{w}')]}{\frac{1}{\eta} Ay^{\frac{1-\eta}{\eta}} V(\boldsymbol{w})} = \frac{\sum_i \alpha_i (w_i')^{1-\sigma}}{\sum_i \alpha_i (w_i)^{1-\sigma}} - 1 \tag{19}$$

Flexible Functional Forms

Flexible functional forms allow for any regular configuration of Allen-Uzawa elasticities of substitution to be represented. Furthermore, they do not restrict the technology to be homothetic. Examples are the generalized Leontief cost function, the translog cost function and the non-separable CES function.

The informational requirements for using a flexible form are quite extensive: calibration requires exogenous values for all pair-wise elasticities of substitution as well as expenditure elasticities of input demand (for the non-homothetic case) and the elasticity of scale.

In this study, for the sake of simplicity, the single-output Cobb-Douglas technologies were adopted, and shares obtained from previous studies were used.

APPENDIX B: STATUTORY TAX RATES AND AGGREGATION DATA

This appendix contains a summary of the taxes which were included in the analysis. Section B.1 discusses the tax provisions that have an impact on the user cost of capital: corporate income tax rates at the federal and provincial level that affect the user cost of financing capital services and capital cost allowances that affect the user cost of depreciation. Also included is a description of the weights that were used to aggregate depreciable capital assets and a summary of useful service lives of capital assets and their equivalent historical rates of depreciation. In sections B.2 and B.3 the taxes that affect labour and fuel respectively are discussed and presented in a tabular form.

B.1 CAPITAL TAXES AND CAPITAL WEIGHTS

B.1.1 Corporate Income Taxes

Federal Corporate Income Tax Rate (FCIT): The federal corporate income tax is levied on taxable income at a flat rate of 38 percent as of July 1, 1988.

Federal Abatement: All Canadian resident corporations, with the exception of federal Crown corporations,[15] are eligible for an abatement on federal tax payable to ease the burden of provincial corporate taxation. This abatement is equal to 10 percent of a corporation's taxable income earned in a province. The definition of taxable income earned in a province varies across modes of transportation as the Act treats transportation differently from other corporations. This aspect will be further analyzed when examining the effects of the CIT on the costs of financing capital for each mode.

Federal Surtax: As of 1987, a federal surtax of three percent is applied to federal tax payable. The 10 percent abatement is deducted from tax otherwise payable for the purpose of calculating the federal surtax, but the abatement is calculated on the whole of the corporation's taxable income earned in the year. All corporations with the exception of Crown corporations are eligible for the 10 percent reduction in the FCIT.

Table 13 exhibits the federal corporate income taxes for different business classifications. Transportation service industries are subject to the general business rate unless they qualify for the small business deduction; this analysis, however, precludes this possibility. The corporate rates presented are inclusive of the 10 percent reduction in the basic rate for provincial taxes paid.

Table 13
Federal Corporate Income Taxes, 1991

	Corporate rate	Surtax	Total rate
	(%)		
Effective July 1			
General business	28.00	3.00	28.84
Manufacturing and processing	23.00	3.00	23.84
General small business	12.00	3.00	12.84
Small business manufacturing and processing	12.00	3.00	12.84
For the calendar year			
General business	28.00	3.00	28.84
Manufacturing and processing	23.50	3.00	24.34
General small business	12.00	3.00	12.84
Small business manufacturing and processing	12.00	3.00	12.84

Source: Canadian Tax Foundation publications.

Provincial Corporate Income Tax Rates: Provinces in Canada may levy corporate taxes on corporations that are deemed to have a permanent establishment in their province. Table 14 presents a summary of provincial corporate income tax rates in effect as of 1991.[16] The federal government has an agreement with most provinces, whereby it collects provincial corporate income taxes for the province in exchange for the province's agreement to use the same tax base.[17] If a corporation has a permanent establishment in only one province, then that province applies its own tax rate to the total taxable income of the corporation. If a corporation has a permanent establishment in more than one province, then the taxable income attributable to a province is calculated according to an allocation rule.[18] For most corporations these allocation rules dictate that the proportion of taxable income attributable to a province is some average of the proportion of gross revenue earned in the province to total gross revenue earned in Canada, and the proportion of wages and salaries paid in the province to total wages and salaries paid in Canada. However, the *Income Tax Act* gives

Table 14
PROVINCIAL CORPORATE INCOME TAX RATES, 1991

Province	Small	Large
	(%)	
Newfoundland	0/10	17
Prince Edward Island	10	15
Nova Scotia	0/10	16
New Brunswick	5/9	17
Quebec	0/3.75	6.90/16.25
Ontario	0/10	14.5/15.5
Manitoba	10	17
Saskatchewan	0/10	15
Alberta	6	15.5
British Columbia	9	15
Yukon	2.5/5	2.5/10
Northwest Territories	5	12

Sources: Canadian Tax Foundation publications and Arthur Andersen & Co., *Tax Forum*, Vol. 3, June 1991.

Note: Where two figures are shown, the first figure applies to businesses that qualify for preferential tax status.

differential treatment to the transportation industry with respect to allocation rules: the allocation rule in each mode is unique. The rules for allocating taxable income to a province for rail, bus and air are as follows:

- Rail

Taxable income earned by a railway in a province in which it has a permanent establishment is defined as the taxable income of the railway times one half of the aggregate of the proportion of equated track miles[19] in a province equated to track miles in Canada; and, the proportion of gross tonne-miles in a province to gross tonne-miles of the corporation in Canada.[20]

- Bus

Taxable income earned by a bus corporation in a province in which it has a permanent establishment is defined as the taxable income of the bus corporation times one half of the aggregate of the proportion of the number of kilometres driven by the corporation's vehicles, whether owned or leased, in a province to the total number of kilometres driven in Canada; and, the proportion of the aggregate of salaries and wages paid in the province to the aggregate of all salaries and wages paid in Canada.[21]

• Air

Taxable income earned by an airline corporation in a province in which it had a permanent establishment is defined as the taxable income of the airline times one quarter of the aggregate of the proportion of the capital cost of the corporation's fixed assets, except aircraft, in a province, to the capital cost of the corporation's fixed assets, except aircraft, in Canada; and, the proportion of three times the number of revenue plane miles flown by its aircraft in a province to the total number of revenue plane miles flown in Canada by its aircraft.[22]

To summarize, tax instruments that affect the real cost of financing through debt are: the federal corporate income tax, the federal abatement for provincial taxation, the federal surtax, provincial corporate income taxes and the rules used for allocating taxable income to a province. To the extent that any of these differ among modes, the real cost of financing through debt will differ among modes. In turn, this will affect the real cost of finance across modes of transportation. Table 15 shows combined federal and provincial corporate income tax rates by province for small businesses and other types of establishments, while Table 16 depicts combined federal and provincial corporate income rates for rail, bus and air by province, inclusive of the

Table 15

COMBINED FEDERAL AND PROVINCIAL CORPORATE INCOME TAX RATES BY PROVINCE, 1991

Province	Small	Large
	(%)	
Newfoundland	22.84	45.84
Prince Edward Island	22.84	43.84
Nova Scotia	22.84	44.84
New Brunswick	21.84	45.84
Quebec	16.54	35.74
Ontario	22.84	44.34
Manitoba	22.84	45.84
Saskatchewan	22.84	43.84
Alberta	21.84	44.34
British Columbia	21.84	43.84
Yukon	17.84	38.84
Northwest Territories	17.84	40.84

Sources: Canadian Tax Foundation publications and Arthur Andersen & Co., *Tax Forum*, Vol. 3, June 1991.

Note: Large transportation firms are taxed at the lower provincial rate for large businesses in Quebec.

allocation rules used for calculating taxable income in a province. When all is said and done, it turns out that the combined rounded corporate income rates are very similar across the modes: bus has the lowest rate at 42% followed closely by air and rail at 43%.

Table 16

COMBINED FEDERAL AND PROVINCIAL CORPORATE INCOME TAX RATES BY PROVINCE, 1991

Province	Rail	Bus	Air
	(%)		
Newfoundland	0.18	0.09	0.05
Prince Edward Island	0.00	0.00	0.04
Nova Scotia	0.67	0.90	1.35
New Brunswick	1.24	2.29	1.83
Quebec	4.22	9.04	7.15
Ontario	15.34	17.87	16.85
Manitoba	3.94	1.19	1.83
Saskatchewan	5.00	0.75	1.75
Alberta	4.66	3.33	3.55
British Columbia	7.93	6.60	8.05
Total	**43.00**	**42.00**	**43.00**

B.1.2 Capital Cost Allowances

Allowable capital costs may be deducted from taxable income for tax purposes. These deductions are specified by the *Income Tax Act* and are allowed on depreciable capital assets. For tax purposes, assets are grouped into different classes; these classes are then assigned a rate at which capital costs may be deducted from taxable income. A constant declining-balance rate is used for most classes of capital assets, although some classes receive straight-line treatment. The *Income Tax Act* dictates that the allowable CCA rate be applied to the original undepreciated cost of the asset, and in the first year of acquisition the allowable rate is one half of the rate applied to subsequent years.[23] In this section the data used to calculate the present value of CCA deductions are presented. In Table 17, classes of assets prescribed by the *Income Tax Act* and the associated, applicable CCA rate are shown. These classes are then aggregated into five categories of depreciable capital: building construction, engineering construction, machinery and equipment, and capital items charged to expense accounts. These categories and their associated CCA rates are presented by mode in Table 18.

Table 17
CCA Rates by Class of Asset

	Class	Rate (%)
Airplane hangars	6	10
Aircraft —		
furniture, fittings, equipment, or spare parts	9	25
Airplane runways	1	4
Asphalt surface, storage yard	1	4
Automobiles	10	30
Buildings —		
brick, stone, cement, etc. acquired after 1987	1	4
Buses	10	30
Fittings, aircraft	9	25
Machinery and equipment	8	20
Radar equipment	9	25
Railway cars	35	10
Railway locomotives	6	10
Railway system	4	6
Railway track or grading	1	10
Railway traffic control or signalling equipment	1	4
Roads	1	4
Spare parts for an aircraft	9	25

Source: Canadian Tax Foundation publications.

Table 18
CCA Rates by Type of Asset and by Mode

	Rail	Bus	Air
	(%)		
Building construction	4	4	4
Engineering construction	8	4	8
Buses	na	30	na
Machinery and equipment	10	na	25
Capital items charged to operating expenses	100	100	100

B.1.3 Capital Asset Taxes and Property Taxes

Canadian capital asset taxes and property taxes enter into the equation for the marginal effective tax rate on capital in an additive fashion.

Capital Asset Taxes: General Canadian capital asset taxes are levied by Quebec, Ontario, Manitoba and Saskatchewan on asset values yearly. These taxes are deductible from corporate income tax. The respective rates for the above listed provinces are: 0.5%, 0.3%, 0.4% and 0.25%.

Property Taxes: Property taxes have not been included in this study due to difficulties in finding disaggregated data for the modes under examination.

B.1.4 Historical Depreciation Rates and Capital Weights

Table 19 contains a summary of weights in capital expenditures by category of asset; these weights were used to aggregate categorical marginal effective tax rates on capital in order to arrive at an overall rate for each mode.[24] Table 20 presents the useful service life[25] of each category of capital asset by mode as well as the equivalent constant declining-balance historical depreciation rate.

Table 19
SUMMARY OF WEIGHTS IN CAPITAL EXPENDITURES

	Rail	Bus	Air
		(%)	
Building construction	6.0	19.1	19.1
Engineering construction	62.3	1.1	1.1
Buses	0.0	79.0	0.0
Machinery and equipment	31.5	0.0	79.0
Capital items charged to operating expenses	0.2	0.8	0.8
Total	**100.0**	**100.0**	**100.0**

Source: Statistics Canada publication.

Table 20
SUMMARY OF USEFUL SERVICE LIVES AND EQUIVALENT CONSTANT DECLINING-BALANCE DEPRECIATION RATES

	Rail		Bus		Air	
	Years	Rate %	Years	Rate %	Years	Rate %
Building construction	55	4	50	4	40	5
Engineering construction	55	4	55	4	50	4
Buses	na	na	10	20	na	na
Machinery and equipment	28	7	na	na	20	10
Capital items charged to operating expenses	5	40	5	40	5	40

Source: Statistics Canada publications.

B.2 PAYROLL TAXES

This section provides a summary of payroll taxes at the federal and provincial levels. Employer contributions to the Canada/Quebec Pension Plans (CPP/QPP), federal unemployment insurance contributions (UIC) and provincial health and education payroll taxes have been taken into account. In the remainder of this section these taxes are itemized and discussed briefly.

Canada/Quebec Pension Plans (CPP/QPP): The Canada Pension Plan has been in effect since 1966 in all provinces in Canada except Quebec, which operates the Quebec Pension Plan under the same contribution rules as the CPP. Currently, maximum pensionable earnings of $30,500 and a basic exemption of $3,000 are taxed at 2.3%. Table 21 provides a summary of CPP/QPP rates and earnings ceilings for 1991, while Table 22 illustrates effective rates by income class where the rate is calculated for the upper limit of each income range presented.

Table 21
CANADA/QUEBEC PENSION PLAN RATES FOR 1991

Maximum pensionable earnings ($)	30,500
Basic exemption ($)	3,000
Contribution rate (%)	
Employers	2.3
Employees	2.3
Self-employed	4.6
Maximum contribution ($)	
Employers	632.50
Employees	632.50
Self-employed	1,265.00

Source: Canadian Tax Foundation publications.

Table 22
CPP/QPP Effective Rates by Income Bracket, 1991

Income (CAN$)	Effective rate (%)		
	Employers	Employees	Self-employed
0–30,500	2.3	2.3	4.6
30,501–35,000	2.0	2.0	4.0
35,001–40,000	1.7	1.7	3.4
40,001–45,000	1.5	1.5	3.0
45,001–50,000	1.3	1.3	2.7
50,001–55,000	1.2	1.2	2.4
55,001–60,000	1.1	1.1	2.2
60,001–65,000	1.0	1.0	2.0
65,001–70,000	0.9	0.9	1.9
70,001–75,000	0.9	0.9	1.8
75,001–80,000	0.8	0.8	1.6
80,001–100,000	0.7	0.7	1.3

Unemployment Insurance Compensation (UIC): Currently employers contribute 3.15% on maximum earnings of $35,360, while employees must contribute 2.5%. Table 23 provides a summary of effective UIC rates by income class; these rates are calculated for the upper limit of income in the income range presented.

Table 23
Effective Unemployment Insurance Commission (UIC) Rates by Income Bracket, 1991

Income (CAN$)	Effective rate (%)	
	Employers	Employees
0–30,500	0.37	0.34
30,501–35,000	3.18	3.00
35,001–40,000	2.78	2.62
40,001–45,000	2.48	2.33
45,001–50,000	2.23	2.10
50,001–55,000	2.03	1.91
55,001–60,000	1.86	1.75
60,001–65,000	1.71	1.61
65,001–70,000	1.59	1.50
70,001–75,000	1.49	1.40
75,001–80,000	1.39	1.31
80,001–100,000	1.11	1.05

Provincial Payroll Taxes and Health-Care Premiums: Payroll taxes are levied on employers' payrolls by four provinces — Newfoundland, Quebec, Ontario and Manitoba — while Alberta and British Columbia levy health-care premiums. Table 24 presents the current rates and premiums for payroll taxes and health-care premiums. Table 25 shows effective tax rates for health care in Alberta and British Columbia for single individuals and families.

Table 24
Provincial Payroll Taxes, 1991

Province	Payroll taxes (%)	Health-care premiums (yearly) (CAN$) Single	Health-care premiums (yearly) (CAN$) Family
Newfoundland	1.5	na	na
Prince Edward Island	na	na	na
Nova Scotia	na	na	na
New Brunswick	na	na	na
Quebec	3.45	na	na
Ontario	0.98/1.95	na	na
Manitoba	0/2.5/3.5	na	na
Saskatchewan	na	na	na
Alberta	na	276	552
British Columbia	na	372	744

Table 25
Effective Rates for Health-Care Premiums by Income Bracket, 1991

Income (CAN$)	Alberta Single (%)	Alberta Family (%)	British Columbia Single (%)	British Columbia Family (%)
0–30,500	0.09	0.18	0.12	0.24
30,501–35,000	0.79	1.58	1.06	2.13
35,001–40,000	0.69	1.38	0.93	1.86
40,001–45,000	0.61	1.23	0.83	1.65
45,001–50,000	0.55	1.10	0.74	1.49
50,001–55,000	0.50	1.00	0.68	1.35
55,001–60,000	0.46	0.92	0.62	1.24
60,001–65,000	0.42	0.85	0.57	1.14
65,001–70,000	0.39	0.79	0.53	1.06
70,001–75,000	0.37	0.74	0.50	0.99
75,001–80,000	0.35	0.69	0.47	0.93
80,001–100,000	0.28	0.55	0.37	0.74

Two different marginal effective tax rates were computed on labour; one rate was defined by income class, while the other was aggregated for each mode using employment statistics available from Statistics Canada publications. The rate defined by income class and presented in the main body of the paper was simply an average of all the above federal and provincial rates.

B.3 FUEL TAXES

In this section, the data used to determine the marginal effective tax rate on fuel for each mode are presented. Before proceeding with summaries of provincial and federal fuel taxes, it should be noted that conversations with industry officials indicate that commercial/industrial fuel prices are representative of industry average prices.[26] Fuel that is purchased as a final product is classified as retail, while fuel that is purchased from the refinery as raw material is classified as commercial/industrial. The analysis was carried out for both categories of fuel under the assumption that any one carrier may be qualified to purchase fuel under one category or another but not both.

In Canada, provinces levy taxes on fuels of different types and different vendor categories. Quebec, Ontario, Manitoba, Saskatchewan and Alberta levy per-unit excise taxes on fuels, while the remaining provinces levy *ad valorem* taxes based on prices observed by provincial ministers.

In addition to provincial fuel taxes, the federal government levies a four cents per litre excise tax on all fuels. This was converted into an effective *ad valorem* rate using Canadian average fuel prices.[27] Combined federal and provincial *ad valorem* tax rates on fuels are summarized in Table 26.

For each mode of transportation, the effective provincial tax rate was calculated as a weighted average of the tax rates, where the weights are equal to the proportion of fuel consumption in a province to total fuel consumption.[28]

Finally, to arrive at an overall effective rate on fuel by mode, Statistics Canada information on proportions of fuel types used within a mode was employed. This was then combined with the figures contained in Table 26 to arrive at the marginal effective tax rates on fuel, shown in Table 4.

Table 26

AVERAGE SALES PRICES (NET-OF-TAX) FOR FUELS, UNIT TAXES AND EQUIVALENT AD VALOREM TAX RATES (COMBINED PROVINCIAL AND FEDERAL TAXES)

	Nfld.	P.E.I.	N.S.	N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Diesel	24.4	24.4	24.4	24.4	21.7	23.4	22.0	22.0	22.0	22.6
Federal excise tax	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Provincial tax	15.6	12.4	16.2	13.7	11.5	10.9	9.9	10.0	7.0	11.2
Total tax (¢/L)	19.6	16.4	20.2	17.7	15.5	14.9	13.9	14.0	11.0	15.2
Tax rate (%)	80.3	67.2	82.8	72.5	71.6	63.7	63.2	63.6	50.0	67.2
Locomotive diesel	24.4	24.4	24.4	24.4	21.7	23.4	22.0	22.0	22.0	22.6
Federal excise tax	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Provincial tax	0.0	12.4	0.0	4.3	3.0	4.0	13.6	15.0	5.0	3.3
Total tax (¢/L)	4.0	16.4	4.0	8.3	7.0	8.0	17.6	19.0	9.0	7.3
Tax rate (%)	16.4	67.2	16.4	28.7	32.3	34.2	80.0	86.4	40.9	32.5
Aviation turbine	28.4	28.4	28.4	28.4	25.0	21.4	22.2	22.2	22.2	21.7
Federal excise tax	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Provincial tax	0.7	0.7	1.0	2.5	5.7	2.1	5.8	7.0	5.0	3.3
Total tax (¢/L)	4.7	4.7	5.0	6.5	9.7	6.1	9.8	11.0	9.0	7.3
Tax rate (%)	16.5	16.5	17.6	22.9	39.0	28.5	44.1	49.5	40.5	33.8
Aviation gasoline	44.1	44.1	44.1	44.1	41.7	41.4	41.6	41.6	41.6	42.6
Federal excise tax	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Provincial tax	0.7	0.7	1.0	2.5	7.6	2.1	5.8	7.0	5.0	3.3
Total tax (¢/L)	10.2	10.2	10.5	12.0	17.1	11.6	15.3	16.5	14.5	12.8
Tax rate (%)	23.1	23.1	23.8	27.2	41.1	28.0	36.8	39.7	34.9	30.1

Notes: **All price data are net-of-tax and were obtained from Energy, Mines and Resources Canada (EMR); data are available on a regional rather than on a provincial basis. Tax data are for April 1, 1991 (locomotive diesel tax data are for May 1991 and were obtained from provincial governments) and are taken from the following EMR publication: *Federal and Provincial Petroleum Product Taxes*, Vol. 3, June 1991. Note that the provincial tax for Quebec includes 8% PST; this tax is not levied on locomotive fuel. Prices of road and locomotive diesel are identical and are those charged to commercial and industrial customers. Information obtained from various railway and bus companies in Canada indicates that these prices are representative. Bus industry officials suggest that theirs is a diesel based industry; therefore, we assume that diesel is the only fuel used by the bus industry. So far as aviation gasoline is concerned, EMR suggests that the large majority is leaded; therefore, a federal excise tax of 9.5 cents is used (rather than 8.5 cents for unleaded).**

APPENDIX C: UNITED STATES STATUTORY TAX RATES AND AGGREGATION DATA

This section contains a summary of U.S. tax instruments that affect labour, capital and fuel in the transportation industry. Corporate income taxation and capital cost provisions of the U.S. tax system are discussed first. The methodology used to compute t_i, i = k,l,f, for the U.S. tax system is identical to the one used for the Canadian computations; also, the data and parameters used for aggregation purposes are those employed in the Canadian study.

C.1 CAPITAL TAXES

C.1.1 U.S. Corporate Taxes

In the United States, corporate tax rates are graduated at very low levels of income, with a maximum rate of 34% applied to income in excess of $75,000. To prevent large corporations from benefiting from the graduated tax rates at low income levels, taxable income between $100,000 and $335,000 is taxed at 39%, rather than the basic 34% rate. This serves to phase out the benefits of the graduated rate structure for corporations earning more than $100,000, completely eliminating it for firms earning more than $335,000 by subjecting these corporations to a flat 34% tax rate at the federal level.

Forty-five U.S. states levy a corporate income tax; of these, eight use a tax base which differs slightly from the federal base — Alabama, Arkansas, Louisiana, Minnesota, Mississippi, Montana, Utah and Wisconsin. Most of the states have mildly progressive rate structures at very low levels of income.

State income taxes are deductible from the federal base. This lowers the effective statutory tax rates of the states by a factor of one minus the federal tax rate. The average state tax rate, based on the highest tax brackets in each state, is about 6.6%. Thus, allowing for the deductibility of state from federal taxes, the average corporate tax rate in the United States is approximately 40.49% This is the rate used in the above calculations. However, significant differences exist across states.

For example, for the five U.S. states which levy no corporate income tax (Nevada, South Dakota, Texas, Washington and Wyoming), the total tax rate is the basic federal rate of 34%. The U.S. state with the highest tax rate is Pennsylvania, at 12%, implying a 41.92% combined tax rate. Table 27 provides a list of U.S. state tax rates for 1992.

Table 27
U.S. STATUTORY CORPORATE INCOME TAX RATES

State	(%)
Maine	8.9
New Hampshire	8.3
Vermont	9.0
Massachusetts	8.3
Rhode Island	8.0
Connecticut	11.5
New York	10.0
New Jersey	9.0
Pennsylvania	9.5
Ohio	9.2
Indiana	3.0
Illinois	4.0
Michigan	2.4
Wisconsin	7.9
Minnesota	12.0
Iowa	12.0
Missouri	5.0
North Dakota	10.5
South Dakota	0.0
Nebraska	6.7
Kansas	4.5
Delaware	8.7
Maryland	7.0
Virginia	6.0
West Virgina	7.0
North Carolina	6.0
South Carolina	6.0
Georgia	6.0
Florida	5.5
Kentucky	7.3
Tennessee	6.0
Alabama	5.0
Mississippi	5.0
Arkansas	6.0
Louisiana	8.0
Oklahoma	5.0
Texas	0.0
Montana	6.8
Idaho	7.7
Wyoming	0.0
Colorado	6.0
New Mexico	7.6
Arizona	10.5
Utah	5.0
Nevada	0.0
Washington	0.0
Oregon	7.5
California	9.6
Alaska	9.4
Hawaii	6.4

C.1.2 Capital Recovery

Depreciable assets include most tangible assets except land. Like Canada, the United States calculates depreciation allowances on the basis of the original cost of the asset rather than its replacement cost. The depreciation base is not indexed for the rate of inflation.

In the United States each asset is assigned an asset depreciation range (ADR) midpoint life which is stipulated by statute. The ADR lives are based on the estimated "useful life" of the asset. The ADR midpoints are grouped into various modified accelerated cost recovery system (MACRS) classes, each defining the period over which the capital expenditure is to be recovered: 3, 5, 7, 10, 15 or 20 years for machinery and equipment, and 31.5 years for non-residential structures. The MACRS recovery periods tend to be accelerated relative to the ADR midpoint lives. For example, seven-year property includes assets with ADR midpoint lives of 10 years but not less than 16. Property of 3, 5, 7 and 10 years is written off according to a 200% declining balance rule (two times the straight-line rate for the recovery period), with a switch to straight-line depreciation over the remaining recovery period when it is beneficial to do so. Property of 15 and 20 years is depreciated according to a 150% declining-balance rule (1.5 times the straight-line rate for the recovery period), with a switch to straight line. Non-residential buildings are written off on a straight-line basis over 31.5 years.

A put-in-use rule applies in the United States. This means that an asset may not be depreciated until the year in which it is placed in service, regardless of when it was purchased. A half-year convention applies in both the first and the last recovery years (or the year of disposition). The depreciation deduction in the first year of service is therefore one half of the amount that would normally be claimed for a full year of depreciation. In the final year of service life the firm can claim the other half year of depreciation. The effect is to add another year to the recovery period (that is, seven-year property is actually recovered over eight years).

By way of illustration, the depreciation allowances for seven-year property are given in Table 28 for a $100 expenditure while the relevant MACRS categories for the passenger transportation sector are shown in Table 29.

Table 28
MACRS ALLOWANCE FOR SEVEN-YEAR PROPERTY

Year	US$
1	14.29
2	24.49
3	17.49
4	12.49
5	8.92
6	8.92
7	8.92
8	4.47

Table 29
MACRS CATEGORIES

Category	Recovery period (years)
Buses used in the (urban and suburban) transportation of passengers	5
Railroad machinery and equipment (including locomotives, passenger and freight train cars, shops and roadway machines, signals and inter-lockers, etc.)	7
Air transportation assets (including aircraft fittings, radar, spare parts, etc.)	7
All buildings and structures (including hangers, terminals, bridges, trestles, water and fuel stations, station and office buildings, runways, railway track and grading, etc.)	31.5

The list of assets contained in Table 29 was broken down into the five categories of capital expenditures: building construction, engineering construction, buses, and machinery and equipment. The present value of MACRS deductions using the Canadian financial parameters previously presented in Appendix B of the Canadian report were calculated. Summaries of the present values of MACRS deductions are presented for rail, bus and air in Table 30.

Table 30
PRESENT TAX VALUE OF MACRS DEDUCTIONS BY MODE

	Rail	Bus	Air
	(%)		
Building construction	12	12	12
Engineering construction	12	12	12
Buses	na	31	na
Machinery and equipment	29	na	29

The U.S. tax code allows for nominal debt interest expenses to be deducted in full (as in Canada). The taxpayer may elect to capitalize interest by including it in the cost base of the asset and recovering the interest expenses through depreciation deductions. This may be desirable if it gives rise to an operating loss that could expire. There is no deduction for the opportunity cost of equity finance (either retained earnings or new share issues), nor are adjustments made for inflation to restrict deductibility to the real, as opposed to the nominal cost of debt.

C.1.3 The Alternative Minimum Tax

The U.S. tax code contains provisions to ensure that "profitable" corporations pay at least a minimum amount of tax. The alternative minimum tax (AMT), introduced in the 1986 tax reform, is in fact a parallel tax which must be computed in addition to the regular corporate income tax (CIT): the actual payable tax is the greater of the two. The lack of data precludes the inclusion of the AMT in these calculations.

The t_k calculations for the U.S. tax system were calculated using Canadian historical depreciation rates shown in Appendix B and presented again in Tables 31 and 32.

Table 31
ECONOMIC DEPRECIATION RATES (DECLINING BALANCE) BY MODE AND ASSET CATEGORY

	Rail	Bus	Air
	(%)		
Building construction	4	4	5
Engineering construction	4	4	4
Buses	na	20	na
Machinery and equipment	7	na	10
Capital items charged to operating expenses	40	40	40

Table 32
Summary of Weights in Capital Expenditures

	Rail	Bus	Air
	(%)		
Building construction	6.0	19.1	19.1
Engineering construction	62.3	1.1	1.1
Buses	0.0	79.0	0.0
Machinery and equipment	31.5	0.0	79.0
Capital items charged to operating expenses	0.2	0.8	0.8
Total	**100.0**	**100.0**	**100.0**

C.2 U.S. PAYROLL TAXES

Payroll taxes in the United States are higher than payroll taxes in Canada. The U.S. federal government is entitled to levy social security taxes on employers and employees under the auspices of the *Federal Insurance Contribution Act* (FICA), while federal unemployment insurance taxes on employers are levied through the *Federal Unemployment Income Tax Act.* Individual states also levy unemployment taxes on employers.

Federal Insurance Contribution Act: All employers are required to withhold social security taxes and hospital insurance contributions from employees' wages; they must also match the employee contributions using their own funds. Social security levies are 7.51% on the first US$48,000 of gross wages. This limit was converted into an equivalent Canadian levy by assuming a 15% exchange rate on the U.S. dollar. U.S. social security rates and maximum contributions expressed in Canadian dollars are shown in Table 33, while Table 34 depicts the effective rate by Canadian income class in Canadian dollars.

Table 33
U.S. Social Security Rates and Maximum Contributions

Maximum pensionable earnings (CAN$)	55,200
Basic exemption	0
Contribution rate (%)	
Employers	7.5
Employees	7.5
Maximum contribution (CAN$)	
Employers	4,145.52
Employees	4,145.52

Table 34

EFFECTIVE SOCIAL SECURITY RATES BY INCOME CLASS

Income (CAN$)	Salary (CAN$)	Contribution (CAN$)	Employers (%)	Employees (%)
0–30,500	30,500	2,290.55	7.51	7.51
30,501–35,000	35,000	2,628.50	7.51	7.51
35,001–40,000	40,000	3,004.00	7.51	7.51
40,001–45,000	45,000	3,379.50	7.51	7.51
45,001–50,000	50,000	3,755.00	7.51	7.51
50,001–55,000	55,000	4,130.50	7.51	7.51
55,001–60,000	60,000	4,145.52	6.91	6.91
60,001–65,000	65,000	4,145.52	6.38	6.38
65,001–70,000	70,000	4,145.52	5.92	5.92
70,001–75,000	75,000	4,145.52	5.53	5.53
75,001–80,000	80,000	4,145.52	5.18	5.18
80,001–100,000	100,000	4,145.52	4.15	4.15

Federal Unemployment Tax Act: The U.S. federal government levies a 6.2% tax, on employers only, on the first $7,000 paid in wages per employee. Employing a 15% exchange rate, a Canadian dollar maximum contribution of $499.10 was computed on the first CAN$8,050. Effective U.S. unemployment tax rates by Canadian income bracket are expressed in Table 35.

Table 35

EFFECTIVE UNEMPLOYMENT INSURANCE RATES BY INCOME CLASS

Income (CAN$)	Salary (CAN$)	Contribution (CAN$)	Employers (%)
0–30,500	30,500	499.1	1.64
30,501–35,000	35,000	499.1	1.43
35,001–40,000	40,000	499.1	1.25
40,001–45,000	45,000	499.1	1.11
45,001–50,000	50,000	499.1	1.00
50,001–55,000	55,000	499.1	0.91
55,001–60,000	60,000	499.1	0.83
60,001–65,000	65,000	499.1	0.77
65,001–70,000	70,000	499.1	0.71
70,001–75,000	75,000	499.1	0.67
75,001–80,000	80,000	499.1	0.62
80,001–100,000	100,000	499.1	0.50

State Payroll Taxes: Employers are required to contribute to state-funded unemployment insurance programs. The taxable wage base varies from state to state as do the individual tax rates. An average state rate of 2.7 percent was assumed on a maximum of US$7,000.

Table 36 shows combined U.S. effective social security tax rates and unemployment tax rates at the federal and state level. These combined rates were then weighted using Canadian employment statistics to arrive at a U.S. weighted marginal effective tax rate on labour.

Table 36
COMBINED EFFECTIVE SOCIAL SECURITY RATES AND FEDERAL AND STATE UIC RATES BY INCOME CLASS (CAN$)

Income (CAN$)	Salary (CAN$)	Employers' contributions (%)		
		UIC	SS	UIC + SS
0–30,500	30,500	2.35	7.51	9.86
30,501–35,000	35,000	2.05	7.51	9.56
35,001–40,000	40,000	1.79	7.51	9.30
40,001–45,000	45,000	1.59	7.51	9.10
45,001–50,000	50,000	1.43	7.51	8.94
50,001–55,000	55,000	1.30	7.51	8.81
55,001–60,000	60,000	1.19	6.91	8.10
60,001–65,000	65,000	1.10	6.38	7.48
65,001–70,000	70,000	1.02	5.92	6.95
70,001–75,000	75,000	0.96	5.53	6.48
75,001–80,000	80,000	0.90	5.18	6.08
80,001–100,000	100,000	0.72	4.15	4.86

C.3 U.S. FUEL TAXES

The U.S. federal government levies an excise tax of 6.2 cents per litre on highway diesel and 0.8 cents per litre on locomotive diesel. There is no federal tax on aviation fuel in the United States. The weighted average of state fuel tax rates were calculated for Washington, Montana, North Dakota, Minnesota, Michigan, New York and Maine using Canadian fuel statistics. These weighted averages were then converted from U.S. dollar tax rates to Canadian dollar tax rates by applying an exchange ratio of 1.15 Canadian dollars for one American dollar. Then, using Canadian realization fuel prices for each type of fuel, the marginal effective tax rate on fuel for each mode was obtained. Table 37 depicts the combined federal and state excise taxes and equivalent *ad valorem* rates for the United States.

Table 37

COMBINED U.S. FEDERAL AND STATE FUEL TAX RATES

	Highway diesel		Locomotive diesel		Aviation fuel	
State	**(%)**	**(CAN$ per L)**	**(%)**	**(CAN$ per L)**	**(%)**	**(CAN$ per L)**
Maine	51	0.14	9	0.02	4	0.01
New York	58	0.18	9	0.02	20	0.04
Michigan	41	0.12	8	0.02	3	0.01
Minnesota	48	0.14	4	0.01	8	0.02
North Dakota	8	0.13	6	0.01	4	0.01
Montana	48	0.14	4	0.01	1	0.00
Washington	48	0.15	13	0.03	9	0.02

ENDNOTES

We appreciate the assistance of Ashish Lall who obtained new data on fuel taxes and corrected earlier errors in empirical work. The remaining errors are of our own responsibility. The last author wishes to thank the Social Sciences and Humanities Research Council of Canada for its financial support.

1. In particular, data acquisition difficulties have precluded the inclusion of property taxes in the analysis. Excluding property taxes may, however, be justified on other grounds; see the discussion below.

2. The assumption of perfect competition is made for expositional purposes only, as the analysis also applies to an industry with a non-competitive industrial structure.

3. Note that in the calculations of t_k, relative price changes of capital assets are assumed to be zero (see Appendix A). This assumption does not qualitatively change the results.

4. See Appendix B for a summary of CCA rates.

5. See Appendix B for a summary of weights in capital expenditure.

6. Conversations with officials of various bus companies in Canada indicate that some large firms may be purchasing fuel at prices that are lower than those used here because some bus companies are members of buying cartels. Due to their confidential nature, these data were not released to us. Richard Lake of the Royal Commission on National Passenger Transportation suggested the use of a Canadian average (net-of-tax) price for bus diesel of 20 cents per litre, a federal excise tax of 4 cents per litre and provincial taxes of 11 cents per litre. This implies a tax rate for bus fuel of 75%. If these rates were used in the calculations in Table 5, the effective tax rate on marginal cost for the bus industry would rise only marginally from 21.0% to 21.7%.

7. The study abstracts from the international aspects of passenger transport and uses effective fuel tax rates in the commercial and industrial category for all modes.

8. Note that the bus industry has the lowest labour taxes and the highest share of labour in total cost.

9. The seven-year carry forward of operating losses applies to reported losses. Companies are allowed to carry forward capital losses and discretionary deductions indefinitely.

10. The federal government has announced a loss offset program whereby companies can reduce fuel excise taxes on diesel and aviation fuel by renouncing $10 of corporate income tax losses for a one dollar reduction in the federal excise tax. At a 40% corporate income tax rate, companies with a 15% discount rate would find that it would be profitable to give up corporate tax-loss deductions for an immediate reduction in the fuel tax, if the company does not expect to pay taxes for at least nine years or if the losses were about to expire.

11. Calculations indicate that the Canadian equivalent to the modified accelerated cost recovery system (MACRS) for seven-year property would be a CCA rate of 26%, while five-year property would require a CCA rate of 33%.

12. The effective U.S. tax rates on fuel were determined by calculating state and federal fuel taxes levied in the states that lie along the Canadian border. These taxes were weighted by applying provincial fuel consumption statistics to each state according to its geographical proximity to each province. This served as a proxy for state weights on fuel taxes.

13. In Canada the half-year convention applies to most classes of capital assets. In this case the present value of CCA deductions becomes:

$$Z^* = \frac{d}{2} = \left(1 - \frac{d}{2}\right) \frac{de^{-r^F} + \pi}{r^F + d + \pi}$$

14. There are limitations of this assumption to the analysis; however, it is far beyond the scope of this project to allow for elasticities of labour supply which differ from infinity.

15. See s. 124 and s. 124(3) of the *Income Tax Act*.

16. Regulation 400(2) of the *Income Tax Act* states that "a permanent establishment means a fixed place of business of the corporation, including an office, a workshop or a warehouse, and where the corporation does not have any fixed place of business it means the principal place in which the corporation's business is conducted."

17. Ontario, Alberta and Quebec are the only provinces that have not entered into this agreement with the federal government; however, the tax bases used in each of these provinces are similar enough to the federal base that any substantive differences can be assumed to be negligible.

18. It is worth noting that Ontario, Quebec and Alberta use the same allocation rules as the rest of the provinces even though they have not entered into an agreement with the federal government.

19. For tax purposes an equated track mile is the total of the number of miles of first main track, 80% of the number of miles of other main track and 50% of the number of miles of yard tracks and sidings.

20. Regulation 406 of the *Income Tax Act*.

21. Regulation 409 of the *Income Tax Act*.

22. Regulation 407 of the *Income Tax Act*.

23. This is the half-year convention referred to above.

24. The source for the capital stock weights was Statistics Canada, Catalogue No. 13-211. The mid-year net stock figures in constant dollars were used.

25. Useful service lives were obtained from Statistics Canada, Catalogue No. 13-211.

26. There are other fuel categories, but these are not generally applicable to transportation industries.

27. Canadian average fuel prices were obtained from Energy, Mines and Resources Canada and are current to April 1, 1991.

28. These weights were arrived at by computing end uses of fuel by mode and province according to Statistics Canada, Catalogue No. 57-003.

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NOTES ON INTERCITY PASSENGER TRANSPORTATION TECHNOLOGY

Richard Lake*
November 1990

INTRODUCTION

The following notes on passenger transportation technology relevant to Canadian intercity travel, and prospects for its intermediate future,[1] identify but do not explain the technologies or scientific principles involved. Rather, the perspective of the political scientist, economist, policy analyst, etc., is taken.

Two reasonably discrete sections follow. The first addresses amodal general technology issues pertinent to the Royal Commission's mandate. The second section discusses technology forecasting and provides a forecast of prospective technology relevant to Canadian intercity passenger transportation modes over the intermediate term (approximately 25 years).

I. FUNDAMENTAL PRINCIPLES

The principles selected here include material that the reader doubtless already knows. They are stated here, however, to emphasize their importance and to contribute understanding and background relevant to often-advanced, technological solutions to Canada's transportation issues.

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SPEED

Speed is usually the most important determinant of the competitive success of a passenger transportation technology. Obviously, speed (lower origin/destination time[2]) increases the attractiveness of a travel option to consumers, and they will pay more for speed. Less obvious but at least as important, particularly within a given mode, faster is generally *cheaper*. Although higher speeds increase fuel costs, they usually also increase system capacity. Most importantly, both labour and equipment productivity (generally a much more important cost item than fuel) improves almost linearly with speed.

ENERGY CONSUMPTION

At intercity passenger transportation speeds, power requirements and fuel consumption are dominated by aerodynamic resistance. This resistance increases (for subsonic speeds) *as the square of* the speed but decreases with air density, and approaches zero at very high altitude. This is a powerful equation; all else equal, higher is much better. Thus, surface systems reach a practical limit while airborne technology can achieve ever increasing speeds by travelling at greater altitudes. High-speed (relatively) rail (and/or maglev which has the potential to be superior aerodynamically) may have a niche in the intermediate distance travel market — to 500 kilometres or conceivably even 1,000 kilometres — but it would seem that air will dominate longer distances, indefinitely.

ALTERNATIVE FUELS

With only insignificant exception, Canadian intercity passenger transportation is powered by hydrocarbon fuels. Alternatives are commonly advanced on the premise that fossil fuels will be saved and carbon dioxide emissions avoided. Insofar as portable transportation fuels are necessary for most modes, petroleum (a convenient and light source of concentrated chemical energy) is uniquely suited to the purpose.

Every conversion of energy form (chemical, electrical, nuclear, compression, momentum, heat, etc.) is accompanied by substantial efficiency losses. Most often, losses exceed 50 percent. In general, heat (the "lowest" form of energy) is emitted and wasted. Energy-use patterns that require the fewest and simplest conversions are generally the most efficient use of society's diverse energy resources, both financially and in terms of energy conservation and minimizing emissions to the environment.

Solar Power

While solar power can be used for space and water heating with minimal loss, its conversion into transportation fuel (which would involve a chain of conversions) would be very costly, and only a small fraction of the original energy would remain. Electricity, on the other hand, is ideal for the operation of motors, and the middle distillates of petroleum (diesel/furnace oil) are relatively efficient portable fuels. Presuming alternative demand, the use of these energy forms for space or water heating, while lower forms of energy such as solar were available, would be wasteful.

Electricity

Battery-operated vehicles can serve to reduce urban emissions, and electrified rail has distinct advantages. At the margin and during peaks, however, in most of Canada, electricity is produced by burning coal, oil or natural gas. For rail, the provision of electricity from central generating stations is somewhat more energy- and emissions-efficient than separate diesel electric generators on each locomotive unit. Peak intercity (and urban/suburban) passenger travel demand, however, tends to coincide with periods of high household electricity consumption, and electrification would exacerbate the electric utilities' peak loading problems. This is not the case for battery power; batteries can be charged off-peak, but they are relatively inefficient, costly and have low capacity.

Hydrogen

Hydrogen is a benign fuel; the sole product of its combustion is water vapour. This would be attractive in an urban setting. Hydrogen would also have particular advantages in supersonic flight; the vaporization of liquid hydrogen would provide needed cooling.

Hydrogen, however, does not occur naturally. It is commonly produced from hydrocarbons, particularly methane, but the net effect is less efficient with greater carbon dioxide emission than would be the case were the methane used directly as transportation fuel. Another economically attractive means of hydrogen production, the partial oxidation of coal, poses still more serious environmental problems. For urban areas, however, where air quality threatens the health of the population, the advantage of hydrogen as a clean fuel remains. The pollution is transferred to a remote site. Although hydrogen can be produced from the electrolysis of water, this is futile for electricity produced from carbon or hydrocarbon fuel. However, the use of surplus electricity (where the energy would otherwise be wasted) generated from nuclear or hydro facilities could achieve the desired end. Unfortunately, with present technology and the Canadian mix of electricity generation and markets, operating an electrolysis plant on surplus power alone would not be economic. Exacerbating this situation, hydrogen molecules are very small and light. Containment is a problem, and vessels for either liquid or absorbed hydrogen are heavy and very bulky.

Commercial production of portable hydrogen fuel by electrolysis would require enormous quantities of energy. It would take some 46 kilowatt hours to produce one kilogram of hydrogen gas and a further 11 kilowatt hours to liquefy it. To be competitive with hydrogen produced from methane or coal, electricity would have to be purchased for less than two cents per kilowatt hour. Ultimately, the widespread use of hydrogen as a transportation fuel may come, but only with power from nuclear fusion, or another dramatic (presumably nuclear) breakthrough in the production of cheap electricity. When this occurs, hydrogen should rapidly become an important transportation fuel.

Alternative Hydrocarbon Fuels

A great deal of progress has been made in the use of a broader range of hydrocarbons as transportation fuel, including coal derivatives, methane and propane. This is important for the continued availability of affordable transportation fuel; for example, hydrocarbon fuels with engine-cooling properties, liquefied gases and/or chemicals could prove useful to future supersonic flight.

GREENHOUSE EFFECT

It is possible to prevent or substantially reduce emissions of the most harmful polluting substances from internal combustion engines. However, chemical removal of carbon dioxide (responsible for 50 percent of the greenhouse effect) from emissions is scarcely conceivable and not currently contemplated. Unfortunately, the concentration of this natural and necessary component of the earth's atmosphere is increasing. There are fears, supported by logic and some empirical climatological research, that this increased carbon dioxide[3] will have (and is having) a deleterious effect on the world's climate. Primary concerns are further desertification and a reduced ability to produce food. Since the problem is worldwide, it seems logical to seek an international solution. Beyond the reduction of carbon dioxide emissions to levels that the biosphere can tolerate, however, no solution is apparent.

There is presently absolutely no incentive even to study the chemical fixation of carbon dioxide. It is doubtful that there could be for some decades. Large emission sources (electricity generating plants are the most obvious) that might lend themselves to chemical fixation approaches are few, and a technology that would not, itself, require enormous energy input is not apparent. (It is presumed that such technology would involve fixation as calcium carbonate — limestone.)

Perhaps as a pessimistic but necessary perspective, it seems that there is only limited commitment to the very much easier task of removing chemicals that cause acid rain (which has conspicuous regional and local, rather than only global, impact). It is also noted that the favoured solution to the effects of acid rain is natural or induced neutralization with calcium carbonate (with a consequent emission of carbon dioxide).

A fashionable response to the carbon dioxide problem is the planting of trees. Most frequently mentioned are the rain forests of the Amazon. Certainly, this restoration of (red soil) forests would be environmentally desirable but would do no more than re-fix the carbon emitted when they were cleared. This is important but it is not a long-term solution to emissions from fossil fuels. Mature red-soil forests, as these are, do not continue to fix carbon indefinitely; the carbon dioxide is naturally re-emitted to the atmosphere as the vegetation decays. Strange to note, Canadian (black soil) muskeg and swamp retain substantial quantities of carbon over the long term, but not in quantities that would solve the problem of fossil fuel emissions.

An analysis of tree-planting as a solution, in the Canadian context, puts this approach into perspective. Canada emits some 500 million tonnes of carbon dioxide annually. The global figure is 25 billion tonnes. A hectare of actively growing pine, under Southern Ontario conditions, would only fix a modest one to one-and-a-half tonnes of carbon (say five tonnes of carbon dioxide) annually. Even Canada does not have 100 million hectares of suitable land — for 150 billion trees; the total conversion of Prairie farmland to trees might contribute 25 million hectares.

Fixation as limestone is the most obvious technical answer for the removal of greenhouse gases; the question is, how can the natural process of the creation of limestone be accelerated or supplemented without exorbitant consumption of energy? The economic prospects of such a process, on either a national or a global scale, seem dismal. For a solution, it seems that society must look at the other side of the equation: How can carbon dioxide emissions be reduced?

Given the present state of scientific knowledge and the Canadian climate, the only feasible approach to achieve a dramatic reduction would seem to be large-scale substitution, for current fuels, of electricity and, produced from it, hydrogen. Further, this would only be acceptable were the power produced from hydroelectric and nuclear energy sources, and it would be very expensive — too expensive for the Canadian economy (in isolation) to withstand. Finally, non-urban passenger transportation accounts for approximately 7 percent of Canada's carbon dioxide emissions, and approximately 0.15 percent of global emissions.

II. Technological Prospects

FORECASTING TRANSPORTATION TECHNOLOGY

Technological forecasting — the forecasting of what science will allow in the future — is difficult. The forecasting of whether a technology will prove economically viable in a future market is more difficult. And the forecasting of actual transportation implementation, where governments play so large a role in the market, is still more difficult, especially since transportation applications usually substantially lag behind scientific knowledge that enables them. The shorter-term horizon examined here is less difficult than looking farther ahead.

Except under highly unusual circumstances, technological possibility, in the sense of scientific theory and results that can be achieved in a laboratory, precedes any possible practical transportation application by at least a decade. Further, especially in aviation, most research and development that result in practical transportation applications for civilians will first emerge as technology developed for military or space exploration. The military/space path of technology that is ultimately implemented in civilian passenger transport gives insight into which applications are likely to lead technologically. It is logical to conclude that, with a military/space bias:

- Speed and performance will be favoured relative to efficiency, comfort, energy economy, etc.;
- Technology development will focus on more flexible and less vulnerable modes, free of fixed infrastructure (helicopters will receive the greatest relative attention, railways the least); and
- The air mode, particularly high-performance aircraft and those that require little or no runway, will receive most research.

With technological development, market and regulatory circumstances, particularly market imperfections, are at least as influential as scientific discovery and its potential economic benefits. The possible is not always realized; opportunities may be missed for reasons unrelated to applicable technology and the benefits achievable from it. For public (common carrier) transportation in particular, carrier and modal evolution falls short of the economically justifiable implementation of state-of-the-art technology, sometimes far short.

The cost and service characteristics of a transportation mode depend on the technology employed, restricted by whatever institutional constraints may apply. In an open competitive industry, one does not expect an appreciable lag between availability of a cost-effective technological advance and its implementation. Such lags may be attributable to the substantial cost of entry into the industry and a high degree of monopoly and regulation. In transportation, the high entry cost may be accompanied by a high level of operating complexity, with a consequence that long job-specific experience and the ability to keep the physical systems running are the essential managerial qualities. This, and the need for intercarrier compatibility, leads to retardation of innovation, both with respect to operations and to commercial practices. The railway industry, practically worldwide, is a classic example.

Also, in a society where less than total free enterprise prevails, regulatory restriction or the presence of government in the market has a restraining effect. The implementation of technological, financial and/or commercial innovation is further complicated by state ownership of some transportation infrastructure and/or systems. Investment in government enterprises usually hinges on fiscal and sociopolitical factors as well as cost effectiveness. The views of employees, with respect to job security, tend to carry substantial weight, as do those of users of the system with respect to service convenience and price. Return on investment achievable from technological change is less dominant.

The cost and performance characteristics of emerging technology may have less influence on its development for transportation purposes than institutional influences relevant to its implementation. Also important is the corporate and/or government will to devote the resources necessary for research and development from scientific discovery to an operational reality. Such a process is more predictable in the case of an open, competitive equipment market (for example, automobiles or aircraft) than it is for common infrastructure (for example, air traffic control systems) or high entry-cost integrated systems (for example, maglev).

The process of technological innovation — the development of operational technology from scientific knowledge — is as much political as technical. In the short term, all elements of society do not benefit equally from new processes, especially capital-intensive, labour-saving ones. A particular institutional structure would encourage and support certain innovations, while obstructing others.

AVIATION

The principal thrust of the development of fixed wing transport through the 1990s is expected to be achievement of comparable performance at reduced operating cost. Lighter weight composite materials, involving lighter and more rigid alloys, synthetics and metal/synthetic sandwich construction could see progressively increased use. New wing designs, including controlled surface permeability and thicker sections, could achieve aerodynamic efficiencies such that equivalent or greater lift would be provided by smaller, lighter structures. Turbojet engines could be lighter and quieter, and some 20 percent more fuel efficient. Still greater fuel economy, however, could be achieved through propulsor blade-powered (fan) engines. These would be capable of mach .7 or .8 at fuel economies of 35 to 40 percent over present jet engines.

High-capacity freight transports, developed for military applications, could see increasing civilian application. Through to the turn of the century, however, only a marginal increase in the passenger capacity of the largest aircraft is foreseen, with B-747 derivatives accommodating up to 600 passengers. More importantly, it is anticipated that, by the turn of the century, carriers will be able to choose from a broader, virtually continuous spectrum of capacity, range and speed. Turboprop aircraft, most suited to shorter-range applications, could be available in higher capacities — to 100 seats — and capable of operating at speeds to mach .6 with propulsor fans adapted to aircraft as small as the de Havilland Dash 8.

Helicopters are inherently extravagant and relatively slow. Their use for more than short distances is expected to be limited to unusual circumstances. Civilian versions of military powered lift (probably tiltrotor) developments should become available in the early 21st century. It is interesting to note that cancellation of the U.S. military tiltrotor development program is being opposed on the grounds of future civilian applications. These aircraft, capable of 500 kilometres per hour, will combine helicopter manoeuvrability with the speeds of fixed wing aircraft. They will be designed for the city centre market that STOL (Short Take-Off and Landing) failed to develop, but the economics of such an operation are still uncertain.

The demise of the U.S. Supersonic Transport (SST) program and the limited success of the Concorde notwithstanding, a second-generation, supersonic passenger transport is anticipated. In operation by the middle of the first quarter of the 21st century, this aircraft would fly at three times the speed of sound and cruise at an extremely high altitude, perhaps 75,000 feet. With a 12,000-mile range, it would be designed exclusively for long-distance intercontinental travel, particularly trans-Pacific routes. Although hypothetical at this stage, economics would demand a substantially greater capacity than Concorde — at least 350 seats. Suborbital transports, capable of mach 5 and greater, seem dominated economically by the mach 3 or 3.5 SST. Offshoots of the space program, their development would depend on total government financing.

The most important technological advances in the aircraft of the early 21st century could be invisible to the casual observer. The controls of large aircraft would be electrical/mechanical and computerized. Aerodynamic surfaces could be instrumented and attached to a pair of control computers by hard-wired, probably fibre-optic, electronics. Aerodynamic pressures could be sensed, readings credibility checked through an on-board artificial intelligence system, and adjustments made automatically. Engines could be similarly monitored and controlled. The above, and navigation system advances discussed below, could permit operation with little or no human intervention.

Aircraft maintenance will doubtless be increasingly mechanized. Diagnostic test equipment would be pervasive and sophisticated. Engines and other mechanical equipment could be monitored in service with microelectronic sensors reporting to intelligent computers for comparison with normal and abnormal histories of performance degradation. Maintenance cycles based on flight times could be largely replaced by identification of incipient failure. On-board computers could integrate the condition of all components, and the aircraft could be delivered to maintenance with a listing of necessary work. Inspection could be greatly reduced, with corresponding reductions in maintenance cost and time out of service for maintenance.

The pivotal element in navigation systems for the 21st century is anticipated to be a computerized, worldwide, satellite-based, aircraft-location, identification system. All commercial aircraft of participating countries could be located in three dimensions within a few metres by means of identification transponders. This system could be paired with an independent radar-based collision avoidance system on each aircraft. Weather information would also be assembled from satellite instrumentation and communicated by an artificial intelligence (really *expert systems*) computer system to each aircraft in real time. The artificial intelligence system would communicate only new information relevant to the flight in question, updating the on-board visual display. The weather information would also flow, of course, to the traffic control system, where it would serve as input to the runway use (re)configuration, routing, and take-off and landing scheduling functions — also computerized.

Voice contact between controller and aircraft would not be necessary. Instructions and/or advice could be visually displayed on-board, and communicated directly to the two on-board navigation computers. There, they could be compared automatically with the aircraft's location, direction and speed and double checked against the readings from the collision avoidance system. On-board altitude would be measured and automatically compared with that computed as appropriate by the navigation system. Necessary control adjustment sequences, achieving the stipulated parameters at minimum fuel consumption, would be prepared. Before adjustments are made, the computers' artificial intelligence memories and the collision avoidance system would be automatically consulted for unsafe conditions.

How much pilot confirmation is needed prior to course correction would depend largely on public acceptance of automatic operation.

Labour and nationalist considerations, power failure and hostile acts aside, one air traffic control centre would suffice for North America. Two such centres at dispersed locations would provide backup to protect against a serious emergency at either one. Such a system could remotely control traffic in and out of all controlled airports. The computer system would plan flight paths and, considering weather conditions, each aircraft would be scheduled, before take off, for landing at its destination, with changes only occurring because of emergencies or unexpected weather. Landing queues would be virtually eliminated and, most importantly, aircraft separations would be reduced and airway capacity dramatically increased. Other obvious results of this technology would be an end to the air traffic controller's function as we now know it, an increase in fuel economy and improved safety.

Computer reservation systems currently track the movement of each passenger. By the turn of the century, these systems could be able to interpret early bookings against the history of demand for the service, predict evolving demand, and adjust capacity offered at various fares to maximize revenues. Increasingly sophisticated equipment-planning software could permit carriers to match capacity more closely to fluctuations in demand. Both yields and load factors should rise.

Technology for terminals would include containerized baggage and cargo handling, with automated aircraft loading enabling faster turnaround. The science of security screening is in its infancy, and the technology of remotely identifying forbidden objects and substances could be greatly advanced.

Artificial intelligence systems could aid in the identification of potential offenders. On the other hand, the ingenuity of those bent on defeating the system will continue to advance.

The aeronautical industry has traditionally pursued technological advances well before such would be justified on purely economic grounds. The aircraft manufacturing industry throughout the world is heavily subsidized, both directly and under the guise of national defence. Particularly important in the United States, development costs can be written off against defence work. This was the case for the B-707, and would apply to tiltrotor and sub-orbital mach 5 transports. Regardless of Canada's attitude to subsidizing its aeronautical industry, Canadian carriers will have access to aircraft technology, the development of which was publicly subsidized by the nation of origin.

Technology for terminals is less advanced than that for aircraft, and government support of research is modest, except with respect to physical accessibility for people with mobility impairments, and signage and emergency warning systems for those with impaired hearing or sight. Automated information systems and translation systems could be developed and implemented at publicly owned airports.

GUIDED GROUND PASSENGER TRAVEL

Although the science that enables intercity, repulsive-mode maglev has been known for two decades, development and demonstration of this technology are expensive, and there are no military applications against which such expenses could be defrayed. There is little doubt, however, that repulsive-mode magnetically levitated vehicle systems (maglev), capable of 500 kilometres per hour, could be developed. Driverless vehicles for perhaps 100 passengers would offer service quality comparable to air travel. Such a system was designed in Canada more than ten years ago (but not recommended for further Canadian development). The technology to make such vehicles work on an experimental basis has been developed; a Japanese prototype works.

Until recently the operational practicality of repulsive-mode maglev has remained in question because of the extremely low temperatures believed necessary for operation of the superconductive magnets that enable efficient levitation. However, what is presumed to be the final technological breakthrough necessary for commercial development of maglev systems — economical, moderate temperature superconductors — is rapidly advancing. The necessary electronic control systems and linear synchronous motors already exist. Infrastructure designs also exist, but there remain safety concerns. Such will doubtless be resolved overseas before a Canadian installation is considered.

Another high-technology prospect, attractive-mode maglev with linear synchronous motors, avoids the superconductivity problems of the repulsive-mode, and is currently being tested at full scale. Commercial implementation in Germany before the year 2000 is planned, and a Las Vegas–Los Angeles system has been proposed.

Driverless rail transit systems, employing linear induction motors and computerized control, are designed, manufactured and now operate in Canada. High-speed, automatic electric rail for transit or intercity application is the current technology available for installation.

Electrified railway passenger systems, designed for operation to 300 kilometres per hour, are operating commercially overseas, and are being considered for the U.S. and Canada. It is, however, significant to note that these are really *not* innovative technology. The use of microelectronics aside, present and proposed high-speed rail designs contain few technological features that were not available half a century ago. As for the microelectronics employed, the integration of infrastructure and vehicle operation characteristic of the rail mode is most compatible with implementation of the automated control systems made feasible through microelectronics and computers.

Sophisticated microelectronics, however, are not fundamental to high-speed, electrified railway operation, and more sophisticated applications are common in modern automated manufacturing processes (not to mention high-technology aircraft and the state-of-the-art car). This is not to demean high-speed rail. Rather, it is a suggestion that it be viewed as existing and mature technology. Replacement of some aircraft and car use by a less technological but fast fixed-infrastructure system might well be the choice of an environmentally aware 21st century society faced with air and highway congestion.

Progressing from the relatively low-technology high-speed rail currently being considered for the Quebec–Windsor corridor, driverless, high-speed railway systems could be operational in Canada early in the next century. Repulsive-mode maglev could be operating within a decade thereafter but will probably not be implemented in Canada before 2020.

ROAD

Anticipated advances in shorter-run highway design are important but not spectacular. New pavements should be stronger, more frost resistant and more rigid, and chemicals may be added to the surface layer of asphalt to prevent the formation and adherence of black ice. Technological changes that could substantially affect road use are longer term. Dedicated controlled roads with automated electronic guidance, on which traffic could operate safely at high speeds and densities, are not far beyond the current state of technology. Because of diverse vehicle design, ownership and maintenance, however, questions of reliability remain far from resolution.

The underlying technology for vehicle guidance systems, usable even when all vehicles are not equipped for such a system, is close. The technology, whereby vehicles with increasing degrees of automatic operation travel ordinary roads in mixed traffic with unequipped vehicles, is under active development. Such vehicles would be capable of locating other vehicles, objects and road geometry, and would steer and adjust speed automatically. Operation of a mix of equipped and unequipped vehicles at substantially differing speeds, however, is physically difficult and poses safety problems.[4]

Some research is directed at automatic guidance without vehicle modification. It is not obvious, however, where the capital for such an investment, even for development of the technology, and an effective institutional mechanism, would come from. Short of the point where such systems would allow greatly reduced distances between vehicles, much higher speeds or driverless operation, automated driving is unlikely to have an important impact on highway cost or performance.

State-of-the-art microelectronic technology would permit economical implementation of sophisticated user-charge systems. Vehicle-mounted "smart" cards, issued with the vehicle licence, could be read by roadside sensors communicating with central computers. User-fees could then be assessed according to the road used and the time of the day, week or year.[5] Operating in conjunction with reliable automatic weigh scales, which could record at road speed, the system would be able to factor weight into the user-charge.

The key to improving the cost effectiveness of intercity bus on high-density routes is to increase the capacity of the vehicles. Capacity and size also govern seat comfort. A few more inches of width would allow rail-competitive seating; the alternative is two + one seating with 22 to 25 per-cent loss of capacity. Relaxation of the width constraint is not foreseen for the shorter term. The alternative would seem to be longer and/or higher coaches. Capacities of the order of 100 seats, if they could be achieved, would allow substantial economies of labour, and improve modal competitiveness. They would improve the economics of shorter-distance, intercity travel more than any foreseen technological improvement.

The most likely configuration would seem to be a double-decked unit, but a conventional double-decked bus would be unable to negotiate many underpasses. Articulated designs are in experimental use, and a triple design with a separate trailer has been suggested. A double-deck design (except at the rear end) with a height below five metres would be possible if the chassis were lowered. For 100 seats, an articulated double is indicated.

Improved (active) suspension and (anti-lock) braking systems would provide the necessary high-speed stability for a larger bus to operate safely and comfortably. Such vehicles, with professional drivers, could safely travel significantly faster than mixed traffic, were a dedicated right-of-way provided. Technology to improve the safety of faster vehicles within mixed traffic is conceivable. With implementation being politically questionable, however, economic incentive for its development is lacking.

With state-of-the-art technology, vehicle speeds could increase without corresponding increases in damage to the roadway or a deterioration in safety. The alternative is reduced wear and increased safety at current speeds. Active (microelectronically controlled) suspensions could improve passenger comfort, reduce dynamic loading and improve stability. Microelectronics will enable resistance-sensitive, skid-control braking systems, and monitoring of axle load distribution and automatic headways. Intelligent braking systems, balancing application to each wheel on the basis of sensed resistance, will doubtless make buses and cars safer.

Instrumentation and computer control of engine and transmission would improve fuel economy, as could the use of ceramics and higher combustion temperatures within engines. Related is improved tolerance for a broader range of fuels, particularly (for diesels) with respect to cetane number.

Ergonomic improvements in cars and buses are continuing. Included are seating improvements, reduced noise, digital instrumentation, electronic controls and dashboard convenience. With a single driver, and total human control a constant factor, ergonomics offer a greater potential for road than for the other modes. In buses, microcomputers monitoring mechanical and electrical systems would allow maintenance on an exception basis, and would improve reliability and on-time performance.

The size of the car market suggests a greater incentive for investment in technological research than is the case for buses. On the other hand, the investment necessary to equip a bus with advanced technology can be written off against several times the mileage of the average car, and much greater fuel consumption.

Innovative passenger car designs abound. They always have, and doubtless the future will be replete with them. Very small vehicles have been introduced before but have not survived. If appreciably smaller vehicles are to occupy a significant position in the transportation scene,[6] it will probably be by means of a progressive extension of the small end of a manufacturer's size range. Introduction of dramatic new designs is less likely. The exception to this could be vehicles with revolutionary new two-stroke internal combustion or superconductive electric motors. A three-cylinder, two-stroke engine could improve fuel economy by 10 percent.

Car energy efficiency can be improved in three basic ways: reduced vehicle weight has a proportionate effect on energy used for acceleration and lost in braking; frictional resistance includes tire/road loss (approximately constant for a given gross vehicle weight), and aerodynamic friction which depends on vehicle volume and shape but, most importantly, on speed;[7] and improved engine and mechanical efficiency.

Vehicle weights could be reduced by a mechanical design that allows more efficient use of vehicle volume; front-wheel drive has allowed a 5 to 10 percent weight reduction. Similarly, reduced use of mild steel and its replacement with high-strength alloys and other metals, particularly aluminum, synthetics and composite materials, should allow a weight reduction of 10 percent by 2010. There could be weight reduction in smaller vehicles, but consumer resistance to lighter vehicles, based on occupant safety considerations, must be recognized. The change in momentum of the occupants of rolling vehicles in collision (a major determinant of injury) is the inverse of the relative weights of the vehicles; all else equal, occupants of the lighter vehicle will suffer more. Of course, if both vehicles were proportionately smaller, there would be no differential effect.

Although its thermal efficiency is not high, revolutionary replacement of the reciprocating internal combustion engine is not predicted for the next few decades. However, incremental improvements are expected. In general, an internal combustion engine has two types of losses: those relating to thermodynamic efficiency and heat recovery, and those related to friction, both mechanical and aerodynamic/fluid-dynamic (pumping). Improvements should include increased use of overhead cam engines, four- and five-speed automatic transmissions, improved lubricating oil, four- and five-valve engines, multipoint fuel injection and automatically varied compression ratio and cylinder displacement. By 2010, these innovations could improve thermal efficiency by 7%, reduce pumping loss by 65%, and friction losses by 40%. In total, the above would not match the potential of the diesel engine which has a 20% to 30% advantage over the gasoline engine.

Gains from aerodynamic improvements show lower relative potential, a fact that affects total, achievable, energy-efficiency improvements, particularly at highway speeds where aerodynamic resistance is so dominant. Overall, the next 20 years could see a 50 percent improvement in specific fleet, average-fuel economy, much of it relating to the retirement of older-model vehicles presently in operation. From the perspective of the Royal Commission, intercity car energy efficiency will have much less impact. Most of the projected technology will have greater impact on urban/suburban fuel economy.

MARINE

Passenger ferries on both coasts have become larger and faster in recent years. In the face of steadily increasing demand and increasing real labour costs, this trend can be expected to continue. Multiple and complex hull and hydrofoil designs, in use elsewhere and which offer higher speed, could see greater use in Canada. However, neither is the technology new, nor have past Canadian experiments with such vessels been particularly successful.

Automation technology will be implemented to some extent. For passenger services, however, potential passenger control and evacuation in an emergency are factors, docking is more frequent, and restaurants and other facilities must be staffed. Thus, the scope for labour economies is less. With their restricted routings, and schedule sensitivity, ferries are prime candidates for automated navigation. All control would be from the bridge, and crew roles could be reduced to a monitoring function, with direct control only taken on exception.

Engine condition could be monitored electronically, probably using fibre-optic circuitry, and maintenance could be scheduled on the basis of incipient problems detected. Marine diesel engines of current design can exceed 40 percent thermal efficiency. Ceramics and consequent higher-temperature operation could improve this still further and, more importantly, ceramic engines would tolerate broader fuel specifications and hence cheaper fuels.

INTERMODAL

Exotic ideas for intermodal passenger capsules emerge periodically but have never come to anything. Walking out of one vehicle and into another does not seem to be a major deterrent to the multistage journey, as long as the connecting vehicle can be boarded conveniently, the walk is short and there is no delay. Rather than an exotic vehicle, the primary technological need is for improved design of transportation systems. Better systems will open the door to innovative design of terminals.

Most intercity travel is intermodal; for example, taxi-walk-escalator-walk-airplane-bus-walk. Intermodal travel need not involve more than one line-haul carrier, mode or vehicle. The future will doubtless see improvements in the technology of many of the modal links concerned, which will improve quality of travel. So will improvements to the nodes (terminals). The greatest improvement expected within the next decade, however, will not involve the transport itself but rather the delays and activities at the nodes between the links.

Improvements to intermodal systems are expected to include airline check-in remote from the airport (before boarding the airport bus or connecting train), origin-destination intermodal baggage handling, intermodal reservation systems and intermodal ticketing. On-line multimodal scheduling systems would synchronize the capacity and departures of connecting carriers with arriving passengers (not just the capacity of the vehicles concerned, but the actual number of passengers boarding). For example, the transit system departing from the airport would have capacity that is consistent with the number of incoming air passengers and the history of onward modal travel of those passengers.

The technology involved would be computer systems, both the high-capacity hardware and the scheduling and expert systems software necessary for its operation. Such systems would bestow competitive advantage to the multimodal carriers or cooperating modal carriers that subscribe. They would also serve to reduce congestion and improve travel at larger terminals, particularly airports.

ENDNOTES

1. These notes are the result of preparation of an initial draft and its review with transportation technology specialists. Some of the material is taken from *Canadian Transportation in 2000 and 2015: Environmental Scanning Study* by the Research and Traffic Group for Transport Canada, and the continuing update of that material.

2. Travellers assess their alternatives in terms of the total time from departure at origin (home, office, etc.) to arrival at the ultimate destination. Allowances are also included for anticipated arrival delay and for (schedule) convenience with respect to desired arrival/departure time. In this regard, vehicle speed is only one element.

3. There are a number of substances emitted from transportation vehicles and systems that contribute to warming of the global atmosphere and the predicted climatic change colloquially referred to as the *greenhouse effect*. These include methane, nitrous oxide, sulphur dioxide, ozone and chlorofluorocarbons and carbon monoxide, but the predominant emission of concern is carbon dioxide. Although on a unit basis the other greenhouse gases are an order of magnitude more harmful to the atmosphere, it is carbon dioxide that has received the greatest attention, and rightly so. Quantities of carbon dioxide emitted overshadow those of all other gases, and opportunities to significantly ameliorate the problems posed by carbon dioxide are not apparent.

4. Here is the essence of the intercity bus limitation. Modern intercity coaches with trained and experienced drivers can safely negotiate most roads at speed substantially above speed limits. Were they to do so in mixed traffic, however, passing situations and the effect on less equipped motorists would detract from safety.

5. Impediments to the implementation of such a system are not likely to be technological or economic. Rather, a system that tracks vehicles in space and time could (used with insufficient security) constitute an invasion of privacy.

6 Smaller vehicles have been suggested as a solution to congestion. However, safe capacity is dictated by speed, driver reaction and vehicle stopping time. Vehicle length is of minor consequence, and the impact of some small vehicles tends to be perverse. As regards highway capacity, a fleet of identical vehicles would be optimal.

7. For a vehicle with aerodynamic resistance of one (force) unit at 25 kilometres per hour, a doubling of the speed to 50 kilometres per hour would increase resisting force by a factor of approximately 3.5. Doubling it again, to 100 kilometres per hour, would increase aerodynamic resisting force a further four or five fold. A trend towards increasing mean vehicle speeds could rapidly neutralize any gains through fuel efficiency technological improvement. As an indication of the magnitude of this effect, it is estimated that the difference between a vehicle speed of 77 kilometres per hour and one of 100 kilometres per hour causes a 20 percent increment in per kilometre fuel consumption. As mentioned above, improving technology should allow higher vehicle speeds without loss of safety.

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