Examining Regional Sensitivity to Climate Change Using Aggregate Input-Output Data: The Case of Transportation in the Northwest Territories

Richard J. DiFrancesco
Department of Geography
McMaster University
Hamilton, ON L8S 4K1

Stephen C. Lonergan
Centre for Sustainable Regional Development
and Department of Geography
University of Victoria
Victoria, BC V8W 2Y2

The notion that human activities could be having an effect on the global climate is not new. Scholarly research conducted in the late 1800s suggested that human activities such as the burning of fossil fuels and deforestation could contribute to a global warming (Arrhenius 1896). Keeling et al. (1984) reported measurements taken at Mauna-Loa, Hawaii and the South Pole which suggested that the atmospheric concentration of CO₂ had increased by 33 percent over preindustrial levels. In fact, many contemporary researchers have confirmed that a rapid increase in atmospheric CO₂ concentrations coincided to a considerable degree with the advent of the industrial revolution (Keeling et al. 1984; Oeschger et al. 1985; Gammon et al. 1985). Global climate modelling experiments have suggested that a doubling of the pre-industrial
concentration of atmospheric CO₂ could cause the earth to gradually become warmer and wetter. Most disturbing is the fact that most of these experiments have consistently identified Northwestern Canada as a zone of maximum change (Barry 1985; Smith 1986; Ripley 1987; Schneider 1988). Cohen (1988) regionalised a set of "state-of-the-art" global climate projections and reported that the Mackenzie Valley region was consistently identified as a zone of maximum change, in terms of temperature and precipitation patterns. Recent work by Lonergan and Woo (1990), DiFrancesco (1990), Woo (1992) and Lonergan et al. (1993) has suggested that climate induced physical changes in the Northwest Territories (NWT) could have a significant impact on the region’s economy. The economy of the NWT, like all systems in the region, is fundamentally tied to the region’s climatic extremes. If the NWT were to warm appreciably, as the previously cited research suggests, then the economy would be affected in an unprecedented fashion. Nearly every aspect of the region’s economic future would be altered. Previously uneconomic resource projects may become economic, economic projects may become uneconomic, or entirely new economic opportunities could emerge. A fundamental element of all of the aforementioned potential economic changes is the effect a warmer climate could have on transportation in the NWT vis-à-vis direct impacts on the operational feasibility of various transportation modes in the region. We argue, therefore, that while transportation will be among the many affected sectors in the NWT, it will act as a major conduit for the transmission of impacts onto other facets of the northern economy.

The fact that the transportation system of the NWT is sensitive to climate change is apparent. This paper presents an examination of two scenarios of the way an altered climate could affect the NWT economy, and both of these scenarios focus on the transportation system of the NWT which is concentrated in the Mackenzie River Valley. To be more accurate, these scenarios represent two ways of visualizing how an altered climate could affect the NWT economy. In each case a static input-output model formed the core of the economic analysis. This work represents an experimental attempt to link climate change information with conventional methods of economic impact assessment, and to examine the usefulness of the available aggregate NWT input-output data, in this context. Both of these objectives were formulated in the context of providing information on how global warming could affect the regional economy. Although a normative planning model was not the objective, this paper does suggest what types of information would be required if such a model were to be built. The most valuable information for such a task would be micro level time series data on operations and maintenance costs, freight rates, and tonnages carried, for the various transportation modes used in the region. This type of information would provide a strong empirical connection between physical changes in the region and direct effects on the land and water based components of the transportation system. Field interviews indicated that this type of proprietary data would not be forthcoming unless the various operators saw that they had a vested interest in knowing how climate change could affect their operations, and this was not the case.

The next section will provide a more detailed discussion of what climate modelers have predicted in terms of global, and NWT specific, climate change. The following section will highlight the predicted physical impacts for the NWT which are most relevant to an analysis of economic impacts. The fourth section of the paper provides a brief description of the existing transportation infrastructure in the NWT. The following section highlights key methodological issues associated with climate impact assessment work generally, and with this project specifically. The final three sections present two scenarios of the way in which an altered climate could affect the economy of the NWT, and close the paper with a brief discussion of the results, the applicability of the static methodology to this task generally, and of ongoing research which could allow for a more dynamic conceptualization of this problem.

Global and Regional Scale Climatic Impacts

While the magnitude of climate change predictions are model specific, certain commonalities have been noted across modelling efforts. Many global climate change researchers have noted that a global warming is likely by the middle of the twenty-first century (Barry 1986; Smith 1986; Kellogg 1983; Ripley 1987; Carter 1988; Schlesinger 1988; Schlesinger and Mitchell 1987; Waggoner 1988; Wigley et al. 1980). The majority of these studies also indicated that climatic changes would be most severe in high latitude regions in the northern hemisphere during the winter months. In terms of regional impacts, Barry (1986) and Ripley (1987) reported simulated temperature increases of between 2 and 3°C for the Northwestern portion of the Canadian sub-Arctic and Arctic zones. Smith (1986) reported a simulated Arctic warming on the order of 7°C, with winter temperature increases of 11°C. Cohen (1988) reported that, under one scenario of climate change (the General Fluid Dynamics Laboratory (GFDL) model), winter temperatures could increase by 5 to 15°C in the Mackenzie Valley.

Historically, there has been much less agreement across models with regard to precipitation impacts, but experiments have suggested increasing precipitation levels in the high latitude areas of the northern hemisphere during the winter months (Schlesinger 1988; Ripley 1987; Barry 1986; Carter 1988; Kellogg 1983; Wigley et al. 1980). Ripley (1987), reported that precipitation levels could increase by 50 percent in the Northwestern regions of Canada and the United States, and Smith (1986) reported that snowfall levels in the North-
western Arctic could increase by 60 percent. Cohen (1988) noted, that under one scenario of global climate change, precipitation levels in the Mackenzie Valley could be 11 to 38 percent higher than present.

In summary, current climate simulations have indicated that the North-western Canadian sub-Arctic and Arctic zones could experience significant temperature and precipitation impacts over the next 30 to 50 years. These simulations also suggested that the Mackenzie Valley region could experience the most severe of these impacts.

Region Specific Physical Impacts Relevant to Socioeconomic Systems.

Lonergan and Woo (1990) conducted a comprehensive study of the potential physical impacts in the NWT of three scenarios of global climate change. Their study focused on the potential for changes in temperature, precipitation, water balance, permafrost, and slope stability. This assessment was conducted primarily for the purpose of modelling, via deterministic and stochastic methods, how projected climatic changes could impact the ice and snow cover regime of the NWT, and subsequently, how this could affect the operation of land and water based shipping modes in the region.

Lonergan and Woo (1990) reported that under one scenario of climate change (the GFDL scenario), the number of ice free days on the Mackenzie River could increase from a present level of 164 (± 15.3) days per year to 206 (± 15.5) days per year. They noted that such an extension would have a positive impact on the operating season of the Mackenzie barge system. They also noted that such an impact would be disruptive for land based modes which rely on the winter/ice road network for access to remote areas in the region. To illustrate this, they showed that the ice crossing season at Norman Wells could be reduced from a present season of 178 (±15.1) days per year to 132 (±20.8) days per year.

Based on these results, it appears that if the physical systems in the NWT react as Woo’s models suggest (Woo 1992), the region’s transportation system would be directly affected.

Transportation in the Mackenzie Valley

This study focused on three general modes of transportation in the Mackenzie Valley, barge, truck and air. Data on the volume of flows for the various modes was unavailable at the start of the study, and a great deal of work went into in to mapping these flows. Figure 1 presents a summary of commodity flows in the Mackenzie corridor between 1980 and 1985. Most commodity shipments were made via the Mackenzie barge system, with Arctic sea-lift providing a substantial portion during the period of large scale oil and gas activity in the Beaufort Sea. The decline in oil and gas activity in the North has resulted in a decline in the volume of shipments generally, and in 1988 barges carried little more than half of their 1983 peak volume. Most shipments consisted of fuel, with bulk goods and general commodities accounting for the remainder.

Mackenzie Barge System

The Mackenzie barge system extends from Hay River on Great Slave Lake to Tuktoyaktuk which is located on the northern edge of the Mackenzie Delta. The only barge operator in the NWT, Northern Transportation Company Ltd. (NTCL), operates a major terminal at Hay River which, for many years, served as a transhipment point for goods shipped by rail from Edmonton. This rail link has since been closed due to the closure of the Pine Point Mine which was located just east of Hay River, and south of Great Slave Lake. Although this rail link was also used to ship goods to Hay River for ultimate delivery to the far north, the Pine Point Mine closure made this operation uneconomic. The previous flow of goods from Edmonton still passes through Hay River by truck along the Mackenzie Highway. The barge system also extends east of Tuktoyaktuk, through the lower Arctic Islands to Spence Bay, and west to the North Slope of Alaska. Due to the extent of multi-year pack ice and yearly land-fast ice, these deliveries are usually only possible during a two week

2. The 30 to 50 year time period represents the length of time required for a doubling of pre-industrial levels of atmospheric CO2. This time frame is dependent upon many factors such as the rate of fossil fuel consumption, deforestation, and the uptake of alternative sources of energy which do not add to the Greenhouse Effect.

3. These were the GFDL, GISS and OSU general circulation model (GCM) experiments. GFDL, GISS and OSU are acronyms for General Fluid Dynamics Laboratory, Goddard Institute for Space Studies and Oregon State University respectively.

4. Winter and ice roadways are a major component of the region’s transportation system. In excess of 25% of all land based freight moves over frozen surfaces. Many of these roadways run over frozen streams and small lakes and Lonergan and Woo (1990) noted that many of these streams and lakes may no longer freeze under one scenario of climate change. Note that a winter road is built over “right of ways” cleared on land during the summer months. Ice roads extend over frozen lakes, rivers and along the Beaufort coast.

5. It is important to note that the interpretation of this scenario rests on the assumption that current river crossing technology is not improved. An ice breaking ferry, for example, could reduce the significance of this impact.

6. Arctic sea-lift represents a type of open ocean barge operation that was used to transport heavy rigs, etc. from the West Coast around Alaska to the Beaufort Sea.
period each year. The barge system currently delivers approximately 250,000 tonnes of freight in a four month shipping season, most of which is northbound, and half of which is community resupply oriented. Interviews with Coast Guard and NTCL officials indicated that the navigation season on the Mackenzie was determined entirely by the date of ice breakup. Once the river ice breakup begins, the Coast Guard has the responsibility of marking the shipping channels.

Trucking System

The trucking system accounts for a significant proportion of all freight moved in the NWT (see Figure 1). The northern highway system connects with southern Canada via the Alaska highway which runs from Whitehorse in the Yukon Territories, to Dawson Creek in British Columbia. The Mackenzie highway runs from Hay River south to Grimshaw Alberta. A key highway route completed in 1979 was the all-weather version of the Dempster Highway which stretched north to Tuktoyaktuk. The Dempster extension provided the first year-round land route to the Mackenzie Delta/Beaufort Sea region. The Dempster’s season is still constrained by two river crossings; the Peel River crossing at Fort MacPherson and the Mackenzie River crossing at Arctic Red River. The crossing at Arctic Red River for example, is one kilometre wide, and it acts as a severe constraint on the season through which land based shipments can be made to the Delta. Currently, this crossing is inoperable for 3 to 4 weeks in the spring and 6 to 8 weeks in the fall, each year. Technological improvements in reinforcing river crossing ferries and in constructing ice platforms for winter crossings has allowed many of these crossings to be operated with shorter interruptions, but these crossings still represent major bottlenecks in the supply of land based transportation services during the spring and fall of each year.

North of Fort Simpson, the Mackenzie highway operates as an ice road only. This section of the Mackenzie highway is opened only after authorities determines that the ice can support a vehicle weight of 20,000kg. Nearly 25 percent of all land based shipments take place on the ice road system (Lonergan and Woo 1990).

Air Shipping System

The air shipments sector represents a necessary component of the NWT transportation infrastructure. Air shipping is generally reserved for the delivery of high value, time sensitive, and/or emergency items. The viability of air freight operations in the NWT has been curtailed by the opening of the northern extension of the Dempster Highway. Trucks using the Dempster Highway now carry much of the freight that used to be shipped to the Arctic coast by air.

Rail Freight System

Railway lines extend north to Hay River where bulk deliveries, prior to 1992, were broken down and transhipped to Mackenzie barge for delivery to the Northern portions of the Valley and the Delta. The rail link to Hay River was a crucial component of the NWT shipping system because it provided a relatively inexpensive method of getting bulk freight from the south to Hay River. As mentioned above, the closure of the Pine Point Mine resulted in the closure of this rail link, and subsequently all freight coming north from Edmonton is shipped via truck.
This brief description suggests two main points of interest. Firstly, the barge system is the primary freight mover in the region, followed by the land based trucking system, and secondly, the entire system is governed, to a significant extent, by climatic variables. It should be clear that any alteration of the existing climatic regime in the NWT could have a significant effect on the region’s economy via direct effects on the water and land based shipping systems. We argued that the net effect of a significant ice free season extension would be positive since any freight which could no longer be shipped by truck, could be transshipped to Mackenzie barge. The remainder of this paper operates on this contention.

It is important to note that this very aggregate view of the net effect of climate change on the transportation system in the Mackenzie Valley ignores the fact that, on a micro scale, certain communities may be adversely affected since barge shipments cannot substitute for inland delivery systems. A significant portion of the resources of the Mackenzie Basin Impact Study, of which this work is a part, is directed toward this issue of micro level impacts (for example, increased flooding of communities, increase in the spatial extent of discontinuous permafrost and the effect on traditional lifestyles, etc.). The work presented below necessarily retains a very macro focus.

**Methodological Considerations**

In developing our methodological approach it was necessary to assume that the relationship between the climate and the economy of the region could be represented in a linear cause and effect manner (for example, feedbacks between physical and economic systems were not considered). That is, a simple impact assessment framework was used as the basis for the presentation of both climate change impact scenarios. Although it is recognized that an integrated assessment should include feedback mechanisms as well as the dynamic nature of other systems besides climate (see Kates et al. 1985), our primary goal was to integrate available climate change information with conventional models of economic analysis in an attempt to illustrate the utility of such integrated modelling for climate change impact assessment. This abstraction allowed us to focus on the integration aspect of the study.

In addition to selecting the structure of the underlying impact assessment framework, Robinson and Finkelstein (1991) and McKenney and Rosenberg (1991) identify a number of key issues which must be addressed when performing any climate impact assessment work. These authors note that assessing the impacts of climate change on various systems (for example, physical, biophysical, and/or socioeconomic) involves the use of models which necessarily operate at different temporal and spatial scales. The following three sections discuss these issues, and in so doing provide an impression of how the various scales encountered in the different modelling schemes were accommodated.

**Temporal Resolution**

The stochastic simulation models of the physical regime in the Mackenzie Valley upon which this economic assessment was based (see Woo 1992; Lonergan and Woo 1990, and Lonergan et al. 1993 for details) were based on thirty years of actual daily temperature and precipitation records for Norman Wells, NWT, a station midway between Great Slave Lake and the Mackenzie Delta. Woo (1992) and Lonergan et al. (1993) used changes in monthly mean temperature and precipitation (obtained from the global climate models) for the regional hydrological simulation models, since it was felt that estimates of climatic variability are still of questionable reliability. Although McKenney and Rosenberg (1991) note that daily temperature and precipitation data would be particularly useful in assessing hydrological impacts, the climate scenarios in the Mackenzie study were used to provide projections of climate variability based on existing daily climate data. This allowed us to base the impact assessment on existing climate data and monthly projections, rather than relying strictly on the daily projections generated by the climate models (Lonergan et al. 1993). The end result of this physical process modelling was an estimate of the ice cover on the Mackenzie River at Norman Wells for each climate change scenario. Although the hydrological models were stochastic in nature, they were static in that they did not address the transition from current conditions to the end state portrayed by the climate models. The economic impact methodology used these estimates under each climate change scenario as primary impacts on the water based shipping system in the region. The economic impact assessment was also static.

**Spatial Resolution**

The models used for this assessment also varied in terms of their spatial resolution. As mentioned earlier, the GCMs provide output for spatially aggregate zones whereas the hydrological and economic models were defined at the regional level. The case for a regional study can be made as follows. Climate change is expected to be greatest in Arctic regions. McKenney and Rosenberg (1991) note that high resolution data may be required in regions with a complex physiography and/or topography. The Mackenzie River Valley, however, does not have a complex physiography and climate, at least within the valley, is not spatially heterogeneous. In addition, the size of the GCM grid cells is much smaller in the far north. With a reasonably uniform topography and smaller grid sizes, there is less need for meso-scale modelling than there would be along the coast or in mountainous regions. No attempt was made, therefore, to use statistical descriptions of climate to translate GCM values to the local scale.

Also, as noted above, Cohen (1988) has generated several Mackenzie
Transient versus Steady-State Climate Scenarios

This study did not consider ecosystem changes, the role of technological change, or adaptation and, therefore, the need for transient scenarios was diminished. This is not to say that adaptation responses (physical, or socio-economic) are not available to mitigate some of the effects of climate warming on the region. Climate change will likely exacerbate existing problems (such as low flow periods on the river), and responses (such as dredging the river, or the use of improved northern transportation technology) may be implemented long before a 2XCO₂ (doubled CO₂ climate) scenario occurs. Permafrost changes, which will have major impacts on vegetation, animals and infrastructure in the North, would be very sensitive to the transient course of climate change, and such scenarios would be important. However, this is less true for thermal ice breakup and ice freeze-up (for example, examining ice cover impacts before and after a 2XCO₂ climate was imposed was not considered to be unrealistic). Since these ice cover impacts served to drive the assessment we concluded that the single 2XCO₂ scenario (instead of a transient year by year scenario leading to a 2XCO₂ state) sufficed for this study. Viewing the economic response in a similar manner was not as easily defended since mitigation strategies and other adjustments could certainly alter the effect such changes could have on the region. Given that all of the physical models were static in nature, combined with the fact that a transient (or dynamic) economic methodology was far beyond the scope of this project, the economic impacts were assessed in a similar "before and after" fashion.

Scenario One: Integrated Physical-Economic Approach

The following two sections present, and examine the impacts of, two scenarios of how transportation sector impacts could affect the economy of the NWT. While it is conceivable that climate change could lead to spontaneous changes in other aspects of the NWT irrespective of the transportation system, this work focused solely on the economic effects associated with transportation sector impacts.\(^7\)

The first scenario was designed to link, conceptually and operationally, general circulation model (GCM) results, regional physical changes, transportation sector impacts and economic impacts. The three climate change scenarios used by Woo (1992) were also used as the basis for this analysis. This scenario offered one perspective on the way an altered NWT climate could affect the economic system of the region.

Under one scenario of climate change (the GFDL scenario), our models indicated that the ice free season on the Mackenzie River could increase by 40% or, 6 to 9 weeks (see, Woo 1992 for a detailed discussion of the methodology used to model regional ice cover impacts). An extension of the current barge season of this magnitude, a positive effect, would imply a concurrent attenuation of the season for land based shipping, a negative effect. To translate these physical impacts into impacts upon the modal distribution of freight (between barge, truck and air), it was assumed that the commodity shipments system of the region (barge, truck and air) was operating at (or near) capacity, and that the demand for shipments in the region was very elastic with respect to freight rates. Under these assumptions, the barge system (the least expensive mode on a per tonne basis) would be filled to capacity first, followed by truck and air. As the season for barge operations became longer (that is, as the capacity of the cheapest mode increased), we assumed that it would be met with an appropriate level of demand at the expense of demand for truck and air service. This series of assumptions was made in lieu of data on transhipment thresholds.\(^8\) Admittedly, these abstractions did not deal well with the fact that air shipments were not generally used as a substitute for barge or truck shipments. This assumed nature of the transhipment dynamic provided the foundation for the first scenario of how transportation sector impacts could affect the NWT economy. Table 1 presents the results of the projections of freight volumes carried by each of the three modes based upon the above \textit{a priori} assumptions. Low and medium probability outcomes for the three climate change

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\(^7\) The NWT economy is fundamentally related to the region's climate. Everything from the threshold size of oil and gas reserves, to the economics of pipeline systems, are determined largely by the cost of operating and transporting goods in and out of the region -- hence our focus on how transportation sector impacts will affect the rest of the economy.

\(^8\) Issues such as the additional barge capacity opening export opportunities (via back-haul possibilities) was not considered here. Historically, nearly 100% of all barge capacity has been northbound, and 50% has been re-supply oriented. A longer barge season, while potentially significant, would not allow new export opportunities to be exploited (for example, potential Beaufort oil will be shipped either by pipeline or by tankers, lead and zinc from the high Arctic mines will be shipped via ore freighters to European markets and to southern Canada and the rest of North America via the Northwest Passage).
scenarios are presented. Table 1 illustrates that, as expected, the volume carried by barge increased under all scenarios with the low probability scenarios showing the maximum deviation from current conditions. Barge volume was projected to increase by 51% under the GFDL low probability scenario, while the tonnage carried by truck and air was projected to decrease by this amount.10

While data on the percentage of the cost of commodities which could be attributed to transportation was minimal (estimates ranged from 5 to 50% depending on the type of good shipped), it was assumed that as the proportion of the total volume carried by barge increased, the delivered cost of commodities to retailers in the region would decrease. Assuming that a competitive market for commodities existed in the region, we reasoned that this could translate into a reduction in the overall price level. We also reasoned that any reduction in the regional price level would stimulate consumption in the NWT, in a manner dictated by the price elasticity of aggregate consumption.

Two econometric specifications were used to connect the projected modal freight distributions to changes in the regional price level, and secondly, to translate the projected price level impacts into impacts upon aggregate consumption spending by households. The first of these models explained the variation in the regional price level as a function of the modal distribution of freight in the region as follows:

\[ P = \mu + \beta B + \gamma T + \delta A + \epsilon \]  

where:
- \( P \) = regional price level (the Yellowknife CPI is used as a proxy for regional price level);
- \( B \) = barge tonnage carried on the Mackenzie River;
- \( T \) = truck tonnage carried in the Mackenzie Valley;
- \( A \) = air tonnage carried in the Mackenzie Valley;
- \( \mu, \beta, \gamma, \) and \( \delta \) represent parameters to be estimated and \( \epsilon \) is an error term.

9. It should be noted that the ice cover impact simulation model, which was stochastic in nature, produced high probability outcomes which showed little change from present conditions. Woo (1992) found that this convergence toward 1.0 at the tail of the output distribution was a manifestation of a problem with the simulator, and not a reflection of the fact that the high probability outcome would be little or no change from present conditions. Therefore, the decision was made to focus on the low to medium probability end of the output distributions.

10. Due to the fact that air shipments were relatively small, and that the northern extension of the Dempster Highway has significantly reduced the importance of air shipping to the Mackenzie Delta, truck and air shipments were treated as a cumulative "other" shipping category. This greatly simplified the transshipment dynamic. As a tonne was added to the barge system, it had to be removed from the "other" category. As mentioned earlier, this implies that air shipments act as a substitute for barge shipments when this is not the case. However, air shipments were so small that the decision was made to treat them as such.

Although it is true that the regional price level is determined by a more complex system (relative to that represented in equation 1), we hypothesized that the modal distribution of freight was a primary determinant of the price level in the region. More specifically, we hypothesized that as barge tonnage (barge being the cheapest shipment mode on a per tonne basis) increased at the expense of the tonnage carried by the other two modes, the regional price level would decrease.11 As Table 2 indicates, barge tonnage had a significant negative effect on the regional price level, as did tonnages carried by truck and air. Table 2 also highlights the fact that barge tonnage had the strongest influence on the regional price level relative to the tonnages carried by truck and air (as reflected by the elasticities of the explanatory variables calculated).

The second model explained the variation in NWT aggregate consumption as a function of disposable income and the regional price level as follows:

\[ C = \theta + \lambda P + \varphi Y + \epsilon \]  

where:
- \( C \) = aggregate consumption in the NWT in constant 1984 dollars (most of which occurs within the Mackenzie Valley);
- \( P \) = regional price level (Yellowknife CPI used as a proxy);
- \( Y \) = personal disposable income in the NWT in constant 1984 dollars, and
- \( \theta, \lambda, \) and \( \varphi \), represent parameters to be estimated.

The relationship expressed in equation 2 represented an attempt to test the hypothesis that the regional price level and the level of disposable income

11. While it is acknowledged that such a model should include supply as well as demand factors, the paucity of requisite data and the overwhelming role of supply-side factors led us to this formulation.
would have negative and positive effects respectively on aggregate consumption in the region. Table 2 indicates that this hypothesis was substantiated in terms of the signs on each of the coefficients and in terms of their significance. A primary motivation for estimating this simple model was to generate an estimate of the price elasticity of consumer demand. This elasticity (see Table 2) was estimated to be -1.06 which implied that a one person decrease in the price level would cause an increase in aggregate consumption on the order of 1.06. Both models were estimated separately via ordinary least squares.

A static input-output (I-O) model was then used to translate the projected aggregate consumption level impacts into impacts on sectoral activity levels as follows,

$$\Delta X = [I - D' \hat{d} B]^{-1} D' \hat{d} \Delta F$$

where:

- $X$ - vector of gross sectoral output levels - (16x1);
- $I$ - an identity matrix - (16x16);
- $D$ - a matrix of sectoral shares derived from the Make matrix (43x16);
- $\hat{d}$ - a diagonal matrix of domestic share coefficients (acts to net out the contribution from foreign sectors) - (16x16);
- $B$ - a matrix of commodity based direct input coefficients derived from the Use matrix - (43x16);
- $F$ - a commodity based final demand vector - in this case the $\Delta F$ vector represents the change in the personal (aggregate) consumption vector - (43x1).

Specifically, the price elasticity of aggregate consumption, as estimated in equation 2, was used to alter the consumption vector of the NWT final demand matrix. For example, under the GFDL Low Probability scenario (the upper bound scenario) equations (1) and (2) projected a 5.3% increase in aggregate consumption expenditures. This was allocated across all sectors (down the consumption column of the final demand matrix) according to the proportion of total consumption expenditures each captured in 1984. This altered final demand vector was then translated, via the static I-O model presented above, into impacts on the gross output levels of all sectors operating in the NWT.

The I-O model shown in equation (3) represents a static model which was closed with respect to households and competitive imports from abroad. That is, in this particular formulation the commodity balance equations were designed to incorporate the linkage between sectoral output levels, the demand for intermediate and primary inputs (labour being one), payments to labour and to unincorporated businesses, aggregate consumption (as dictated by the average propensity to consume), and back to sectoral activity levels (since induced consumption induces a further sectoral output response). The commodity balance equations were also designed to allow the foreign contribution to the domestic supply of commodities to be netted out when sectoral output impacts were computed (via the domestic share matrix referred to above). Table 3 provides a listing of the sector specific impacts as computed by the I-O model, for all climate change scenarios (the 16 sectors listed in Table 3 represent the industry aggregates tracked in the Canadian S level I-O accounts). These impacts are presented as percentage changes relative to 1984 (base period) output levels. These changes represent the changes in sectoral output levels that could be realized in period $t_0 + n$, where $30 < n < 50$, after 2XCO$_2$ climatic changes have affected the physical regime of the Mackenzie Valley. Hence, the base period I-O data (1984) and this set of sectoral impacts represent two "snap-shots", of the NWT economy (as it is represented in the aggregate I-O data) before and after the climatic change. Implicit in this approach is the assumption that the economy of the NWT will not undergo any measurable qualitative (for example, the sectoral distribution of backward and forward linkages) change over the time-frame of climate change.

Although the previously discussed models were run under all climate change scenarios, only the GFDL low probability scenario will be discussed in
TABLE 3 Percentage Changes in Sectoral Gross Output by Scenario

<table>
<thead>
<tr>
<th>Aggregate 5-Level Sectors</th>
<th>GFDL Low % Change</th>
<th>GFDL Med % Change</th>
<th>GISS Low % Change</th>
<th>GISS Med % Change</th>
<th>OSU Low % Change</th>
<th>OSU Med % Change</th>
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<td>0.00</td>
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<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<td>0.00</td>
<td>0.00</td>
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<tr>
<td>4 Mines, Quarries, &amp; Oil Wells</td>
<td>1.14</td>
<td>1.12</td>
<td>1.13</td>
<td>1.10</td>
<td>1.11</td>
<td>1.09</td>
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<td>5 Manufacturing</td>
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<td>28.46</td>
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<td>6 Construction</td>
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<td>7 Transportation &amp; Storage</td>
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<td>36.92</td>
<td>35.86</td>
<td>36.27</td>
<td>35.55</td>
</tr>
<tr>
<td>9 Electricity, Gas, &amp; Other Utilities</td>
<td>51.91</td>
<td>50.63</td>
<td>51.30</td>
<td>49.81</td>
<td>50.41</td>
<td>49.40</td>
</tr>
<tr>
<td>10 Wholesale Trade</td>
<td>18.93</td>
<td>18.46</td>
<td>18.70</td>
<td>18.17</td>
<td>18.37</td>
<td>18.01</td>
</tr>
<tr>
<td>11 Retail Trade</td>
<td>82.03</td>
<td>80.00</td>
<td>81.07</td>
<td>78.77</td>
<td>79.65</td>
<td>78.08</td>
</tr>
<tr>
<td>12 Finance, Insurance, &amp; Real Estate</td>
<td>69.95</td>
<td>68.22</td>
<td>69.12</td>
<td>67.17</td>
<td>67.93</td>
<td>66.58</td>
</tr>
<tr>
<td>14 Transportation Margins</td>
<td>4.81</td>
<td>4.69</td>
<td>4.75</td>
<td>4.62</td>
<td>4.67</td>
<td>4.57</td>
</tr>
<tr>
<td>16 Travel, Advertising, &amp; Promotion</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

detail since it represents an upper bound impact scenario.

The results presented in Table 3 and Figure 2 illustrate that all sectors that were active in 1984 would experience an increased level of gross output in response to the positive increment to aggregate consumption, with the retail trade (#11), finance, insurance and real estate (#12), electricity, gas and other utilities (#9), communication (#8) and manufacturing (#5) sectors showing the greatest impact. Clearly, the service related sectors would experience the greatest output changes under this scenario.

This first scenario attempted to establish a conceptual and operational linkage between physical and economic impact methodologies. It also represented an attempt to take a systems approach to the problem of assessing how the region could be affected by an altered climate. The utility of this integrated approach however, was vitiated by a lack of operations and maintenance cost (O&M) data for the various shipping modes which would have provided an empirical connection between the transportation system, and the economy of the NWT. The approach was also hampered by very aggregate I-O data which provided only a "hazy" picture of the structure of the NWT economy, and the various sectoral impacts. Our primary objective was to develop a detailed scenario of the pathway climate change could traverse to finally affect the regional economy, and to analyze this scenario using conventional methods and available data. This objective was accomplished. This scenario, represents one plausible scenario of how the NWT economy could be affected by climate change.

**Scenario Two: Sectoral Linkage Analysis**

Another way of viewing the effect of climate change on the NWT economy would be to accept the notion that the transportation system would receive the primary impact of a climatic change, and proceed to examine the backward and forward linkages associated with the sector, or sectors, which record the transactions associated with this system. An examination of these linkages would highlight those sectors in the NWT which could stand to be most
If the NWT input-output (I-O) data were sufficiently disaggregate, then an analysis of the backward and forward linkages associated with a "water based transportation sector" or a "land based transportation sector" would suggest how the NWT economy would react to any change in the output levels of these sectors. The present state of the NWT I-O data however did not afford us this clarity. The available NWT I-O data was compiled for 1984 at the S level of sectoral aggregation which is the highest level available in the published Provincial I-O database. Using this aggregation scheme, 16 industrial aggregates are represented in the transactions tables, and each of these represents an amalgam of many types of economic activity. The manufacturing sector for example, consists of approximately 120 different types of manufacturing activity, ranging from metal fabricating, to oil refining, to textile production. The S level sector which contains the transactions we were interested in was the transportation and storage (T&S) sector (#7). This sector includes three main industry aggregates, transportation industries, pipeline industries and storage and warehousing industries. The transportation industries aggregate is also an amalgam of sub-sectors such as air transportation and services incidental, and likewise for barge, truck, and rail systems. Also included within this sub-sector are finer sub-sectors such as urban transit, inter-urban and rural transportation systems, taxi cabs, other transportation industries, and highway and bridge maintenance activities (all of which are nearly non-existent in the NWT). The pipeline industries aggregate represents the sales and purchases made by pipeline operators. In the NWT, there was only one such operator in 1984, Interprovincial Pipelines Ltd. (IPL), and as of 1984, it was not operating. It was however active in completing the line from the Norman Wells field to Zama, Alberta. While it is certainly true that these construction activities would have resulted in a considerable amount of pipeline related activity in 1984, the majority of the linkages were interregional, and, as a result, the pipeline component of the T&S sector would not have been a major consumer of locally produced goods and services in 1984. Even the NWT share of the total labour input to the pipeline project was relatively small. The third component of the T&S sector, the storage and warehousing aggregate, represents a sector which exists mainly to sell storage space to the major shipment modes, such as barge, truck, pipelines and air. The proportion of the total T&S sector activity accounted for by this component was considered to be relatively small. Therefore, given this context, along with the fact that the Norman Wells Pipeline did not begin operating until 1985, we reasoned that the transactions associated with the T&S sector represented, by and large, the sales and purchases made by the land and water based shipping systems in the region. Therefore, we interpreted the linkages associated with the T&S sector as being representative of linkages to a sector which provided water and land based transportation services to the NWT economy, with the intraregional sales and purchases of the pipelines and warehousing components being relatively small.

Implicit in this analysis was the assumption that the net effect of climate change on the transportation system in the NWT would be positive and large, and that the volume carried by pipelines would remain unchanged. These abstractions allowed the linkage analysis to proceed on the premise that linkages associated with the T&S sector represented those of an aggregate shipping sector which was dominated by water and land based shipping.

If the T&S sector were to experience a significant net expansion in overall capacity (due to an extension of the water based shipping season), and if this capacity were fully utilized, then the broader NWT economy could be affected via the backward and forward linkages associated with this sector. Specifically, the T&S sector would draw more intermediate inputs from all supplying sectors, and sectors which draw on the T&S sector would be affected by efficiency gains which would be passed along via forward linkages. To measure these effects, Rasmussen's (1956) power and sensitivity of dispersion indices \( U_j \) and \( U_i \) were computed for all NWT sectors as follows:

\[
U_j = \frac{1}{m} \frac{\alpha_{j}}{\alpha},
\]

\[
U_i = \frac{1}{m} \frac{\alpha_{i}}{\alpha},
\]

where;

\( U_j \) - the power of dispersion index for sector \( j \);

\( U_i \) - the sensitivity of dispersion index for sector \( i \);

\( \alpha_{j} \) - the sum of all Leontief Inverse coefficients down column \( j \) of the matrix;

\( \alpha_{i} \) - the sum of all Leontief Inverse coefficients across row \( i \) of the matrix;

\( \alpha \) - the sum of all row sums in the Leontief Inverse matrix - the grand sum of all coefficients in the matrix;

\( m \) - the number of sectors in the model - 16 in this case; and

\( \alpha \) - a coefficient taken from a demand-side Leontief Inverse matrix.

A high value of the \( U_j \) index for example, suggested that a marginal increase in the final demand for a particular sector's output would result in a relatively large impact on the output of all supplying sectors in the economy. Figure 3
presents $U_i$ and $U_j$ indices for all NWT sectors. The linkage analysis suggested that the T&S sector could indeed be classified as a key sector according to the definition proposed by Hirschman (1958).

Given that the T&S sector was identified as a key sector, the pattern of intraregional backward and forward linkages associated with this sector were analyzed. An examination of the coefficients in the T&S column of the Leontief Inverse matrix (LIM) indicated that this sector was most strongly linked to itself, followed by manufacturing (#5), mines, quarries and oil wells (#4), community, business and personal services (#13), wholesale trade (#10), and finance, insurance and real estate (#12). All of these sectors, with the exception of the community, business and personal services (#13) sector, were also identified as key sectors. Given the definition of the T&S sector, combined with the interpretation given to it in the NWT context, these backward linkages represented, by and large, the intermediate input purchases made by the barge, truck, pipeline, railway and air shipping modes in the region, with the purchases made by the barge and truck systems accounting for the majority.

In terms of forward linkages, the T&S row of the LIM indicated that this sector was most strongly linked to itself, followed by transportation margins (#16), travel, advertising and promotion (#15), and to operating, office and laboratory supplies (#14), with intraregional forward linkages to all other sectors being much weaker.

The finding that the T&S sector had strong backward and forward linkages to itself was interesting since the T&S sector represented a very aggregate industrial category. This result suggested that an increase in the capacity/output of the water and/or land based portion of the T&S sector could have impacts on all facets of the NWT transportation system. Experience suggested that the largest input to the barge system would be trucking activity followed by labour, and storage and warehousing. The strong intrasectoral forward linkage suggested that any efficiency gains experienced by the barge system as a result of a longer season, could be passed on to modes which purchase barge capacity, such as the trucking and pipeline components of the T&S sector. Therefore, a major impact of a climatically induced reorganization of shipping seasons could be lower costs passed on from the basic carrier in the region, Mackenzie barge, to secondary modes such as trucking. The mines, quarries and oil wells sector, which accounted for all of the resource related activity in the NWT, could also experience a positive impact if the barge system of the region were to become more efficient, since the movement of equipment, ore and oil could become less costly.

The linkage analysis illustrated that the T&S sector of the NWT was strongly linked with the broader NWT economy via backward and forward linkages. The forward linkage analysis suggested that the T&S sector had a strong forward linkage to itself. We reasoned that this intrasectoral linkage was dominated by transactions between the various shipment modes in region, and that efficiency gains experienced by the water based shipping system of the region (the dominant seller in the T&S sector) could be passed on to the other shipment modes in the NWT. Once again, this linkage analysis represented one way of visualizing the way in which the NWT economy could react to the climate induced changes to physical regime of the region.

**Conclusion**

The evaluation of these two scenarios suggested that if the climate of the NWT were to change, as climate modellers are suggesting, then the economy of the NWT could experience a measurable economic impact. The first scenario related climate change to the regional economy by translating this change into an impact on exogenous consumption via an impact on the modal distribution...
of freight in the NWT. The results indicated that a reorganization of freight between the three modes in favour of the barge system could result in a significant increase in sectoral output levels generally, with the service sectors showing the greatest percentage changes in gross output. This first scenario represented an attempt to conduct an integrated assessment of the economic impacts.

The conceptual basis for the first scenario was a simple cause and effect model. Although it was recognized that an integrated assessment should include feedback mechanisms, as well as the dynamic nature of other systems besides climate (see Kates et al. 1985), a simple impact model formulation was chosen for this first cut so that we could focus on integration. This integration did provide a pleasing conceptual treatment of the key role played by the physical environment in the NWT economy. However, the set of assumptions used in lieu of an empirical connection between the ice free season and the modal distribution of freight, illustrated a major impediment to conducting this sort of analysis - the lack of requisite, often proprietary, data (for example, detailed O&M data).

The second scenario attempted to trace a more general pathway for the propagation of climate change effects through the NWT economy. This scenario rested on the assumption that the T&S sector would experience a positive net impact, and that this would be passed on to the rest of the NWT economy via backward and forward linkages. The results indicated that the T&S sector was most strongly linked to itself in a backward and forward manner. This suggested that the primary effect of an extended barge season could be the increased use of the other components of the T&S sector (such as trucking, warehousing and storage) by the barge sector. The strong intrasectoral T&S forward linkage suggested that any efficiency gains experienced by the barge sector, as a result of a longer season, could be passed on to the consumers of barge capacity - truck, rail, pipelines and air.

Use of a static input-output model for this analysis also deserves some discussion in terms the applicability of the methodology to this task generally, and the usefulness of the NWT data in particular. The fact that the static model relies on a fixed technology assumption, which precludes the examination of relative price changes, and the associated effects on the input mix structures, limits the applicability of the approach to longer term forecasting. The dynamic input-output framework proposed by Duchin and Lange (1992) which would allow for the endogenous determination of input mix patterns, would certainly be more appropriate for this sort of long term forecasting. We defend this application in this first cut by noting that any effects attributable to climate change such as those suggested above would likely not induce any sort of closure of the NWT economy. In fact, current work dealing with the potential effects on the structure of the NWT economy as a result of various Arctic Oil development scenarios suggest that even these grand schemes will likely not lead to a measurable restructuring of the input mix pattern of the NWT sectors. Detailed discussions with statisticians at the Government of the NWT Bureau of Statistics revealed that conservative expectations under such scenarios include the retention of transportation margins, wholesale margins and minimal labour income effects. Based on this work, our earlier assumption of a static economic structure in the NWT even over the time frame of climate change (30 to 50 years), seems less heroic. This is especially true given the aggregate industrial structure being considered. This is not a justification for ignoring potential effects on input mix structures, but it does suggest that a static model is less problematic in this application than it would be in a region like Ontario.

Furthermore, the impacts discussed represented a stylized interpretation of what these impacts could be at time $t+n$ (where, $30 < n < 50$) with nothing said about the transition from $t = t_0$, $t_0 + 1$, ..., $t_0 + n - 1$, $t_0 + n$. A dynamic formulation such as the one previously referenced would allow for the transient nature of this impact scenario to be more appropriately modelled. Given the very aggregate nature of the available I-O data however, one has to question the utility of such an exercise.

The NWT I-O data used for this analysis was very aggregate. Specifically, the NWT economy was represented as 16 aggregate sectors interacting through trade. This high degree of sectoral aggregation obscured the true structure of the NWT economy, and hence, decreased the usefulness of the results. The fact that the results of this analysis would have been more compelling if sectorally disaggregate data were used is acknowledged. The fact remains that the main purpose of this research was to conceptualize climate change in a manner which was amenable to conventional methods of economic impact assessment, and to ascertain the extent to which these methods are suitable for such analyses, and not to provide a normative planning framework. We believe that this was accomplished.

The next natural step would involve refining this framework in three major ways. Firstly, a strong empirical connection between the transportation system and the regional economy has to be made (a likely starting point would be the acquisition of detailed O&M data for the various modes). Secondly, a rigorous model of transshipment dynamic has to be incorporated (perhaps based on a discrete choice framework). Thirdly, the economic model used here has to be superseded by one that has the ability to incorporate structural change, as well as a sufficient degree of sectoral disaggregation. The third of these is the subject of current work by this author.

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