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Enhancing Performance Measurement: Implementing Computable General Equilibrium Models in Truck-Freight Network Investment Prioritization

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Abstract

The adoption of defensible performance measures and establishment of proven results has become a necessity of many state Transportation Departments. A major factor in demonstrating results is the impact a transportation infrastructure improvement project has on the region's economic climate. Though often previously underrepresented in policy and planning of transportation systems, freight movement plays a critical role in the transference of infrastructure improvement benefits into regional economic impacts. The degree of impact influenced by freight movement improvements is dependent upon location and geographic scale of evaluation. This paper assesses the geographic scale considerations in selecting the modeling framework to evaluate economic impacts. Specifically, we consider the results of regional input-output (I-O) models as compared to those of computable general equilibrium (CGE) models in response to reduced travel time and operating costs in the freight highway network. Though widely used for policy and planning purposes, I-O models have come under criticism for their inability to realistically model the behaviors of a regional economy. Despite their increased flexibility in real-world modeling, CGE models have been resisted due to their complexity of use. We consider the implications of selecting between ease of use and model flexibility at scales ranging from a single county to statewide.

Keywords

Economic Impact, Computable General Equilibrium, Input Output, Truck Freight, Washington

1. Introduction

As we progress further into the 21st Century, the language of current and future federal transportation funding and bills (e.g. MAP-21) point to a growing need among agencies for rigorous analysis of the economic impacts generated via efficiency and productivity gains resultant of infrastructure investment. This paper addresses two common methods used by transportation agencies in evaluating these impacts: the oft used status quo of the Input-Output (I-O) model, and the Computable General Equilibrium (CGE) model—a more sophisticated method which has gained popularity over I-O in academic literature as well as among federal government agencies (e.g. the EPA's EMPAX-CGE) but not necessarily among state-level government agencies.

1.1 Benefit Cost Analysis

Benefit Cost Analysis (BCA) is the common first step, and often the only step, in generating support for, and an understanding of the effects of policies or projects. BCA is readily accepted as an excellent tool for estimating direct benefits. However, as a standalone tool, it fails to account for secondary benefits as well as economic impacts. These impacts, generated by efficiency and productivity gains, could be manifested as changes in the number of jobs, the total output, or the value added of various sectors in a regional economy. In situations where it is unlikely that there will be growth affects or impacts from a policy or project—and that the only substantive change will be in producer and consumer welfare—the BCA is sufficient. This is often the case with small regional or local projects.

It has been pointed out (Banister and Berechman 2001) that for growth to occur, there needs to be a focus on improvements at a network level (e.g. opening new connections between production and consumption centers). It is important to be able to model the relationship between primary transport benefits and potential economic growth effects (Banister and Berechman 2001). If there is no measurable relationship (perhaps because it is too small) then BCA can account for all important economic or welfare changes. However, in order to incorporate growth effects the analysis must "draw on forecasting or economic modelling of impacts" (Abelson 2011 p. 52). Thus, by augmenting a BCA with a general equilibrium impact study, the networks can be made explicit and the resulting growth effects can be teased out. If a project is likely to have a network effect, because it opens a new link or significantly improves an existing one, then a study of its efficacy must include some measure of growth impacts.

1.2 Growth Impact Models

In light of the need to model these sort of impacts, substantial use of statistical models representing the flow of dollars between industries has been used to relate transportation investments to productivity and employment. Abilities garnered from the age of simulation models in the 1980s have allowed transportation planners and academics to forecast transportation project impacts on regional growth. The earliest among these models were based on the I-O models first developed by the Nobel Prize winning economist Wassily Leontief. These models permit the analyst to empirically identify and calculate the relationships between various aspects of a given economy, including production, consumption, and all inter-industry relationships associated with the factors of production (labor and capital) and consumption (earnings or payments).

Despite its age, I-O is still among the most popular methods for determining economic impacts of transportation infrastructure projects and has been used in several recent studies (e.g. RESI 1998, Liu and Vilain 2004, Economic Development Research Group, Inc 2006, Guiliano et. al. 2011). Nevertheless, it comes with a set of well documented liabilities. These arise chiefly from the underlying assumptions built into the model and are summarized in Table 1.

Table 1

I-O assumptions and resulting implications.

Assumption	What it means
Fixed Prices	The model cannot capture changes in production and consumption decisions with respect to changes in relative prices. Price effects are neutral in the model, whereas in reality there may be capacity constraints that cause prices to increase as economies expand. These input price and wage increases could reduce the net impact on output and jobs—even leading to contractions in some sectors of economies. Because I-O does not take into account changes in prices, it is likely to overestimate net impacts (Bandara 1991, Alavalapati et. al. 1998, Dwyer et. al. 2005, Rose and Liao 2005, Dwyer et. al. 2006).
Perfectly Elastic Supply of Factors	In I-O models, there exists an infinite supply of all factors. Because of this, sectors that compete for the same scarce resources in reality will not compete in an I-O model. This framework fails to account for negative impacts that occur when one sector's demand for a resource drives up the price for all other sectors that also depend on that resource (Alavalapati et. al. 1998, Dwyer et. al. 2005, Dwyer et. al. 2006).
Fixed Input Mix	As I-O models use fixed proportion Leontief production functions, it is impossible for them to show substitution effects. For instance, "an industry cannot expand its output in the short run by combining increasing amounts of labor with its fixed capital stock" (Alavalapati et. al. 1998, p. 712). While some have said this fixed input mix more closely models long run outcomes (Cassey et al. 2011), this would only be true if the base year corresponded to the long run optimal input mix.
Exogenous Final Demand	Generally, I-O models are shocked by exogenously shifting final demand. This suggests that any regional and/or international trading activities do not depend on relative prices (Bandara 1991, Alavalapati et. al. 1998).

In their 2005 paper, Rose and Liao point out that because of these assumptions (Table 1), I-O analysis provides only an upper bound estimate of the impacts of a policy or project. Similarly, Dwyer et. al. (2005, p. 351) suggest the method has "inherent biases that overstate the impacts on output and jobs." Attempts have been made to deal with these assumptions by extending I-O models (see Rose and Liao 2005 for examples). However, the basic problems remain.

In contrast, within the context of a CGE model, all of the above-tabulated assumptions can be relaxed—albeit at the cost of adopting a new set of assumptions. Table 2 highlights these adjustments.

Table 2

CGE mechanisms to address I-O assumptions.

I-O Assumption	CGE Comparison
Fixed Prices	CGE models are solved by allowing relative prices to vary until a vector of market-clearing prices is reached.
Perfectly Elastic Supply of Factors	CGE models are capable of incorporating upward sloping supply curves and downward sloping demand curves—though they do not have to. It is also possible to include supply and budget constraints.
Fixed Input Mix	Within a CGE, it is possible to include elasticities of substitution greater than zero, thus the input mix is not necessarily fixed for any of the production functions in the model.
Exogenous Final Demand	While final demand can be shocked in a CGE model, it is also possible, using Armington functions, to mathematically describe final demand endogenously.

The underlying premise of all CGE models is the assumption that if all markets in a given economy are in equilibrium, then any individual market within that economy will also be in equilibrium and therefore a market clearing price and quantity exists for any individual sector of the economy, as well as the whole regional economy. The conceptual flow of activities is relatively simple and straightforward with all firms in an economy producing their own unique goods from inputs (labor and capital) which are provided by the households. These goods, services and commodities are then either utilized as inputs for other firms or consumed by households at the respective market clearing price.

1.3 History of I-O vs. CGE

While the development of I-O models was ground-breaking, the now obvious limitations of those models continue to lead to various attempts to expand them. The first of these came in the early 1960s with the development of Linear Programming (LP) models which allowed for the explicit introduction of primary factor constraints and prices to the models. The CGE model can be thought of as an extension of these early LP models but borrowing from the I-O framework as well. The seminal work on CGE modeling is attributed to Johansen (1960) and is as a blend of neoclassical theory applied to contemporary policy issues (Bandara 1991). Since the development of CGE models, there have been few credible attempts to argue for the use of I-O over CGE. One of these few comes from West (1995) who maintains that in cases for which data is limited and the scope of the project is only for a small region the I-O model may be the only practical option. Similarly, it has been pointed out that where the use of CGE models is "impracticable for reasons of availability or cost, and where only the local regional economic impacts are of interest, I-O models may suffice, but their limitations must be acknowledged" (Dwyer et. al. 2005, p. 351). Rose and Liao (2005) add further argument with the suggestion that the difference between direct and indirect impacts is clearer in an I-O framework. However, they also provide a method for making that distinction in a CGE model. Most peer-reviewed articles dealing with the topic recommend always using CGE over I-O if possible (e.g. Seung et. al. 1997, Rose and Liao 2005, Dwyer et. al. 2005, Dwyer et. al. 2006, Partridge and Rickman 2010, Cassey et. al. 2011).

1.4 Impacts vs. Net Social Benefits

Another issue that ought to be discussed when dealing with regional policy decisions is the difference between economic impacts, as measured through economic impact analysis, and net social welfare, generally estimated using BCA. Welfare is touted as the more appropriate metric for decision making (Abelson 2011, Edwards 1990); however impact is very widely used. This is not for theoretical reasons, but rather because impacts are more readily understood by a lay audience. An impact can be stated as a change in the number of jobs—a very easy to understand and increasingly demanded performance metric; net social benefits are defined in terms of utility, something only economists tend to discuss. It also could be the case that impacts are so popular due to the long-time dominance of I-O models in regional science. Unmodified I-O models are incapable of estimating net social benefits, leaving impacts as the only available metric.

CGE models, on the other hand, can be used to directly estimate social welfare, generally by calculating equivalent variation (e.g. Hirte 1998, Böhringer and Welsch 2004, Nam et. al. 2010). Alternatively, Dwyer and Forsyth (2009) explain that BCA and Economic Impact Analysis (EIA) can be married by subtracting the costs of factors of production from the impact of an event (as calculated in a CGE model) and adding the remainder to the other surpluses calculated through BCA to generate a robust, general equilibrium cost-benefit ratio. While this seems somewhat round-about given that CGE models can directly estimate welfare, it is nevertheless effective.

2. Case Studies

To examine the appropriateness of the application of either a CGE or I-O model to freight impacts from an infrastructure investment, two sample case studies of projects in Washington State were evaluated using both model frameworks. The following section provides the basic background on these sample projects. Refer to Sage et al. (2013) for a complete depiction of the travel demand models implemented to generate the counterfactual values used in the economic impact analysis (EIA) models.

2.1 Project A

Project A was selected as one of the two case studies to test the proposed methodology. The extension project seeks to fill a missing link in the state's highway network. An identified tolling scenario was analyzed for this case study. The scenario assumes building one lane in each direction along segments of the highway, and two lanes in each direction along another (a six-mile long highway). The scenario will also build five partial interchanges. The test scenario additionally assumed that the transit/HOV lane will be converted from the current requirement of at least 2 travelers (a 2+ person HOV lane) to 3 travelers (a 3+ person HOV lane).

The travel performances in the 2030 no-build and build scenarios were modeled by WSDOT's Urban Planning Office (UPO) using the Region A TDM. Truck travel demand in the TDM is pre-defined based on household and employment data. Region A's TDM is a four step gravity model for travel forecasting and has seven basic components: household vehicle availability, person trip generation, trip distribution, mode choice, time of day, truck model, and trip assignment. Within the model, truck trips are generated and attracted at different rates according to the employment categories. For the same forecast year, the number of truck trips remains the same for the no-build scenario and build scenario, and is not affected by highway network improvement. However, truck trips may be re-distributed among origin-distribution (O-D) pairs and re-assigned to other links in the updated network of build scenario, and therefore, there may be changes in truck travel time, travel distance and speed along each link. Trucks in the TDM are subdivided into three categories: light, medium and heavy. Truck traffic is modeled during five time periods including: AM, Midday, PM, Evening, and Night. The TDM converts truck trips to passenger car equivalents during trip assignment, and assumes heavy and medium trucks travel at slower speed compared to passenger cars while formulating the travel cost function. However, the model generates the same travel time and travel speed for all three types of trucks and passenger cars.

2.2 Project B

Project B was selected as the second case study to evaluate the capability of the proposed framework in evaluating the project cost efficiency. The Highway is 9.7 mile critical truck freight corridor serving approximately 5,000 to 7,000 trucks daily in 2011. It is also a strategic freight corridor carrying international and domestic trade. Freight demand in this area is projected to increase by 30 percent over the next 10 years, which will lead to considerable congestion and other negative impacts if the segment cannot accommodate the growing passenger and freight demand. Project B will add two additional lanes (one lane each direction). The impact of the project is modeled using the associated Regional TDM.

Similar to the Region A TDM, Region B's TDM is a standard four-step gravity model, which includes trip generation, trip distribution, mode choice and network assignment components. The truck demand is determined by household and employment data. Therefore no induced demand will be captured by the model. Different from the Region A model, truck trips in the Region B model are modeled as a single category, and are evaluated in four time periods including AM, Midday, PM and Night. The model converts truck counts to passenger car equivalents and employs the same impedance function for passenger car and trucks. The model estimates the same passenger car and truck speed, unless the passenger car speed is greater than the truck speed limit, and in this case the truck speed limit is assigned as the truck speed.

3. Data Inputs and Model Initiation

Economic data for both the I-O and CGE models are generated from the 2010 IMPLAN data. Social Accounting Matrices (SAMs) are generated within IMPLAN and used internally for I-O, and exported to the Generalized Algebraic Modeling System (GAMS) for modeling in the CGE framework. Subsequently, both impact models are generated from the same data source, increasing the comparable nature of the two. IMPLAN's basic structure contains 440 industries, of which we aggregate into 20 sectors in rough accordance with their 2-digit NAICS code (Table 3). The 20 sectors represent common industry classification aggregations that make visualization and interpretation of the model results more fluid. Despite the ability to utilize the same SAM and aggregation scheme, the model initiation cannot be implemented similarly in both frameworks. The implementation strategies for each are detailed next.

TABLE 3
Industry Aggregation Scheme

Aggregation Code	Freight Dependent Industries[a]	Aggregation Code	Other Industries
AGFOR	Agriculture and Forestry	INFO	Information Services
MIN	Mining	FININS	Financial and Insurance
UTIL	Utilities	REAL	Real Estate
CONST	Construction	PROTEC	Professional and Technical
MANUF	Manufacturing	MANAG	Management
WTRAD	Wholesale Trade	ADMIN	Administration
RTRAD	Retail Trade	SOCSER	Social Services
TRAWAR	Transportation and Warehousing[b]	ARTS	Arts and Entertainment
TRUCK	Transport by Truck	FOOD	Food Services
WMAN	Waste Management	OTHR	Other (Including Government)

[a] Industries are classified to largely coincide with the aggregations created in the WSDOT commissioned *Cost of Congestion* study (Taylor, 2011).
[b] The TRAWAR aggregation consists of all transport modes other than Transport by Truck.

3.1 Implementing the Input-Output Model

The nature of IMPLAN's I-O model framework allows an examination of only the backward linkages of industrial interaction. A backwards linkage is that connection where an increase in the output of an industry is modeled. Refer back to Table 1, for potential implications of this strategy. This 'shock' results in the output of all those industries from which the affected industry procures intermediate inputs to also increase to fill the new demand. Thus, modeling a change in output of just the Transport by Truck (TRUCK) sector will not provide proper indication of the forward linkage effects of those who use trucks as an intermediate input for their production; as such, direct modelling of any induced change in truck transport demand due to the benefits generated in the TDM cannot be easily conducted. What this setup would do, via its backwards linkages, is produce indirect effects on those industries from whom the TRUCK sector purchases intermediate inputs. This reflects the required additional output from those sectors to meet the new input demands of the transport by truck sector.

The benefits experienced on the network by carriers are not a direct increase in their output; rather, it is an increase in their productivity. The I-O model in IMPLAN is typically shocked by simulating an increased output (An 'industry change' activity may be modeled in IMPLAN via an event that suggests an increase in sales (output) by the industry). As such, the changes in operating costs and travel time experienced by the trucking firms, as revealed by the TDM, are first converted to a reduction in cost experienced by other sectors; identified as freight dependent industries. Next, the estimates for reduction in production costs must be converted to a change in the output of each sector and thus the amount of trucking services demanded by freight dependent and other sectors (shown in Table 4). By affecting the output of freight users, the backwards linkages of the I-O model may be captured and utilized.

This conversion assumes that a reduction in operating costs and travel time results in a decrease in the price paid for freight transportation services, thus reducing production costs of all freight using sectors. We further assume that this reduction in production costs results in an increase in output by said sectors (amount is dependent upon the elasticity of output with respect to production cost) and the transportation, along with other intermediate input sectors must then follow – as per the associated backward linkages - by increasing their own output (Table 4). Central to the methodological steps outlined here, is the ability to assume a production cost reduction for every industry that directly purchases trucking services in a manner that is consistent with their current usage patterns. Friedlaender and Spady (1980) characterize freight transportation as a productive input that should be treated analytically like any other input. Further, they find - as have others since (Abdelwahab 1998) - own price elasticity of demand for trucking services to be near unity ($e = -1$); particularly in the Pacific Northwest. The estimated values tend to be dependent upon both commodity and region. Regional consideration in this literature is at the national level, thus providing no indication of variability of this elasticity within a state like Washington.

The functional relationship between production cost reductions experienced by each sector and their output changes is given by (Seetherman et al. 2003):

(1) $$D_{1i} = D_{0i}(X_{1i}/X_{0i})^{e} ,$$

where,

D_{0i} = Output before Infrastructure Investment for Industrial Sector i (IMPLAN generated)

D_{1i} = Output after Infrastructure Investment for Industrial Sector i

X_{0i} = Cost of Production attributable to trucking before Infrastructure Investment for Industrial Sector i

X_{1i} = Cost of Production attributable to trucking after Infrastructure Investment for Industrial Sector i

e = Elasticity of output with respect to production cost (Currently set to -1)

(2) $$X_{1i} = X_{0i}(1-\Delta TC*a_{i}) ,$$

where,

ΔTC = Percent change in trucking costs

a_i = Technical coefficient (relates the dollar value of TRUCK services required by an industry to produce a dollar of output)

Equations 1 and 2 are repeated for each industry sector (Table 4). The value generated by the difference between D_{0i} and D_{1i} is the value by which the I-O model is shocked for each industrial sector (Table 5 and 6). The I-O model is conducted as a single *Industry Change Activity* with 20 E*vents* occurring. It should be noted here that the operating cost reductions experienced by the transport by truck sector are the benefits experienced in the year calculated by the associated TDMs and discounted to a 2010 value. Unlike BCA, Economic Impact Analyses do not calculate NPV. Instead, the impact is expected to occur and change the state of the region's economy, putting it on an altered trajectory that can be assumed to be carried forward in time, all else being equal.

It should be observed that the values by which the I-O models are shocked (Table 4) do not add up to an equivalent number as that which is reported as the TDM Outputs (Tables 5 and 6). This difference is a result of the operation of Equations 1 and 2, and dependent upon the given industries technical coefficients. In other words, the benefits experienced by the TRUCK sector (TDM Output) do not simply get divided equally among each user. Each freight-using sector experiences its own benefit based on its truck usage and does not take away from the benefit experienced by other sectors. The changes are all based on percent changes in costs of a productive input; transport by truck.

TABLE4
Direct impact values used to 'shock' the I-O model. (D_{0i}-D_{1i}).

Sector	Output Difference (Direct Impact)			
	Project B		Project A	
	Region B	State	Region A	State
AGFOR	$ 99,403	$ 332,880	$ 142,267	$ 599,489
MIN	$ 22,384	$ 11,838	$ 10,821	$ 21,319
UTIL	$ 34,608	$ 11,186	$ 12,683	$ 20,146
CONST	$ 814,596	$ 891,195	$ 1,903,838	$ 1,604,970
MANUF	$ 1,538,011	$ 3,676,578	$ 8,231,583	$ 6,621,221
WTRAD	$ 124,007	$ 123,123	$ 295,483	$ 221,730
RTRAD	$ 448,051	$ 440,302	$ 927,216	$ 792,941
TRAWAR	$ 60,858	$ 103,532	$ 284,331	$ 186,449
TRUCK	$ 394,358	$ 393,869	$ 709,479	$ 709,368
INFO	$ 50,992	$ 216,427	$ 701,978	$ 389,759
FININS	$ 35,449	$ 28,964	$ 67,010	$ 52,161
REAL	$ 46,310	$ 64,485	$ 147,809	$ 116,130
PROTEC	$ 58,235	$ 110,303	$ 283,016	$ 198,642
MANAG	$ 42,199	$ 40,484	$ 117,242	$ 72,907
ADMIN	$ 37,673	$ 40,103	$ 95,887	$ 72,222
WMAN	$ 11,048	$ 37,069	$ 44,170	$ 66,757
SOCSER	$ 366,592	$ 278,242	$ 598,448	$ 501,083
ARTS	$ 34,771	$ 47,652	$ 116,446	$ 85,817
FOOD	$ 150,378	$ 165,760	$ 355,526	$ 298,516
OTHR	$ 335,883	$ 430,895	$ 919,828	$ 775,992
Total	$ 4,705,806	$ 7,444,887	$ 15,965,060	$ 13,407,618

TABLE 5
Productivity Increases from Project B

TDM Output	$ 4,533,563[a]
Region B Intermediate Expenditures (TRUCK)	$ 139,875,763
Statewide Intermediate Expenditures (TRUCK)	$ 1,760,368,000
Change in Truck Transport Productivity (ΔTC) –Region B	3.24%
Change in Truck Transport Productivity (ΔTC) -State	0.26%

TABLE 6
Productivity Increases from Project A

TDM Output	$	8,164,392[a]
Region A Intermediate Expenditures (TRUCK)	$	869,913,300
Statewide Intermediate Expenditures (TRUCK)	$	1,760,368,000
Change in Truck Transport Productivity(ΔTC) - Region A		0.94%
Change in Truck Transport Productivity (ΔTC) -State		0.46%

[a] IMPLAN is all 2010 data, so the TDM model outputs are converted to 2010. Benefits include reduced operating costs and travel time savings. Emissions not included.

3.2 Implementing the Washington State CGE Model

Professors David Holland, Leroy Stodick and Stephan Devadoss developed a statewide regional CGE model that has been used extensively for evaluating economic impacts from a host of policy changes. These include applications ranging from statewide economic impacts from mad-cow disease to impacts from tariffs on Canadian softwoods and, more recently, for the legislative mandated "Biofuel Economics and Policy for Washington State" study completed in 2010. For a detailed description of this model, including model closure, specified import demand functions, export supply functions, factor demand functions and household demand functions, please see http://www.agribusiness-mgmt.wsu.edu/Holland_model/index.htm.

For the application at hand, four versions of the regional CGE are built; a statewide model and a county or counties level model for both case studies. For each case, models are established as a long-run (LR) evaluation in which capital and labor are mobile across sectors and the region-wide endowment is allowed to vary. The LR scenario depicts full realization of the benefits through the economy once it has had time – several years - to fully adjust. Short-Run (capital is fixed across industrial sectors and the total endowment for the geographic region is also fixed)

CGE models were also evaluated, though dropped in favor of the long-run model due to the nature of the projects in which the expectation is that an economic trajectory change is induced that should be permanently in place. The CGE model utilizes a set of equations and elasticities to reproduce the economy's inter-sector relationship in response to the produced counterfactual statements. Prior to introduction of the counterfactual, the models' parameters are calibrated such that it regenerates the original SAM. Example parameters used in calibration include various demand, substitution, and transformation elasticities.

Arguably, a transportation improvement project that reduces freight movement travel time and operating costs is in essence a technology improvement that permits the truck transportation industry to become more productive (increased efficiency) for a given level of capital and labor. These efficiencies are generally realized through reduced driver time on the road resulting in reduced labor costs; increased trip miles per unit of time per vehicle, resulting in more productive individual vehicles and thus requiring fewer trucks to accomplish the workload; and reduced vehicle repair and operating costs (FHWA, 2002). As such, each CGE model is initiated using the shift parameter (ad_A) for the industry's production function. This shift parameter, when adjusted, causes a shift to the industry's Leontieff-Constant Elasticity of Substitution (CES) production function (1). The production function is Leontieff-CES in such a manner that the intermediate inputs are in fixed proportions (Leontieff) while the factors of production possess CES technology. The value assigned for the shift parameter is dependent upon the percent change in operating costs of the trucking industry (ΔTC in Tables 5 and 6). The percent change is dependent upon outputs of the travel demand model, the intermediate demand, and the selected regional coverage.

(3) $$QA_A = \frac{ad_A}{1-tb_A-\sum_C ica_{C,A}} * \left(\sum_{FF} del_{FF,A} QF_{FF,A}^{-rho_A}\right)^{\frac{-1}{rho_A}}$$, where

The shift parameter (2) is expressed as:

(4) $$ad_A = \frac{\left(\frac{SAM_{TOTAL,A}}{PAO_A}\right) * \left(1-tb_A-\sum_C ica_{C,A}\right)}{\left(\sum_{FF} del_{FF,A} * QFO_{FF,A}{}^{-rho_A}\right)^{\frac{-1}{rho_A}}}, where$$

QA_A =	Activity Level (endogenous variable; where truck transport in the present model is the activity of concern
tb_A =	Indirect business tax rate of industry A (parameter calculated from initial data)
$ica_{C,A}$ =	Quantity of C (commodity) as intermediate input per unit of activity A (parameter calculated from initial data)
$del_{FF,A}$ =	Share parameter
$QF_{FF,A}$=	Quantity of FF (factors of production) demanded by activity A (endogenous variable)
PAO_A =	Initial activity price of A (user established)
rho_A =	Exponent for production function
$SAM_{TOTAL,A}$ =	Social accounting matrix exported from IMPLAN
$QFO_{FF,A}$ =	Initial quantity of FF demanded by activity A (calculated from initial data)

3.2.1 Regional Coverage

The model developed by Holland et al. is a generic representation of Washington's economy, although one developed to closely represent how the state's economy functions and adheres to traditional neoclassical economic theory. Currently the model represents Washington State's economy, the rest of the U.S., and the rest of the World (only to the extent that Washington's economy interacts in these larger economies). However, by simply changing the region of consideration in IMPLAN, both the CGE and I-O models can be formulated to consider a subset of counties within Washington. Thus, in addition to comparing outputs between modeling frameworks, we also consider the effects of a changing geographic scale. For each of the two case studies, we construct the statewide models and sub-state models containing the county or counties (Identified as Region A or B) where the infrastructure improvement activity occurs and is related to the geographic scale of the TDMs.

4. Results: Regional Economic Impacts

The resulting outputs and changes in employment are displayed in the tables below for the various operations described above. Both infrastructure improvement projects were evaluated at two geographic scales to better examine how variations in the structure of the local economy impact model output. Both projects were examined at the state level (indicated as 'statewide' in the tables). Due to the nature of the evaluated projects, Project B was evaluated at the scale of a single county. Project A was evaluated at the scale of four contiguous counties. The four counties were selected due to their incorporation in the Region A TDM.

Though there are multiple ways to display the results of economic impact models, the most common and straightforward are in relation to changes in employment and regional output (this is also the standard method of display in IMPLAN). It is important to note here that the recorded outputs in the tables below are not directly indicative of the quantity of activity occurring within the sector. The outputs are a measure of change of sales generated in the region by the sector. As such, the outputs displayed here are a function of the calculated price of the commodity in the sector and the quantity of activity. For instance, in all CGE models, the price of the transport by truck commodity is reduced and its activity quantity is increased; however, not all models generate an increased sale dollar amount. The interplay of price and quantity dictate the direction of sales output change.

- A job in IMPLAN = the annual average of monthly jobs in that industry (this is the same definition used by QCEW, BLS, and BEA nationally). Thus, 1 job lasting 12 months = 2 jobs lasting 6 months each = 3 jobs lasting 4 months each. A job can be either full-time or part-time.
- Output represents the value of industry production. In IMPLAN these are annual production estimates for the year of the data set and are in producer prices. For manufacturers this would be sales plus/minus change in inventory. For service sectors production = sales. For Retail and wholesale trade, output = gross margin and not gross sales.

Infrastructure improvements such as those considered here provide a change in the state of the interactions of the factors within the economy. The change in state can be visualized as a step-up in the employment or output trend lines (Figure 1). The units of the figure are not included, as this is a generic representation of what may be expected. Thus, the changes in employment and output in the tables to follow represent the vertical value of the step and are characterized as the employment or output change in a single year. As this is not a forecasting model, we do not project the model forward. We only indicate that a change of state occurs and from that point forward, numerous factors influence the employment levels and industrial output.

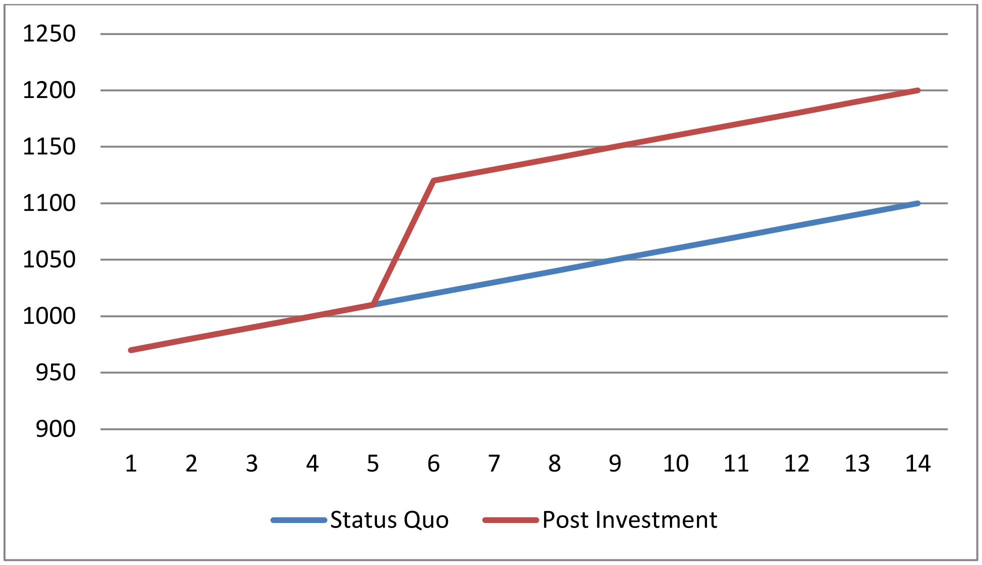

Fig. 1. Generalized Change in the State of the Economy Following Infrastructure Investment

Given the calculated output changes (direct impacts) resulting from the projects (Table 4) and the changes to trucking productivity (Tables 5 and 6), Tables 7 through 9 display the produced results for Project B, while Tables 10 through 12 display those for Project A. Interestingly, the results reveal that in all of the long-run CGE models, TRUCK has negative changes in employment numbers; job loss. At first glance, this may appear counterintuitive. However, these results can be thought about in relation to a cost of congestion study done previously in Washington State (Taylor, et al. 2013). Taylor's survey and subsequent Input-Output modeling suggests that freight-dependent companies may respond to increased congestion (reduced productivity) by adding trucks (increasing employment). An opposite reaction is simulated here. In the present case, the TDMs suggest congestion relief stemming from the infrastructure improvement producing a positive effect, in that they simulate consumers increasing purchases of services and non-freight dependent goods (increased activity), as well as a negative effect that simulates the trucking industry's response of reducing employment.

In addition to the jobs modeled to be lost in the trucking sector, the sector associated with other transportation modes and warehousing (TRAWAR) also projects some, though markedly fewer, losses in each CGE model. Due to the aggregated nature of the sector, it cannot be directly determined which components of this sector are suggested to lose jobs; however, warehousing activity is the likely culprit given its intimate relationship with the TRUCK sector. Often, warehousing is aggregated with the transport by truck sector. Most of the sectors demonstrate only marginal changes in employment levels, with most experiencing less than a five job change. The information services sector is shown in three of the four CGE models to lose jobs, these numbers are low and likely an artifact of the model seeking equilibrium.

The sectors where job gains are substantial enough to take notice are found in several heavily freight dependent sectors. This is particularly true for the manufacturing sector in all models, as well as agriculture and forestry in the Region B and statewide models. These two sectors combined, more than offset the losses experienced in the truck-transport sector. Other notable sector employment gains include retail trade gains resulting from Project A. Unlike manufacturing or agriculture and forestry, whose impacts are primarily direct effects, the impacts seen in relation to the social services sector are largely generated by induced effects.

It is important to preface the I-O model results by noting that the I-O will never produce a negative number when modeling an increase in output by a sector. This goes for the sectors directly impacted as well as all the indirect and induced effects. In essence (due to lack of information about the number of trucks added or reduced), we are only modeling one piece of the potential response. We see congestion relief from the project producing a positive effect in that it stimulates consumers to increase purchases of services and non-freight dependent goods (consumer benefit). The I-O model does not account for the trucking industry becoming more efficient and able to do more with fewer trucks. Given this, it is not surprising that in for three of the four models (only Region B differs), the I-O model results in higher job growth estimates. However, taking the output change under consideration, CGE models result in greater changes than their I-O counterparts. This observation is a result of the flexibility built into the CGE model through the counterfactual used that increases the productivity of the trucking sector for given levels of capital and labor. Additionally, the long-run scenario creates a more flexible system that allows the allocation of both factors of production, capital and labor in an optimal manner.

The Region B model produces markedly different outcomes than do the other three models. As already stated, the CGE model in Region B produced employment gain numbers greater than the I-O and generated output changes more than three times that of the I-O; a substantially larger difference than the other models. These differences largely stem from the structure of the economy in the various regions of consideration. The structure of the economy, here, is meant to relate the relative size of the various sectors and their interrelationships with each other (e.g. the technical coefficients relating how much trucking services are purchased by the various sectors). Given the total size of the Region A economy in relation to the state as a whole, it is not surprising that the relationships between sectors are more similar than that of Region B.

PROJECT B

TABLE 7
Summary results (Project B)

	Employment	Output
Statewide Model		
LR-CGE	47.3	$22,241,506
I-O	81.5	$13,272,773
Region B Model		
LR-CGE	78.0	$28,675,616
I-O	65.5	$8,071,935

TABLE 8
Industry sector specific results in Region B from Project B

	Employment Change		**Output Change**	
Sector	**LR-CGE**	**I-O**	**LR-CGE**	**I-O**
AGFOR	14.5	2.1	$ 810,244	$ 122,594
MIN	0.2	0.1	$ 116,766	$ 47,671
UTIL	0.5	0.2	$ 574,019	$ 108,358
CONST	2.8	6.3	$ 400,511	$ 849,474
MANUF	45.8	5.6	$13,676,449	$1,732,818
WTRAD	5.6	2.2	$ 1,281,445	$ 325,035
RTRAD	9.6	10	$ 1,070,359	$ 690,476
TRAWAR	-2.6	1.2	$ 125,054	$ 148,070
TRUCK	-38.0	4.1	$ (179,227)	$ 463,447
INFO	0.8	0.6	$ 338,942	$ 154,072
FININS	1.6	2.6	$ 1,658,911	$ 564,862
REAL	3.1	2	$ 2,032,816	$ 579,957
PROTEC	5.0	3.1	$ 1,123,688	$ 292,864
MANAG	4.1	0.8	$ 852,326	$ 143,644
ADMIN	6.5	2.6	$ 579,023	$ 149,181
WMAN	0.2	0.1	$ 89,747	$ 22,833
SOCSER	2.5	7.9	$ 1,661,203	$ 724,719
ARTS	2.1	1.7	$ 129,897	$ 67,695
FOOD	5.8	4.7	$ 532,115	$ 277,366
OTHR	7.8	7.6	$ 1,801,328	$ 606,799
Total	**78.0**	**65.5**	**$28,675,616**	**$8,071,935**

TABLE 9
Industry sector specific results statewide from Project B

	Employment Change		Output Change	
Sector	LR-CGE	I-O	LR-CGE	I-O
AGFOR	13.7	4.6	$ 1,353,582	$479,343
MIN	0.4	0.1	$ 91,114	$30,208
UTIL	0.3	0.1	$ 338,505	$65,987
CONST	2.5	6.4	$ 165,292	$939,173
MANUF	27.0	9.9	$11,510,000	$4,668,419
WTRAD	2.9	2.7	$ 749,878	$447,570
RTRAD	6.8	10.9	$ 631,774	$792,796
TRAWAR	-3.2	1.7	$ 166,450	$264,503
TRUCK	-32.8	4	$ 80,113	$479,240
INFO	-0.9	1.1	$ 214,267	$548,862
FININS	2.5	3	$ 1,030,947	$660,760
REAL	2.4	3	$ 1,497,725	$890,036
PROTEC	2.3	4	$ 763,024	$475,012
MANAG	1.7	1	$ 410,089	$198,876
ADMIN	3.4	3	$ 350,103	$195,586
WMAN	0.1	0.2	$ 60,675	$66,798
SOCSER	6.8	8.3	$ 1,165,260	$755,616
ARTS	1.3	2.1	$ 98,533	$102,694
FOOD	3.8	5.7	$ 294,753	$343,971
OTHR	6.2	9.7	$ 1,269,422	$867,323
Total	47.3	81.5	$22,241,506	$13,272,773

PROJECT A

TABLE 10
Summary results (Project A)

	Employment	Output
Statewide Model		
LR-CGE	85.1	$40,032,564
I-O	147.0	$23,903,155
Region A Model		
LR-CGE	55.5	$34,797,920
I-O	135.9	$23,163,908

TABLE 11
Industry sector specific results in Region A from Project A

	Employment Change		Output Change	
Sector	LR-CGE	I-O	LR-CGE	I-O
AGFOR	2.6	0.9	$ 458,833	$ 162,220
MIN	0.5	0.1	$ 81,161	$ 24,809
UTIL	0.2	0.1	$ 282,394	$ 82,423
CONST	3.5	11.2	$ (220,120)	$ 1,765,154
MANUF	65.8	16	$26,940,775	$ 7,287,183
WTRAD	4.9	4.6	$ 1,217,588	$ 828,811
RTRAD	11.8	18.1	$ 856,045	$ 1,421,375
TRAWAR	-22.5	3.6	$ (1,972,232)	$ 619,333
TRUCK	-52.3	6.6	$ (443,142)	$ 846,983
INFO	-6.2	2.6	$ (1,770,518)	$ 1,449,344
FININS	4.1	5.6	$ 1,576,007	$ 1,266,748
REAL	2.9	5.4	$ 1,846,269	$ 1,582,808
PROTEC	2.3	7.4	$ 865,956	$ 987,127
MANAG	5.2	2.2	$ 1,188,807	$ 455,877
ADMIN	2.7	5.6	$ 382,313	$ 412,955
WMAN	0.2	0.3	$ 63,573	$ 84,163
SOCSER	12.4	15.2	$ 1,538,130	$ 1,466,137
ARTS	2.3	4.2	$ 124,164	$ 219,494
FOOD	5.9	10.3	$ 321,379	$ 649,390
OTHR	9.2	15.9	$ 1,460,538	$ 1,551,574
Total	55.5	135.9	$34,797,920	$23,163,908

TABLE 12
Industry sector specific results statewide from Project A

	Employment Change		Output Change	
Sector	LR-CGE	I-O	LR-CGE	I-O
AGFOR	24.7	8.3	$ 2,434,388	$863,258
MIN	0.7	0.2	$ 163,883	$54,401
UTIL	0.6	0.2	$ 609,093	$118,837
CONST	4.4	11.6	$ 297,974	$1,691,373
MANUF	48.5	17.8	$20,710,000	$8,407,446
WTRAD	5.3	4.8	$ 1,349,171	$806,033
RTRAD	12.2	19.7	$ 1,137,063	$1,427,753
TRAWAR	-5.7	3.1	$ 301,464	$476,347
TRUCK	-58.9	7.3	$ 150,264	$863,115
INFO	-1.6	2	$ 387,011	$988,445
FININS	4.5	5.4	$ 1,855,827	$1,189,973
REAL	4.2	5.4	$ 2,695,406	$1,602,876
PROTEC	4.1	7.1	$ 1,373,595	$855,452
MANAG	3.1	1.8	$ 737,807	$358,158
ADMIN	6.2	5.4	$ 630,411	$352,234
WMAN	0.1	0.4	$ 109,365	$120,297
SOCSER	12.3	15	$ 2,097,184	$1,360,793
ARTS	2.3	3.8	$ 177,371	$184,943
FOOD	6.9	10.3	$ 530,516	$619,458
OTHR	11.1	17.4	$ 2,284,771	$1,561,963
Total	85.1	147	$40,032,564	$23,903,155

5. Discussion and Recommendations

Infrastructure improvement projects that reduce operating costs and travel time of freight users on the roadway is an activity that inherently affects the productivity and economic efficiency of the user; two critical components that are addressed in the National Freight Policy provisions of MAP-21. As readily available and user friendly as I-O models are, their major drawback is the difficulty and often inability to fully simulate a change in productivity directly. To assess the economic impacts of such infrastructure improvement projects, the benefits experienced by the users must be manually translated into a change in demand by freight users. The preceding sections detail the methods by which this conversion may be accomplished. Despite being able to compute the change in demand, the I-O model described here is not able to fully account for the improved productivity of the trucking industry, and thus cannot confidently model how the trucking sector meets the increased demand.

Where infrastructure projects are large enough and productivity is increased to the point that now fewer trucks – and therefore fewer drivers – can meet the demand needs, we may experience a reduction in employment in the transport-by-truck sector. The I-O model does not pick this up. However, the CGE is able to directly model increased productivity of an industry and are thus able to model the entire economy-wide reaction to the infrastructure improvement that is a result of decreased operating cost and travel time. It is for this specific ability to model productivity changes that a regional CGE model should be incorporated into the prioritization process as an add-on tool to the BCAs commonly used in policy decision support. Together, these analyses will better inform agency prioritization decisions with regard to the affect infrastructure projects have on freight systems and the economy that is necessarily interwoven with them. As more benefits accrue and are accounted for, the impact on the economy will continue to grow. Thus, as capabilities to account for benefits stemming from increases in reliability are developed, a more complete impact can be assessed.

This research represents an early phase of a developing program in which the researchers aim to enhance the capacity of transportation planners to reasonably anticipate the potential implications of competing projects and management systems. Future efforts along this line will develop dynamic feedback opportunities between the CGE model and the TDM models such generalizations such as that shown in Figure 1 may be modeled and better understood. Other possible research directions could include quantitative measures of equity resulting from transportation projects and more direct modeling of welfare effects.

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