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Economic loss analysis to Prince Edward Island resulting from a prolonged closure of the Confederation Bridge

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This article models the economy of Prince Edward Island (PEI) and its dependency on value of goods, services and people moving in both directions across the Confederation Bridge (linking PEI with mainland New Brunswick). Based on extensive interviews, responses to a company survey, and economic data from Statistics Canada, we develop models to estimate the economic loss caused by the closure of the Confederation Bridge for periods of seven days, thirty days, and ninety days. These time periods are based on a single example scenario which, depending on the speed and effectiveness of HazMat response, could result in the closure of the Confederation Bridge for approximately 7 days if minor repairs are necessary, approximately 30 days if moderate repairs are necessary or approximately 90 days if major repairs are necessary.

In 2011, a Consolidated Risk Assessment (Lebel 2012) on Prince Edward Island (PEI) identified a disruption in the service of the Confederation Bridge as an extreme risk requiring further study. In addition to the immediate risk to public health and safely, the potential harm to the local economy of Prince Edward Island constitutes a critical second order concern.

This study models the effect that a forced closure of the confederation bridge would have on the PEI economy, specifically employment and GDP. We employ a new approach making use of a combination of industry consultation and surveys paired with a comprehensive general equilibrium model. The survey data informs an assessment of the direct industry level productivity implications of a forced bridge closure. We then use a Computational General Equilibrium (CGE) Model to simulate the general equilibrium effects of such a productivity shock to the PEI economy.

Our methodology is novel in that the usual approach to simulating the impacts of transportation disruption does so via a direct shock to trade costs rather than via a productivity shock to productive sectors.[1] The model is similar to that used by Fellows & Tombe (2018) in their assessment of northern Canadian infrastructure quality and related trade costs. However, because of the transient nature of the shock we use a short run CGE model formulation wherein capital and resource factor supplies are perfectly inelastic and immobile (cannot be reallocated across sectors) while labour factor supply is perfectly elastic. While this approach is somewhat novel, it is nonetheless directly analogous to a typical short-run production function as developed in a principles microeconomics course and we assert it is a useful abstraction of economy wide effects resulting from a short run shock.[2]

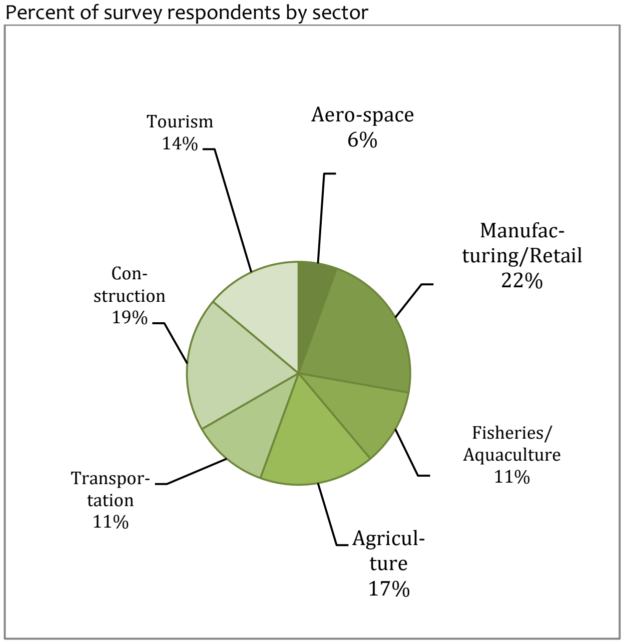
Historically, the multiplier style effects of this type of short run shock have been analyzed via the use of traditional Input Output (IO) models. However the assumptions underpinning Input Output models and the interpretation of their results has been subject to significant criticism (Grady & Muller 1988; Alavalapati, Adamowicz, & While 1998; Gretton 2013).

More specifically, Hall (2004) (in reference to port impact studies, which are conceptually similar to our case of a land-link bridge for an island economy) indicates several criticisms of traditional multiplier input-output approaches for this kind of study. Hall notes that the use of fixed proportions production and trade functions (as in an IO multiplier model) and the assumption of fixed demand do not represent accurate or useful abstractions, noting specifically the need to recognize the role that substitution plays in this kind of disruption. Hall also takes issue with the nature of the initial shocks fed into the model noting that these analysis typically stimulate a fixed and exogenous change in port cargo throughput, which may not be a reasonable approach. To rectify these issues, Hall proposes that a better quality impact assessment would be achieved through gathering "additional data" about the nature of the initial shock and employing a more sophisticated general equilibrium approach.[3]

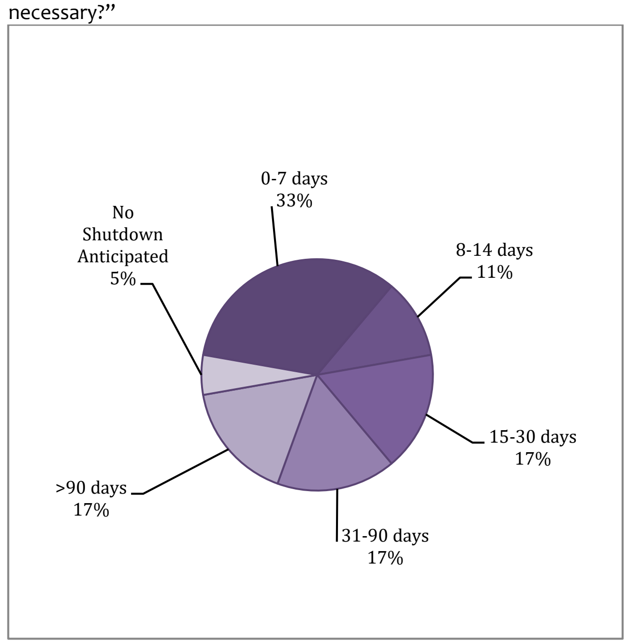
We assert that our analysis does exactly that. Rather than calculating or assuming a specific exogenous change in throughput (goods shipped across the bridge) we collect data on the expected productivity implications of a forced bridge closure via our survey results. These are then fed into a CGE model which allows for substitution both between productive inputs to specific sectors, and between regional sources of inputs within PEI and in other regions. The use of a CGE framework also allows us to implement the aforementioned fixed and immobile capital assumptions.[4] As-

Figure 1 Survey results.

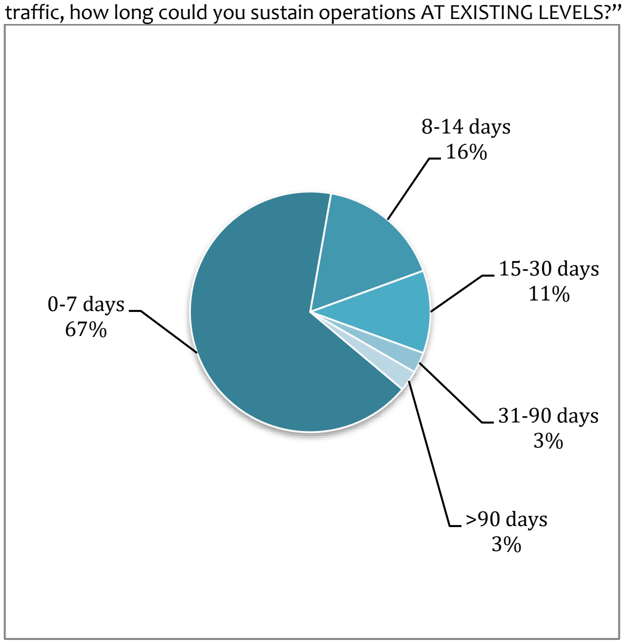
Percent of survey respondents by sector



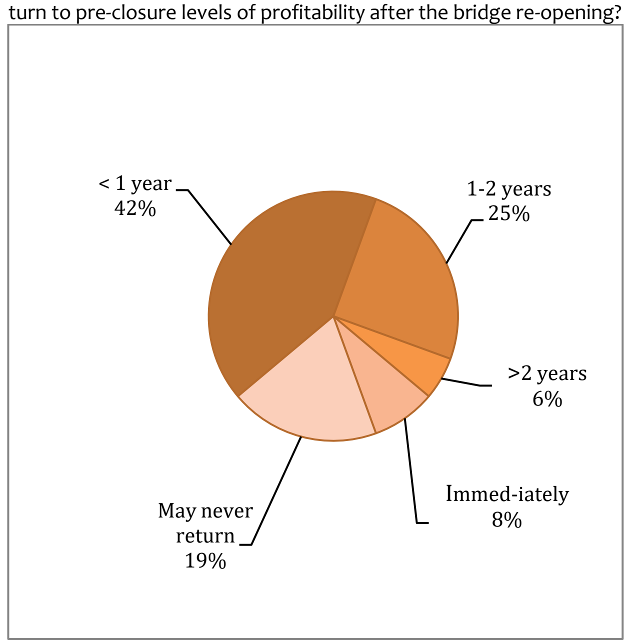
Question Response: “If there were a closure to the bridge to ALL traffic, when would a complete shutdown of your organization be necessary?”



Question Response: “If there were a closure to the bridge to ALL traffic, how long could you sustain operations AT EXISTING LEVELS?”



Question Response: “How long would it take for your business to return to pre-closure levels of profitability after the bridge re-opening?



sumptions which represent a more accurate abstraction of the PEI economy in the short run (before wages and capital allocations adjust to the shock).

Transport Canada has acknowledged the Government of Canada’s responsibility to provide a continuous link between PEI and the mainland (Transport Canada 2012). Currently a review with respect to the contingency plan is underway and revisions to the existing plan are expected.

The current contingency plan states that the estimated time required to fully replace a span of the bridge is approximately 32 months and outlines three phases:

1. Short-term (1-18 days): assessment period to determine the length of time the bridge may be closed;
2. Transition period (18-90 days): arrangement for permanent “replacement ferry service” including

Table 1. Direct economic shock (per cent reduction in industry productivity) across PEI sectors and scenarios.

Survey Results	Summer						Winter					
	Week		Month		Quarter		Week		Month		Quarter	
Sector	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accommodation and Food	58.0%	76.0%	76.0%	100.0%	76.0%	100.0%	79.0%	100.0%	76.0%	100.0%	76.0%	100.0%
Arts, Entertainment, Rec*	51.0%	100.0%	76.0%	100.0%	76.0%	100.0%	N/A	N/A	N/A	N/A	N/A	N/A
Crop and Animal Production	18.3%	42.3%	19.0%	43.0%	37.5%	61.5%	20.5%	44.5%	26.8%	50.8%	44.3%	68.3%
Engineering Construction	16.8%	41.0%	30.6%	54.8%	52.6%	77.0%	0.8%	24.8%	12.6%	36.6%	34.9%	58.9%
Fishing, Hunting and Trapping	76.0%	100.0%	76.0%	100.0%	76.0%	100.0%	76.0%	100.0%	76.0%	100.0%	76.0%	100.0%
Manufacturing	29.8%	49.3%	53.0%	72.5%	67.7%	87.3%	31.6%	46.7%	43.8%	64.1%	46.4%	89.4%
Non-Residential Construction	16.8%	41.0%	30.6%	54.8%	52.6%	77.0%	0.8%	24.8%	12.6%	36.6%	34.9%	58.9%
Other construction	16.8%	41.0%	30.6%	54.8%	52.6%	77.0%	0.8%	24.8%	12.6%	36.6%	34.9%	58.9%
Repair Construction	16.8%	41.0%	30.6%	54.8%	52.6%	77.0%	0.8%	24.8%	12.6%	36.6%	34.9%	58.9%
Residential Construction	16.8%	41.0%	30.6%	54.8%	52.6%	77.0%	0.8%	24.8%	12.6%	36.6%	34.9%	58.9%
Transport and Warehousing	10.3%	34.3%	32.5%	56.5%	48.5%	72.5%	11.0%	35.0%	33.0%	57.0%	48.8%	72.8%

Prorated On Length of Shock	Summer						Winter					
	Week		Month		Quarter		Week		Month		Quarter	
Sector	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Accommodation and Food	1.12%	1.46%	6.35%	8.36%	19.05%	25.07%	1.52%	1.92%	6.35%	8.36%	19.05%	25.07%
Arts, Entertainment, Rec*	0.98%	1.92%	6.35%	8.36%	19.05%	25.07%	N/A	N/A	N/A	N/A	N/A	N/A
Crop and Animal Production	0.35%	0.81%	1.59%	3.59%	9.40%	15.42%	0.39%	0.86%	2.24%	4.24%	11.11%	17.12%
Engineering Construction	0.32%	0.79%	2.56%	4.58%	13.19%	19.30%	0.02%	0.48%	1.05%	3.06%	8.75%	14.77%
Fishing, Hunting and Trapping	1.46%	1.92%	6.35%	8.36%	19.05%	25.07%	1.46%	1.92%	6.35%	8.36%	19.05%	25.07%
Manufacturing	0.57%	0.95%	4.43%	6.06%	16.98%	21.89%	0.61%	0.90%	3.66%	5.36%	11.62%	22.42%
Non-Residential Construction	0.32%	0.79%	2.56%	4.58%	13.19%	19.30%	0.02%	0.48%	1.05%	3.06%	8.75%	14.77%
Other construction	0.32%	0.79%	2.56%	4.58%	13.19%	19.30%	0.02%	0.48%	1.05%	3.06%	8.75%	14.77%
Repair Construction	0.32%	0.79%	2.56%	4.58%	13.19%	19.30%	0.02%	0.48%	1.05%	3.06%	8.75%	14.77%
Residential Construction	0.32%	0.79%	2.56%	4.58%	13.19%	19.30%	0.02%	0.48%	1.05%	3.06%	8.75%	14.77%
Transport and Warehousing	0.20%	0.66%	2.72%	4.72%	12.16%	18.17%	0.21%	0.67%	2.76%	4.76%	12.23%	18.25%

*Arts, Entertainment and Recreation is not directly shocked in the winter scenarios. Survey responses indicated no noticeable loss of business in this scenario given the relative lack of economic activity in this sector in the winter months in PEI.

Source: Authors

finding an operator and commencing the service;

3. Long term (90 days to 32 months); operation of "replacement ferry service".

Thus, the first ninety days are to be spent assessing and planning the arrangements for implementation of replacement ferry service. We estimate the economic loss caused by the closure of the Confederation Bridge for a period of seven days, thirty days, and ninety days. These time periods are based on a single example scenario as defined by Transport Canada (2012) under which a potential closure of the Confederation Bridge for ~7 days if minor repairs are necessary, ~30 days if moderate repairs are necessary or ~90 days if major repairs are necessary.[5]

PEI represents the smallest region within Canada where detailed input output data, required for the calibration of a CGE model, is available.[6] While our analysis is specific to the PEI case, it is likely that the general conclusions here may be indicative of the impacts of similar shocks to other regional economies. A prime example is the town of Churchill, which has faced a significant adverse shock due to natural flood damage washing out the only rail line linking it to the rest of the Canadian overland transportation grid (there is no highway connectivity to Churchill), a situation that is analogous to a forced closure of the confederation bridge.

Our survey analysis and by extension the direct shocks simulated via our CGE model focus on industries that rely most heavily on the Confederation Bridge (as identified via industry interviews). These industries include: Agriculture, Forestry, Fishing and Hunting; Construction; Manufacturing; Retail Trade; Transportation and Warehousing; and Tourism. The survey methodology produced a range of likely productivity impacts for these sectors further differentiating between potential summer and winter disruptions. As such, we run a total of 12 independent scenarios representing all combinations of the impact range (high, low), season (winter, summer) and duration (7 days, 30 days, 90 days). Based on these scenarios our simulations project PEI GDP losses to be a minimum of $14.5 M (the low end for a 1 week closure during winter) and a maximum of $287.6 M (The high end for a 90 day closure during summer).

Interview and Survey Methods and Results

Methods

To understand the implications to the PEI economy if a catastrophic event to

Table 2. Simulated reduction in Annual PEI GDP due to a closure of the Confederation Bridge across all scenarios.

	Summer					
	Week		Month		Quarter	
	Low	High	Low	High	Low	High
Percent Change From Benchmark	-0.28 %	-0.38 %	-1.49 %	-2.09 %	-4.33 %	-5.37 %
Level Change (in Constant 2011 dollars)	-$13.25 M	-$21.74 M	-$79.89 M	-$112.08 M	-$232.20 M	-$287.58 M
	Winter					
	Week		Month		Quarter	
	Low	High	Low	High	Low	High
Percent Change From Benchmark	-0.27 %	-0.40 %	-1.34 %	-1.91 %	-3.98 %	-4.91 %
Level Change (in Constant 2011 dollars)	-$14.53 M	-$21.54 M	-$71.99 M	-$102.52 M	-$213.06 M	-$263.19 M

Source: Authors

Table 3. Computable General Equilibrium model estimates of job losses on PEI, as percentages of total employment, due to a closure of the Confederation Bridge for a period of one week, one month and one quarter (7, 30 and 90 days).

	Summer					
	Week		Month		Quarter	
	Low	High	Low	High	Low	High
Percent loss	-0.52%	-0.87%	-3.52%	-4.91%	-11.58%	-14.69%
Jobs lost	-530	-754	-3,206	-4,460	-10,536	-13,541
	Winter					
	Week		Month		Quarter	
	Low	High	Low	High	Low	High
Percent loss	-0.57%	-0.86%	-3.12%	-4.52%	-9.60%	-14.61%
Jobs lost	-530	-784	-2,806	-4,035	-8,723	-13,062

Source: Authors

the Confederation Bridge would occur, we initially interviewed representatives from PEI's Sector Councils as well as a number of businesses. We then distributed surveys to target companies across seven sectors.

Companies across all of the target sectors were contacted to identify company representatives who had detailed knowledge of the company's finances. A researcher emailed or called the respective individual to organize a date and time to conduct an in-person interview whenever possible. All company representatives were notified that the interviews would be voice-recorded for later transcribing, and should take between 30-45 minutes. Then a research assistant met with the company representative and asked a series of questions to better understand their company's reliance on the bridge. If the company representative was not currently situated in PEI, the interview was completed by phone.

At the time of the interview, the research assistant met the company representatives in their offices or a meeting area located at their respective workplaces and asked a series of pre-defined questions regarding the effects of possible supply chain disruptions to their business. The research assistant could ask for clarification or additional details to given responses. Interviews generally lasted between 15-45 minutes, depending on the nature of the company representative's responses. Following the interview, the research assistant used the audio recording to transcribe a text version of the conversation, allowing easier analyses and comparisons between responses. Responses received via the semi-structured interviews were used to identify common themes and relevant areas of interest to be included in the Economic Impact Assessment survey.

It became clear during the process of interviewing sector council representatives and companies across major industries that we needed to develop a survey tool to measure the economic impact from an individual company perspective. Company representatives were reluctant to discuss financial matters in an interview setting. We controlled the distribution of the survey to ensure that the recipients would possess the expertise and knowledge needed to answer the questions with authority; by design, the sample size was small. However, given the relative size of the PEI economy, the firms in the sample (those that responded to the survey) account for approximately 5.3% of total provincial employment and a higher percentage of employment in the target sectors indicated above.[7]

Survey questions were designed to limit bias and inconsistencies following Bickman *et al*. 2009. Overall methodology, survey design and the online delivery of the survey was based on accepted and established methods (Evans & Mathur 2005; Saris & Galihofer 2007; Sudman, Bradburn, & Schwarz 1996; Ponzi, Fornbrun, & Gardberg 2011). In particular, short-form scales were included to ease design and delivery of the survey, specifically length and page formatting, in ways that enhance respondent participation and survey effectiveness (Couper, Michael, & Mark 2001).

Surveys were distributed to PEI businesses across all target sectors and an effort was made to ensure a representative sample including small, medium, and large businesses. The terms of the survey clearly indicated that responses should be educated estimates, not official business statements. Respondents did not have to identify which business they were rep-

Equation 1

$$\hat{Y}_{(i,r)} = \theta_{i,r}[(Capital\ Labour\ Nest)^{\rho_s} + (Composite\ Input\ Nest)^{\rho_s}]^{(1/\rho_s)}$$

$$Capital\ Labour\ Nest = \left[\beta_{K,i,r}(\bar{K}_{i,r})^{\rho_{va}} + \beta_{L,i,r}(L_{i,r})^{\rho_{va}}\right]^{(1/\rho_{va})}$$

$$Composite\ Input\ Nest = \left[\sum_j \beta_{j,i,r}(A_{j,i,r})^{\rho_m}\right]^{(1/\rho_m)}$$

resenting, but were asked to provide some basic information including the firm's industry sector and size (as measured by number of employees).

Responses to questions were multiple choice and included ranges of values. For example, for the question of the effect on a company's revenue should the bridge be closed the responses included 0-25%, 26-50%, 51-75% and 76-100%. For each sector the responses were weighted by company size and averaged separately for the lower and upper limits of each quartile. Averages based on the lower quartile range correspond to the "Low" impact scenarios fed into the CGE model while those based on the upper quartile range correspond to the "High" impact scenario.

Survey Results

We distributed surveys to 76 target companies across seven sectors. The response rate in excess of 45% is well above the average cited for similar surveys (Fan & Yan 2010). Figure 1 summarizes the survey population as well as key survey responses.

The top left panel of Figure 1 shows the sectoral breakdown of the survey population, which includes a sampling from all major private sectors in PEI. As the bottom left panel shows, most businesses (67%) would not be able to sustain operations at existing levels for more than a week and only 6% of businesses would be able to sustain operations at existing levels for more than thirty days indicating that any productivity shock would be widely disseminated across firms. As shown in the top right panel, a closure of the Confederation Bridge to all traffic would cause one in three PEI businesses surveyed to completely shut down within one week. Four out of five businesses would completely shut down within three months. Only five percent of PEI's private businesses expect to be able to continue operations in the event of an extended closure of the bridge.

Further to the immediate impact, firms expect any negative productivity impacts to continue even past reopening of the Confederation Bridge. As the bottom right panel of Figure 1 shows, one in five businesses expect that they may never fully return to pre-closure levels of profitability. This suggests long-term, lingering effects for some sectors, even after the bridge reopening. Other sectors are more resilient with half of respondents indicating a return to pre-closure profitability within a year (8% immediately on the reopening of the bridge and 42% at some point during the first year after reopening).

CGE Model

Method/Formulation

In order to simulate the economy wide impacts of the bridge closure we employ a CGE model of the Canadian economy. The model in question is programmed as a mixed complementarity problem in the GAMS language (Brooke, Kendrick, & Meeraus 1996) using the MPSGE Syntax developed by Rutherford (1999).

The productive side of the economy is modelled as a set of nested constant elasticity of substitution production functions for each of 35 sectors across 13 regions.[8] There is a single representative consumer and a single representative government for each region. Consumer income is generated through factor markets whereby consumers are compensated for providing labour, capital and natural resources to productive industries. The representative governments provide a fixed level of government services which is paid for through a combination of output taxes on productive sectors and a lump sum tax on representative consumers. The output tax rate is determined by the calibration parameters while the lump sum tax adjusts endogenously to cover any government budget shortfall. Bilateral trade between provinces and territories within Canada and with international trading partners is modeled using the Armington (1969) composite approach, which allows for the differentiation of goods produced in the same sector in different regions.

Labour is assumed mobile across sectors but not across regions (that is, the supply of labour in PEI is assumed fixed). Given the short-run nature of the initial shock, capital and resource endowments are fixed and immobile (sector specific) while we assume perfectly elastic labour supply consistent with a sticky wage model of involuntary unemployment in the short run.

We present a full mathematical description of the CGE model logic in an appendix below. However it is useful to present the modelled production function for exposition here to provide clarity on how the model parameters are varied to represent the sector specific productivity shocks.

All sector level production is represented by nested constant elasticity of substation (ces) functions. The general form for these functions is presented in *Equation 1* where, for industry i in sector r: $\hat{Y}_{(i,r)}$ is the total industry production; $\theta_{i,r}$ is the total factor productivity; $\beta_{K,i,r}$, $\beta_{L,i,r}$ and $\beta_{j,i,r}$ are input share parameters for the Capital (K), Labour (L) and intermediate goods (from industries j). $\bar{K}_{i,r}$ is the (exogenous) capital input to the sector, $L_{i,r}$ is labour usage in the sector and $A_{j,i,r}$ is the intermediate goods (from industries j) usage as delivered through an Armington composite. The elasticity of substitution within each nest is determined by ρ_s for the top

Table 4. Computable General Equilibrium model estimates of job losses (Number of Jobs Lost) on PEI by Sector due to a closure of the Confederation Bridge for a period of one week, one month and one quarter (7, 30 and 90 days).

	Summer						Winter					
	Week		Month		Quarter		Week		Month		Quarter	
Sector (NAICS)	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Manufacturing	-147	-242	-1,037	-1,391	-3,225	-3,834	-155	-230	-879	-1,255	-2,469	-3,890
Accommodation and Food Services	-109	-146	-630	-835	-1,907	-2,494	-146	-188	-621	-826	-1,872	-2,476
Retail Trade	-44	-75	-300	-426	-1,055	-1,380	-46	-71	-256	-380	-840	-1,324
Health Care and Social Assistance	-34	-58	-226	-321	-767	-992	-36	-56	-200	-295	-640	-975
Transportation and Warehousing	-11	-33	-136	-227	-558	-791	-12	-34	-134	-226	-545	-790
Crop and Animal Production	-18	-38	-90	-181	-481	-770	-19	-40	-111	-203	-527	-843
Other Services (Except Public Administration)	-13	-22	-88	-126	-307	-403	-14	-21	-77	-114	-251	-387
Arts, Entertainment and Recreation	-24	-46	-156	-207	-477	-628	-3	-4	-15	-22	-48	-72
Residential Construction	-14	-21	-89	-117	-259	-315	-18	-24	-90	-119	-237	-348
Finance, Insurance, Real Estate etc.	-11	-19	-75	-109	-272	-363	-11	-18	-64	-98	-221	-347
Fishing, Hunting and Trapping	-15	-21	-77	-104	-256	-339	-15	-21	-73	-100	-230	-339
Educational Services	-9	-16	-63	-91	-225	-302	-10	-16	-53	-81	-184	-278
Engineering Construction	-9	-14	-59	-78	-174	-212	-12	-16	-60	-79	-158	-234
Non-Residential Building Construction	-8	-13	-53	-70	-155	-188	-11	-14	-54	-71	-142	-208
Wholesale Trade	-5	-9	-37	-53	-131	-172	-6	-9	-32	-48	-105	-169
Professional, Scientific and Technical Services	-3	-6	-23	-33	-82	-109	-4	-6	-20	-30	-68	-106
Other federal government services	-3	-6	-22	-33	-80	-106	-3	-5	-18	-29	-64	-99
Admin, Waste Management and Remediation	-3	-4	-18	-25	-63	-84	-3	-4	-15	-22	-50	-76
Other municipal government services	-2	-3	-11	-15	-37	-47	-2	-3	-9	-13	-29	-46
Information and Cultural Industries	-1	-2	-8	-12	-29	-38	-1	-2	-7	-10	-23	-37
Other provincial and territorial government services	-1	-2	-6	-9	-22	-29	-1	-2	-5	-8	-18	-28
Utilities	-1	-1	-4	-5	-14	-19	-1	-1	-3	-5	-11	-18
Other activities of the construction industry	0	0	-1	-2	-6	-9	0	0	-1	-2	-4	-7
Support Activities for Agriculture and forestry	0	0	-1	-2	-5	-8	0	0	-1	-2	-5	-8
Other (non-energy) Mining	0	0	-1	-1	-2	-3	0	0	-1	-1	-2	-3
Forestry and Logging	0	0	-1	-1	-2	-2	0	0	0	-1	-1	-2
Support activities for oil and gas extraction and mining	0	0	0	0	-1	-1	0	0	0	0	0	-1
Repair Construction	0	2	4	14	55	96	-3	0	-6	3	22	48
Grand Total	**-530**	**-754**	**-3,206**	**-4,460**	**-10,536**	**-13,541**	**-530**	**-784**	**-2,806**	**-4,035**	**-8,723**	**-13,062**

Sectors modelled but not appearing on this table are excluded either because they show no activity in the benchmark or because they show no significant labour response to the counterfactual shock. These include: Government education services; Government health services; Non-profit institutions serving households; Other provincial and territorial government services; Owner occupied dwellings; Crude Oil Extraction, Natural Gas Extraction; Coal mining.

Source: Authors

level nest, ρ_{va} for the Capital Labour nest and ρ_m for the composite input nest. Specifically $\rho = (\sigma - 1) / \sigma$ where σ is an elasticity parameter specific to each sector (i) and nesting level. Values for each share parameter are calibrated to data while the values for the elasticities are presented in the Appendix.

In application, the model uses three ces function variants depending on the type of industry. Most industries follow *Equation 1* exactly, however the utilities sectors includes an additional nest representing a fuel composite (see *Equation **2*** in the appendix) and resource extraction sectors have an added term in the top level nest to represent the resource factor endowment (see *Equation **3*** in the appendix).

For each sector and region in the model, the production function is paired with a standard zero profit condition and a market clearing condition (see *Equation **9***, *Equation **10*** and *Equation **12*** in the appendix).

Given that the CGE model is calibrated to annual data, model shocks are scaled based on the indicated duration for different scenarios: 1/52 for a 1-week duration, 4.34/52 for a 1-month duration and 13.04/52 for a 1-quarter duration. The direct productivity shocks are indicated in Table 1. To introduce the shocks to the model, we scale the benchmark calibrated TFP parameters ($\theta_{i,r}$ in *Equation 1*) by a

Table 5. CGE Model sensitivity analysis.

	2009	2010	2011
Week Winter Low	-0.25 %	-0.28 %	-0.27 %
Month Winter Low	-1.22 %	-1.40 %	-1.34 %
Quarter Winter Low	-3.39 %	-4.22 %	-3.97 %
Week Winter High	-0.37 %	-0.41 %	-0.40 %
Month Winter High	-1.70 %	-2.01 %	-1.91 %
Quarter Winter High	-3.55 %	-5.42 %	-4.90 %
Week Summer Low	-0.23 %	-0.25 %	-0.25 %
Month Summer Low	-1.38 %	-1.56 %	-1.49 %
Quarter Summer Low	-3.61 %	-4.70 %	-4.32 %
Week Summer High	-0.38 %	-0.42 %	-0.40 %
Month Summer High	-1.90 %	-2.20 %	-2.09 %
Quarter Summer High	-4.19 %	-5.87 %	-5.35 %

Source: Authors

factor of (1 – Shock Value), where the Shock value is the percent value from the bottom panel of table 1. It is important to note here that the shocks fed into the model are based on point estimates of the productivity losses as informed by the survey results discussed above.[9]

The GDP for the province of PEI is approximately $6 billion. From Table 2, the CGE model estimates that after a one week closure of the Confederation Bridge, the effect on GDP is relatively low, between $13M and $22M (0.3% to 0.4% of the total PEI GDP). After one month, the effect would be between $72M and $112 million (1.5 to 2.1% of the total GDP). Once the bridge has been closed three months simulated GDP decreases by between $213 and $288 million (4-5.3% of the total GDP).

The CGE estimate of job loss (as measured by FTEs) is shown in Table 3. After a 1 week closure PEI is projected to lose between 530 and 784 FTEs. After a one-month closure, the number increases to between 2,806 and 4,460. After a closure of three months, the CGE model simulates very significant losses of 8,712 to 13,541 FTEs.[10]

Table 4 shows that generally across all scenarios job losses tend to fall predominantly across a small set of subsectors. Specifically: Manufacturing, Accommodation and Food Services, Retail Trade, Health Care and Social Assistance, Transportation and Warehousing, and Crop and Animal Production. Of these, the two sectors that standout are Retail Trade and Health Care and Social Assistance. Unlike the other sectors listed, neither of these sectors receives a direct shock.

As modelled, the impact on both of these sectors comes through 2 channels. First, each sector uses inputs from other sectors (some of which do receive a direct productivity shock), meaning that their input costs will rise. Due to the associated zero profit assumption for all productive sectors (see the appendix) this in turn implies an increase in the prices of industry outputs. Second, because of other job losses and productivity losses throughout the PEI economy, consumer income has fallen. So, even though these sectors do not receive a direct shock, the price effect (higher price implies lower demand) and the income effect (lower income implies lower demand) both drive down the demand for production from these sectors which implies a reduction in sectoral output and employment.

While the public (government demand sector) demand for output from the Health Care and Social Assistance sector remains fixed, there is scope for varying private consumer demand. In the benchmark private PEI consumption spending in this sector accounts for $100 million out of the total $213 million in revenue. Still job loss figures for this sector in particular should be interpreted with caution given that our model uses a very simple abstraction of consumer preferences.[11]

To investigate the robustness of our results we provide a basic sensitivity analysis using alternative calibration years. The results presented above in the text and in Tables 2, 3 and 4 derive from a model calibrated to a 2011 base year. Table 5 presents the GDP results using 2009 and 2010 alternatives in addition to the base 2011 calibration.[12] As table 5 shows, there is little variation in the shock results across the various calibrations for the shorter (week long and month long) shocks. However, for the Quarter long shock, especially in the summer, the variation is more pronounced (between 4.19% and 5.87%) suggesting a moderate degree of uncertainty as the length of the shock grows.

Discussion

During the in-person interviews, several of the company representatives commented on the importance of this study. They hoped that it would have a positive impact on developing a more efficient contingency plan (e.g., shorter time period with no transport on/off PEI) and a more robust preventative plan (e.g., preventative measures that would decrease the chance of an event like this from happening). They felt confident in their ability to estimate the effects of a prolonged bridge closure. Many companies have been affected by short bridge closures as well as other situations that have occurred and have drastically affected their ability to transport goods and services (e.g., impact on the potato industry by the potato wart, which limits the export of the product).

Furthermore, as the survey responses demonstrate, the localized stresses to the supply chain networks may result in a major negative impact on the PEI economy for a significant timeframe even after the bridge is repaired. Based on interviews with local PEI businesses, the first scenario (7-day bridge closure) would result in localized stresses but not cause a major impact. However, the second and third scenarios (bridge closures of 30 and 90 days respectively) could have destructive impacts to the local businesses including shutdowns, major layoffs, and loss of investment. This highlights the need for a robust emergency response plan which prioritizes the safety of the bridge structure with the aim to mitigate the risk of damage to the bridge and to reduce the time of closure. Currently, if a section of the bridge is severely damaged and needs to be replaced, repairs may take up to 32.5 months to complete (Transport Canada 2012). The results of this study suggest that shortening this timeframe dramatically reduces the scale of risk faced by the PEI economy.

While the survey sample focused on private sector firms, the potential impact on the public sector also deserves discussion. The interview portion of this study included detailed discussions with the Health Authority on PEI (Health PEI), from which it became clear that a closure could also present significant challenges for the delivery of healthcare in the province.

Representatives from Health PEI suggested that compromising the daily utilization of the bridge could lead to supply chain challenges in terms of medication, equipment, and standard consumables and could impact the standard and unplanned maintenance of equipment and building systems. A contingency plan which specifically addresses these concerns would be an asset to the PEI population. This concern is reinforced through the CGI simulations which predict significant detrimental impacts on the Health Care and Social Assistance sector despite the fact that this sector is not directly shocked in our simulations (all impacts come through secondary impacts via upstream and downstream linkages in the sector).

Conclusion

The present study quantifies the loss in economic activity due to the closure of a critical piece of infrastructure to PEI, the Confederation Bridge. The objective was to provide insight into the sectors of the provincial economy that would be most adversely affected by such an event. This may assist infrastructure owners and operators, federal and provincial governments, security and law enforcement agencies, first responders and academic experts in assessing how to effectively allocate resources for future disaster prevention and mitigation.

The report findings demonstrate a significant economic impact associated with a prolonged closure of the Confederation Bridge. Using CGE model estimates, the GDP economic impact on PEI due to a 90 day closure could be $288 million representing 5.4% of total GDP and a loss of 8,723 to 13,541 FTE jobs representing 10% to 15% of the PEI workforce.

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Appendix – Summary Mathematical Description of the CGE model

Prior to expositing the functions, we first outline the relevant variable and set declarations:

Set, Alias	Definition
i,j	The total set of productive sectors in the model
e	A subset of sectors indicating extractable resource production (e.g.- Crude oil, Coal, Natural Gas)
r,q	The total set of regions
CIG	The set of final demand categories (sectors) $\{C: Consumption, I: Investment, G: Government\}$

Variable	Definition
Endogenous	
$\hat{Y}_{i,r}$	Total production of good I in region r
$Y_{i,r,q}$	Total production of good i in region r moving to region q
$\hat{A}_{i,j}$	Total Armington composite of good i available as an intermediate input in region r
$A_{i,j,r}$	Total Armington composite of good i used as an intermediate input in sector j in region r
$L_{i,r}$	Total use of Labour by sector i in region r
$\tilde{L}_r$	Total Labour supply in region r
X_i	Total international export demand for sector i
$M_{i,r}$	Total international imports
$P_{Y\ i,r}$	Price of good i in region r
$P_{X\ i,r}$	International export price of good I to region r
$P_{A\ i,r}$	Price of the Armington composite of good i in region r
$P_{K\ i,r}$	Price of Capital in sector i and region r
$P_{R\ i,r}$	Price of effective resource stock e in region r
Exogenous	
$\bar{R}_{(e,r)}$	Total stock of extractable resource e in region r
$\bar{K}_{i,r}$	Total stock of Capital in sector i and region r
$\bar{P}_{M\ i,r}$	International import price of good I to region r
$\bar{W}_r$	Wage rate in region r

Parameter	Definition
$\theta_{i,r}$	Total factor productivity for sector 1 in region r
$\beta_{*,i,r}$	Production share for each * into sector i in region r.
$\alpha_{i,*,r}$	Armington share for sector i moving from region * to region r.
$\tau_{i,r}$	Effective output tax rate in sector i for region r
ρ_*	$\rho_* = (\sigma - 1) / \sigma$ where σ is an elasticity parameter for a CES nest (defined by *). This parameter takes on different values depending on the sector over which it is indexed, however for notational simplicity we omit the sector index from the parameter.

In general elasticities of substitution for the production functions are set consistent with the General Equilibrium Emissions Model (GEEM) and Canadian Integrated Modelling System (CIMS) models (Peters *et al*. 2010 and Paltsev *et al.* 2005). Internal and International trade elasticities (those governing the behavior of the Armington composite) use the same approach as Albrecht & Tombe (2016) and Fellows and Tombe (2018) and are set consistent with Caliendo & Parro (2015) where possible and equal to 5 elsewhere. Calibration data for the model's technical parameters is drawn directly from Statistics Canada (2011) Provincial Symmetric Input-Output Tables.

CES Production Functions

Intermediate production sectors other than Utilities and Extractable Resource Production

(such that $i \neq \{e, Utilities\}$):

Restatement of Equation 1

$$\hat{Y}_{(i,r)} = \theta_{i,r}[(Capital\ Labour\ Nest)^{\rho_s} + (Composite\ Input\ Nest)^{\rho_s}]^{\left(1/\rho_s\right)}$$

$$Capital\ Labour\ Nest = \left[\beta_{K,i,r}\left(\bar{K}_{i,r}\right)^{\rho_{va}} + \beta_{K,i,r}\left(L_{i,r}\right)^{\rho_{va}}\right]^{\left(1/\rho_{va}\right)}$$

$$Composite\ Input\ Nest = \left[\sum_j \beta_{j,i,r}\left(A_{j,i,r}\right)^{\rho_m}\right]^{\left(1/\rho_m\right)}$$

Utilities (such that $i \equiv Utilities$):

Equation 2

$$\hat{Y}_{(i,r)} = \theta_{i,r}[(Capital\ Labour\ Nest)^{\rho_s} + (Fuel\ Input\ Nest)^{\rho_s} + (Composite\ Input\ Nest)^{\rho_s}]^{\left(1/\rho_s\right)}$$

$$Capital\ Labour\ Nest = \left[\beta_{K,i,r}\left(\bar{K}_{i,r}\right)^{\rho_{va}} + \beta_{L,i,r}\left(L_{i,r}\right)^{\rho_{va}}\right]^{\left(1/\rho_{va}\right)}$$

$$Fuel\ Input\ Nest = \left[\sum_{j \in \{Coal, Natural\ Gas\}} \beta_{j,i,r}\left(A_{j,i,r}\right)^{\rho_n}\right]^{\left(1/\rho_n\right)}$$

$$Composite\ Input\ Nest = \left[\sum_{j \neq \{coal.Natural\ Gas\}} \beta_{j,i,r}\left(A_{j,i,r}\right)^{\rho_m}\right]^{\left(1/\rho_m\right)}$$

Extractable Resource production:

Equation 3

$$\hat{Y}_{(e,r)} = \theta_{e,r}\left[\beta_{R,i,r}\left(\bar{R}_{(e,r)}\right)^{\rho_s} + (Extraction\ Nest)^{\rho_s}\right]^{\left(1/\rho_s\right)}$$

$$Extraction\ Nest = [(Capital\ Labour\ Nest)^{\rho_u} + (Composite\ Input\ Nest)^{\rho_u}]^{\left(1/\rho_u\right)}$$

$$Capital\ Labour\ Nest = \left[\beta_{K,i,r}\left(\bar{K}_{e,r}\right)^{\rho_{va}} + \beta_{L,i,r}\left(L_{e,r}\right)^{\rho_{va}}\right]^{\left(1/\rho_{va}\right)}$$

$$Composite\ Input\ Nest = \left[\sum_j \beta_{j,i,r}\left(A_{j,i,r}\right)^{\rho_m}\right]^{\left(1/\rho_m\right)}$$

The nested CES function generating final goods production is:

Equation 4

$$Y_{(CIG,r)} = \theta_{CIG,r}\left[\sum_j \beta_{j,CIG,r}\left(A_{j,CIG,r}\right)^{\rho_s}\right]^{\left(1/\rho_s\right)}$$

CES Aggregation:

The Armington Composite CES function (used to aggregate inputs from trade) is:

Equation 5

$$\hat{A}_{(i,r)} = \left[\alpha_{i,r,r}\left(Y_{(i,r)}^{r}\right)^{\rho_s} + (Imports\ Nest)^{\rho_s}\right]^{\left(1/\rho_s\right)}$$

$$Imports\ Nest = \left[\alpha_{i,M,r}{M_i}^{\rho_m} + \sum_{q \neq r} \alpha_{i,q,r}\left(Y_{i,q,r}\right)^{\rho_m}\right]^{\left(1/\rho_m\right)}$$

CES Demand Functions

Consumer Demand/Budget Function:

Equation 6

$$\left(P_{Y\ C,r} \times \hat{Y}_{C,r}\right) + \left(P_{Y\ I,r} \times \hat{Y}_{I,r}\right) = \left(\overline{W}_r \times \sum_i L_{i,r}\right) + \sum_i \left(P_{K\ i,r} \times \overline{K}_{i,r}\right) + \sum_e \left(P_{R\ i,r} \times \overline{R}_{(e,r)}\right) - (Lump\ Sum\ Transfer)$$

Government Demand/Budget Function:

Equation 7

$$\hat{Y}_{(G,r)} = \left(P^{y}_{(i,r)} \times Y_{(i,r)} \times \tau_{(i,r)}\right) + (Lump\ Sum\ Transfer)$$

Export Demand:

Equation 8

$$X_{i,r} = \overline{X_{i,r}}\left(P_{X\ i,r}\right)^{\rho_f}$$

where $\overline{X_{i,r}}$ is an exogenous constant (in application, this constant is equal to the benchmark value of international exports).

Zero Profit Conditions

Producing sectors (other than extractable resource such that $i \neq \{e\}$):

Equation 9

$$\left(P_{Y\ i,r} \times \hat{Y}_{i,r}\right)\left(1 - \tau_{(i,r)}\right) = \sum_j \left(P_{A\ j,r} \times A_{j,i,r}\right) + \overline{W}_r \times L_{i,r} + P_{K\ i,r} \times \overline{K}_{i,r}$$

Zero Profits for all extractable resource producing sectors:

Equation 10

$$\left(P_{Y\ e,r} \times \hat{Y}_{e,r}\right)\left(1 - \tau_{(e,r)}\right) = \sum_j \left(P_{A\ e,r} \times A_{j,e,r}\right) + \overline{W}_r \times L_{e,r} + P_{K\ e,r} \times \overline{K}_{i,r} + P_{R\ i,r} \times \overline{R}_{(e,r)}$$

Zero Profits for all Armington sectors:

Equation 11

$$\left(P_{A\ i,r} \times \hat{A}_{i,j}\right) = \sum_q P_{Y\ i,r} \times Y_{i,r,q} + \overline{P}_{M\ i,r} \times M_{i,r}$$

Market Clearing Conditions

Market clearing conditions for all producing sectors:

Equation 12

$$\hat{Y}_{i,r} = \sum_q \left(Y_{i,r,q}\right) + X_{i,r}$$

Market clearing conditions for all Armington sectors:

Equation 13

$$\hat{A}_{i,j} = \sum_j \left(A_{i,j,r}\right)$$

Market clearing condition for labour:

Equation 14

$$\sum_i L_{i,r} = \tilde{L}_r$$

Endnotes

[1] See for example Nguyen & Wigle (2009, 2011).

[2] See for example undergraduate level textbooks such as Mankiw *et al*. (2002) who describes a short run scenario in which capital is not mobile across sectors and regions. See also Eaton, Eaton, & Allen (2005) wherein a short run production function is developed with a fixed capital input and a variable labour input.

[3] Hall (2004) page 364.

[4] Under an IO model all factor supply functions are perfectly elastic. This is required for the model to function due to the assumed Leontief production structure. As a short proof, consider an IO model with a fixed input to one or more sectors. Given any shock to the model, production in that sector, as well as any sector it supplies an input to, would also be fixed since all inputs (and by extension, the sector's output) must maintain a fixed proportion to the sector's fixed input.

[5] We do not assess the economic impact of closures beyond the 90 day as the stated contingency plan asserts that a replacement transportation system will be fully operational with minimal inconvenience to the travelling public and businesses prior to the 90 day mark.

[6] Statistics Canada only produces input output data at the provincial level.

[7] The total self-reported employment figure for surveyed firms is approximately 3819. Total provincial employment for PEI was 71,500 while provincial employment in the target sectors was 27,100 in 2016 (Source: CANSIM table 282-0125).

[8] The number and grouping of regions is driven by the detail available in the statistics Canada symmetric input output tables, which are used for calibration. There is one region for each province (including PEI), a region for Nunavut, a region for Yukon and Northwest Territories (jointly) and a region for Canadian territorial enclaves abroad.

[9] Because of the method of collection (a multiple choice survey) the survey results provide insufficient information to inform an accurate statistical measure of the standard deviation of these point estimates. In designing the survey, preference was given to instruments that limit bias and inconsistencies and those that ease design and delivery of the survey as described above. That being said, it is common practice to present CGE counterfactuals as a single comparative static absent information on standard error. This is because CGE modelling is not a statistical instrument but rather an exercise in applied theory using an empirically calibrated model.

[10] Because the nominal wage rate is held fixed, total quantity of employment and total quantity of labour compensation are directly proportional when moving between the benchmark and counterfactual outcomes. As such we produce FTE equivalent job losses by scaling benchmark FTE measures from CANSIM table 282-0125 by the proportional change in nominal labour income for each sector. This is necessary since the IO tables used for calibration provide dollar value measures of inputs only.

[11] The "Health Care and Social Assistance" sector is broadly defined in the calibration data and includes (among other subcategories) ambulatory health services and nursing and residential care facilities, subsectors that we speculate account for the bulk of the sector's private spending. Our model relies on a simple abstraction of consumer behavior, using a single substitution parameter for all consumer goods. Therefore it is likely that our model overestimates income and price elasticities of demand for these services, and underestimates them for some others. A more nuanced representation of consumer preferences, potentially with a Stone Geary (Geary 1950; Stone 1954) formulation, has the potential to address this issue. However, the introduction of Stone Geary preferences into the model calls for additional data and/or assumptions to determine the minimum consumption level and/or implied income elasticity of demand for every sector in the model. Such an exercise falls beyond the scope of this study.

[12] Due to the structure of the provincial level Input Output data made available by Statistics Canada, calibration to years outside the 2009 to 2011 range would require modifications to the model. Prior to 2009 some sectors present in the model were only presented in aggregate. Post 2011 the input-output tables have been replaced with supply-use tables which make use of both the North American industry classification codes (NAICS) and the North American product classification codes (NAPCS).