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Estimation of indirect cost and evaluation of protective measures for infrastructure vulnerability: A case study on the transalpine transport corridor

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Abstract

Infrastructure vulnerability is a topic of rising interest in the scientific literature for both the general increase of unexpected events and the strategic importance of certain links. Protective investments are extremely costly and risks are distributed in space and time which poses important decision problems to the public sector decision makers.

In an economic prospective, the evaluation of infrastructure vulnerability is oriented on the estimation of direct and indirect costs of hazards. Although the estimation of direct costs is straightforward, the evaluation of indirect cost involves factors non-directly observable making the approximation a difficult issue. This paper provides an estimate of the indirect costs caused by a two weeks closure of the north-south Gotthard road corridor, one of the most important infrastructure links in Europe, and implements a cost-benefit analysis tool that allows the evaluation of measures ensuring a full protection along the corridor. The identification of the indirect cost relies on the generalized cost estimation, which parameters come from two stated preference experiments, the first based on actual condition whereas the second assumes a road closure. The procedure outlined in this paper proposes a methodology aimed to identify and quantify the economic vulnerability associated with a road transport infrastructure and, to evaluate the economic and social efficiency of a vulnerability reduction by the consideration of protective measures.

1. Introduction

Interruptions in infrastructure networks generate considerable economic and social damages at the regional and national level according to the overall dependency of the network on certain links and the risk associated with this interruption. In the context of increasingly vulnerable networks due to climate change, the attention on transport network reliability has grown substantially in the recent years in the international science community (Bell and Iida 2003, Nicholson and Dante 2004). Berdica (2002) introduces the road transport vulnerability as a complement of reliability, that is, the non-operability of a system due to incidents caused by either natural or man-made hazards.

Vulnerability assessment of a given transport infrastructure is mostly oriented on an engineering approach and regards the identification of the weakest points in a transportation network. Numerous methods have been proposed based on, for example, connectivity reliability (Bell and Ida, 1997), capacity reliability (Cheng *et al.*, 2002) or accessibility index (Taylor *et al.*, 2006).

In an economic prospective, the evaluation of infrastructure vulnerability is oriented on the estimation of direct and indirect costs of hazards. The former are associated with damages on the infrastructure caused by an unexpected event whereas the latter regard the consequences that the damaged infrastructure provokes on the society that depends on it. Although the estimation of direct costs is straightforward, the evaluation of indirect cost involves factors non-directly observable making the approximation a difficult issue. D'Este and Taylor (2003) proposed to calculate the loss of amenity of a link interruption as the change in generalized cost weighted by travel demand. Different algorithms have been proposed, as, for example, the short path algorithm. However, Taylor and D'Este (2004) recognized the limit in using algorithms as estimates of change in the utility of travel.

The estimation of the cost associated with an interruption of an infrastructure link is necessary in order to evaluate the desirability of any protective measure that allows a reduction of the vulnerability of the network to which it belongs. In this sense, a given vulnerability of a network represents a level of (expected) direct and indirect cost of a given hazard risk. Reducing vulnerability via costly protective measures can lead, as a function of the type of measure implemented, to an increased reliability (hazards have less or no consequences due to increased protection) or an increased resilience (networks recover faster from hazards).[1] We will concentrate here on the evaluation of protective measures creating "perfect" reliability (equivalent to a full insurance policy). This does not imply that we advocate zero vulnerability networks. Rather, a cost-benefit analysis of full protection measures on a given link will reveal whether this is economically justified and will in consequence contribute to move towards an economically optimal reliability. A methodology that allows the economic evaluation of the optimal reliability is still needed and required.

The aim of this paper is to estimate the indirect costs caused by a two weeks closure of an important trans-Alpine road corridor and to implement a cost-benefit analysis tool that allows the evaluation of measures ensuring a full protection along the corridor. We analysed one of the most important road infrastructure links in Europe, i.e. the north-south Gotthard road corridor. This corridor exhibits a high level of vulnerability because of its alpine geographical position and its long two-lane only tunnel (the third longest road tunnel in the world). The paper aspires to expand knowledge on how risk management has to be implemented to reduce potential damages and expected impacts and to improve the wider benefits due to enhanced network reliability.

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[1] For a more detailed explanation of these concepts in a transport context see Husdal 2006)

In order to reduce the complexity of the evaluation – evaluating the costs and benefits across the whole European road- and rail network would be an enormous task - the perspective has been reduced in several important ways. In a geographical sense we restrict the analysis to the Swiss Canton of Ticino, a part of the country south of the Alps and north of Italy, with two main trans-Alpine connections to the north – the Gotthard as a main connection and the San Bernardino a less important but still relevant link. Regarding cost we concentrate on indirect cost we limit our analysis to the sector that most depends on that road corridor, that is the Ticino freight transport market (inbound and outbound towards north). For this well delimited context we carried out two stated preference experiments addressed to logistic managers of 27 medium to large firms in Ticino. The first experiment involves choices in actual conditions whereas the second assumes a two week road closure.

Discrete choice model specification allows the generalized cost estimation through the derivation of the willingness to pay measures. Indeed, stated preference experiments are the most common techniques used in willingness to pay derivation and they allow to investigate the consumer behaviour in situations where few (or even none) data are available.

The cost benefit analysis is based on the change that an unexpected road interruption caused in the freight transport generalized cost. The evaluation of the economic sustainability of the risks identified along the corridor is then carried out by comparing the increase in the generalized cost with the cost of the protective measures. Finally, a cost benefit analysis tool is provided as a valid support of policy decision makers.

The paper is organized as follows. In section two we provide a brief geographical description of the infrastructure and we introduce the data. In section three we outline the discrete choice theoretical formulation. We present and discuss the model results in section four. The cost benefit analysis is performed in section five along with the introduction of the tool. Finally, conclusion and suggestion for further research are given in section six.

2. Data

The study concerns a choice based experiment, analysing the economic impact of a hypothetical closure of the Gotthard corridor[2]. Consequently we investigated the possible adaptive behavioural patterns of different actors in the face of disastrous and/or risky events. The investigation is based on the method of stated preferences. We basically want to model by means of an experimental design how the different actors react to the closure of this important road link across the Alps.

2.1 Geographical context

Due to its strategic position the corridor is one of the most important links between the north and the south of Europe. It represents a very important element of the national and international road and rail network facilitating transport and economic interaction between the north and the south of Europe.

Today, roughly 200 km of the Swiss national highway network are exposed to natural hazards, or in other words, every ninth kilometres leads through hazardous areas and hence

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[2] The experiment began with some pilot interviews during February 2008, officially started in March 2008 and was finally concluded in June 2008.

needs protection. A total of 137 galleries protect the traffic, more than 90 of them are rock fall protection measures. Additionally there are constructive measures directly in the hazard zones, such as protection nets, anchors, etc. The maintenance of these protection measures costs 30 Mio CHF every year[3].

Between 1994 and 2004 freight transport by road and rail across the Alps grew by 68% (rail traffic plus 25%, road traffic plus 60%). Today, the Alps are crossed each year by about 10 million trucks, a third of which passes through Switzerland, 85% of these using the Gotthard route[4].

2.2 Stated preferences experiment

We introduced the experiment by conducting an interview with the logistics managers of the most concerned industries (manufacturing) asking them about their general logistics and transportation framework and typical transportation relations across the Alps[5]. These managers were then confronted with alternative transportation services described by the use of three attributes, respectively, cost, time and punctuality. Cost and time attributes are pivoted to the reference values according to the levels shown in Table 1, whereas punctuality is expressed in absolute values.

Table 1. Attributes and their levels.

Transport Cost	Transport time	Transport Punctuality
-10 %	-10 %	100 %
-5 %	-5 %	98 %
Equal to the reference cost	Equal to the reference time	96 %
+5 %	+5 %	
+10 %	+10 %	

The whole experiment was based on a Computer Assisted Personal Interview (CAPI) instrument that randomly generates different profiles according to the assumption of experiment orthogonality. To each respondent 15 choice situations were presented.

The experiments refer to two different scenarios getting two different datasets. Examples of choice cards that the logistic manager was confronted with are given in Figures 2 and 3. In the first scenario we want to model behaviour with respect to the risk of frequent but short closures experienced currently along the road corridor, whereas in the second scenario we make the hypothesis of a rare incident provoking a two-week closure of the A2 highway. The first experiment analyzes the strategic decision on whether to stick to the currently chosen alternative (A2) given a known risk, or switch to a different one. In this sense we consider it to be a long-run choice among three different alternatives, namely, road (A2), piggyback and combined transport under the actual possibility of finding the A2 closed on a specific day. The road (A2) alternative remains fixed during the whole experiment since it describes the reference alternative. Its characteristics are those described by logistic managers for the typical transportation service across the Alps.

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[3] "La A2 a Gurtnellen un anno dopo la frana". Comunicato Stampa, Ufficio federale delle strade USTRA.

[4] MONITRAF, Synthesebericht, Monitraf Aktivitäten und Ergebnisse, Endbericht, febbraio 2008, Innsbruck/Zürich.

[5] The decision to concentrate on the freight transport sector stems from past studies demonstrating that the passenger sector (tourism and business travel) exhibit almost negligible additional costs in the sequel of past closures. In particular, we refer to the closure of two months occurred in November 2001 following a frontal truck crash inside the 17 km long tunnel.

Figure 1. Example of choice card for long-run decision experiment (first scenario)

	Road (A2)	Combined Transport	Piggyback
Suppose a situation where the road Gotthard corridor is going to be closed for a maximum of two consecutive days every month. Which of the following alternatives would you prefer?			
Actual cost		5% more than actual cost	5% less than actual cost
Actual time		10% more than actual travel time	5% more than actual travel time
Actual punctuality		100% punctuality	96% punctuality
	○	○	○

The second experiment regards a short-run decision since we make the hypothesis of a two-week road closure - a rare event calling for a short term reaction. This choice situation is characterized by four alternatives, namely, road (A13), new road (regulated A13), piggyback and combined transport. In this second experiment the reference alternative is represented by the road (A13) alternative (that is the San Bernardino corridor) since it is the immediate re-routing alternative chosen by most road users when the Gotthard road corridor is closed.

In order to quantify the cost and time for the reference alternative (San Bernardino) we used the additional cost and the additional time with respect to Gotthard corridor resulting from a previous survey with six of the most important Ticino. There, all interviewed shippers replied with very similar additional cost and time, respectively 300 CHF and 5 hours more for a detour via the San Bernardino route rather than along the Gotthard corridor. We get the values for the road (A13) alternative by summing these additional cost and time to the original reference values. Regarding the punctuality we assume a decrease of 2% with respect to the original value, with a minimum level fixed to the lowest level considered, that is, 96% of transports being punctual. This statement has been confirmed by the shippers interviewed, in particular if we consider the high volume of flows that occurs in a similar situation. To be noted that the validity of the transitional values is restricted to the closure period, that is fourteen days. The new road (regulated A13) alternative has been introduced to simulate a congestion free San Bernardino alternative (assume a sort of priority policy for trucks) with the original punctuality maintained.

Figure 2. Example of choice card for short-run decision experiment (second scenario)

	Road (A13)	Piggyback	Combined Transport	New Road (regulated A13)
Suppose a situation where the road Gotthard corridor is closed for two weeks. Which of the following alternatives would you prefer?				
Transitional cost		10% less than transitional cost	5% less than transitional cost	10% more than transitional cost
Transitional travel time		10% more than transitional travel time	5% more than transitional travel time	Equal to transitional travel time
Transitional punctuality		98% punctuality	96% punctuality	100% punctuality
	○	○	○	○

The sample is composed by 27 firms active in the manufacturing sector and, as mentioned before, all of them based in Ticino. The typical transport service described by logistic

managers is reported in Table 2. As expected, cost and time vary substantially since they are characterized by the distance between origin and destination and by the weight of the shipment, whereas punctuality is very homogenous and apart from two cases stating a 90% of punctuality in the transportation services all others are between 95 and 100 percent. This is in line with previous studies (see, for example, Bolis and Maggi 2003 and Maggi and Rudel 2008) and confirms the high level of importance that a logistics manager puts on a quality attribute like punctuality.

The descriptives for the damage and loss variables report a very low occurrence, with a sample mean of 0.97% and a median of 0.4%. The damage and loss attribute is widely used but a matter of debate in literature because of its inconsistency and its frequent insignificance in the model estimation. In fact, it is meaningless to have a systematic damage or loss in the transport service because shippers/forwarders will self insure via a systematic solution, for instance a different packaging, or a different truck, or even a different mode of transport. Indeed, accidental damages might be happening but remain an occasional feature and not a characteristic of a transport service. For this reason, we chose to not include this attribute in our experiment. The descriptive statistics collected during the analysis confirm this decision.

Table 2. Sample descriptive statistics of typical transport service

Variable	Mean	Median	Std.Dev.	Minimum	Maximum
Cost (CHF)	1300.15	1000	1152.95	136	5400
Time (hr)	33.35	24	27.30	2	96
Punctuality (%)	96.52	98	3.04	90	100
Weight (ton)	7.1309	5.50	7.17	0.04	25
Distance O-D (km)	474.33	300	332.62	92	1360
MADD	2.29	2	0.97	1	5
Damage (%)	0.97	0.4	1.98	0	10
Value (CHF/kg)	203.28	40	487.38	0.36	2400

Finally, from revealed market shares obtained for the whole logistic in the entire sample results, as expected, that the majority of the transport services rely on road alternative while the rest uses combined transport, either via rail or via ship and air. The piggyback alternative is not relevant confirming the weakness characterizing it due to technical problems and high operational cost.

3. Theoretical background

In a stated choice experiment, the respondent n is supposed to select the alternative j that maximizes his utility,

$$U_{nj} = \boldsymbol{\beta}'\mathbf{x}_{nj} + \varepsilon_{nj} \tag{1}$$

where $V_{nj} = \boldsymbol{\beta}'\mathbf{x}_{nj}$ is the systematic part of the utility and ε_{nj} is the random term that is Independent and Identically Distributed (IID) extreme value type 1. The estimation of the beta coefficients relies on the class of Random Utility Models (McFadden, 1974).

An advanced and widely used discrete choice model is the Random Parameter Logit (RPL) model, which allows for taste heterogeneity among respondents by letting the beta parameters

randomly vary across the sample population (see Hensher and Green, 2003 for a detailed discussion). The following equation describes the choice probability for a RPL model:

$$P_{nj} = \int_{\beta} \left(\frac{\exp(\boldsymbol{\beta}'_n \mathbf{x}_{ni})}{\sum_j \exp(\boldsymbol{\beta}'_n \mathbf{x}_{nj})} \right) f(\boldsymbol{\beta}) d(\boldsymbol{\beta}) \tag{2}$$

where parameters β are drawn by continuous distributions (e.g. normal, log-normal, triangular etc.). The selection of a specific distribution, whenever possible, is based on previous knowledge or on particular behavioural assumptions. However, if no particular hypotheses are available or required, the selection is arbitrary and generally based on the goodness of fit of the data.

In a context of stated choice with repeated choice situations, an additional and indispensable feature of RPL models is the capability to deal with the panel structure by constraining the random parameters to be constant over choice situations. The choice probability in Equation (2) becomes then:

$$P_{nj} = \int_{\beta} \left(\prod_t \frac{\exp(\boldsymbol{\beta}'_n \mathbf{x}_{nit})}{\sum_j \exp(\boldsymbol{\beta}'_n \mathbf{x}_{njt})} \right) f(\boldsymbol{\beta}) d(\boldsymbol{\beta}) \tag{3}$$

where t = 1,…,T indicates the number of choice situations. Since in any RPL model the choice probability integral has no closed form solutions, the estimation process is based on simulations and the log-likelihood takes the following form:

$$LL_n = \sum_n \ln \frac{1}{R} \sum_r \prod_t \frac{\exp(\boldsymbol{\beta}'_n \mathbf{x}_{nit})}{\sum_j \exp(\boldsymbol{\beta}'_n \mathbf{x}_{njt})} \tag{4}$$

where, r = 1,…,R indicates the simulation draw. The following models are based on 200 Halton draws[6].

4. Model estimation results

Different Panel RPL models were estimated[7] for the two scenarios and the selection was based according to both model fit indicators and behavioural meaning. Specifically, the evaluation of the model goodness of fit is provided by the final log-likelihood as well as the McFadden pseudo ρ^2 and the Akaike's Information Criterion (AIC).

The estimation of the utility functions for the first scenario is based on the following panel RPL specification:

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[6] See Train (2003) for details.
[7] Models estimation is performed by Nlogit 4.

$$\begin{cases} V_{n(\text{PB})} = ASC_{\text{PB}} + \beta_{(PB)\text{C}}\text{C}_{\text{PB}} + \beta_{(PB)\text{T}}\text{T}_{\text{PB}} + \beta_{\text{P}}\text{P}_{\text{PB}} \\ V_{n(\text{CT})} = ASC_{\text{CT}} + \beta_{(CT)\text{C}}\text{C}_{\text{CT}} + \beta_{(CT)\text{T}}\text{T}_{\text{CT}} + \beta_{\text{P}}\text{P}_{\text{CT}} \\ V_{n(\text{RD})} = \beta_{(RD)\text{C}}\text{C}_{\text{RD}} + \beta_{(RD)\text{T}}\text{T}_{\text{RD}} + \beta_{\text{P}}\text{P}_{\text{RD}} + \beta_{n\text{D}}\text{D} + \beta_{n\text{W}}\text{W} \end{cases} \qquad (5)$$

where $ASC_{(j)}$ refers to the alternative specific constant, $\beta_{(j)C}$, $\beta_{(j)T}$ and β_P are the coefficients associated to cost, time and punctuality while β_{nD} and β_{nW} are the parameters of the firm's logistics specific variables referring to transport service origin-destination distance (in kilometres) and shipment weight (in tonnes). Coefficients β_{nD} and β_{nW} are selected to be triangular distributed[8] whereas all the other coefficients are supposed to be invariant over the sample, that is, the entire information is supposed to be captured by the sample mean.

The estimation results for the first scenario are shown in Table 3. The road (A2) alternative has been set as the reference alternative, and then the signs of the alternative specific constants indicate a slight preference for the road alternative even if the t-ratio test does not confirm their statistical significance. The alternative specific coefficients associated to cost and time attributes are all significant at an alpha level of 0.01 (0.05 for road time coefficient) and present the expected negative sign. The generic parameter for punctuality is also strongly significant and positive, reflecting an increase in utility in correspondence of an increase in transport service punctuality.

Table 3. Panel RPL estimate for the first scenario

	Coefficient	(t-ratio)
Means for Random and Non-Random parameters		
Piggyback Constant	-0.98342	(-0.69)
Combined Transport Constant	-1.29087	(-0.91)
Piggyback Cost	-0.00554	(-5.92)
Combined Transport Cost	-0.00539	(-5.79)
Road (A2) Cost	-0.00624	(-4.55)
Piggyback Time	-0.10645	(-3.48)
Combined Transport Time	-0.09660	(-3.22)
Road (A2) Time	-0.10668	(-2.44)
Punctuality	0.37771	(6.62)
Distance O-D	0.00315	(1.29)
Weight	0.06435	(0.60)
Standard deviations for Random parameters		
Ts Distance O-D	0.02570	(3.20)
Ts Weight	0.36608	(2.22)
Sample		405
Final Log-l		-294.70
McFadden pseudo ρ^2		0.338
AIC		1.519

The coefficients associated with the two firm specific variables show a mean not statistically different from zero, however they capture a significant heterogeneity among respondents, indicating that part of the respondents prefer to switch to rail-based alternatives as either the transport distance or the shipment weight increases.

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[8] The selection of the triangular distribution was based on model fit preference. See Hensher and Green (2003) for discussion about triangular distribution use in discrete choice modelling.

The analysis of the first scenario continues with the estimation of the monetary values of the quality attributes (time and punctuality) defined as the ratio of the marginal utility of the quality attribute to the marginal utility of the cost attribute. Within discrete choice class of models the derivation is straightforward since the parameter estimates refer to the marginal utility. In this context, we indicate the value of time (VOT) as β_{jC}/β_{jT} and the willingness to pay for punctuality (WTPP) as β_P/β_{jC}.

In Table 4 we report the monetary measures (per shipment and per tonne) of time and punctuality obtained for the three transport alternatives presented in the first scenario. The road alternative shows a value of time (17.1 CHF/hour) similar to previous studies (Bolis and Maggi, 2003, Maggi and Rudel 2008, Zamparini and Reggiani 2007). The VOT for the two rail-based alternatives result in a higher value compared to the road alternative, namely 17.9 and 19.2 for piggyback and combined transport, respectively. This is in contradiction with Zamparini and Reggiani (2007) who analyse the value of time reported in published studies in the period 1990-2005 and observe a VOT higher for road than for rail freight transport. However, it should be noted that among the 46 studies analysed by Zamparini and Reggiani (2007) only 5 contained rail values, , 4 of which were conducted in the period 1990-1992 and one in 2000.

The willingness to pay for an increase of 1% in punctuality goes from 60.5 CHF for road alternative to 70.1 CHF for combined transport. These values confirm recent studies regarding the high importance of punctuality as a transport service quality (see for example, Danielis *et al.*, 2005, Fowkes *et al.* 2004).

Table 4. WTP measures and generalized cost for the first scenario

	VOT	VOT/ton*	WTPP	WTPP/ton*	Market Share	Generalized Cost
Piggyback	19.21	2.63	68.15	9.34	24	1901
Combined	17.93	2.46	70.13	9.61	33	2183
Road (via A13)	17.09	2.34	60.50	8.29	43	1886
* Average tons loaded (from sample average) = 7.3						

The estimation of the model parameters and the derivation of the monetary values of quality changes makes the computation of the generalized cost straightforward. In fact, according to Hensher and Button (2000), the generalized cost is a linear combination of cost and any variable that is likely to impact on a given transport service. In our case, we assume that transport cost, time and punctuality have an impact on logistics manager's choice. The generalized cost associated to each alternative is then given by the following equation:

$$GC_j = C_j + VOT_j \times T_j + WTPP_j \times (100 - P_j) \qquad\qquad (6)$$

where C_j, T_j and P_j are the alternative specific variables cost, time and punctuality. In Table 4 we report the average generalized cost for each alternative alongside the proportion in percentage points indicating the share of the preferences among the alternatives (market share).

The results indicate a consistent proportion of the logistics managers (24%) willing to switch mode of transport from road to piggyback under the hypothetical market condition assumed by the experiment design, that is, a piggyback mode transport really thought as a concrete and efficient alternative to the road.

The combined transport shows the highest generalized cost and confirms the market share registered in the actual market. As expected, the freight transport via road reports the lowest generalized cost and it still is the most preferred alternative even if the logistics manager is well-aware of the chances that frequent road closures might cause a delay to his transport. This result could be explained in several ways, from risk propensity to mode switch inelasticity. However, a more realistic explanation is that, as reported by the majority of the respondents, the rail-based alternatives are not sufficiently competitive in the given logistics context (high frequency low weight shipments, relatively short distance covered across the Alps within Switzerland) to allow a risk reduction by switching the transport mode from road to rail-based alternatives. This holds in spite of important policy efforts (heavy subsidies, open access of freight operators on rail) to shift freight traffic from road to rail, and a high frequency of short closures in winter (mostly due to the heavy snowfall) and in summer (caused by the long queues at the tunnel bottleneck leading to a postponing of departure).

According to the objective of quantifying the economic vulnerability of the road infrastructure under an unexpected and long closure, we set the average generalized cost of a freight transport via road, 1886 CHF, as the starting point of the cost-benefit analysis[9].

In order to obtain the monetary values for time and punctuality associated with an unexpected total closure of the road Gotthard corridor for two consecutive weeks, we introduce the logistics managers to the second scenario. The specification of the panel RPL model is given by:

$$
\begin{cases}
V_{n(TrNR)} = ASC_{TrNR} + \beta_{(TrNR)C}C_{TrNR} + \beta_{(TrNR)T}T_{TrNR} + \beta_{TrP}P_{TrNR} \\
V_{n(TrPB)} = ASC_{TrPB} + \beta_{(TrPB)C}C_{TrPB} + \beta_{(TrPB)T}T_{TrPB} + \beta_{TrP}P_{TrPB} \\
V_{n(TrCT)} = ASC_{TrCT} + \beta_{(TrCT)C}C_{TrCT} + \beta_{(TrCT)T}T_{TrCT} + \beta_{TrP}P_{TrCT} \\
V_{n(TrRD)} = \beta_{(TrRD)C}C_{TrRD} + \beta_{(TrRD)T}T_{TrRD} + \beta_{TrP}P_{TrRD} + \beta_{MD}MD + \beta_{nD}D + \beta_{nW}W
\end{cases}
\tag{7}
$$

where the two rail-based alternatives share now the choice set with two road alternatives, road via A13 (TrRD) and new road (TrNR). The suffix "Tr" indicates that the attributes (as well as the coefficients and the utility functions) refer to the transitional detour values. We also introduce a further logistics characteristic of the firm, called maximum acceptable delivery delay (MADD), which is a 5 point discrete variable and expresses the delay tolerance allowed by the client, during an unexpected event, without any additional charge to be paid by the supplier.

The logistics managers were then faced with the updated reference alternative profile, and they were reminded that these new conditions hold just for two transitional and consecutive weeks. The results for this second scenario are shown in Table 5.

The sign and the magnitude of the alternative specific constants indicate the new road (regulated A13) alternative as the most preferred since it presents the highest ASC value. Nevertheless, the two rail-based alternatives, namely, piggyback and combined transport, are also preferred to the actual road alternative (A13). The cost and time alternative specific

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[9] In order to verify that our insistence on the frequent risk of short closures had not influenced the respondents' parameters we also have derived the generalized cost by using a dataset collected among Swiss firms aimed to evaluate the quality attributes in freight transport (described in Rudel and Maggi, 2008). Even running different specification models the resulting generalized cost was very similar to the one obtained with this first scenario.

coefficients are highly significant (at an alpha level of 0.01) and with the expected sign as well as the generic punctuality parameter.

Table 5. Panel RPL estimate for the second scenario

	Coefficient	(t-ratio)
Means for Random and Non-Random parameters		
New Road Constant	3.81419	(1.98)
Piggyback Constant	3.31834	(1.72)
Combined Transport Constant	3.03794	(1.58)
New Road Cost	-0.00576	(-8.60)
Piggyback Cost	-0.00568	(-8.47)
Combined Transport Cost	-0.00562	(-8.35)
Road (via A13) Cost	-0.00719	(-6.53)
New Road Time	-0.13314	(-5.79)
Piggyback Time	-0.13192	(-5.61)
Combined Transport Time	-0.12924	(-5.41)
Road (via A13) Time	-0.11486	(-3.59)
Punctuality	0.38859	(9.10)
MADD	1.64419	(2.36)
Distance O-D	-0.00041	(-0.12)
Weight	0.01737	(0.13)
Standard deviations for Random parameters		
Ts Distance O-D	0.00983	(2.87)
Ts Weight	0.37209	(2.06)
Sample		405
Final Log-l		-387.22
McFadden pseudo ρ^2		0.509
AIC		1.996

The parameter associated with the logistics firm specific "MADD" variable is significant and positive, showing the logistics manager's aversion to look for better temporary alternatives as the flexibility in the delivery delay increases. As for the first scenario, the origin-destination distance and the transport weight variables result with mean values of zero but with significant standard deviation helping to capture the heterogeneity across respondents.

From the coefficient estimates we derive the monetary values for time and punctuality associated with each of the four alternatives considered in the second scenario. The VOT and WTPP values, calculated as the ratio of the quality attribute coefficient to the cost coefficient, are shown in Table 6. Compared to the first scenario, the two rail-based alternatives experience a significant VOT increase whereas the WTPP values do not show consistent differences. Similar VOT and WTPP values are identified for the new road alternative. On the contrary, the VOT and WTPP for freight transport on the San Bernardino road corridor (A13) are valued less than those for the Gotthard road corridor (A12) reflecting the well known problems that trucks face along the former corridor (i.e. steep road with low average curve radius). Thus, apart from the road (A13) alternative, the results obtained for the monetary values highlight that in a short term emergency condition the logistics managers increase their perception of time without altering their perception of punctuality. This confirms, as previously stated, the high importance of the transport punctuality that is at its maximum all year long.

Table 6. WTP measures and generalized cost for the second scenario

	VOT	VOT/ton*	WTPP	WTPP/ton*	Market share	Generalized Cost
New Road	23.13	3.17	67.52	9.25	32	2455
Piggyback	23.22	3.18	68.40	9.37	28	2523
Combined	23.01	3.15	69.17	9.48	27	2602
Road (A13)	15.98	2.19	54.07	7.41	13	2304
* Average tons loaded (from sample average) = 7.3						

Finally, the average generalized cost for each transport mode alternative has been computed according to the following equation:

$$Tr(GC_j) = Tr(C_j) + Tr(VOT_j) \times Tr(T_j) + Tr(WTPP_j) \times [100 - Tr(P_j)] \qquad (8)$$

where $Tr(GC_j)$ are the alternative specific generalized costs during the two-week closure period, $Tr(VOT_j)$ and $Tr(WTPP_j)$ refer to the monetary measures estimated from the second scenario and $Tr(X_j)$ are the typical transport cost, time and punctuality variables updated to the new values according to the emergency situation. The results are given in Table 6 together with the second scenario market shares. The reference alternative (A13) shows both the lowest generalized cost and the lowest market share because of the low punctuality set for this alternative. However, the transport by road is still the most preferred since the regulated road alternative (an "uncongested" A13) shows the highest market share and a lower generalized cost than the two rail-based alternatives.

In general, the additional generalized cost estimated is approximately 600 CHF per transport. In particular, the value of travel time saving increases consistently while the willingness to pay for 1 percent more of punctuality is more stable.

5. Cost-Benefit Analysis tool

The construction of this module relies on the results of both stated choice experiments described in the previous sections. In particular, the module is built in order to estimate the indirect user cost of a two week closure of the road Gotthard corridor[10]. The results obtained from the first scenario provide the starting value for the generalized cost in an everyday condition while the results obtained from the second scenario are used in the estimation of the additional generalized cost. Figure 3 shows how the main worksheet appears to the user. A detailed help page is also provided by clicking the apposite button.

The structure of the module is organized in six sections:

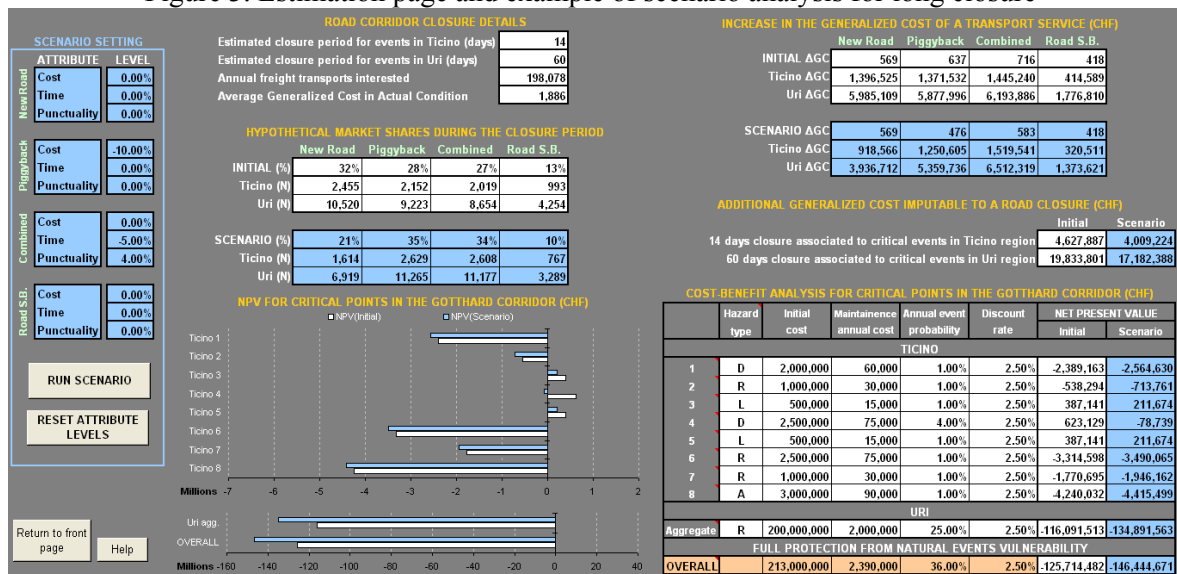1. Scenario setting: shows the alternatives and the attributes used in the estimation modelling. Zero correspond to the default values, by inputting different values (either positive or negative) we generate a scenario;

2. Closure details: allows different closure period settings and changes in traffic flow and reference generalized cost;

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[10] The tool is available upon request from the corresponding author.

3. Market shares: shows the market shares in percentage and in number[11] for both default and scenario values;

4. Generalized cost: shows the additional generalized cost[12] caused by a two-week closure of the road corridor for the Ticino economy;

5. Cost-benefit analysis for critical points in the Gotthard corridor: allows the computation of the net present values of the selected measures aimed to reduce the whole vulnerability of the road Gotthard corridor;

6. Net present values chart: highlights in a histogram chart the net present values of the selected measures distinguishing between default and scenario values.

In the Ticino freight transport market, the estimated indirect cost caused by an unexpected two-weeks closure of the road Gotthard corridor is 4.63 Mio CHF (see Figure 3). Therefore, any infrastructure investment aimed at reducing the probability of a two-week closure should be compared with a saved cost of 4.63 Mio CHF.

Figure 3. Estimation page and example of scenario analysis for long closure

SCENARIO SETTING

	ATTRIBUTE	LEVEL
New Road	Cost	0.00%
	Time	0.00%
	Punctuality	0.00%
Piggyback	Cost	-10.00%
	Time	0.00%
	Punctuality	0.00%
Combined	Cost	0.00%
	Time	-5.00%
	Punctuality	4.00%
Road S.B.	Cost	0.00%
	Time	0.00%
	Punctuality	0.00%

RUN SCENARIO
RESET ATTRIBUTE LEVELS
Return to front page | Help

ROAD CORRIDOR CLOSURE DETAILS

Estimated closure period for events in Ticino (days)	14
Estimated closure period for events in Uri (days)	60
Annual freight transports interested	198,078
Average Generalized Cost in Actual Condition	1,886

HYPOTHETICAL MARKET SHARES DURING THE CLOSURE PERIOD

	New Road	Piggyback	Combined	Road S.B.
INITIAL (%)	32%	28%	27%	13%
Ticino (N)	2,455	2,152	2,019	993
Uri (N)	10,520	9,223	8,654	4,254
SCENARIO (%)	21%	35%	34%	10%
Ticino (N)	1,614	2,629	2,608	767
Uri (N)	6,919	11,265	11,177	3,289

NPV FOR CRITICAL POINTS IN THE GOTTHARD CORRIDOR (CHF) — NPV(Initial), NPV(Scenario)

INCREASE IN THE GENERALIZED COST OF A TRANSPORT SERVICE (CHF)

	New Road	Piggyback	Combined	Road S.B.
INITIAL AGC	569	637	716	418
Ticino AGC	1,396,525	1,371,532	1,445,240	414,589
Uri AGC	5,985,109	5,877,996	6,193,886	1,776,810
SCENARIO AGC	569	476	583	418
Ticino AGC	918,566	1,250,605	1,519,541	320,511
Uri AGC	3,936,712	5,359,736	6,512,319	1,373,621

ADDITIONAL GENERALIZED COST IMPUTABLE TO A ROAD CLOSURE (CHF)

	Initial	Scenario
14 days closure associated to critical events in Ticino region	4,627,887	4,009,224
60 days closure associated to critical events in Uri region	19,833,801	17,182,388

COST-BENEFIT ANALYSIS FOR CRITICAL POINTS IN THE GOTTHARD CORRIDOR (CHF)

	Hazard type	Initial cost	Maintenance annual cost	Annual event probability	Discount rate	NET PRESENT VALUE Initial	NET PRESENT VALUE Scenario
				TICINO			
1	D	2,000,000	60,000	1.00%	2.50%	-2,389,163	-2,564,630
2	R	1,000,000	30,000	1.00%	2.50%	-538,294	-713,761
3	L	500,000	15,000	1.00%	2.50%	387,141	211,674
4	D	2,500,000	75,000	4.00%	2.50%	623,129	-78,739
5	L	500,000	15,000	1.00%	2.50%	387,141	211,674
6	R	2,500,000	75,000	1.00%	2.50%	-3,314,598	-3,490,065
7	R	1,000,000	30,000	1.00%	2.50%	-1,770,695	-1,946,162
8	A	3,000,000	90,000	1.00%	2.50%	-4,240,032	-4,415,499
				URI			
Aggregate	R	200,000,000	2,000,000	25.00%	2.50%	-116,091,513	-134,891,563
			FULL PROTECTION FROM NATURAL EVENTS VULNERABILITY				
OVERALL		213,000,000	2,390,000	36.00%	2.50%	-125,714,482	-146,444,671

Regarding the cost-benefit analysis section we illustrate nine critical points along the whole corridor, eight of which are those identified in Ticino (south of the Alps) with the geo-scientific risk analysis[13] and one is an assumed hazard in the Canton of Uri (north of the Alps). For each of them a mitigation measure can be defined establishing zero hazards at this point. In other words, the protection of the link against an unexpected long closure is complete regarding this location. The user has to input the initial cost, the annual maintenance cost of the selected measure, the risk of closure according to the annual event probability and the appropriated discount rate. Then, the tool provides the net present value (NPV) for each one of the measures considering a project lifetime of 50 years. Calculating a separate NPV for each mitigation measure implies that we simulate a situation where the whole benefit (savings

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[11] The source of the total amount of trucks passing through the Gotthard corridor is the last AQGV 04 census. We consider only trucks departing from or arriving to Ticino. This amount is inputted in the cell called N and it is free to be changed by the user.

[12] The reference value is put into the cell GC_Gotthard and stems from the first scenario results.

[13] The critical points and the protective measures are reported in Appendix, Table A1. We thank Mirko Baruffini for providing with the information.

in generalised cost) is attributed to a single measure but weighted by the probability of the hazard.

Assuming a low discount rate of 0.025 and a realistically low event probability of 0.01, measures 3 and 5 against landslides and measure 4 against debris flow result in a positive NPVs. Together they would reduce the risk of closure by 6%. The other measures show negative NPV. This implies that large investments, like e.g. the hypothetical one in URI, or smaller ones in Ticino but for low event probability are not justified if we consider only the indirect benefit for Ticino. Expanding the analysis and adding the direct benefits and above all indirect benefits for the rest of Switzerland, and Europe (transit traffic accounts for 50% of the trans-Alpine passages) might change the results significantly in favour of the measures.

By changing the infrastructure parameters the user can explore alternative policy measures that might lead to different vulnerability outcomes changing the economic efficiency of a given protective measure. For example, by assuming a ten percent cost reduction for the piggyback alternative and, a five percent time reduction and a four percent punctuality increase for the combined transport alternative, the cost of a two-week road closure would be 4 Mio CHF (see Figure 3), that is, 13.4 percent less than the actual estimated loss. This makes the net present value of protective measure 4 not positive anymore.

Finally, the versatility of the module allows the integration of any further information gathered about the exact number of sensible points located along the Gotthard road corridor and the exact monetary value of each measure aimed at mitigating the risk of a long closure.

6. Conclusion

This paper has investigated the economic consequences associated with a two-week closure of the Gotthard road corridor, and has analysed the economic efficiency of different protective measures through the implementation of a cost-benefit analysis.

Due to its geographical location and to the seventeen kilometres long two-lane tunnel, the Gotthard corridor experiences a high degree of vulnerability towards unexpected events. In fact, in recent years two disastrous events occurred. In November 2001, a head-on collision between two trucks inside the tunnel caused a two months road interruption while, in May 2006, a rock fall caused a closure of one month.

We provide the indirect cost in the economic sector that most heavily depends on the road corridor, that is, the Ticino freight transport market. The identification of the indirect cost relies on the generalized cost estimation, which parameters come from two stated preference experiments, the first based on actual condition whereas the second assumes a road closure.

The results indicate that a two-week closure of the Gotthard road corridor generates an indirect user cost to the Canton Ticino of 4.63 Mio CHF. As a consequence, the cost of any measure avoiding this risk has to be compared with the potential benefit of saving at least this sum (if benefits to other regions and direct benefits are neglected). In this context, nine critical points along the corridor were identified and the cost-benefit analysis indicates a positive net value for three protective measures resulting in a reduction of the road closure risk of six percent.

The implementation of the cost-benefit tool is essential in testing different scenarios useful in the evaluation of different policy setting. In fact, the tool lets the service transport parameters, cost, time and punctuality, free to change. For example, an improvement of the rail-based alternatives in term of cost, time and punctuality can reduce significantly the road vulnerability.

The procedure outlined in this paper proposes a methodology aimed to identify and quantify the economic vulnerability associated with a road transport infrastructure and, to evaluate the economic and social efficiency of a vulnerability reduction by the consideration of protective measures. Nevertheless, this procedure should be considered as a starting point and further improvements are strongly recommended. We suggest the extension of the economic loss with the estimation of the direct cost. It would be also interesting to enlarge the analysis to a wider geographical area in order to cover a better proportion of the potential infrastructure consumers. Finally, the integration of this module in a GIS environment would make the practitioner confident with the geographical context and the related hazards.

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Appendix

Table A1. Critical points along the Ticino highway (A2) segment [*].

Location	Hazard	Return period [years]	Type of protection	Cost [CHF]
Giornico	flooding	100	Paving ditch and retaining chamber reinforcement	2'000'000
Giornico	rockfall	100	Rockfall barriers	1'000'000
Bellinzona	landslide	100	Retaining wall	500'000
Capolago	flooding	25	Retaining chamber and related frames reinforcement (check dams, ditches, etc.)	2'500'000
Collina d'Oro (Gentilino)	landslide	100	Retaining wall	500'000
Faido (Chioggiona)	rockfall	100	Wall coupled by rock fall ring nets	2'500'000
Faido (Chioggiona)	rockfall	100	Rockfall barriers	1'000'000
Quinto	avalanche	100	Active measures (avalanche prevention structures as snow barriers, snow racks and wire rope structures) and passive measures (retention or control dams)	3'000'000

[*] We thank Mirko Baruffini for providing whit the information.

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