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THE TRAFFIC IMPACT OF ROAD PRICING

Lessons from the Toll Road Sector

Robert Bain & Deny Sullivan

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THE TRAFFIC IMPACT OF ROAD PRICING: LESSONS FROM THE TOLL ROAD SECTOR

KEY FACTS AND FIGURES

1\.

Just 2 small-sample studies have previously examined this issue

2\.

83 international case studies

76 carried forward for full analysis

3\.

49 cases of activation (toll on)

27 cases of deactivation (toll off)

4\.

35 roads

20 bridges

8 tunnels

13 cordons

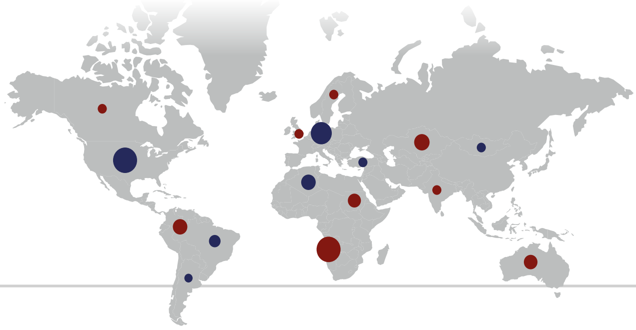
5\.

46 urban and

30 interurban facilities

6\.

16 different countries

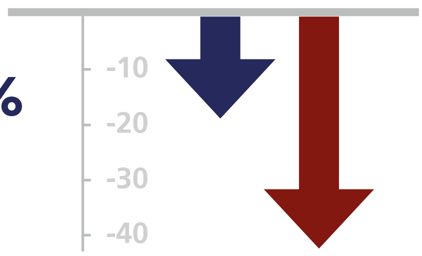


7\.

Median traffic impact of tolling = **-25%**

8\.

Interquartile range = **-17%** to **-44%**



9\.

The traffic impact in the absence of any alternative = **-15%**

10\.

The traffic impact in nearly a quarter of the case studies was **-45%** or higher

Summary

Whereas the topic of toll price elasticity has received some attention in the literature (how drivers react to tariff changes), very little has been written about how drivers respond to the initial introduction of tolls. Given mounting pressure on transportation budgets - exacerbated by reducing fuel tax receipts as the popularity of electric vehicles grows - this issue is of increasing interest to planners, policymakers, treasury officials, investors and others with a focus on infrastructure finance. What is the traffic impact of road tolls?

To answer this question, we analysed data from 76 international toll road, bridge, tunnel and cordon case studies. Of these, 49 were activations (tolls on) and 27 were deactivations (tolls off). The data demonstrates that the traffic impacts are significant, with a median response to tolling (traffic impact) of -25%. The interquartile range is -17% to -44%.

We collected additional data for each of our case studies in terms of the toll facilities' characteristics, toll prices, and the quantity and quality of alternative routes and modes available to local drivers. From these candidate explanatory variables, we were able to construct a simple predictive model that can be used to provide 'first cut' estimates of the likely traffic response to toll charging under different circumstances.

Our model is not necessarily a substitute for a full traffic study - however it can be used to independently benchmark the outputs from traffic models. Is the model behaving reasonably? Do the results align with the evidence on toll-related traffic diversion?

As investment analysts, we regularly come across traffic advisors who underplay the potential impact of tolling, suggesting infeasibly low diversion rates. Low diversion estimates need to be treated with caution. In nearly a quarter of our case studies, the toll related traffic diversion rates were -45% or higher.

Corresponding Author
Robert Bain PhD CEng
Senior Partner
CSRB Group
rob.bain@csrbgroup.com

"We regularly come across traffic advisors who underplay the potential impact of tolling"

Keywords:
Toll roads; Road pricing; Congestion charging; Road user charging; Traffic diversion; Toll price elasticity.

Contents

In line with our commitment to reproducible research, our database (including all sources, our analysis and our results) is available from

research@csrbgroup.com

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Introduction

As investment analysts who specialise in international transportation projects, we are asked about the likely traffic impact of road tolls on an increasingly frequent basis. Our clients are infrastructure investors (sovereign wealth funds, pension plans, private equity houses and other institutional investors) who retain us to undertake commercial due diligence of candidate investment projects. However, we have been asked the same question when working for multilateral development banks, toll road management companies or their owners, government departments and regulatory agencies. *What is the likely traffic response to road tolls*?

Our initial approach - some years ago - was to compile an ad hoc database of empirical evidence to inform our thinking. More recently, given the increased interest, we decided to examine the topic in a more structured and detailed way. This paper presents our research and findings.

The heightened interest in tolls as a possible funding source for transportation arises from the fact that the demands of the travelling public are growing at a time when the existing road infrastructure in many countries is deficient - or old (and is delivering increasingly substandard levels of service). This has been documented across both the developing and the developed world. In the US, for example, approaching 50% of the road system is reportedly in 'mediocre' or 'poor' condition[1].

The deteriorating state of road infrastructure has been documented for many years, commonly being linked to reduced prospects for growth[2]. More recently, the fact that fuel tax revenues have decreased (due to improving fuel efficiency and the increasing popularity of electric vehicles - trends which will continue[3]), set against a backdrop of constrained government budgets and fiscal restraint, is focussing more professional and political attention on the applicability of road user charges as a complementary or alternative funding solution.

In the past, tolling has generally been restricted to greenfield (new build) projects. Today, it is being contemplated for rehabilitation, reconstruction and upgrading projects, or to raise funds for wider transportation improvement projects by charging for the use of existing roads. And beyond toll roads, a number of cities globally are considering how road pricing could be used to address chronic urban congestion and/or to meet environmental - usually improved air-quality - objectives.

Against this backdrop - summarised in **Figure 1** - developing a deeper understanding of the traffic impact of road user pricing would appear to be timely.

"More attention is being focussed on road user charges as a complementary or alternative solution for transportation funding"

[1] '2021 Infrastructure Report Card: Roads', American Society of Civil Engineers (ASCE), 2021 (https://infrastructurereportcard.org/wp-content/uploads/2017/01/Roads-2021.pdf)
[2] In 2023, the UK's National Infrastructure Commission found that more than two-thirds of manufacturing businesses said the UK's national infrastructure had got worse over the past decade (*https://www.rsmuk.com/news/decaying-infrastructure-damaging-growth-prospects-warn-manufacturers*).
[3] Total fuel duty revenue from cars and taxis in the UK is forecast to drop by 57% by 2035. RAC Foundation, 2021.

Aside from the 'key factors' identified right, discussions with industry stakeholders over the years have suggested additional factors - often specific to particular situations or jurisdictions - that are prompting the increasing interest in tolling:

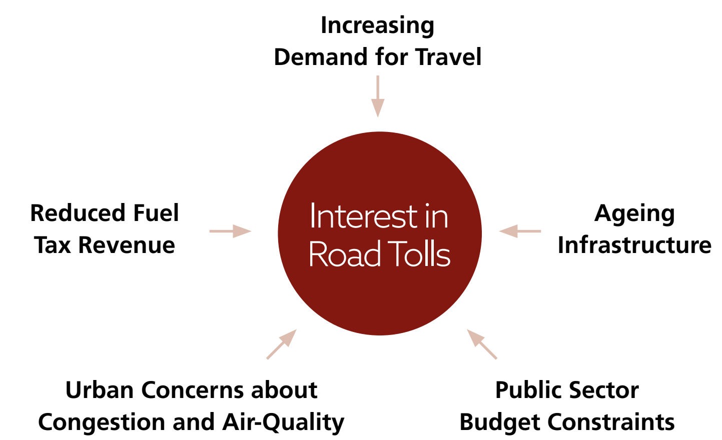
- **Legislative Easing**[4]. In some countries (eg. the United States), laws have been amended to permit tolling in situations where it was previously prohibited.

- **The Unattractiveness of Alternatives**. When surveyed, drivers generally prefer (or object less to) road tolls than, for example, sales or fuel tax increases[5].

- **Project Acceleration**. Cited as being "*perhaps the most significant benefit of tolling untolled roads*"[6]. By providing a dedicated funding source, tolling can be used to bring forward the completion date of projects that otherwise would be delayed (perhaps indefinitely).

- **Economic Fundamentals**. Policymakers with an infrastructure remit are generally warming to point-of-use charging and the 'user-pays' principle.

Figure 1: Key Factors Contributing to the Increasing Interest in Road Tolls



- **Blended Funding**. Financiers are actively exploring and combining funding from various sources to achieve common objectives.

- **Advances in Technology**. Free-flow electronic toll collection is deployed in most start-up operations today. This significantly reduces the land required[7]- see **Figure 2** - and allows for the adoption of sophisticated tariff schedules (multi-period toll differentials or fully dynamic pricing).

- **Contemplating the Inevitable**. Acknowledgement that, at some stage in the future, some form of road user charging - for individual or all vehicle classes - will likely become the norm.

[4] This is an example of bidirectional causality. Relaxation of the legal framework encourages an interest in tolling, but the legal framework was relaxed partly because of the increasing interest in tolling.
[5] Duncan D et al (2017), 'Searching for a Tolerable Tax: Public Attitudes Toward Roadway Financing Alternatives', Public Finance Review, Vol. 45(5), pages 678-700, September 2017.
[6] Davis R et al (2018), 'The Tradeoffs of Tolling Untolled Roads', Transportation Research Record, Vol. 2672(4), National Academy of Sciences.
[7] In the past, this was a key constraint in many urban areas where land was prohibitively expensive or simply unavailable.

Figure 2: Freeflow Electronic Toll Collection

Literature Review

The academic literature on the traffic impact of road tolls is limited. It can be divided into two categories: studies that examined the impact on a single road, bridge or tunnel (or a complementary pair of facilities), and studies that compared the impacts across multiple, separate projects (meta-analyses). The individual study findings are often carried forward to the multiple-facility research papers which are, themselves, somewhat dated and generally small-sample based.

In short, the same few case studies feature repeatedly in the literature. This limitation was a primary motivator for conducting our own research.

A good example of an individual-facility study is Nichols & Belfield (2015). In their paper, the authors examined the traffic impact of toll collection on the heavily congested Midtown and Downtown Tunnels in Virginia. Toll revenue was (later) used to fund rehabilitation of the tunnels and the addition of new capacity at the Midtown Tunnel.

The headline finding was that weekday traffic reduced by 8% at the Midtown Tunnel and by 20% at the Downtown Tunnel. The authors also reference earlier findings from the SR-520 bridge in Seattle, Washington, where tolling reportedly "*reduced traffic across the bridge by about 30%*".

The strength of papers such as Nichols & Belfield (as opposed to the meta-analyses discussed later) is depth. The authors examined the traffic impacts of tolling from multiple perspectives (eg. weekday versus weekend and peak versus off-peak). They report separately on the impact on trucks, on transit usage, on average speeds, queues and delays - and on the impact on other (alternative) routes. Their analysis demonstrates that the traffic impact of road tolls is considerably higher during quieter travel periods and/or when trip-making is of a more discretionary nature (ie. off-peak). They report that the impact on trucks was less than that for general traffic - and their wider-area traffic counts demonstrated that the driver response was largely diversion to other routes (trip reassignment) rather than electing not to travel (trip suppression).

Our literature review uncovered two meta-analyses reporting the traffic impact of tolling: one from Portugal, the other from North America.

In Santos & Santos (2012), the authors report on the impact of converting shadow toll road concessions in Portugal (SCUTs[8]) to real tolls. Under the shadow toll model, although the payment mechanism is linked to road usage (transferring traffic risk to the private partner), it is the state, not road users, that makes the investment-reimbursement payments. Critically, from a users' perspective, the roads remain free at the point of use.

Over time, however, the aggregate financing burden on the state became unsustainable and the Portuguese Government decided to reduce its obligations by converting a number of the SCUTS to real tolls (October 2010 - December 2011). The traffic impacts of the 'activation' of real tolls are summarised in **Table 1**[9]. The recorded range runs from around -45% to -55%.

Table 1: Toll Activation (Portugal)

Toll Facility	AADT[10]		Traffic Impact
	2010	2011	
A17	22,425	11,940	-47%
A29	45,174	19,282	-57%
A41	47,539	23,987	-50%
A42	20,250	9,496	-53%
A4	60,414	33,724	-44%

[8] SCUT stands for Via Sem Custos Para o Utilizador, which is Portuguese for 'a road without fees for the user'.
[9] In their paper, Santos & Santos provide 'before' and 'after' traffic data for different sections of the same road (eg. for three sections of the A17). As these impacts are likely to be correlated, we collapsed their dataset into five observations at the road, not section, level.
[10] Annual Average Daily Traffic.

Turning to the second meta-analysis, in 2018 a team of consultants published a research paper (Davis et al) which summarised the traffic impact of tolling nine existing (toll-free) facilities in the US and Canada. The paper describes each facility at length and discusses a number of 'tradeoffs' - the one of primary interest here relating to traffic diversion[11]. In terms of the traffic impact of tolling, the consultants' findings are summarised in **Table 2**.

The consultants report that "*…the facilities…were found to have from 10% to 36% less traffic after tolling, with most in the range of 15% to 25% less*". This range of observations was attributed to the availability - and quality - of alternative routes, willingness-to-pay (income profiles in the catchment areas) and the level of the toll. Interestingly, the consultants note that tolls on the Port Mann Bridge (BC) were later removed ('deactivated') leading to a subsequent rebound in traffic (see **Table 3**).

This prompted us to consider both toll activation ('tolls on') and deactivation ('tolls off') during our data collection stage.

Our review also examined the 'grey literature' - mainly technical reports by government officials and toll road studies by traffic consultants. What insight into the traffic impacts of tolling might it provide? This was, however, largely unproductive.

Table 2: Toll Activation (N America)

Toll Facility	State/ Province	Tolling Activated	Traffic Impact
Port Mann Bridge	BC	2012	-17%
Snapper Creek Expressway	FL	2010	-20%
IL390 (US20 to I-290)	IL	2016	-23%
Ohio River Bridges (all)	IN-KY	2016	-36%
Dominion Boulevard	VA	2017	-24%
Downtown Tunnel	VA	2014	-16%
Midtown Tunnel	VA	2014	-20%
SR-520 Bridge	WA	2011	-25%
Tacoma Narrows Bridge	WA	2007	-10%

Table 3: Toll Deactivation (N America)

Toll Facility	State/ Province	Tolling Deactivated	Traffic Impact
Port Mann Bridge	BC	2017	+27%

The majority of reviewed reports presented limited results (predictions) from traffic models - whereas the emphasis here is on observed responses (hard data). Perhaps the most informative modelling report was prepared for the Minnesota Department of Transportation (MnDOT) back in 2018[12]. In a wide-ranging study, a team of consultants evaluated tolling as a transportation funding source for the state legislature - and considered its implications (one of which was likely traffic diversion to alternative routes ie. the traffic impact).

The consultants confined their analysis to limited-access roadways with a minimum of 10,000 vehicles/lane/day[13], which they divided into four categories:

- Interstates: urban and rural
- Freeways: urban and rural

In practice, interstates and freeways are not dissimilar. The Interstate System was developed in the 1950s to serve long-distance, regional movements between major urban areas in the US. Freeways generally serve more local trips yet share many of the same characteristics (such as being limited access, maintaining separate [directional] travel lanes with a physical barrier between them, and having grade-separated intersections)[14]. For the classification of 'urban' and 'rural', the consultants used the population ranges defined by the US Census Bureau.

[11] The phrase 'diversion' is used throughout the paper to refer to traffic loss irrespective of what drivers choose to do instead (use a different route, use a different mode, do not travel etc.).
[12] 'Minnesota Tolling Study Report: Modern Tolling Practices and Policy Considerations', Minnesota Department of Transportation, January 2018. Available at: *https://www.leg.mn.gov/docs/2018/Mandated/180109.pdf*
[13] It was assumed that traffic volumes below this threshold would generate insufficient revenue to warrant the cost of a tolling system.
[14] 'Highway Functional Classification: Concepts, Criteria and Procedures - 2023 Edition', Federal Highway Administration, US Department of Transportation, February 2023. Available at: *https://www.fhwa.dot.gov/planning/processes/statewide/related/hwy-functional-classification-2023.pdf*

In terms of the study findings, the consultants report a 'base diversion rate' (by roadway classification), to which they then apply a number of overlays. Their estimated base diversion rates were:

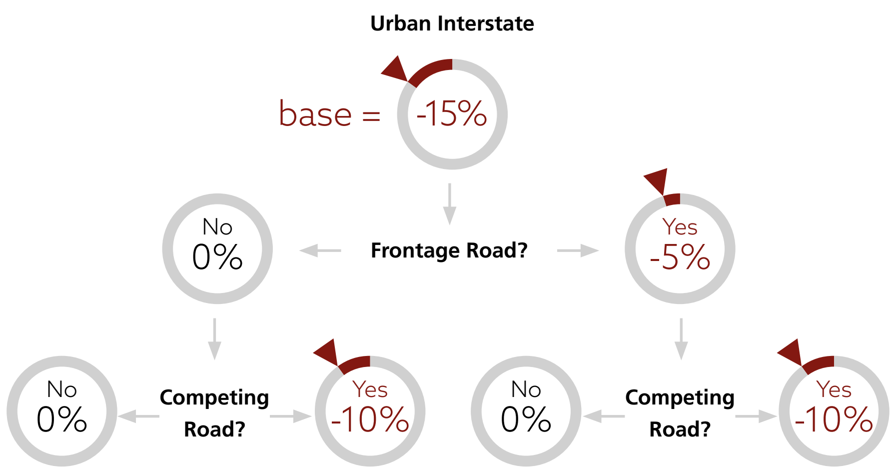
- Urban interstate: -15%
- Rural interstate: -20%
- Urban freeway: -20%
- Rural freeway: -25%

The subsequent application of the overlays accounts for other causal factors:

- The presence of continuous frontage roads (diversion increases by -5%)
- The availability of competing routes within 10 miles (diversion increases by -10%)

This is illustrated in **Figure 3** using an urban interstate as an example. The estimated diversion for an urban interstate with neither frontage nor competing roads is -15% (-15-0-0). The same, in the presence of both frontage and competing roads is -30% (-15-5-10).

Figure 3: MnDOT's Estimates of the Traffic Impact of Tolls



Finally, the consultants' analysis suggested adding a modifier to account for the toll rate itself:

- A 20% reduction in diversion if the rate is low (then, 4c/mile)
- No change for a medium toll rate (7c/mile)
- A 20% increase in diversion if the rate is high (10c/mile)

Taken together, the range suggested by the MnDOT study runs from a traffic impact (diversion) of -12% for a low-priced urban interstate with no frontage or competing roads to -48% for a high-priced rural freeway with both frontage and competing roads.

Table 4 summarises the toll-related traffic impact ranges for the three main studies considered in this literature review.

Table 4: Literature Review Summary

Study	Country	Data Source	Traffic Impact Range	
Santos & Santos (2012)	Portugal	Observed	-44%	-57%
Davis et al (2018)	N America	Observed	-10%	-36%
MnDOT (2018)	USA (MN)	Modelled	-12%	-48%

Data Collection & Description

The primary aim of data collection was to extend the literature both in terms of the number of case studies and geographical coverage. The Portuguese paper discussed earlier summarised five case studies whereas the North American paper reported the results from nine toll activations and one toll deactivation. Having independently verified these 15 data points[15], we were able to identify and add a further 68, bringing our sample to 83 international case studies. This is the largest and most up to date sample of toll activation and deactivation traffic data ever compiled.

We consulted multiple sources to compile our data. Over the past 16 years we have accumulated a library of nearly 300 toll road traffic and revenue study reports, so we started there - looking for examples of toll activation and deactivation and recording the associated traffic response.

Other sources of data included research reports and academic papers (such as those mentioned earlier in our Literature Review). We also consulted industry contacts, media reports and press releases, and toll operator and transportation department websites. Additionally, we searched public sources online. In a number of cases, our experience guided these searches.

For example, in some countries toll roads become toll-free upon concession termination and, in others, tolling commences only after an upfront toll-free period of operations - to encourage drivers to try-and-test the facility. This semi-structured approach was supplemented by more general searches. Finally, we reviewed traffic data passed to us by clients and incorporated those findings as relevant.

Of our 83 case studies where road tolls had been switched 'on' or 'off', we were unable to find traffic data relating to five, reducing our sample to 78. In two of our case studies, tolls only applied to commercial vehicles (trucks). They, too, were set aside - allowing us to carry forward 76 cases for analysis; 49 of which were toll on (activation) and 27 were toll off (deactivation). Our case study list can be found later - see Appendix. The data relating to 71 of the case studies is in the public domain and is cited (with hyperlinks) in the database that accompanies this paper. The data relating to five of them was provided as commercial-in-confidence by our clients. This data cannot be shared. As such, it is anonymised in our database.

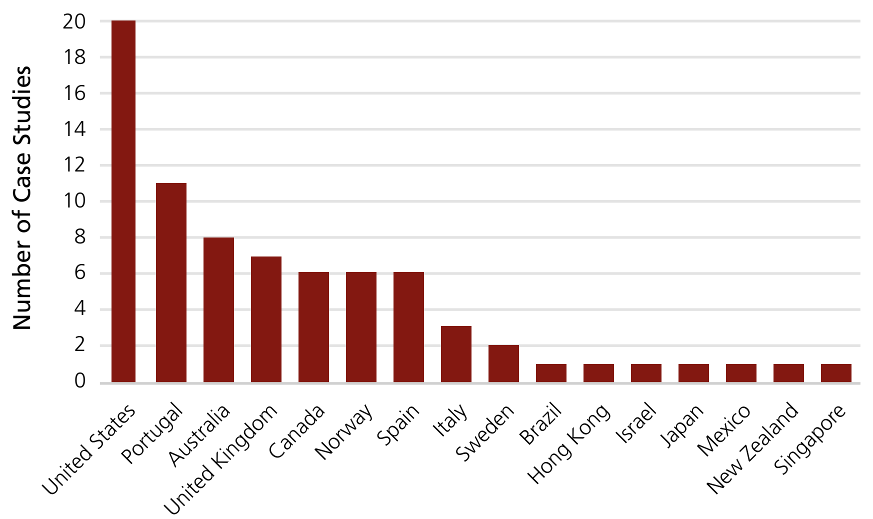
The breakdown of our case studies by facility type is summarised in **Table 5**. According to their geographical setting, the case studies were categorised as being 'urban' (46) or 'interurban' (30).

Finally, we reviewed our case studies according to host jurisdiction (see **Figure 4**). Given the popularity of road tolls in North America, it is no surprise that projects located in the US (and, to a lesser extent, Canada) featured prominently in our dataset.

Table 5: Tolling Case Studies by Facility Type

Facility Type	Number of Case Studies
Roads	35
Bridges	20
Tunnels	8
Cordons[16]	13
Total	**76**

Figure 4: Tolling Case Studies by Host Jurisdiction



[15] Independent verification uncovered some data anomalies. For example, the traffic impacts of tolling the Downtown and Midtown Tunnels in Virginia reported in Davis et al (2018) are different from those reported earlier in Nichols & Belfield (2015) - despite Davis et al referencing the Nichols & Belfield paper. In this case, the impacts reported originally in Nichols & Belfield were used as the basis for our analysis.
[16] The term 'cordon' refers to a clearly demarcated geographic boundary that surrounds a tolling area (such as a city centre). Vehicles that cross the boundary - or drive within the cordon - are subject to the toll.

Toll Activation versus Deactivation

For a small number of our case studies, we had both toll activation traffic data (when the tolls were switched on) and toll deactivation traffic data (when the tolls were later turned off) - or vice versa. The reported percentage changes were different - but this was primarily a function of reporting percentages. For example, if toll activation causes a drop in traffic from 100 to 80, that is a -20% change [(80/100)-1]. However, if toll deactivation subsequently causes the traffic to rebound to its original level (100), that appears as a +25% change [(100/80)-1]. The starting points for the calculation (the denominator) is different, hence the percentage change is different - despite identical volume changes.

This issue can be circumvented in situations (as here) in which our primary interest is in 'one direction of travel' (toll activation) if the research question is reframed, from:

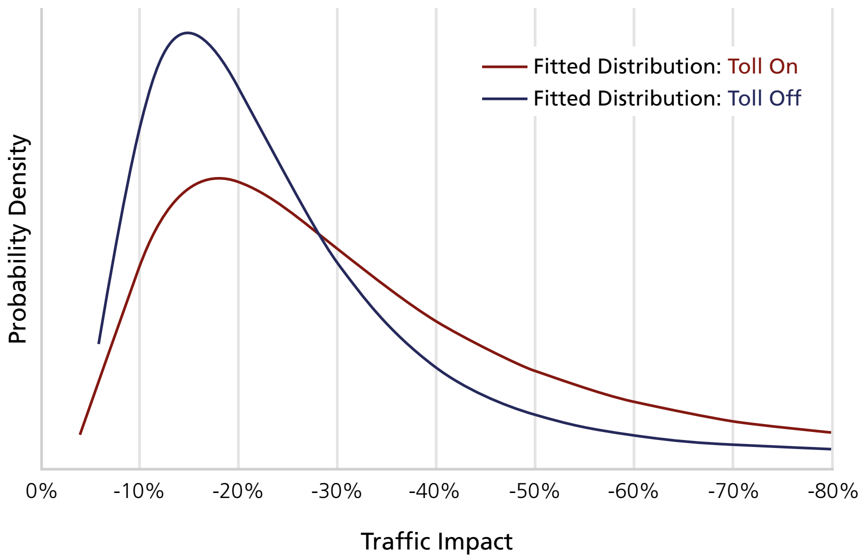
(1) What happens to traffic if tolls are switched on or off?

to…

(2) What is the difference in traffic between the 'toll off' and 'toll on' situation?

Answers to question (2) retain a constant denominator. The starting point is always 'toll off' traffic - allowing for the two separate samples to be merged. But is data consolidation justified?

Figure 5: Traffic Impact Distributions (Toll On v Toll Off)



To answer this question, we first compared the traffic impact distributions for the 'toll on' and 'toll off' samples (see **Figure 5**). The 'toll off' distribution displays more peakiness, but this is largely a function of the fact that this data contains more case studies with poor or no alternatives - associated with lower traffic diversion. Otherwise, the samples appeared to be broadly comparable.

Subsequent tests suggested that, when we controlled for the imbalance in cases studies with no alternative, the difference between the two samples was not statistically significant[17]. This validated our approach of combining the samples for analytical purposes - consistently considering the traffic data in terms of the difference between toll off and toll on.

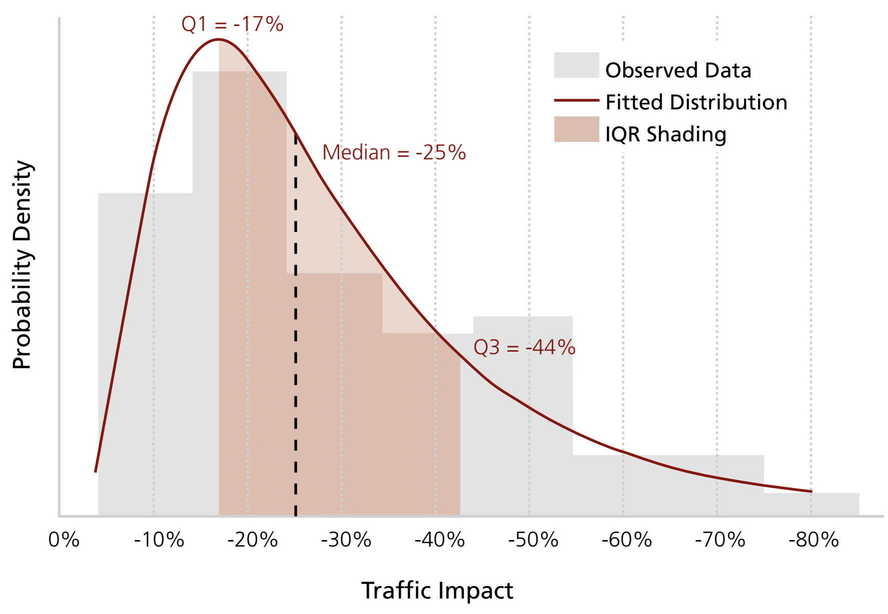
[17] The result of the Mann-Whitney U Test yielded a test statistic of 574.0 and a p-value of approximately 0.208. Since the p-value was greater than the common significance level (0.05), this suggested that there was no statistically significant difference between the traffic impacts in the 'toll on' and the 'toll off' samples.

Headline Results

The results from our data collection are summarised in **Figure 6**. The median traffic impact associated with tolling was found to be -25%. A wide spread of observations was recorded (-4% to -85%) due to the presence of outliers at both extremities.

The interquartile range[18] (IQR) extended from -17% to -44%. This range is arguably more useful from a practical perspective as it is more robust against outlier influence than other measures of data variability.

Figure 6: The Traffic Impact of Road Tolls (*n* = 76)



Digging below the headline results, we analysed the data from various perspectives to determine if different facilities or facilities with different attributes were associated with specific traffic impacts. Were bridges or tunnels associated with different levels of traffic diversion than roads? Were the traffic impacts on urban facilities fundamentally different from those observed for interurban ones? No clear (statistically significant) patterns could be identified.

However one pattern that did emerge concerned monopolistic facilities (toll roads, bridges or tunnels with no alternative routes). The associated traffic impacts were clustered around -15% with limited variability (see **Table 6**). This finding is carried forward to the specification of our predictive model - described later.

[18] The interquartile range measures the spread of the middle 50% of a data sample. The data is divided into quarters (Q1, Q2, Q3 and Q4). 25% of the distribution lies below the first quartile (Q1) and 25% lies above the third quartile (Q3) - as illustrated in Figure 6.

In **Figure 7** we set our headline results against those reported earlier. Our IQR sits comfortably alongside the findings of Davis et al and the outputs from the Minnesota (MnDOT) study. In contrast, the Portuguese results from Santos & Santos appear high.

On closer examination, it turns out that two factors contributed to the greater traffic impacts recorded in Portugal. First, the SCUTS were converted to real tolls at a time which coincided with the European debt crisis. The reported impacts did not take account of the fact that toll road usage, generally, had decreased by 7%[20].

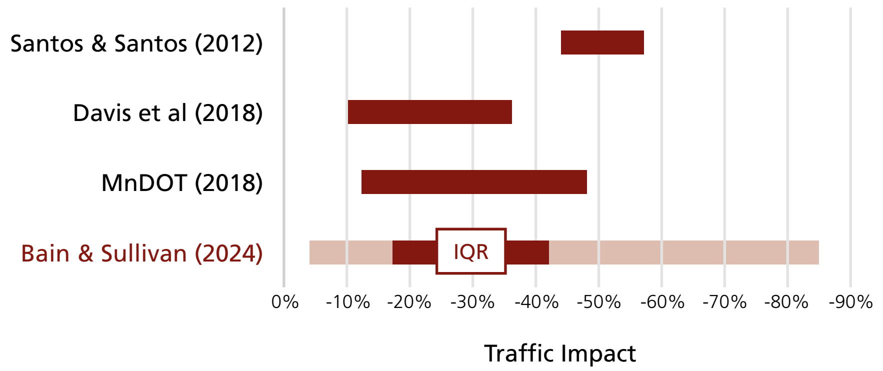
Second, in their report, the authors specifically comment that *"the neighbouring network to these motorways is…very dense, providing many alternatives to those drivers that want to avoid tolled roads"*. Under such circumstances, traffic diversion would be expected to be greater.

Whereas facts and figures are interesting, the following section turns to the more important issue of how the data - summarised above - can be used in a predictive context.

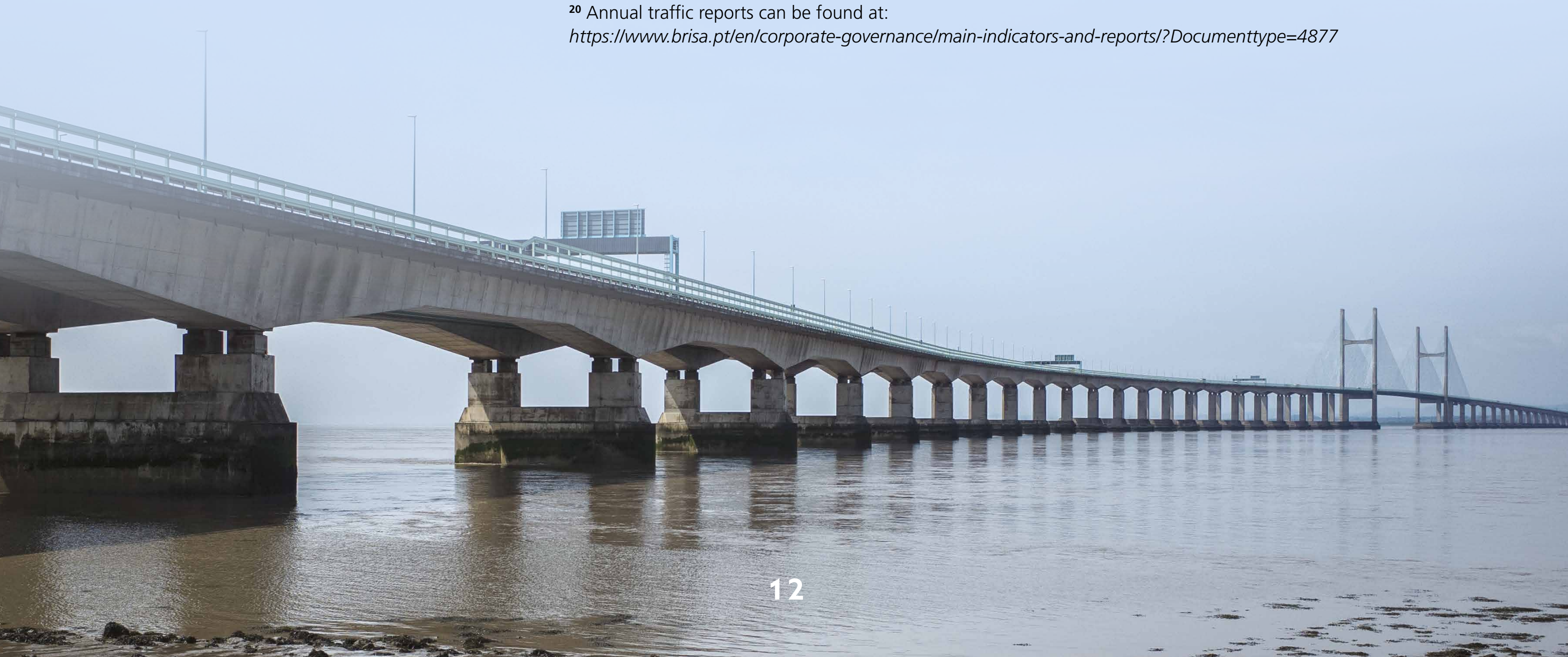
Table 6: Traffic Impact - No Alternative Available

ID[19]	Toll Facility	Traffic Impact
16	Tacoma Narrows (US)	-10%
3	Sanibel Causeway (US)	-17%
55	Osteroy Bridge (Norway)	-14%
41	Skye Bridge (UK)	-18%
40	Severn Crossings (UK)	-14%
44	Forth Road Bridge (UK)	-11%
45	Tay Bridge (UK)	-13%
46	Erskine Bridge (UK)	-16%

Figure 7: Traffic Impacts - Comparison of Findings



[19] ID refers to the database shown later.
[20] Annual traffic reports can be found at:
https://www.brisa.pt/en/corporate-governance/main-indicators-and-reports/?Documenttype=4877



The Predictive Model

Our primary objective was to examine our 76 traffic-impact case studies in the context of their attributes to determine if any relationships could be identified and quantified. Which attributes (if any) best explain the observed traffic responses to tolls?

As mentioned earlier, we collected data about the toll facilities themselves, their location and their price (the toll tariffs). We noted if alternative routes were available to drivers - both in terms of quantity and quality (eg. were the alternatives congested?) - and if alternative modes could be used to substitute for the use of the toll facility (could people, instead, travel by bus or rail?).

Our aim was to use multiple regression analysis with 'traffic impact' (expressed in percentage terms) as the dependent variable and the strongest explanatory features as the independent variables. Our candidate explanatory variables are described below (alongside a description of how they were represented in our model):

- **Toll Facility**
  The facility (toll road, bridge or tunnel) was described in terms of its setting (urban or interurban) and the presence of continuous frontage roads (no = 0, yes = 1).

- **Toll Tariff**
  For comparison purposes (as we had compiled an international data set relating to different years), the toll tariffs were adjusted for inflation and purchasing power parity. From this starting point we calculated two additional metrics. Using facility length, we calculated the rate per mile. We also calculated the rate per minute saved, where possible, by comparing the toll route travel time (and cost) against the quickest, toll-free alternative route. For this we used Google Maps[21].

- **Alternative Route(s)**
  Our first five 'alternative route' variables were dummy variables:

  - Is there an alternative route (0 = yes, 1 = no)?
  - If alternative routes exist, are they tolled (0 = no, 1 = yes)?
  - A 'quality differential' (-1 = the alternative is better, 0 = the alternative is similar, 1 = the alternative is worse)
  - Does the alternative involve a detour (0 = no, 1 = material detour)?
  - Does the alternative suffer from travel time unreliability, usually congestion-related (0 = no, 1 = yes)?

  Our sixth explanatory variable captured the number of alternative routes, using a qualitative scale from 1 to 10.

- **Alternative Mode(s)**
  Our final candidate explanatory variable captured the impact of alternative mode availability, again using a qualitative scale from 0 to 10.

The coding framework for our scaled parameters is shown in **Table 7**.

Table 7: Scoring Scale - Qualitative Variables

Alternative Route(s)	Score
Few alternatives of low quality	1 - 4
Several alternatives of varying quality	5 - 7
Many alternatives of high quality (many city streets, 3+ alternative crossings etc.)	8 - 10
Alternative Mode(s)	**Score**
No public transit	0
Poor, infrequent bus service with long travel time	1 - 4
Higher frequency bus service	5 - 7
Mass rapid transit (subway, regional rail etc.)	8 - 10

For our regression analyses, we used 61 of our 76 case studies. We focussed on toll roads, bridges and tunnels. The omitted case studies were mainly examples of network or area-wide pricing as these differed from traditional tolling deployments.

We tested various combinations of our candidate explanatory variables (individually and collectively) and progressively removed those with weak (or no) explanatory power. We also removed correlated variables such as 'setting' (urban/interurban) - as urban locations were generally associated with increased travel options (greater availability of alternative routes and modes). The individual variables describing different aspects of these alternative travel options had better and more insightful explanatory power than that provided by the single dummy variable (urban/interurban).

The resulting model (our preferred specification) is summarised in **Table 8**.

[21] A full description of this method can be found in 'It's About Time', Bain & Senechal (2022). Available at: *https://csrbgroup.com/its-about-time*

Table 8: Preferred Model - Explanatory Variables

Category	Variable	Representation	Coding
Alternative Route(s)	Any Alternative?	Dummy variable	1 = no alternative
	Quality Differential	Dummy variable	1 = the alternative is worse
	Extent of Detour?	Dummy variable	1 = alternative is a material detour
	Reliability?	Dummy variable	1 = alternative can experience congestion
	Number of Alternatives	Scale 1 to 10	1 = one, 10 = many
Alternative Mode(s)	Alternative Mode Availability	Scale 0 to 10	0 = none, 10 = many

Turning back to model estimation, we solved for coefficients that minimised the sum of squared errors between the modelled and observed data. The resulting coefficients made sense both in terms of their sign and their relative magnitude.

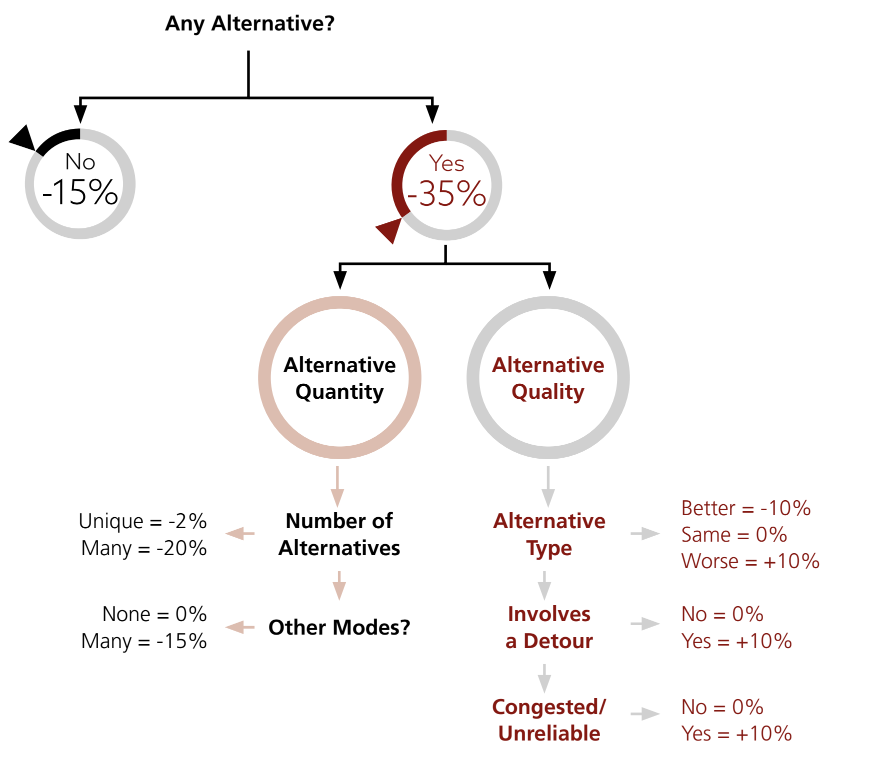
However, the mathematical outputs were deceptively precise, inferring a degree of accuracy that we were keen to avoid. Studies of human behaviour are not laboratory experiments. They are, by definition, messy. Driver behaviour is complex and is influenced by a wide range of physical, personal and emotional factors, life experiences and individual desires. It is also influenced by context and how people perceive situations. This last point was emphasised in the MnDOT study reviewed earlier:

> "Traffic diversion...is highly variable and difficult to predict because of the variation in perception among motorists."
>
> *MnDOT Study (2018), page 54*

In short, mathematical models of driver behaviour are, by definition, imperfect. For this reason, we were drawn to the simple 'decision-tree' approach developed by the MnDOT study team - an example of which was shown earlier in **Figure 3**[22]. As a result, we rounded the estimated coefficients from our regression model.

Although this degraded the model's fit (marginally), we did so to emphasise the fact that our model estimation - incorporating both quantitative and qualitative variables - should be used to suggest indicative ranges rather than precise estimates of the traffic impact of tolling. The result - before incorporating the influence of price - is shown in **Figure 8**.

Figure 8: The Decision Tree Suggested by our Analysis



[22] A further reason for adopting rounded coefficients was to ensure that we avoided overfitting our relatively simple model. In our experience, it is easy for behavioural researchers or analysts to over-focus on goodness-of-fit, to the detriment of predictive capability.

The decision tree shown starts (at the top) with a question about the availability of alternatives (routes and modes). If no alternatives are available, the branch stops, suggesting a traffic impact of -15%. If alternatives are available, an initial traffic impact ('base diversion') of -35% is suggested, before overlaying a series of attributes that reflect both the quantity and quality of these alternatives.

The overlay adjustments are shown beside their respective boxes. For example, the presence of congestion (or degraded travel time reliability) on the alternative route makes it less attractive and, all things being equal, this would be expected to dampen traffic diversion. Arithmetically, +10% is added-back to the initial traffic impact (-35%) to give a toll-related traffic impact estimate of -25%.

In terms of traffic impact prediction, our model is dominated by variables describing the quantity and quality of alternative travel options available to local drivers. This aligned with our experience - yet we were surprised that the explanatory power of price (toll tariffs) remained weak.

On reviewing our analysis, it became clear that this was partially a function of our dataset and our objective. We had standardised and consolidated price data from different types of facility in different countries using different currencies at different points in time. Examination of the data suggested that price had an influence, yet - given the diversity in the dataset - this proved to be too challenging for our simple regression-based approach to capture.

A compounding issue is that toll prices are seldom established in isolation. There is generally some relationship between the price charged and the value proposition on offer. That value proposition reflects the attractiveness of the facility which, in turn reflects the unattractiveness of the alternatives - which was already accommodated in our model specification.

As a pragmatic solution, we followed the approach suggested earlier in the MnDOT study of applying a post-overlay 'price modifier' to our estimated traffic impacts. For this, we used research that we had undertaken earlier on toll price elasticities to inform the size of the modifier[23] (having previously identified a strong relationship between toll price elasticities and the attractiveness of alternatives at drivers' disposal).

In short, the price elasticity impact was likely to be more pronounced in cases of higher expected traffic diversion, so - being guided by our earlier findings - it was scaled accordingly. A toll price elasticity of -0.1 was applied when the model was suggesting a 10% diversion (traffic impact) and -0.5 was used at an impact of 50%.

By linking the price modifier to price elasticity - itself related to the attractiveness of the alternatives (and hence, the potential for traffic diversion) - its influence remains proportional. This is a desirable property.

To recap, our predictive model estimates a base diversion rate first before the series of overlays are added (as appropriate). Then (again, as appropriate) the toll price modifier is applied. In the panel below we provide a worked example to demonstrate how the modifier is applied in practice.

[23] Bain R & Cimon B (in press), *'Toll Road Pricing - Demand Elasticity & Affordability: A State of the Practice Review'*.

The Toll Price Modifier: Worked Example

Assume that a road to be tolled has the following characteristics:

- It has an alternative (so 'base diversion' = -35%)
- The alternative is a regional road with at-grade intersections (add back 10%)
- The number of alternatives is limited (subtract 5%)

...gives a traffic impact of -30%.

At this level of diversion (30%), any expected price elasticity would lie around -0.3.

The prevailing toll rate in the area is 15c/mile, however the price proposed for this particular road is 33% higher at 20c/mile. Therefore, the price impact is -10% (33% higher at a price elasticity of -0.3). This impact applies to the retained ie. non-diverted traffic (70%) to reduce it to 63%.

Thus, the high toll tariff (by itself) increases the expected diversion from -30% to -37%.

The toll price modifier is effectively scaled by the presence of alternative travel options. It increases the traffic impact rate (of tolls) in cases where multiple alternatives are available. This underscores the need to fully understand the competitive landscape and dynamics in-play when estimating toll-related traffic diversion.

In terms of outputs (the predicted traffic impacts), as discussed, facilities that lack any alternative lie towards the bottom of our modelled range (estimated diversion ≈ 15%). This reflects the observed data shown earlier in **Table 6**. Towards the upper end of the range lie facilities like the Ohio River Bridges in the US (ID = 9). The observed diversion (-55%) is compared against our model's estimate (-51%) in **Table 9**.

The overall performance of our predictive model is summarised below in **Figure 9**. The blue dots are observations (from our case studies), and the dashed red line represents a perfect model fit.

Table 9: Ohio River Bridges Traffic Impact (Modelled versus Observed)

Ohio River Bridges (US)			**Traffic Impact**
Observed Impact			-55%
Model Inputs	Base Diversion	-35%	
	Several Route Alternatives	-16%[24]	
Modelled Impact			**-51%**

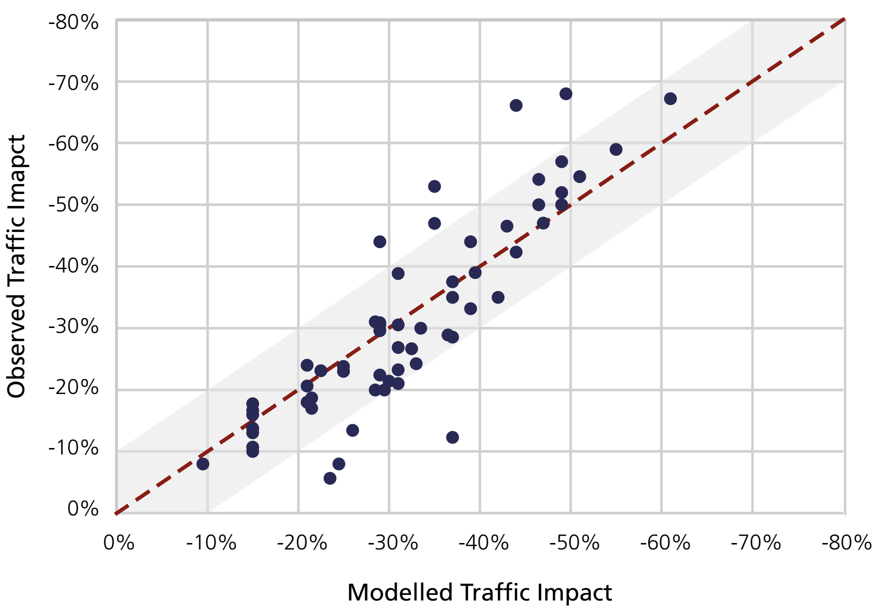
The shaded area shown in **Figure 9** denotes a range of +/-10% around our model estimates. 84% of our case study impacts lie within this range. In terms of applying the model, we recommend that this range (+/-10%) should be reported alongside the model outputs.

A small number of outliers sat beyond our modelled range. The reasons for this were typically project (or jurisdiction) specific and were relatively quick to identify. One-third of them were from Portugal where, as discussed earlier, the reported toll-related traffic impacts were higher than expected.

Another reason arises from the interplay between tolled facilities. For example, the Midtown and Downtown Tunnels in Virginia commenced tolling at the same time with identical tolls. However, the Midtown Tunnel lost less traffic as it is located further from the toll-free alternatives.

Our Appendix lists all of our case studies, showing both the observed and modelled traffic impacts of road tolls for those cases used in the model estimation process.

Figure 9: Toll-Related Traffic Impacts - Modelled versus Observed



"84% of our case study impacts lie within +/-10% of our model estimates"

[24] The scoring for the number of route alternatives was 8/10. This is applied to the -20% reduction suggested in Figure 8 to produce the adjustment of -16%.

Conclusions

The user-pays principle - that beneficiaries of a service should shoulder the burden of paying for it - is applied in many sectors; the most common example in road transportation being fuel tax. In the US, fuel taxes provide nearly 40% of the revenue that states direct to their transportation funds[25]. However, historically, revenue has seldom kept pace with inflation (dropping in real terms) and, looking forward, is facing an even more significant shortfall due to the shift to electric vehicles. Against this backdrop, it is perhaps unsurprising that there has been a noticeable uptick recently in the interest in road pricing.

Despite this, little has been written about the traffic impact of the introduction of road tolls. How much diversion do they cause and what are the determinants of that diversion? These are the questions that we set out to answer.

Estimating initial traffic diversion is an important consideration. Research suggests that, from a financial perspective, a key commercial risk associated with toll roads is start-up risk (Bain & Wilkins, 2002). Despite the common usage of ramp-up profiles, many financial failures can be traced back to overestimating traffic (and revenue) performance in the opening years. Under such circumstances, the project may never recover financially, and future expectations have to be adjusted downwards.

Our research set out to examine the traffic impact of road tolls, looking for evidence-based relationships that could be used to assess the likely diversion rates under different scenarios. Using a sample of 76 case studies from around the world, we were able to construct a simple predictive model which can be used to provide initial estimates of likely traffic diversion when tolls are applied on roads, bridges or tunnels. Our case studies showed that the median impact of tolls (traffic diversion) was -25%. The interquartile range was -17% to -44%.

Our model is based on a simple decision tree which first establishes a 'base diversion' estimate and then asks a series of questions (overlays) to refine that estimate. The questions focus on the quantity and quality of alternatives at drivers' disposal - as we found those, alongside price, to be the key determinants of diversion. The second-order influence of price (the toll tariff) is accommodated by applying a modifier to our diversion estimates. All things being equal, expensive facilities are associated with higher diversion rates.

Our approach is not necessarily a substitute for a full traffic study[26] - however it can be used to independently check the outputs from traffic models[27]. Is the model behaving reasonably? Do the results accord with the evidence on toll-related traffic diversion?

In the course of our work, we regularly come across traffic advisors who underplay the potential impact of tolling, suggesting infeasibly low diversion rates. When faced with low estimates of diversion, planners, policymakers, infrastructure investors and other industry participants need to be cautious. It is perhaps instructive to reflect that, in nearly a quarter of our international case studies, the toll related traffic diversion rates were -45% or higher.

[25] Source: *https://www.pewtrusts.org/en/research-and-analysis/articles/2022/10/03/as-electric-vehicle-growth-squeezes-gas-tax-revenues-data-helps-states-prepare#:~:text=In%20the%20aggregate%2C%20fuel%20taxes,share%20of%20total%20vehicle%20sales*

[26] This statement was contested by one of our more-experienced reviewers who responded as follows: *"Having worked with many full scall urban travel demand models and the forecasts produced by such models for major investment studies, I think your method can be a reasonable substitute for full traffic studies. Due to its simplicity, it can be more easily explained to the public and/or potential investors and the underlying assumptions [can be] challenged or corrected."*

[27] In most traffic models it is relatively easy to switch tolls on and off, to isolate the impact of tolling as predicted by the model.

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[28] *https://zephyrtransport.org/TMIP/*

DATABASE OF TOLL ON (ACTIVATION) AND TOLL OFF (DEACTIVATION) IMPACTS

#	Toll Facility	Country	Toll On/Off?	Date	Traffic Impact	
					Observed	Modelled
1	Baldwin Beach Express	United States	Off	May/2024	-31%	-31%
2	Appalachian Town Bridge		On	Oct/2023	-59%	-55%
3	Sanibel Causeway		Off	Aug/2023	-17%	-15%
4	Midwest Town Bridge		On	Jun/2023	-52%	-49%
5	Midwest City Bridge		On	Feb/2021	-35%	-42%
6	SR-99		On	Nov/2019	-27%	-33%
7	Scudder Falls		On	Jul/2019	-27%	-31%
8	Dominion Boulevard		On	Feb/2017	-24%	-21%
9	Ohio River Bridges		On	Jan/2017	-55%	-51%
10	IL390 (Elgin-O'Hare)		On	Jul/2016	-23%	-25%
11	Midtown Tunnel		On	Jan/2014	-8%	-25%
12	Downtown Tunnel		On	Jan/2014	-20%	-29%
13	Texas State Road		On	Nov/2012	-33%	-39%
14	SR-520		On	Dec/2011	-38%	-37%
15	Snapper Creek Expressway		On	Jul/2010	-20%	-30%
16	Tacoma Narrows		On	Jul/2007	-10%	-15%
17	NY Thruway (Buffalo)		Off	Dec/2006	-13%	-26%
18	Natcher Parkway		Off	Nov/2006	-24%	-25%
19	Coronado Bridge		Off	Jun/2002	-6%	-24%
20	Orlando-Orange County Expressway-NE		On	Mar/1989	-41%	
21	A17	Portugal	On	Oct/2010	-47%	-35%
22	A29		On	Oct/2010	-57%	-49%
23	A41		On	Oct/2010	-50%	-49%
24	A42		On	Oct/2010	-53%	-35%
25	A4		On	Oct/2010	-44%	-39%
26	Via do Infante (A22)		On	Dec/2011	-44%	-29%
27	Beira Interior (A23)		On	Dec/2011	-31%	-29%
28	Viseau Chaves (A24)		On	Dec/2011	-30%	-29%
29	CREL (A9)		On	Dec/2011	-29%	-37%
30	Aveiro-Vilar Formoso (A25)		On	Dec/2011	-18%	-21%
31	A28		On	Oct/2010	-22%	-29%
32	M4	Australia	On	May/2017	-21%	-30%
33	Airportlink		On	Nov/2013	-42%	-44%
34	Clem7		On	Apr/2010	-66%	-44%
35	Eastlink		On	Jun/2008	-50%	-47%
36	Lane Cove Tunnel		On	Apr/2008	-35%	-37%
37	Westlink M7		On	Jan/2006	-30%	-34%
38	CCT		On	Dec/2005	-47%	-47%
39	Westgate Bridge		Off	Nov/1985	-31%	-29%
40	Severn Crossings	United Kingdom	Off	Dec/2018	-14%	-15%
41	Skye Bridge		Off	Dec/2004	-18%	-15%
42	London Cordon		On	Feb/2003	-31%	
43	Durham Cordon		On	Oct/2002	-85%	
44	Forth Road Bridge		Off	Feb/2008	-11%	-15%
45	Tay Bridge		Off	Feb/2008	-13%	-15%
46	Erskine Bridge		Off	Feb/2008	-16%	-15%
47	Ontario Route 412	Canada	Off	Apr/2022	-12%	-37%
48	Ontario Route 418		Off	Apr/2022	-29%	-37%
49	Golden Ears Bridge		Off	Sep/2017	-23%	-23%
50	Port Mann Bridge		Off	Sep/2017	-19%	-22%
51	Port Mann Bridge		On	Dec/2012	-17%	-22%
52	Coquihalla Highway		Off	Sep/2008	-31%	-29%
53	New E18	Norway	On	Sep/2019	-21%	-31%
54	Jaeren Cordon		On	Oct/2018	-8%	
55	Osteroy Bridge		Off	Jan/2015	-14%	-15%
56	Trondheim Cordon		Off	Dec/2005	-10%	
57	Oslo Toll Ring		On	Feb/1990	-4%	
58	Bergen Cordon		On	Jan/1986	-7%	
59	AP-7	Spain	Off	Sep/2021	-47%	-43%
60	C-33		Off	Sep/2021	-54%	-47%
61	AP-2		Off	Sep/2021	-39%	-40%
62	AP-4		Off	Jan/2020	-23%	-31%
63	AP-1		Off	Dec/2018	-24%	-33%
64	Ma-11		Off	Jan/2018	-8%	-9%
65	Milan Cordon	Italy	On	Jul/2012	-15%	
66	Bologna Cordon		On	Jan/2005	-23%	
67	Rome Cordon		On	Jan/2001	-18%	
68	Gothenburg Cordon	Sweden	On	Oct/2013	-12%	
69	Stockholm Cordon		On	Jan/2006	-20%	
70	EixoSP-SP 284	Brazil	On	Jun/2020	-67%	-61%
71	Hong Kong Road Pricing System	Hong Kong	On	Jul/1983	-11%	
72	Trans-Israel Highway	Israel	On	Jan/2003	-68%	-50%
73	Japan Social Experiments	Japan	Off	Nov/2010	-50%	
74	AM Road	Mexico	Off	Jun/2019	-39%	-31%
75	Tauraunga Harbour Bridge	New Zealand	Off	Jul/2001	-21%	-21%
76	Singapore Cordon	Singapore	On	Jan/1972	-45%	

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"Until now, very little has been written about how drivers respond to the initial introduction of road user charges"

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