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THE TOLL PRICE ELASTICITY OF DEMAND

A Guide for Practitioners

Robert Bain & Benjamin Cimon

DRAWING ON AN ANALYSIS OF OVER 450 REAL-WORLD TOLL PRICE ELASTICITIES

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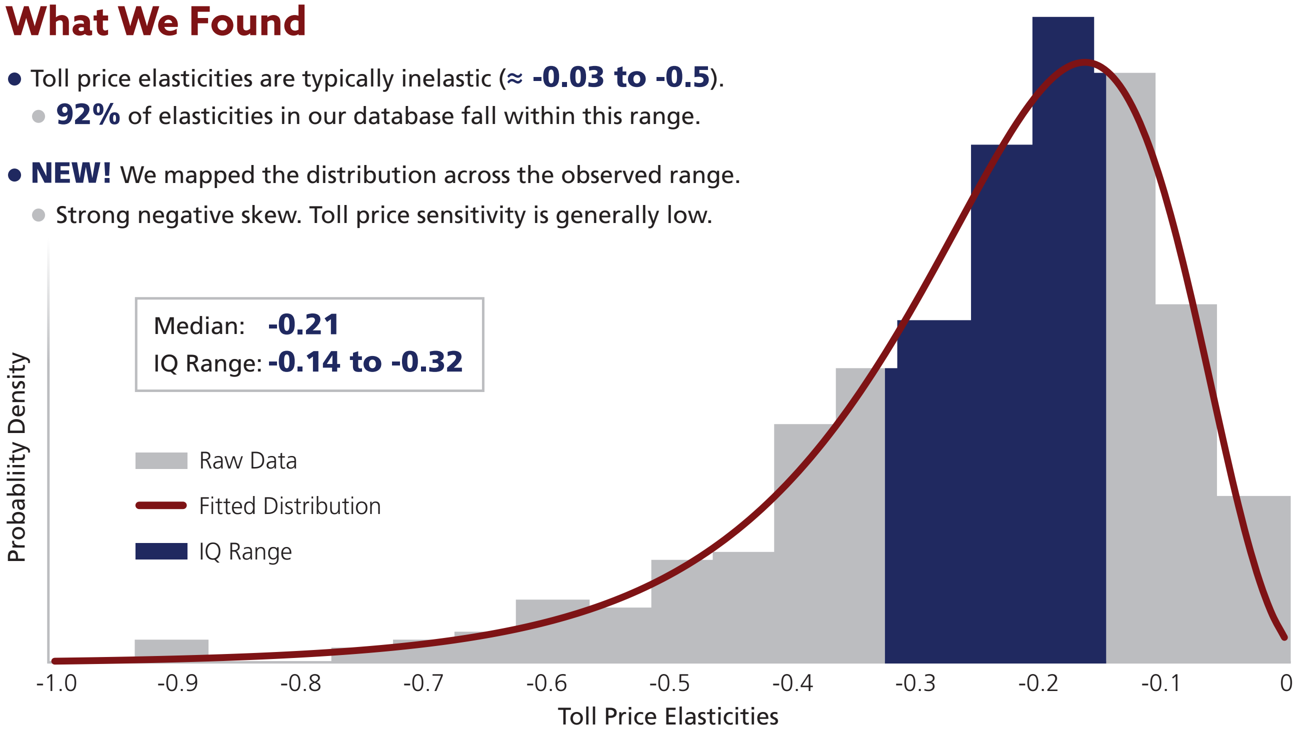
KEY FACTS AND FIGURES

What We Did

- Reviewed **50+** leading academic research papers.
- Analysed **350+** international toll road traffic studies.
- Compiled **450+** unique elasticity observations (data points).
- Identified and summarised **21** practitioner-relevant takeaways.
- Established the **principal determinants** of toll price elasticity.

What We Found

- Toll price elasticities are typically inelastic (≈ **-0.03 to -0.5**).
  - **92%** of elasticities in our database fall within this range.
- **NEW!** We mapped the distribution across the observed range.
  - Strong negative skew. Toll price sensitivity is generally low.



- Our sample is large and diverse (**15 countries**; **29 consultancies**).
  - Multiple observations across different contexts improves the robustness and applicability of our findings.
- The determinants identified in traffic studies **broadly align** with the academic literature.
  - But these influencing factors differ materially in terms of their explanatory strength.
- The primary determinant is the **availability**, **quality** and **substitutability** of alternatives.
  - Other factors - such as income, trip purpose, toll level and the magnitude of the price change - exert second-order, context-dependent effects.

What It Means

- With a clear understanding of the relevant market, practitioners can:
  - Map facility and user characteristics to our determinant framework; and
  - Locate the most plausible position for that market on our empirically-derived elasticity distribution.
- This produces defensible, evidence-based estimates tailored to context and provides a transparent explanation of **where** toll price elasticity is likely to sit and **why**.

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Reproducibility Statement

CSRB Group is committed to transparent and reproducible research.
Our toll price elasticity dataset containing all of our elasticity values along with selected metadata (vehicle type, value source, year, region and client type) is available from:
research@csrbgroup.com

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

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Foreword

This report is an important and timely contribution to the applied economics of road transportation. In the evolving landscape of global infrastructure finance, where toll roads increasingly intersect with regulatory, political and behavioural complexity, the need for robust and practical insight into price elasticity has never been more pressing.

Bain and Cimon, the authors of this study, have delivered a rare blend of intellectual discipline and real-world pragmatism. Combining an exhaustive review of the academic literature with extensive empirical analysis of global toll road data, they not only illuminate prevailing assumptions but challenge several of them. The result is a research product that is as valuable to investors and policymakers as it is to scholars and practitioners.

What sets this report apart is its methodological transparency and analytical depth. The authors are unafraid to confront the complications inherent in elasticity estimation, from behavioural heterogeneity and confounding influences to the shortcomings of traffic modelling. Their willingness to engage with commercial traffic and revenue study data - material generally inaccessible to academic inquiry - broadens the scope of understanding well beyond what standard literature allows.

Particularly commendable is the attention given to contextual variation: across vehicle classes, time periods, facility types and geographic markets. The nuanced treatment of commercial vehicle behaviour, electronic tolling technologies and long-run elasticity dynamics - in practice - exemplifies the report's rigour and relevance.

For those involved in infrastructure policy, planning, valuation or procurement, this report provides not only a reference but a framework. It will, I believe, serve as a foundational text for future empirical work in toll pricing, and a benchmark for what applied transport economics can achieve when grounded in both evidence and experience.

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1. Introduction

CSRB Group is a small, multidisciplinary team of transportation analysts based in the UK and Canada. We operate internationally. Our expertise covers demand forecasting, economics, finance and market research - with a particular emphasis on the road and rail sectors. Given the team's background in financial services - debt and equity - the majority of our work focuses on commercial due diligence (investment analysis and asset valuation).

In terms of toll roads, we have detected a clear trend over recent years. The issue of price is attracting increasing attention from both the public sector - from a policy, regulatory and stakeholder perspective, and as a grantor of concessions - and the private sector - as concessionaires or financiers. Despite this trend, no single reference document is available to guide practitioners on the key issue of how road users are likely to respond to changes in toll price (eg. tariff increases) and, importantly, why.

This report sets out to address that deficiency by integrating a review of the existing evidence with original research and analysis.

Our research was guided by four primary aims:

1. To contribute to and extend the literature on toll price elasticities.

2. To update sector knowledge and understanding through analysis of a recent and detailed global dataset.

3. To examine source material used commercially by investors that offers insights beyond the reach of other researchers.

4. To bridge research and practice by examining toll road study reports produced by traffic and revenue (T&R) consultants, with a focus on real-world applications and prevailing industry approaches.

The report is structured as follows:

- This introductory chapter explains why toll road pricing is attracting increasing international interest from a broad spectrum of professionals. It also summarises key features of the industry that influence price and pricing flexibility.

- Chapter 2 describes the definitions and conventions used throughout the report, and identifies the main analytical challenge faced by researchers in this field.

- Chapter 3 highlights key themes that emerged from a comprehensive review of the academic literature.

- Chapter 4 reflects on alternative ways of calculating toll price elasticities - and their implications.

- Before turning to our own research, Chapter 5 provides historical context and background by reviewing one of the pioneering studies that first examined toll price elasticities.

- Chapter 6 introduces our research through a description of the data compiled for analytical purposes. Our headline results are summarised here.

- Chapter 7 turns the spotlight on commercial vehicles (trucks) and examines their particular sensitivities to toll pricing.

- In Chapter 8, attention switches to the different clients who commission T&R studies to determine whether views on price sensitivity are impacted by risk appetite.

- Chapter 9 considers temporal issues and how the time-of-day of travel influences drivers' sensitivity to toll prices.

- The industry's transition away from cash payments to various forms of electronic toll collection - and its implication for pricing - is discussed in Chapter 10.

- Chapter 11 picks up on an issue raised in the literature - that consumer sensitivity to price often differs between the short and long-run. Is this necessarily the case for toll price elasticities?

- Chapter 12 revisits the alternative methods for estimating toll price elasticities to determine if (and to what extent) the resulting elasticity values are, themselves, method dependent.

- In closing, Chapter 13 reflects on and summarises our research and findings.

The primary audience for this report comprises consultants and professionals engaged in toll road feasibility assessments and extension studies, including planners and policymakers. However, the increasing global emphasis on private sector participation in infrastructure development, financing and operations has broadened the spectrum of industry stakeholders. This now includes bidding consortia and their technical and financial advisors, institutional debt and equity providers, and insurers. Moreover, recent high-profile cases involving litigation and arbitration have heightened interest among legal practitioners, particularly with respect to compensation quantification when toll pricing departs from contractual observance.

One group of stakeholders for whom pricing and its influence on driver behaviour has traditionally been of marginal concern comprises existing toll road operators and owners - particularly those within the public sector. This is explained in **Panel 1.1** and reasons are given for why this may change in the future.

A principal catalyst behind the growing attention being paid to toll pricing has been advancements in toll collection technologies. Traditional cash-based toll systems are being progressively phased out across many operations, with most of the recent start-ups exclusively utilising electronic payment methods. From a pricing perspective, this represents a significant shift.

The transition to electronic tolling enables the implementation of flexible pricing structures and the application of sophisticated pricing strategies that would be challenging under cash-based payment systems.

Additionally, the emerging trend towards dynamic or congestion-based pricing - where tariffs are adjusted, sometimes in real time, to maintain predetermined levels of service - will intensify interest in understanding consumer sensitivity and responsiveness to toll pricing. The same is true in situations where there is a desire to offer differentiated prices to different consumer groups (such as discounts for high-frequency users or low-income drivers).

Panel 1.1: Pricing Constraints in Practice

The majority of investor-financed toll road projects worldwide have tariff escalation mechanisms embedded in contractual (concession) agreements. Although there are instances where private operators are granted unfettered discretion in setting toll rates, these cases remain rare. The more prevalent model permits periodic adjustments to tolls in accordance with inflation indices, thereby maintaining tariffs at or near a constant value in real terms.

Even within such frameworks, there may be scope for marginal refinements to tariff structures - for example, the introduction of peak and off-peak pricing differentials, the reclassification of vehicle types, or the application of different rates for specific movements - provided that overarching constraints, such as average pricing rules or maximum toll ceilings, are respected. And even if operators can inflation-adjust their toll charges, they are seldom under any obligation - and may decide not to do so, or not to exercise their prerogative in full.

This raises a pertinent question for the owners of toll road assets subject to restrictive tariff-setting policies: why should they concern themselves with issues of price elasticity, given their limited capacity to adjust toll rates? To such stakeholders, price elasticity may appear to be of somewhat academic interest.

However, as mentioned, the widespread implementation and maturation of electronic toll collection (ETC) systems has transformed the pricing landscape. These technologies enable the deployment of sophisticated pricing strategies at minimal incremental cost and without the need for physical infrastructure modifications. Pricing changes become a matter of software configuration rather than capital investment. While such capabilities were not anticipated during the drafting of many existing concession agreements, they are better understood by policymakers today.

Globally, there is growing interest among transport authorities in leveraging road pricing as a travel demand management tool. This policy shift may catalyse renegotiations of existing rate-setting frameworks. Accordingly, the fact that many toll road operators are presently constrained in their pricing flexibility does not imply that - in an evolving policy and regulatory environment - these constraints will persist indefinitely.

Characteristics of the Toll Road Industry

Before bringing this introductory chapter to a close, it is worth reflecting on some of the characteristics of the toll road industry as these have important implications for price-setting and pricing flexibility.

Whereas many businesses operate under the assumptions of classical economic theory (competitive markets, free consumer choice and price-driven decision-making), the toll road industry does not. Many toll roads are state-owned and operated. Cost-recovery, congestion management or equity considerations are often the policy objectives - rather than profit-maximisation. In this respect, toll roads more closely resemble the regulated utility sector - industries that provide essential public services for a 'fair return' such as electricity, gas and water. Its structural characteristics, demand determinants and user behaviours deviate substantially from the norms witnessed in traditional free markets.

- **Restricted Substitutability** - drivers often have limited flexibility in terms of travel time, mode or destination. A lack of viable alternatives commonly underpins the relative stability of demand observed in response to toll price changes.
- **Near-Monopolies** - it is rarely feasible (economically, geographically or politically) to construct duplicate roads serving the same corridor. Tolled facilities rarely compete with each other.
- **Regulatory and Political Constraints** - toll rates are subject to concession agreements, government approvals and/or public scrutiny. The pricing environment is often shaped by socio-political trade-offs.
- **Non-Monetary Value Drivers** - toll road users are motivated by travel time savings and improved journey time reliability.[1] Willingness to pay often reflects qualitative experiences and perceptions rather than objective cost-related factors.
- **Multilayered Price Components** - toll charges are just one component of overall travel costs. This complexity introduces cognitive and informational friction, making it harder for users to isolate the toll's impact and dampening their responsiveness to price changes.
- **Infrastructure is Essential** - for many users, travel is necessity-driven. This, too, moderates cost-sensitivity, placing downward pressure on price elasticities.
- **Long-Term Commitments** - users often base residential, employment and/or logistics decisions on transportation availability, accessibility and costs. Once these choices are established, travel behaviour becomes 'sticky', further dampening drivers' responsiveness to price changes.
- **Public Goods** - roads have traditionally been regarded as taxpayer-funded public goods, allowing citizens to move freely. Toll pricing is therefore politically sensitive. As noted, public acceptability thresholds shaped by perceptions of fairness, equity and affordability, limit the extent to which toll operators can behave as unconstrained profit-maximisers.

A distinguishing characteristic of toll road pricing is the structured and often predefined nature of toll rate adjustments. Toll roads (generally) do not adjust prices dynamically in response to market conditions.[2] The regulatory and contractual environment in which they operate prescribes scheduled and incremental tariff adjustments that can be communicated to users in advance. This enhances public acceptance, facilitates financing arrangements and reduces political or legal resistance. Sudden or substantial rate increases are uncommon as they risk undermining public trust, prompting regulatory intervention or reducing usage to levels that are financially unsustainable or politically unacceptable.

In summary, toll roads are not regular commercial businesses. They deviate significantly from the core principles of microeconomic theory (in a free market, the primary role of price is to balance supply and demand). As such, inferences drawn from other industries may not be directly applicable. This underscores the necessity of **sector-specific** research and analysis to inform road pricing policymaking and investment decisions.

1 More accurately, drivers are motivated by their *perceptions* of time savings and improved journey reliability.
2 An exception to this is the managed or express lane model that is becoming increasingly popular in the United States.

2. Definitions, Conventions & the Analytical Challenge

Definitions

In a transportation context, elasticities describe the responsiveness of travel demand to variations in the factors that influence it ('explanatory variables'). Elasticities are widely used by practitioners - and others - as they represent a convenient, quantitative measure of the price-sensitivity of travel demand that is simple to use in practice. The focus of this report - toll price elasticity[3] - examines specifically how changes in toll tariffs impact driver behaviour and the resulting demand for tolled infrastructure.

Despite the simplicity of the elasticity concept, it is important to recognise that the behavioural response to tolls represents the sum of many individual decisions made by heterogeneous groups of users facing (often) multiple interacting choices and complex motivations. While elasticities are undoubtedly useful, they should be interpreted as relatively coarse, approximate, aggregate indicators of group behaviour.[4]

Elasticities are loosely defined as the percentage change in demand divided by the percentage change in the explanatory variable of interest (in this case, toll price).[5]

If, for example, traffic volumes decrease by 2% in response to a tariff hike of 10%, the toll price elasticity would be -0.2 (-2% / 10%). As demand tends to exhibit an inverse relationship with price, elasticities are conventionally expressed as negative numbers. Various methods for calculating price elasticities are described in **Chapter 4**.

In the example given above, a toll price elasticity of -0.2 indicates that drivers are relatively insensitive to changes in toll price. This is referred to as **inelastic demand**. In contrast, elasticities greater than -1.0 (in absolute terms) indicate elastic demand (drivers being very responsive to toll price changes).

The magnitude of price elasticity has important revenue implications for toll operators. In a market characterised by inelastic demand, an increase in the toll tariff leads to higher overall revenue. The proportional reduction in traffic is more than offset by the proportional increase in the toll. Conversely, reducing tolls under inelastic demand conditions results in revenue decline.

Panel 2.1: Popular Criticism of Toll Charges

Members of the public often complain that toll charges are too high. Some suggest that the toll road operator would increase revenue if they reduced the price. While this would be true in an elastic market, empirical evidence (described later) suggests that toll road demand is characteristically price inelastic. Reducing price in an inelastic market promotes usage but not by enough to offset the revenue lost from the lower price. The operator's revenue would not increase, it would decrease.

$$\text{Toll Price Elasticity of Demand} = \frac{\text{\% Change in Traffic Volume}}{\text{\% Change in Toll Price}}$$

[3] For brevity, the phrase 'toll price elasticity' is used throughout this report. It is, however, more accurate to talk about 'demand elasticity with respect to toll price'. In that context, 'with respect to' is commonly abbreviated in the literature to 'wrt'.

[4] Variations in local circumstances and the irreducible complexity of human behaviour mean that demand effects can only be approximated by aggregate measures such as elasticities.

[5] To be precise, price elasticity indicates the decrease (or increase) in demand in response to each one percent price increase (or decrease), calculated in infinitesimally (or vanishingly) small increments, everything else being held constant.

Conventions

This report adheres to conventions commonly used in the literature. When referring to elasticities, size is interpreted as magnitude in absolute terms. Thus, an elasticity of -0.9 is described as being *larger* than one of -0.4, despite -0.9 being numerically smaller.

Unless stated otherwise, the price elasticities discussed in this report refer to own-price elasticities, which measure the responsiveness of demand to changes in the price of the same good or service (eg. the toll for a **specific** road). This is distinct from cross-price elasticities, which describe the change in demand for one good or service in response to price changes in another (eg. the effect on toll road demand due to pricing changes on a competing facility or mode).

To avoid repetition, the term *toll roads* is employed throughout this report as a general descriptor encompassing user-paid highways, bridges and tunnels.

The Analytical Challenge

In the context of estimating elasticities, the core analytical challenge can be encapsulated in a single concept: **isolation**. Specifically, how can the influence of price changes - toll tariff adjustments - be isolated from the array of other variables that hold the potential to (simultaneously) influence travel behaviour?[6] In an ideal scenario, accurately estimating toll price elasticity requires holding all other influencing variables constant - in other words, assuming everything else remains equal (*ceteris paribus*).

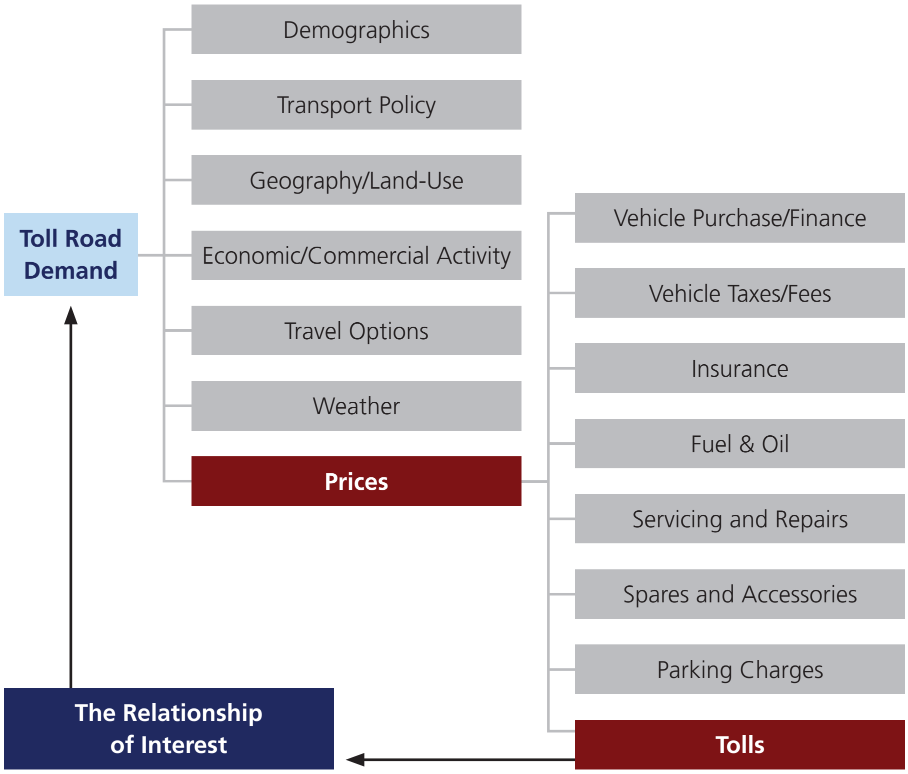
This challenge is illustrated in **Figure 2.1**, which highlights two key points:

1. Many factors influence travel demand, of which price is just one.

2. Many factors contribute to price, of which tolls are just one.

Overall, travel demand is best understood as a multi-determinant function, shaped by numerous influences individually and collectively. The complexity of the analytical task is compounded by two additional issues:

Figure 2.1: Isolating the Relationship of Interest



- Many of the influencing variables are dynamic, continually evolving across different temporal scales - some over relatively short time horizons, and
- Certain factors are more readily quantifiable (travel time, distance, fuel cost), while others remain qualitative and, therefore, more difficult to measure.

[6] A further complication is introduced by the statistical dependency that often exists among these other influencing variables.

Consider the example of stress reduction. User surveys often highlight this as a key motivation for choosing toll roads. Respondents cite reduced congestion, no start/stop traffic, no sudden changes in speed, fewer interchanges, less weaving traffic, minimal lane changes and lower volumes of (intimidating) trucks as attributes that contribute to a more relaxed and less stressful driving experience.

While these attributes are inherently difficult to measure - let alone forecast - they nevertheless have a tangible impact on driver behaviour. Indeed, some toll operators explicitly market 'stress-free motoring' as a central element of their competitive proposition (see **Figure 2.2**). Notwithstanding, most transport forecasting models continue to place predominant emphasis on traditional, quantifiable variables - primarily focusing on the time-savings/cost trade-off.

Figure 2.2: Early Marketing for the UK's M6toll

When estimating toll price elasticities, applied researchers are often acutely aware that the *ceteris paribus* assumption is rarely satisfied due to a range of contextual and exogeneous factors. Changes in toll pricing seldom occur in isolation; instead, they are often accompanied by concurrent developments that complicate the attribution efforts to identify the isolated effect of price on demand. These include, but are not limited to:

- **Operational changes** on the toll facility itself, such as a redefinition or restructuring of the tariff schedule.
- **Infrastructure developments** on complementary or competing routes (maintenance works or capacity enhancement).
- **Performance deterioration** on alternative routes, including degraded levels of service, increased incident frequency or heightened congestion severity and duration.
- **Variations in motoring costs** such as fuel price movements or parking charge reforms.
- **Changes to alternative modes of transport** impacting on fares, service patterns, delivery standards or system performance.
- **Land use changes** especially in corridors or catchment areas experiencing rapid growth.
- **Macroeconomic considerations** such as periods of economic expansion or contraction, or changes to the availability of credit or interest rates.
- **Fiscal policy adjustments** including amendments to the tax treatment of different vehicle or fuel types.

Although this list is not exhaustive, it captures a number of the real-world complexities that practitioners, including the authors, have had to contend with when attempting to isolate toll price elasticities. In some instances, traffic consultants make adjustments to their elasticity calculations (or normalise the underlying data[7]) in an attempt to control for confounding influences. We return to this later. However, commonly, the relevant data required to inform such adjustments is limited or unavailable. As a result, the effects of these concurrent influences often remain unaccounted for - sometimes leading to the derivation of counter-intuitive and misleading elasticity coefficients (see **Panel 2.2**).

The inconvenient truth is that price elasticity is not an independent, standalone concept set apart from other demand determinants. When it comes to understanding the behavioural responses to toll price changes, context is everything. Price elasticities will be different for different tolled facilities - and will typically vary within a single facility (eg. by time period, by user type, by trip purpose - even by section of road, length of trip and direction or frequency of travel). This is explored later; however, for now, it is important to acknowledge that for any one tolled facility, there is unlikely to be a single, uniform coefficient for the toll price elasticity of demand that applies in all contexts.

Panel 2.2: The Toll Price Elasticity Paradox

> A common observation from some well-established toll roads around the world is that traffic volumes continue to rise even as the tariffs increase. In isolation, this may suggest a counterintuitive result - that the toll price elasticity is positive. A more credible interpretation, however, is that elasticity remains negative (as expected) but that the coefficient is relatively low. The observable effects of the tariff change are being masked by dominating influences such as underlying demand growth on the facility itself or escalating congestion on competing routes.

[7] Adjusting for seasonality is a classic example of data normalisation.

3. Literature Review

As part of this study, we conducted a comprehensive review of more than 50 leading academic papers and research reports addressing toll price elasticity. This body of literature includes both studies explicitly focussed on toll roads and broader analyses of transportation cost elasticities. The full list of sources reviewed is provided in Appendix A.[8]

The purpose of our review was to extract information, insights and takeaways which could prove useful to industry practitioners - rather than engaging in a scholarly critique of the literature. While there is a substantial body of research on elasticities of demand with respect to transportation costs, most of it concentrates on cost components other than tolls - such as fuel prices or public transit fares. The literature specifically examining the traffic impact of toll price movements is, in comparison, sparse.[9]

Our review of the literature revealed twenty-one recurring themes. These themes are organised here under three headings:

- Observations: Themes 1 - 11
- Determinants: Themes 12 - 19
- Takeaways: Themes 20 & 21

For clarity - and being mindful of space constraints - the twenty-one themes are presented in a condensed format. In the behavioural sciences, however, few phenomena are straightforward. The field is characterised by complexity, nuance and frequent exceptions to general patterns. To avoid excessive repetition, we have limited the use of qualifiers such as *typically*, *commonly* and *in general*. Nevertheless, such qualifiers are implied throughout the discussion.

At this stage, the objective is to highlight prominent findings and commonly reported insights from previously published research. This should not be interpreted as an endorsement of all perspectives presented, nor as an assumption that these findings will align with practitioner experience. Accordingly, we revisit the key themes arising from the literature later, where they are examined in the light of practitioner perspectives and empirical observations.

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8 It should be noted that the majority of studies reviewed originate from developed countries. Consequently, the applicability of our findings to developing or less-industrialised contexts may be limited and should be approached with caution.

9 An internet search using Google Scholar returns over 1,000 results for "*fuel price elasticity*", yet less than 80 results for "*toll price elasticity*".

Toll Price Elasticity - Observations

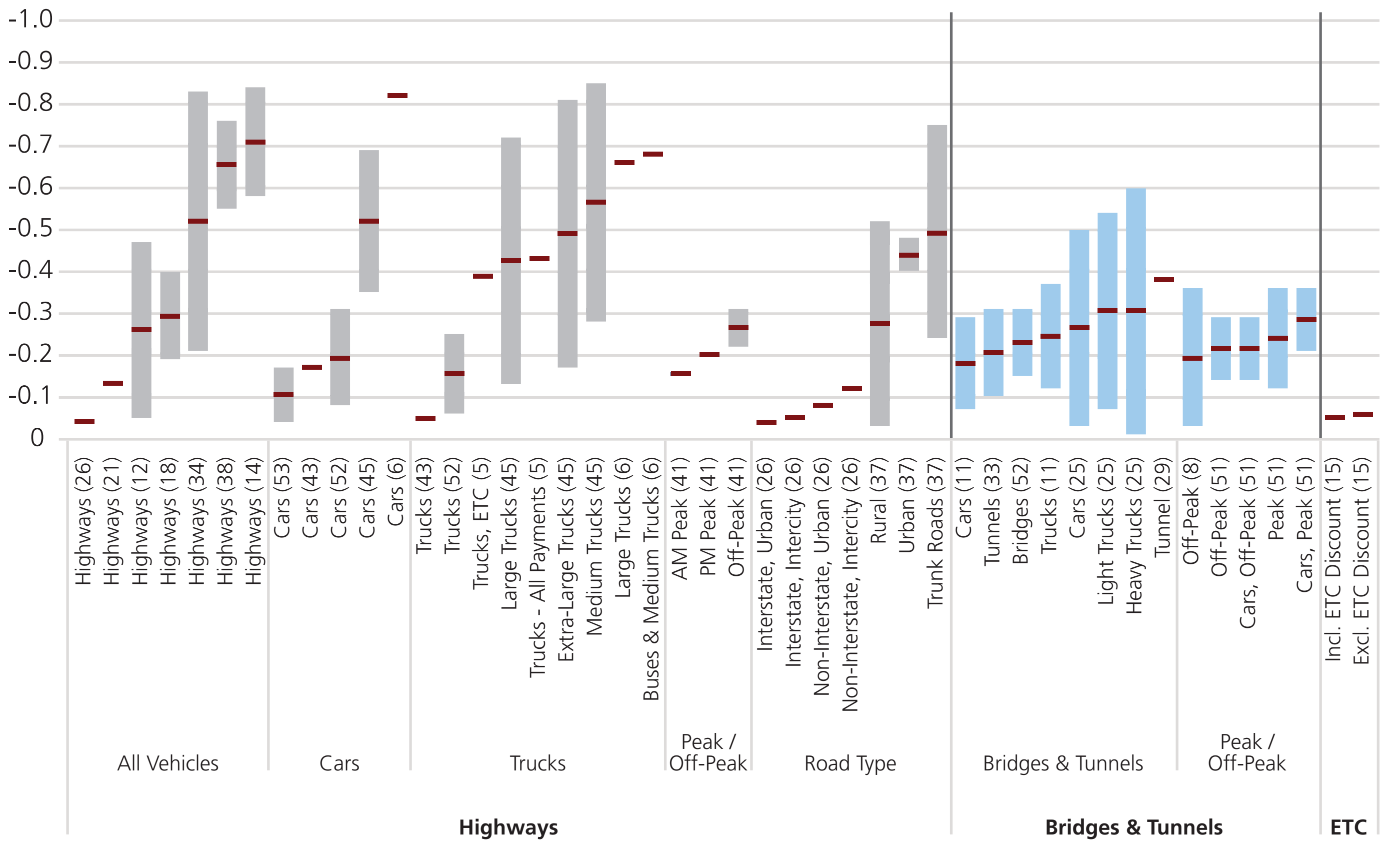
1. Travel Demand is Price Inelastic
There is almost universal agreement across the literature that transport demand is price inelastic. This is often linked to the fact that travel is a derived demand - people rarely consume travel for its own sake. Travel is an enabler that provides access to other activities or destinations. This often takes on the characteristics of essentiality - trips to work, education facilities or healthcare services. People commonly need to travel, which moderates the extent to which demand decreases in response to price increases. A lack of readily available alternatives (to travel) limits the ability of people to immediately switch to another option when prices rise. Theme 8 expands on this point.

One caution sounded in the literature is that consumers appear to be somewhat more sensitive to toll prices than they are to other travel cost components - even of the same magnitude. Reasons for this are touched upon later. Several studies also suggest that demand responses may be asymmetric, with greater driver sensitivity to price increases than decreases (so called *loss aversion*).

2. A Wide Range of Values is Reported
The literature reports a wide range of toll price elasticity values (see **Figure 3.1**). While individual responses to toll pricing can vary significantly due to personal circumstances (making prediction difficult), when dealing with elasticities we are relying on and using aggregate data - a point noted earlier.

This aggregation process smooths out much of the variability observed at the individual level. As a result, extreme responses (highly elastic or inelastic behaviours) are diluted, and aggregate driver behaviour tends to follow more stable and predictable patterns. This makes elasticity estimates useful for many purposes (see **Theme 20**), despite the underlying heterogeneity in individual behaviour and decision-making.

Figure 3.1: Toll Price Elasticities Reported in the Literature



Numbers in parenthesis correspond to the references listed in Appendix A.
The red horizontal lines represent individual elasticities or the midpoint of the respective range.

3. Typical Values Lie Between -0.03 and -0.5

The literature on toll price elasticities often includes authors' expectations regarding the likely range of values, usually informed by syntheses from previous research. These estimates are generally low; higher than zero but lower than -0.8. The most frequently cited values cluster around -0.2 to -0.3, with the typical range extending from -0.03 to -0.5. This places toll price elasticities firmly within the inelastic range, signalling that drivers are relatively unresponsive to toll tariff changes.

There is some, albeit weak, evidence that toll price elasticities have reduced over the past 30 to 40 years. One suggested explanation is that, in many jurisdictions, tariff increases have lagged behind inflation. Consequently, the real cost of tolls has decreased, making them more affordable and potentially contributing to reduced price sensitivity over time.

4. Keep it Real

Toll price elasticities should be estimated using, and applied to, real (inflation-adjusted) price data. This ensures that observed behavioural responses reflect actual changes in affordability rather than nominal price movements.

In most jurisdictions, periodic, modest and well-publicised inflationary toll adjustments are reported to have minimal impact on aggregate travel demand. In such cases, toll price hikes may not represent a meaningful increase in the perceived cost of travel, particularly if real income growth offsets the higher nominal charge.

5. Elasticities Are Correlated With Price

Toll price elasticities tend to increase as the base tariff level rises (elasticity is positively correlated with the toll price itself). As tolls move higher, road users become more price-sensitive leading to larger proportional reductions in demand for each incremental increase in price. Empirical studies consistently demonstrate that higher starting-point (base) tariffs are associated with higher elasticity coefficients, reflecting this heightened sensitivity.

There is, however, a notable and often-reported exception to this pattern. When tolling is introduced for the first time, the initial price elasticity can be surprisingly high - even when the start-up tariff is relatively modest. In such cases, the imposition of a toll represents a step-change in the perceived cost of travel, prompting a disproportionately strong behavioural response. Several studies in the literature have documented this effect, where the initial introduction of tolling yields a high elasticity, followed by lower elasticities in response to subsequent price increases.

6. Elasticities are Larger for Larger Tariff Increases

This theme shifts the focus from the base toll level to the magnitude of the price change itself. Evidence from the literature suggests that larger toll increases tend to be associated with higher price elasticities. In other words, the sensitivity of demand to price grows with the size of the increase.

A key driver of this relationship is linked to consumer perception. Small toll changes - like minor time savings - may fall below the threshold of user awareness or concern. Such incremental adjustments are often tolerated or even go unnoticed. In contrast, larger toll hikes are more evident and more likely to trigger a reassessment of travel choices, prompting users to actively explore substitutes such as alternative routes or destinations.

This behavioural dynamic has important implications for transportation modelling, particularly in relation to what is known as *the constant elasticity assumption* (discussed in Chapter 4). The empirical literature indicates that toll price elasticity is not uniform across all magnitudes of price change. Rather, elasticity appears to be non-linear, with stronger reactions at higher levels of price adjustment - thereby challenging the appropriateness of models assuming a consistent driver response across all pricing scenarios.

7. There are Different Ways of Calculating Price Elasticities

This theme is explored in more detail in the following chapter, but a few critical points from the literature are worth flagging here:

- There are multiple methods for calculating price elasticities, each grounded in different assumptions and data structures.
- The choice of method can influence the resulting elasticity estimate - even when applied to the same underlying data.
- How an elasticity is calculated affects how it should be applied.
- Many studies do not clearly explain how the presented elasticities have been calculated.

These issues give rise to definitional inconsistencies across the literature which can lead to confusion or misapplication. Practitioners need to be precise when presenting elasticity estimates and cautious when interpreting those of others. Key questions to ask include:

- *What definition of 'price' is being used?*
- *What type and source of data underpins the estimate?*
- *What estimation method has been applied?*

Being explicit about these elements is essential for transparency and consistency in practice.

8. Price Elasticities Increase in the Long-Run

Toll price elasticities are often described in the literature as '*dynamic*' in that they vary depending on the analytical timeframe under consideration. In line with broader economic theory, academic researchers regularly distinguish between short-run and long-run price elasticities. When defined, these timeframes are expressed in either temporal or stability terms. Short-run, for example, may refer to 'a period of less than one year' or 'a period during which exogenous variables remain relatively constant'. Clearly, there is a degree of definitional overlap.

Standard economic theory holds that long-run elasticities are greater than those observed in the short-run (*the second law of demand*). In the short-run, consumer options are limited, especially for journeys with fixed destinations and timings (work or education trips) where route choice may be the only available option. Over time, however, constraints relax. Individuals can change jobs, schools or even relocate - expanding their capacity to respond to travel cost changes. The method for differentiating between short-run and long-run price elasticities is described in the next chapter. For now, the point of note is that the literature typically reports long-run price elasticities that are 50-100% higher than their short-run counterparts.

9. Commercial Vehicles

Toll price elasticities for commercial vehicles - trucks - merit specific attention, not due to a prevailing consensus in the literature (which is notably absent) but for two principal reasons. First, trucks constitute a substantial and often disproportional share of revenue on many toll facilities, rendering their response to toll changes economically significant. Second, a number of empirical studies report toll price elasticities separately by vehicle class, offering potentially valuable insights into the behavioural differences between user groups.

The literature on this topic is divided. Half of those who estimated separate elasticities concluded that trucks exhibit greater toll price sensitivity than passenger cars, while the remaining half report the opposite. Later we will demonstrate that, while seemingly unhelpful at first glance, these findings are both important and analytically instructive.

10. It is Easy to Underestimate Toll Aversion

The literature repeatedly sounds cautions about drivers' resistance to paying tolls, even suggesting that standard economic theory may not fully account for the strength of motorists' aversion to road pricing. As mentioned earlier, this appears to be particularly true when tolling is first introduced[10] - yet research suggests that the effect may persist with subsequent tariff increases. The psychological response to tolls is characterised as "*highly complex*", with some drivers being unwilling to pay (or pay more) as a matter of principle - even when the benefits, such as reduced or more reliable travel times, are material and evident.

There is some - albeit weak - evidence that the bias against tolls is lower for bridges and tunnels (barrier crossings) and the data presented earlier in **Figure 3.1** appears to support this argument. The toll price elasticities associated with these facilities sit towards the lower end of the recorded range. However, this probably reflects a lack of immediate and attractive route alternatives. In some cases, toll bridges and tunnels have replaced ferries, whose service is often limited, slow and infrequent - forming the psychological reference point for users evaluating the toll.

As mentioned earlier, empirical studies report that drivers are more sensitive to toll charges than other motoring costs of an equivalent value (fuel prices or parking charges). Motoring costs are often 'forgiven' as being an unavoidable feature of modern life. The same sense of benevolence is seldom extended to road tolls.

[10] Bain R & Sullivan D (2024), *The Traffic Impact of Road Pricing: Lessons from the Toll Road Sector*, ITS International, September/October 2024 (Supplement), Route One Publishing Ltd. UK.

11. Traffic Model Shortcomings
Some of the more technical papers that we reviewed looked beyond the topic of toll price elasticity to reflect on state of the practice in terms of traffic modelling and forecasting. Reservations were expressed about the ability of traditional ('4-step'[11]) traffic models to fully and accurately reflect drivers' behavioural responses to road tolls. Common criticisms centred on how tolls are represented in these models, the use of oversimplified assumptions about the spatial and temporal dynamics of travel behaviour, failure to consider the full range of choices available to drivers and the use of aggregate data - hindering the model's ability to capture nuanced traveller responses to toll variations.

Other authors pointed to the fact that traditional traffic models incorporate limited segmentation (in terms of time-of-day periods, vehicle types, values of time and payment types), making it difficult to realistically model all road pricing markets.

Of note, most of the modelling concerns raised in the literature were articulated in the context of simple, fixed tolls - whereas the industry is trending towards the use of more advanced variable or dynamic pricing. As one economist cautioned, *"Unless* [these deficiencies] *are addressed…greater forecasting errors can be expected particularly if increasingly sophisticated pricing regimes are introduced".*[12]

Toll Price Elasticity - Determinants[13]

12. The Availability of Substitutes
In microeconomic theory, the availability of substitutes is widely recognised as a principal determinant of the price elasticity of demand. According to our literature review, this foundational concept is equally applicable in the context of tolled facilities. The presence - or absence - of alternative travel options is consistently identified as being the most influential factor in shaping toll price elasticities. When multiple determinants are listed, the availability of alternatives is invariably positioned as the dominant factor.

Importantly, it is not the mere existence but the perceived quality and attractiveness of these substitutes that conditions the behavioural response. Urban environments exemplify this distinction. Although alternative toll-free routes may be physically accessible, they are often characterised by high levels of congestion, reduced speed limits and frequently-spaced signalised intersections. Likewise, transit options can be slow, circuitous, infrequent, costly and may require interchanges. Theoretical substitutability does not always translate into behavioural substitutability.

13. Income
A substantial body of literature identifies socio-demographic factors - particularly income levels - as being important determinants of toll road usage. Higher-income individuals are less sensitive to toll charges, as the cost represents a smaller proportion of their disposable income. Price sensitivity is reported to be shaped not only by the absolute magnitude of a toll, but also by its relative burden. What does the toll tariff represent as a proportion of income? What does a week's worth of commuting on a toll road represent as a proportion of the average weekly wage rate? And, if toll tariffs are subject to a formula-driven escalation rate, how will that rate evolve in the future in comparison with income (or wage) trends?

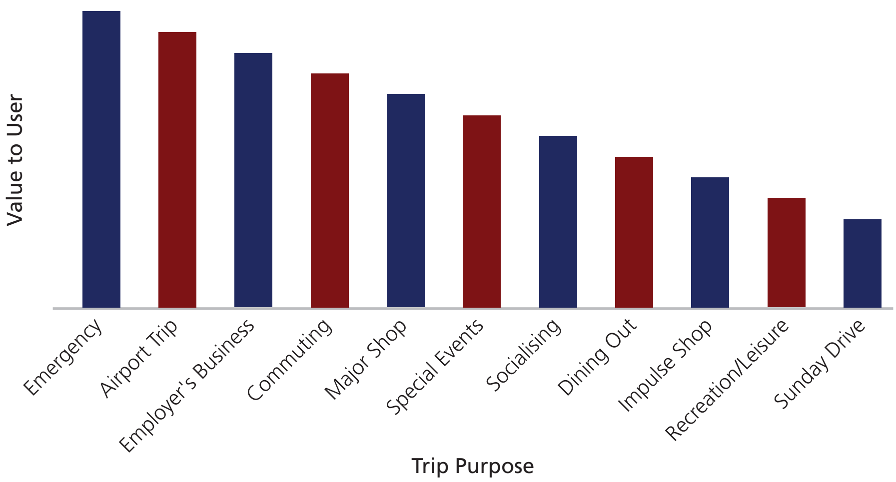
Several studies suggest that high-income individuals may prioritise service quality over cost considerations. It is interesting to reflect on this point in the context of managed (or express) lanes in the United States - where some drivers are paying peak-period tariffs well above industry norms to enjoy a service quality that is focussed on the maintenance of traffic flow at or above a given speed. For some market segments, time savings and travel time reliability emerge as the dominant determinants of demand, surpassing cost in relative importance.

[11] These models are also known as *network assignment models* or simply *network models*.
[12] Source: https://www.frontier-economics.com.au/expecting-the-unexpected-the-challenges-of-traffic-forecasting
[13] As noted earlier, there are commonly interrelationships between the separate determinants of toll price elasticity described in this section.

14. Trip Purpose
Trip purpose is a widely cited determinant of toll price elasticity, with non-discretionary trips (with high value and limited temporal flexibility) being associated with lower price sensitivity. For illustrative purposes, **Figure 3.2** shows different trip purposes, ranked by perceived value to the user. Drivers undertaking trips shown to the left side of the chart would be more likely to pay a premium for a route that offers travel time savings and/or enhanced journey time reliability.

Toll price elasticity exhibits substantial variation across trip types, a factor that helps to explain some of the divergent empirical findings reported in the literature. For example, weekday peak periods may appear price-inelastic in corridors dominated by high-income commuters but more elastic when recreational, leisure and other discretionary travel dilutes the demand profile.

Figure 3.2: Trip Purpose Ranked by Value



Adapted from Litman (2024)

Elasticity is further shaped by the interaction between trip purpose and the prevailing network conditions. Peak periods often align with essential, time-constrained travel but also correspond with the highest levels of network congestion (both of which reduce price sensitivity). Conversely, off-peak periods - including weekends - are typically characterised by more flexible, less-urgent trips and lower congestion. This dynamic (temporal differentiation) contributes to the pronounced 'peakiness' of demand observed on many toll facilities worldwide.

15. Trip (or Facility) Length
Toll price elasticities are reported to vary in complex ways according to trip length. In this context, three factors frequently discussed in the literature are toll cost, substitute availability, and the relationship between trip purpose and distance.

In terms of **cost**, as trip length increases (particularly when part of the journey occurs off the toll facility), the toll comprises a smaller share of total trip cost. Users are reportedly less sensitive to toll price changes when tolls constitute a minor component of total travel expenditure.

The **availability of substitutes** also varies with distance. At one extreme, walking or cycling can substitute for short trips. At the other, intercity rail or air travel can substitute for long trips (longer trips often expand the choice set for travellers). In between, other competitive dynamics may emerge as factors influencing toll price sensitivity across different distance bands.

Additionally, **trip purpose** is often correlated with trip length - further affecting price elasticity. The literature highlights the fact that longer-distance travel is more likely to be discretionary in nature for car drivers (such as vacationing). The contribution of journey-to-work is reduced as long-distance commuting remains relatively rare. As noted earlier, discretionary travel is more price sensitive however, again, context is important. For vacationers, even long-distance (expensive) toll charges are often small relative to their total holiday budget and drivers may view tolls as worth paying if they improve the overall leisure experience.

16. Type of Facility
In a number of studies, researchers compiled data across multiple facility types, allowing for comparative analyses. One US-based study, for example, found toll price elasticities to be lower on urban than on 'intercity' roads, and lower on interstate than on non-interstate highways.[14] Other studies estimated elasticities that were lower on interior than on coastal motorways, or lower for tolled cordons than regular toll roads.

[14] An interstate highway is a limited-access facility designed for high-speed, long-distance travel - originally designed to facilitate military transportation.

By way of explanation, several authors point - not to the facility itself - but to the underlying composition of travellers. Coastal motorways, for example, are more associated with tourism, leisure and recreational travel than their interior counterparts - hence the heightened user sensitivity to price. Although distinctions may be observed by the type of infrastructure, they are not *caused* by the type of infrastructure. Toll price responsiveness remains driven by competitive context, and the blended demographic, behavioural and motivational characteristics of drivers.

17. Toll Structuring, Promotion and Collection

Many industry stakeholder are aware that the migration of a toll collection system from traditional cash-based payments to electronic tolls is associated with an uplift in demand (and revenue). Referred to as 'payment decoupling', the literature similarly points to credit cards and (for transit) travelcards in this regard.[15] The purchase becomes *decoupled* from the payment, encouraging more consumption as awareness is reduced about the amount actually being spent.

Research suggests that, under normal circumstances, drivers rarely consider the cost of individual journeys. Motoring expenses are widely perceived to be unavoidable. This changes when drivers are required to stop and physically pay tolls. Drivers are far more price sensitive about out-of-pocket expenses. They are more noticeable (the behavioural literature talks about them being *more salient*). In summary, electronic toll collection (ETC) reduces the salience of tolls - and this is linked to reduced price sensitivity.

Indeed, surveys have demonstrated that many drivers who pay tolls electronically are unable to state or guess (correctly) how much they paid - and, as one researcher pointed out, this effect extends beyond drivers. ETC reduces the political costs of increasing tolls, the lower salience making it easier to raise tolls. A comparison of different tolling operations suggested that tolls are increased more frequently (and by more) on ETC-equipped facilities. Additionally, toll increases became delinked to the political cycle. Beforehand, toll hikes were significantly lower in election years. That constraint appears to relax upon conversion to ETC.

Turning to toll price structuring, the literature highlights the fact that consumers prefer simple price structures that minimise cognitive effort. Consumers are likely to disengage if they perceive price structures to be too complex - possibly leading to expenditure avoidance. Research has also identified perceptions of fairness as being a key factor underpinning consumers' price-structure preferences.

Finally, there is some evidence that drivers become less resistant towards tolling when they understand why tolling is needed, what its objectives are and when the consequences of alternative (no-toll) scenarios are clearly articulated and understood.

18. Who Pays?

The famous American economist and Nobel Prize winner, Milton Friedman once described four ways in which people spend money: your money on yourself, your money on others, other people's money on yourself and other people's money on others. Consumers tend to be most careful when spending their own money, and considerably less cost-sensitive when spending other people's money. This, unsurprisingly, is a conclusion that similarly emerges from the literature on toll price elasticities.

The standout example is, perhaps, car drivers travelling on business when travel costs are either paid by their employer (as part of corporate expense accounts) or accounted for as tax-deductible business expenses. The literature identifies employers as being less sensitive to toll increases than drivers paying their own tolls.

This issue is equally relevant in the context of trucks. A trucker paying their own tolls is likely to demonstrate different (more cost-sensitive) behaviour than those who are reimbursed by their firm. Similarly, the trucker who can pass-through their travel costs to their customer (the shipper) - in part or in full - will lie towards the lower end of the toll price elasticity spectrum.

19. The Macroeconomic Context

The literature underscores the point that toll price elasticities are not isolated from broader trends in an economy. They are observed to increase during (or immediately following) a recession or macroeconomic downturn - users becoming more price sensitive.

Rising unemployment and economic uncertainty cause consumers (generally) to cut back on discretionary spending, with households prioritising price-saving over convenience or quality. Having earlier identified the 'essentiality'- and, hence, inelasticity - associated with some (but not all) travel, the literature suggests that less-essential travel (related to leisure or recreation, for example) will experience the largest declines. For this reason, researchers sound caution about the derivation and use of toll price elasticities calculated during times of economic downturn or, equally, during times of unusually strong growth.

[15] The introduction of travelcards in London in the early 1980s was reported to increase Underground trips by 10% and bus trips by 16%.

Toll Price Elasticity - Takeaways

20. Elasticities Matter

The literature repeatedly underscores the relevance and value of price elasticities by pointing to the many ways in which they are used across the transportation industry. Researchers talk about them having significant implications for business analysis (understanding your market), and for transportation planning and policy. They also highlight the important role played by price elasticities in investment decision-making - both public sector (with an emphasis on social welfare) and private sector (with a narrower focus on cost-recovery or profitability).

Price elasticities are also identified as playing a key role as demand predictors - especially for short-term forecasting. And, perhaps of most relevance to this report, the literature highlights their role in pricing studies, determining the likely response of drivers to various forms of road pricing, developing price segmentation or differentiation strategies and devising optimal tariff structures (charging more to inelastic market segments). In short, elasticities matter. A lot.

21. Relationships are Durable and Transferable

In closing, if toll price elasticities were uniquely and fully attributable to specific circumstances, a report such as this would be of limited help to practitioners. The literature repeatedly points out that this is not the case, however it cautions that care should be exercised.

Published elasticities are positioned as being a reasonable and useful starting point in terms of providing *first order* estimates of the changes in demand that might be expected in response to changing travels costs. They should not be taken or used as scientifically precise predictors. They indicate the order-of-magnitude response to system changes (in this case, toll price) - as inferred from experience and aggregate data from other (comparable) circumstances. In situations where national policy requires the availability of high-quality toll-free alternatives, it is essential that toll price elasticity estimates be drawn from jurisdictions with comparable policy frameworks. Aligning analytical inputs with the institutional and infrastructural context ensures greater validity and transferability of findings.

Approached judiciously, elasticities are transferable in time and space. Armed with the observed range and understanding what the key determinants are, suggests where, within that range, a particular project with particular market characteristics is likely to lie - and, importantly, why.

4. Calculating Toll Price Elasticities

A number of approaches have been (and are) employed to estimate toll price elasticities. Most of them are variations built around a common set of foundational methodologies - described here. Before examining these methodological frameworks, however, it is important to consider the estimation period typically adopted in toll price elasticity analyses. The estimation period and the estimation approach are interdependent; the choice of timeframe often influencing the suitability and reliability of particular estimation methods.

The Estimation Period

At a high level, one of the distinguishing features among the different estimation approaches lies in if and how they account for influencing factors beyond the toll price change itself. This issue is closely related to the *estimation period* - the period over which the user response is observed and analysed.

At one end of the spectrum, analysts (usually practitioners) often adopt a pragmatic approach - commonly dictated by data limitations. Selection of a narrow estimation period (just days or weeks before and after a tariff change) limits the opportunity for confounding factors to interfere. Accordingly, it is argued that these factors may be disregarded - enabling the analysis to concentrate on the relationship between the price change and the traffic response in relatively simple ways. Given that the primary behavioural responses to toll changes are observed immediately upon or shortly after implementation (discussed below), this approach holds a certain degree of methodological justification.

At the other end of the spectrum, analysts (usually academics) focus on a longer estimation period (months or years), maintaining that the *full* traffic response to price changes unfolds gradually and requires time to stabilise. Extending the analytical period increases the potential for confounding factors to have influence. This requires the use of more complex approaches (multideterminant functions) and - while certainly achievable - can only be accommodated in situations where larger and broader datasets are available.

In short, the choice of method for estimating toll price elasticities in practice is often shaped, if not determined, by the nature, extent and quality of available data. Data constraints can significantly restrict the range of estimation options that may be employed.

Estimation Approaches

The analytical methods for estimating toll price elasticities can be grouped into four broad categories:

1. **Before-and-after studies:** This simple - yet effective - approach compares observed traffic volumes before and after a toll change, attributing the difference to the tariff adjustment.
2. **Econometric models:** This more data-intensive method uses time-series data to examine and quantify how traffic volumes evolve in relation to toll charges in combination with other explanatory variables.
3. **Stated preference surveys:** When real-world data is unavailable, this research technique can be used to examine how individuals respond to hypothetical circumstances such as alternative toll tariff scenarios.
4. **Model-derived estimates:** Transportation demand models can be used to simulate the impact on demand of alternative toll prices - from which elasticity estimates can be derived.

The remainder of this chapter considers each of these approaches in turn.

1. Before-and-After Studies

Before-and-after studies are the most direct and widely used method for estimating transport price elasticities. They compare observed outcomes - here, traffic volumes - **before** and **after** a price change, attributing the difference (exclusively or primarily) to that change.

The textbook formula for calculating the price elasticity of demand is generally presented as follows:

$$\varepsilon = \frac{\%\Delta Q}{\%\Delta P}$$

Where:

- ε is the elasticity
- $\%\Delta Q$ is the percentage change in quantity (traffic)
- $\%\Delta P$ is the percentage change in price (toll tariff)

This basic formula can be operationalised in several ways, some of which are more theoretical than others. For completeness, our discussion starts with point elasticity as it illustrates how data constraints impact on real-world elasticity estimation.

A. Point Elasticity

Point elasticity calculates the sensitivity of demand to changes in price at a single point on the demand curve, using the following formula:

$$\varepsilon = \frac{dQ}{dP} \cdot \frac{P}{Q}$$

Where:

- ε is the point elasticity
- dQ/dP is the slope of the demand curve
- P is the toll price at the point of interest
- Q is the traffic demand at that price

The term (dQ/dP) is known as the derivate with respect to price. This tells you about rate-of-change. A large negative value means that the slope of the curve is steep (demand drops quickly as price increases). A smaller negative value infers a flatter slope (demand is less sensitive to price changes). However the slope of a demand curve does not, by itself, fully describe price-responsiveness. That is captured through the elasticity by scaling the slope with P/Q.

In theory, point elasticity offers a precise insight, however it assumes that the mathematical formula for the whole demand curve is known. In practice, analysts do not have complete and continuous information about traffic demand at all possible toll prices. Only discrete data is available; traffic demand observed at Price A and traffic demand observed at Price B. As such, alternative approaches have to be adopted in practice.

B. Simple Linear Elasticity

For small tariff changes, a simple linear approximation is occasionally used as a ‘rule of thumb’:

$$\varepsilon = \frac{Q_2 - Q_1}{Q_1} \div \frac{P_2 - P_1}{P_1}$$

This method is sometimes labelled as a ‘*shrinkage ratio*’ (discussed in the following chapter). It divides the percentage change in quantity (from the base ie. Q_1) by the percentage change in price (from the base ie. P_1). It assumes that the demand curve is straight, and that elasticity is constant across the observed range. It is easy to calculate and interpret but becomes unreliable for large price changes. As toll changes grow larger, the linear assumption breaks down. Real-world demand is typically non-linear so applying this approach can lead to distortions in the elasticity estimate.

Another shortcoming with this method is known as the ‘directional problem’. Elasticities calculated by this method are not symmetrical when moving up or down a linear demand curve. The percentage change in price or quantity depends on the direction of the change (increase versus decrease). For example, a traffic hike from 8,000 to 10,000 vehicles is a 25% increase whereas the reverse - a decline from 10,000 to 8,000 vehicles - is a 20% decrease. This leads to the estimation of different toll price elasticities depending on whether price increases or decreases - even though the difference in both cases is the same (±2,000 vehicles).

C. Arc Elasticity

To improve accuracy when a price change is not trivial, and to reduce sensitivity to the direction of the change, analysts often calculate **arc elasticities**. Arc elasticity offers a more accurate approach when evaluating changes between two distinct points. Two formulations are commonly used: the **midpoint** (or linear) method and the **logarithmic** (or exponential) method.

C1. Linear (Midpoint) Arc Elasticity:
Linear (midpoint) arc elasticity is one of the more widely used estimation methods in before-and-after pricing studies - when the analyst has two discrete price and quantity data points. The formula, in full, is shown below:

$$\varepsilon = \frac{Q_2 - Q_1}{P_2 - P_1} \cdot \frac{(P_1 + P_2)/2}{(Q_1 + Q_2)/2}$$

Where:

- P_1 and Q_1 represent the initial price and quantity (*before*)
- P_2 and Q_2 represent the new price and quantity (*after*)

This approach avoids the directional problem. The formulation is symmetric because it calculates percentage changes relative to the average (midpoint) of the two values - represented by the terms on the right-hand side of the equation. In short, it gives the same elasticity for both price increases and decreases (between the same data points), making it more robust in real-world situations.

As the 2s on the right-hand side cancel out (they appear in both the numerator and the denominator), the formula shown above simplifies, algebraically, to:

$$\varepsilon = \frac{Q_2 - Q_1}{P_2 - P_1} \cdot \frac{P_1 + P_2}{Q_1 + Q_2}$$

One point worth noting is that some researchers maintain that the midpoint elasticity calculation method is the one (of these simple formulations) that should be used when either P_1 or P_2 is zero. This would be the case where, for example, tolling commences on a previously toll-free road (P_1) or where road tolls are removed (P_2). However, in this case - irrespective of the size of the toll tariff - the second half of the equation always reduces to 2 (or -2) and meaningful interpretation breaks down. A commonly employed workaround is to broaden the definition of 'price' to include additional costs incurred by drivers (such as fuel costs) - thus avoiding the before or after price being zero.

C2. Log Arc Elasticity:
Another way of estimating the price elasticity of demand when only discrete data points are available is to calculate the log arc elasticity. This approach is the one that most closely approximates point elasticities (**A**). The standard formula is given by:

$$\varepsilon = \frac{In(Q_2) - In(Q_1)}{In(P_2) - In(P_1)}$$

As can be seen, this formula uses natural logs (*In*). This is the key departure from linear arc elasticity (**C1**). Rather than calculating elasticity based solely on absolute changes between two points, the log arc specification captures the continuous (multiplicative) rate of change across the interval.

In practice, this distinction (different assumptions about the transition between two data points) makes little difference when price changes are small. However, when price changes are large, the error associated with the straight-line approximation increases and the log arc elasticity estimation method is more appropriate. The log arc formulation is also base-independent, meaning that it gives the same result if a price changes from one year to another directly, or does so via an intermediate year.

To apply log arc elasticities, it is necessary to solve the equation given above for Q_2. This is shown below:

$$Q_2 = Q_1 \left(\frac{P_2}{P_1}\right)^{\varepsilon}$$

The log arc formulation is the elasticity estimation method recommended by the Department for Transport for modelling and forecasting practitioners in the UK.[16]

Table 4.1 illustrates the different elasticities that result from applying the different estimation techniques. The example considers a toll increase from $1 to $1.50 resulting in a decrease of traffic from 10,000 to 9,125 vehicles/day. As can be seen, the midpoint arc and log arc approaches give similar results.

In our experience, practitioners with a classical preference adopt the log arc technique as it is the closest approximation to point elasticity. Others favour the midpoint approach, acknowledging that - specifically for modest price changes - it produces a near-identical outcome. As ever, the important point is that the chosen technique should be clearly identified and communicated to others, in part because it dictates how the resulting elasticity should be applied.

Finally, it is worth reflecting on the fact that all of the simple estimation methods described above assume that toll price elasticity remains constant at different price points, despite evidence to the contrary (see Chapter 3). Analysts involved in long-range forecasting where the toll path anticipates material (real) tariff increases may wish to relax this assumption and allow for price elasticity to be scaled (increased) accordingly. At the very least, this would be a sensible sensitivity test to run.

Table 4.1: Different Approaches, Different Elasticities

Estimation Method	Toll Price			Daily Traffic			Price Elasticity
	Before	*After*	*% Diff.*	*Before*	*After*	*% Diff.*	
Simple Linear	$1.00	$1.50	50%	10,000	9,125	-8.8%	-0.175
Midpoint Arc			40%			-9.2%	-0.229
Log Arc			40.5%			-9.2%	-0.226

[16] Department for Transport (2024), *TAG Unit M2.1*.

2. Econometric Models

In before-and-after studies, the analytical period is either short enough to prevent interference from factors other than price, or - prior to analysis - the data is adjusted (normalised) to take account of confounding influences such as ramp-up, seasonality, moving holidays, weather events, construction disruption, background growth[17] and so forth. Instead of dealing with those influences separately (ie. externally), econometric models attempt to internalise them, specifically incorporating them or some of them within the model formulation itself.

If, for example, toll road demand is posited as being a function of the tariff, fuel price and general citywide traffic trends, and is observed to be seasonal in nature, the econometric model formulation could look something like this:

$$ln(Q) = \beta_0 + \beta_1\, ln(P_{toll}) + \beta_2\, ln(P_{fuel}) + \beta_3\, ln(T_{city}) + \sum \gamma_i D_i + \varepsilon$$

Where:

- Q is the traffic volume
- P_{toll} is the toll price
- P_{fuel} is the fuel price
- T_{city} is the citywide traffic level (a proxy for general traffic trends)
- D is a set of seasonal dummy variables

These models often use logarithms (as shown in the example) as many real-world relationships are multiplicative in nature. Taking logs transforms them into linear relationships, making the models easier to estimate with standard regression techniques. It also allows the coefficients to be interpreted directly as elasticities which, in part, explains their popularity. In the formula example, β_0 represents the *model constant* (the base level of toll road demand in the absence of any of the influencing factors), β_1 can be interpreted as the toll price elasticity and ε is the error term (capturing the impact of influencing factors that have been excluded from the model).

By their nature, these multivariate models are more data intensive than the simple bivariate models shown earlier. They require multiple observations (eg. monthly data for extended periods) for each of the explanatory variables. Academics may argue that the econometric method for elasticity estimation sits more comfortably with economic theory, and it certainly dominates the scientific literature. However the data constraints imposed on academics often differ from those encountered by practitioners. Indeed, academics may select their focus because the required data is available to them. Practitioners, on the other hand, have their focus directed by others. Clients commission them to study particular projects or corridors, and - in response - the practitioner has to compile whatever data they can in support.

A further reason for the popularity of the econometric approach within the academic community is that it allows for short-run and long-run toll price elasticities to be estimated separately. This distinction was introduced earlier in the literature review. For this, dynamic model formulations are used - typically distributed lag models.[18] Theory suggests that including a lagged version of the dependent variable (traffic) as an additional explanatory variable (eg. traffic in time period t-1) allows for the estimation of the long-run effect of a toll price change. However, as this long-run effect (if any) is rarely observable in practice - being swamped by other factors - it is arguably of more academic than practical interest.

[17] Benchmarking a toll facility's performance against other roads in the area is a useful way of identifying background growth so that it can be removed before the traffic impact of a price change (alone) is quantified.
[18] Instead of assuming that a change in toll price affects demand immediately, distributed lag models allow for delayed effects (the price impact is spread out over time).

3. Stated Preference Surveys

Stated preference surveys are often used in transportation research, particularly when real-world data is scarce or unavailable - eg. evaluating a proposed toll facility in a country with limited or no tolling experience. These surveys involve asking respondents about their preferences and likely choices in hypothetical situations. A driver could be presented with a choice between two routes: one with a toll of $5 and a 10-minute travel time or an alternative, toll-free route with a 20-minute travel time. The question is typically repeated, continually varying both attributes (toll price and travel time). Socioeconomic data is collected alongside to understand the responsiveness of different market segments to toll prices (or toll price changes).

Discrete choice models (such as logit models) are generally used to analyse the results from stated preference surveys. Although the detail lies beyond the scope of this report[19], the toll price elasticity can be derived from the coefficients in the estimated model.

Stated preference surveys need to be conducted with care. As the situations are hypothetical, respondents might indicate patterns of behaviour that depart from how they would act in real-life. People may overstate or understate their sensitivity to toll price changes or may respond in ways designed to limit the price changes themselves ('strategic bias').

Additionally, survey responses can be influenced by how the survey is designed and administered, and by how the questions to respondents are framed.

4. Model-Derived Estimates

Toll price elasticities can also be derived from traditional transportation models.[20] This is not the place for a detailed description of these models. Suffice to say, these simulation models, requiring specialist software, are frequently used in toll road forecasting. Baseline demand is first estimated in the absence of any toll price change. Then the toll price is changed, commonly in several discrete increments, the transportation model is re-run and the impact on demand is recorded.

The simple estimation methods presented earlier can then be used to calculate the toll price elasticity from the changes in price and the simulated changes in demand. Our findings in relation to transportation model-derived elasticity estimates are discussed in Chapter 12.

Summary

There is no one-size-fits-all method for calculating toll price elasticity. Although the simple linear elasticity method (shrinkage ratio) is straightforward and is sometimes employed, it suffers from the directional problem described earlier. Point elasticity, although mathematically rigorous, is rarely practical due to data constraints. Arc elasticities offer reasonable precision - especially across wider price ranges. As such, they are frequently used in practice.

Ultimately, the choice of method depends on the analytical context, the scale of the toll change and - critically - the nature, quantity and quality of available data.

For effective policy development and investment decision-making, practitioners should understand the assumptions and limitations underlying their chosen approach and ensure transparency regarding how the results have been derived (and how they should be interpreted and applied).

[19] For further information, see: https://tfresource.org/topics/Choice_models.html
[20] As noted earlier, these are often called '4-step' or 'network assignment' models.

5. A Historical Primer

Transit Fares First

The earliest study examined in our literature review is that of Dash and Vey (1969), who cite their institutional affiliation as the (then) planning consultancy Simpson and Curtin. In their paper, the authors reference a body of work undertaken by the firm since the 1940s, which focussed on the analysis of transit fare elasticities. Building on this foundation, Dash and Vey later extended the methodology employed to assess user sensitivity to transit fare changes and applied it in the context of toll bridges and tunnels.

Simpson and Curtin's transit-related work investigated the relationship between fare increases and changes in patronage, analysing 79 individual cases of fare adjustments across the United States.

For each case, the percentage change in fare was plotted against the corresponding percentage change in ridership, and the line of best fit was derived. The resulting analysis indicated that a 1% increase in fare was associated with a 0.33% decline in patronage. This relationship was termed the loss or shrinkage ratio by the authors. The resulting price elasticity, approximately -0.3, became widely known as the 'Simpson and Curtin Formula', and remained established convention for fare elasticity within the transit industry for decades.

With respect to estimation, Dash and Vey specifically highlight the importance of isolating the effect of price changes from confounding factors such as underlying trends in background growth and prevailing economic conditions. To mitigate these influences, they limited their analysis to relatively short estimation periods, measuring changes over months rather than years. To account for seasonal variation, the authors compared patronage levels during several months preceding the fare increase with the corresponding months in the prior year. An analogous comparison was then conducted for the months following the fare adjustment. This approach remains in use among researchers and practitioners in the toll road industry today.

The authors also examined their empirical results through the lens of revenue yield, illustrating the net revenue impact associated with different levels of fare increases. They observed:

"…by reason of shrinkage in [riders] *because of passenger resistance to the fare increase, and aside from* [ridership] *changes from economic or other causes, a 20 percent fare increase produces about 12 percent more passenger revenue, while a 30 percent increase produces about 17% more passenger revenue".*

As previously noted, this outcome aligns with the characteristics of inelastic demand, wherein price increases lead to higher revenue (while price decreases correspondingly result in lower revenue). **Panel 5.1** illustrates the method used to calculate these revenue impacts.

Panel 5.1: Calculating the Revenue Impact of a Price Increase

To calculate the revenue impact from a price (eg. fare or toll) increase, given a certain price elasticity, you apply the following formula:

$$\Delta R = (1 + \Delta P) \cdot (1 + (\Delta P \cdot \varepsilon_{toll})) - 1$$

Where:

- ΔR is the proportional change in revenue
- ΔP is the proportional change in price
- ε_{toll} is the toll price elasticity

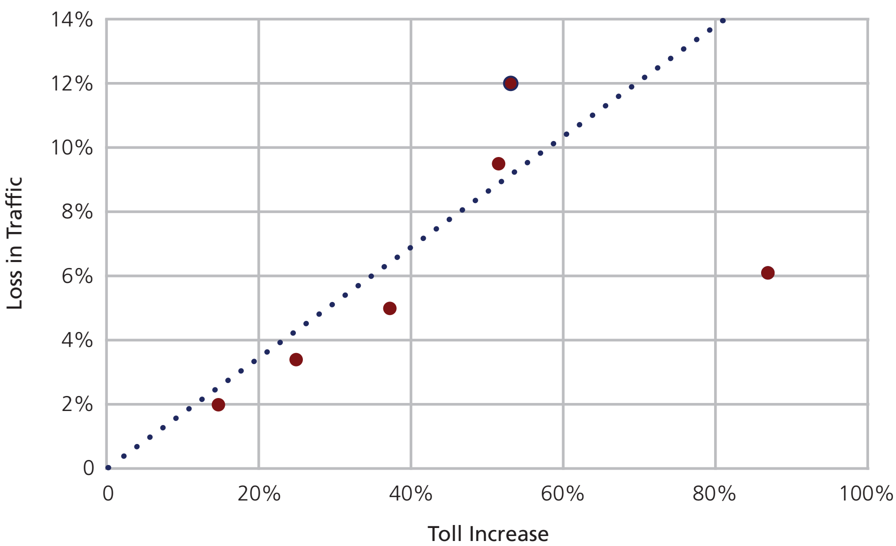
Essentially, $(1 + \Delta P)$ reflects the change in price and $(1 + (\Delta P \cdot \varepsilon_{toll}))$ reflects the change in demand due to the price elasticity. Multiplying the two gives you the combined effect on revenue (price * quantity) and subtracting 1 gives you the net percentage change in revenue (ΔR).

Toll Price Elasticities

Turning from transit to toll facilities, the authors compiled monthly traffic data from five bridges and a tunnel in the US that had experienced tariff increases in the 1950s and 60s. From this, they calculated the percentage increase in toll and the corresponding percentage decrease in traffic. They started with passenger cars and present their results in graphical form (see **Figure 5.1**). The authors comment that "*The before and after trends were then compared for varying periods*", suggesting that they had resized their estimation period to ensure the representativeness (stability) of the before-and-after traffic data.

The resulting toll price elasticity was found to be -0.17, considerably lower than the elasticity derived from their transit analysis (-0.33). The authors attributed this to the availability of "*…fewer acceptable alternatives*".[21]

Figure 5.1: 'Shrinkage' in Passenger Car Traffic



Adapted from Dash and Vey (1969)

The uptick in revenue resulting from the tariff increases ranged from 65% to 87% of the increase that would have been realised had there been no decline in traffic associated with the higher tolls. The authors labelled this *revenue productivity.*

[21] The authors suggest that, if an acceptable alternative route had been available, the toll price elasticity would have been closer to -0.22, albeit that this estimate was based on a single data point (a toll bridge in Boston with competing river crossings).

As an aside, it is worth reflecting on the pricing headroom and revenue implications of elasticities that, at first glance, do not appear to be vastly different. A worked example in Dash and Vey considers the revenue implications of increasing a toll from 25c to 45c (using their formula and their derived toll price elasticity of -0.17). This is shown in blue in **Figure 5.2**. The same is shown in red for their transit-derived elasticity (-0.33). The revenue (and policy) implications are significant. With an elasticity of -0.33, the revenue increase hits a ceiling at +34%. With an elasticity of -0.17, that ceiling extends to above +100%.

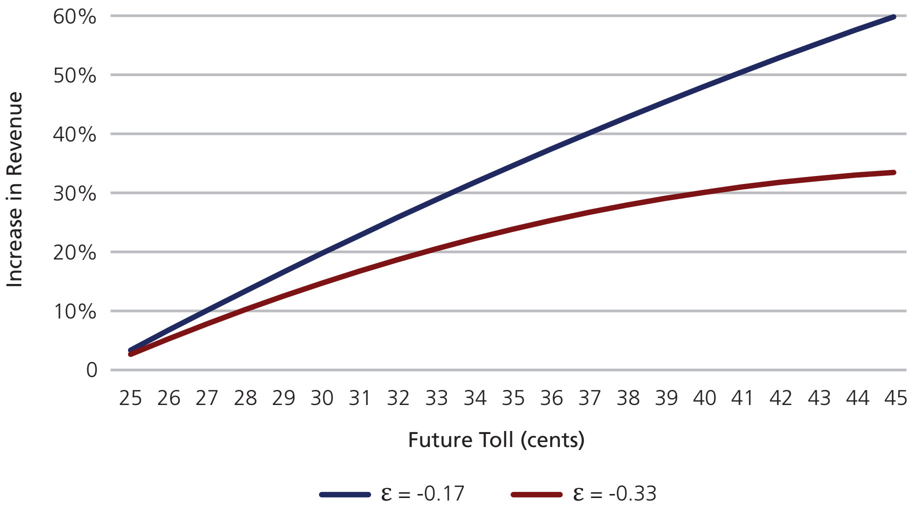
Towards the end of their paper, the authors turn their attention to trucks and replicated their analysis.[22] They comment that, "*Experience indicates that the impact of toll increases on traffic is less for trucks than for passenger cars*" - a finding contradicted in some of the literature but generally supported here. The toll price elasticity for trucks is reported as -0.13.

In three of their case studies, there was no discernible loss in truck traffic resulting in (in their terminology) *100% revenue productivity*. In this regard, the authors comment that:

"The reasons for the higher productivity of truck toll increases are evident. Trucks are engaged in business or commercial activity and are on essential trips. Toll charges are a business expense and, in the aggregate, represent such a small proportion of trip cost that a toll change does not have a major effect on demand".

We reflect on this explanation later in Chapter 7.

Figure 5.2: Revenue Impacts of Alternative Price Elasticities



Aside from being the first published work on toll price elasticities that we found, the landmark paper by Dash and Vey represents applied research conducted by early practitioners. It provides historical information and context, and introduces techniques and language, much of which is still in use today. It also touches on important practical considerations that researchers need to address when assessing driver responsiveness to toll changes. Building on this, the following chapter turns to our own research, analysis and findings.

[22] The reported truck tolls were two to three times higher than for cars.

6. New Research and Headline Results

Introduction

The second half of this report turns to the original (new) research that we conducted in terms of toll price elasticities. Here we present our sources, analyses and findings. To our knowledge, this constitutes the most extensive empirical investigation into global toll price elasticities conducted to date, both in terms of scope and the volume of data analysed.

As investment advisors, we regularly review toll road traffic and revenue study reports to help us to assess demand dynamics, revenue resilience and the credibility of underlying forecasting assumptions. This is unique and rich source material as (a) these reports were compiled by the more prominent consultancies in the field, sometimes with academic advisors, (b) they reflect international practice and experience (albeit primarily from developed countries), and (c) the reports were prepared to support real and substantive commercial decision-making by key industry players.

Data Description

Having reviewed more than 350 traffic study reports over the past two decades, we were able to identify 105 which specifically discussed **and quantified** toll price elasticities. These 105 reports were prepared by 29 different teams of consultants, although the majority were attributable to the foremost practitioners in the field. The traffic studies themselves were conducted in 15 different countries spread across five geographic regions (see **Figure 6.1**).

During our review of the studies, all reported elasticities were systematically extracted and recorded, along with associated metadata relating both to the values themselves and to the source documents. This effort enabled the construction of a comprehensive database of elasticity estimates, structured to support subsequent organisation and analysis across multiple dimensions. The metadata captured for each entry encompassed both high-level characteristics of the original study (publication year, country, road category and client type) and value-specific attributes (calculation methodology, vehicle class, reference time period, base tariff and tariff change).

Figure 6.1: Geographic Regions for the Traffic & Revenue Studies

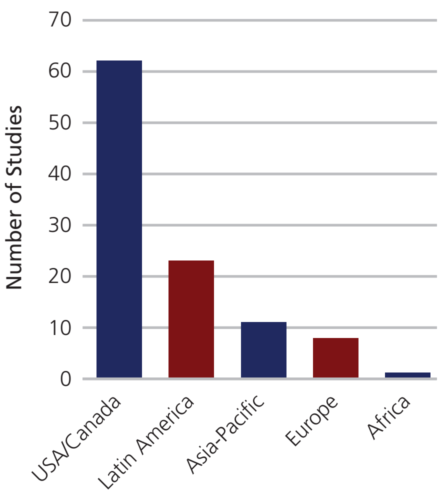
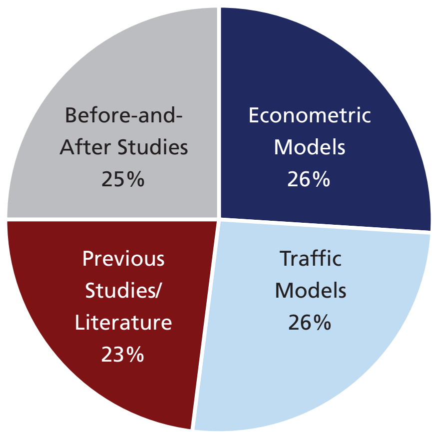


Figure 6.2: Toll Price Elasticities by Data Source



The 105 traffic studies provided a total of 451 data points (individual toll price elasticities). The timeframe relating to these data points stretched from 2002 to 2024.

In terms of sources, these data points were split almost evenly among (a) before-and-after studies[23], (b) econometric models, (c) traffic (network) models and (d) the literature/previous studies (see **Figure 6.2**).

The studies covered all of the main types of toll facility: urban roads, inter-urban roads, bridges, tunnels, ring-roads (beltways) and bypasses. Additionally, a number of the reports looked beyond single assets to consider toll road networks and portfolios. Of the toll price elasticities examined, 182 related to light vehicles (cars), 107 to heavy vehicles (trucks) and the remaining 162 to all vehicles (consolidated).

[23] The simple linear elasticity calculation method - see Chapter 4 - was the dominant one used (and reported) by the consultants.

Headline Results

Our headline results are summarised in **Figure 6.3**. The toll price elasticities display a pronounced negative skew (the bulk of the data sits towards the 'lower' end of the distribution, closer to zero) with a long tail on the left-hand side.[24] The median value of the data is an elasticity of -0.21.

The full range of elasticity values in our dataset extends from 0 to -0.93 however the interquartile range (shown shaded in blue) is clustered between -0.14 and -0.32. The interquartile range - the difference between the 25th and 75th percentiles - is a useful, compact summary of data variability unaffected by outliers (extreme values).

Panel 6.1: The Distribution of Toll Price Elasticities

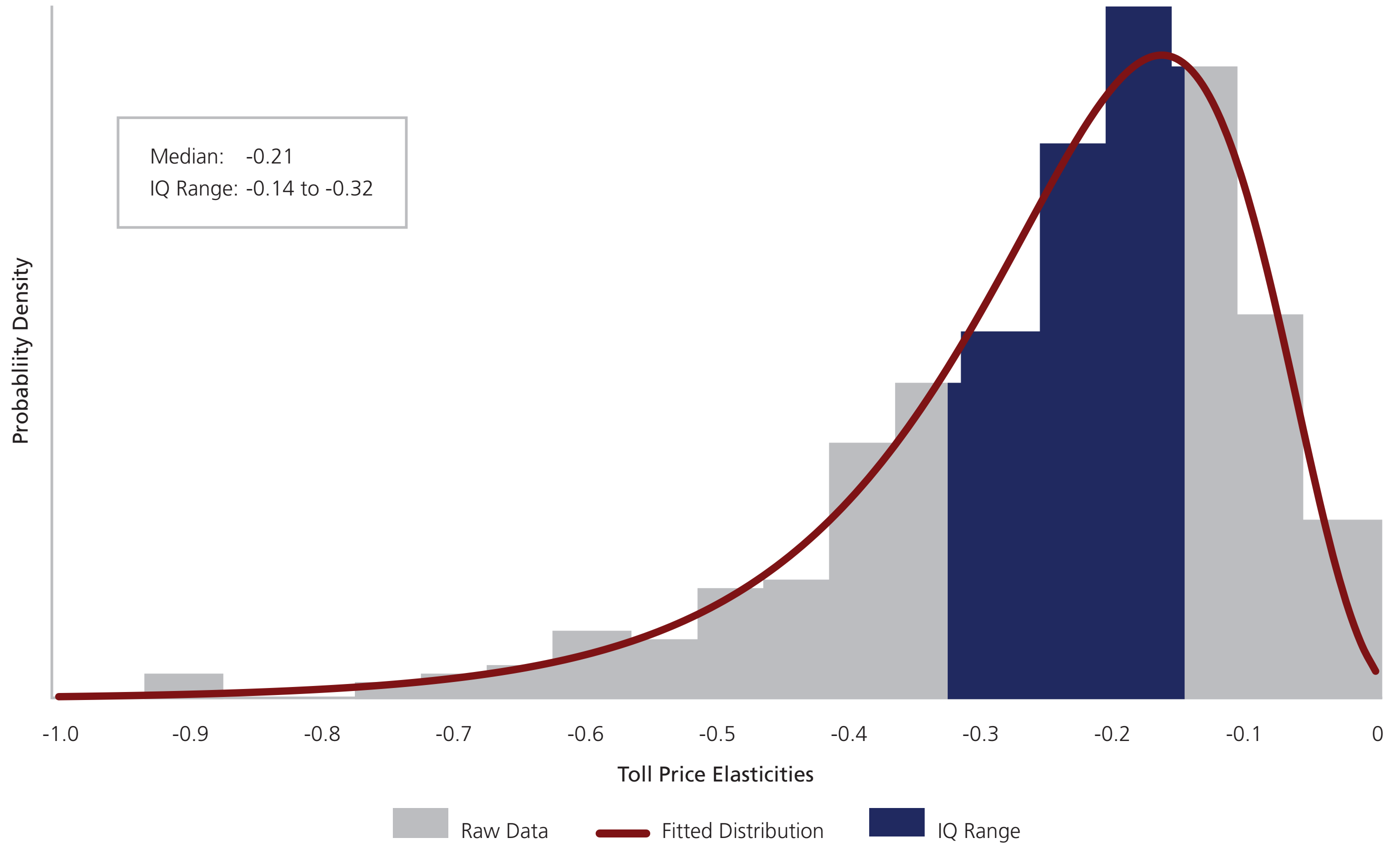
To our knowledge, this is the first study to present the **distribution** of toll price elasticities. Previous research has reported point estimates or summarised findings in terms of an observed range. Although ranges provide a useful indication of the span of plausible values, they do not convey how estimates are distributed across that span. A distributional representation equips practitioners with richer evidence on the concentration of values and their relative likelihood, providing a better understanding of central mass, spread and tail properties.

The distribution shown in **Figure 6.3** aligns well with the findings reported earlier from our literature review (Chapter 3). The literature suggested that toll price elasticities generally sit between -0.03 and -0.5. 92% of our data points lie within this range.

Toll price elasticities above -0.5 are sometimes observed however these are uncommon. Only 6% of our compiled elasticities lie above -0.5.

Building on this aggregate-level overview, the following chapters report our research findings from more granular perspectives.

Figure 6.3: Toll Price Elasticities (*n* = 451)



[24] Parametric estimation software suggested that the best fit was a reverse (or *mirrored*) lognormal distribution.

7. Commercial Vehicles

Context

Our research - and our experience - suggests that understanding why and when trucks use tolled facilities is an area rich in anecdotes but lacking analytical depth. This is surprising - given the material revenue contribution made by trucks on many toll roads - but is not unexpected. In comparison with private cars, commercial vehicles (trucks) are often the 'poor relation' when it comes to traffic analysis and research studies. It is not difficult to understand why:

- Most studies focus disproportionately on private cars (especially commuting movements) as their travel patterns are easier to observe and, critically, easier to model. Cars are ubiquitous. Data is more abundant.

  Truck numbers are considerable fewer (representing around 5% of all vehicles in the US[25]) and they are more complicated. They come in a multitude of sizes and configurations (attracting different toll rates) and are employed in very different ways (eg. long-distance 'line haul' versus local distribution). They carry a vast range of freight from time-sensitive fresh food to parcels, construction materials and hazardous chemicals. Or they may be returning to base, running empty.

  Data about truck movements is less well captured in traditional travel surveys[26] (eg. household interview surveys) and, critically, route choice may be determined by logistics or fleet managers - with or without route-optimising software - not the drivers themselves.

- Private cars are assumed to make route choices based on what 'makes sense' or 'works best' for drivers (utility-maximising behaviour).

  Trucks on the other hand, make tolling decisions based on a complicated blend of factors such as operating costs, fuel efficiency, time-savings, route reliability, delivery time 'windows'[27] and driving hours (or route, weight or height) restrictions. Safety concerns may also be factor (exposure to theft or hijacking). Traffic models generally fail to capture these nuances adequately.

  A further complicating factor is that some truckers pay tolls themselves whereas, for others, the tolls are paid by their employer.[28] And in some circumstances, these costs can simply be 'passed through' to clients (shippers). In others, they have to be absorbed by the driver or the haulage contractor themselves.

In short, in comparison to private cars, truckers' route-choice behaviour is more complex, less well researched and remains poorly understood (despite their disproportionate economic impact due to higher toll tariffs).

[25] Source: https://www.trucking.org/economics-and-industry-data
[26] Traffic studies are often passenger-focussed and involve surveys or interviews. Freight stakeholders (hauliers, logistics companies) are generally less-frequently consulted.
[27] Significant fines can be incurred by hauliers if a trucker misses a delivery window.
[28] This applies, generally to a lesser extent, to cars too.

Conflicting Theses?

When it comes to the topic of toll price elasticity, a number of the traffic study reports we reviewed articulated the view that trucks, generally, should (and will) be *less sensitive* to toll charges (and tariff changes) than cars. All things being equal, the elasticities associated with trucks will be low. Reasons cited in support of this argument include the fact that car drivers have more choice (more substitution options). Car drivers often have more discretion and greater flexibility to change route, journey timing, trip destination or elect not to travel. Car drivers may place a lower monetary value on travel time savings than freight operators. And car drivers - paying out of their own pocket - may be more budget-conscious than truckers.

Other arguments in support of this thesis point to the essentiality of trucks engaged in business or commercial activity (freight delivery), the fact that the toll charge - as a proportion of total trip costs - is generally significantly lower for trucks than it is for cars, the lack of viable route alternatives for long-distance haulage[29], and the assumption that increased toll charges can be passed along, in part or in full, to the shipper (and, ultimately, the consumer). In addition, toll roads may be preferred route choice option for truckers due to their superior vertical alignment, characterised by reduced and more-gradual gradients.

In contrast, other reports maintain that trucks are *more sensitive* to toll charges and tariff changes than cars. Although the arguments provided in support of this view are less well developed, it is certainly what some consultants found from the data they had to hand. Where attempts were made to rationalise this finding, authors often point to strong industry resistance (principled objections) to paying any form of toll, thin profit margins in the road haulage industry, particularly in the general haulage and subcontracted freight segments, and the (sometimes significantly) higher toll tariff multiples imposed on trucks (see **Table 7.1** for illustrative examples).

In many respects, the findings from our analysis of traffic study reports mirrors those from our literature review (Chapter 3). The literature is similarly divided in this regard. Around half of those who estimated separate elasticities by vehicle class concluded that commercial vehicles were less sensitive than cars to toll tariff changes. The other half concluded the opposite. Perhaps it is possible for these conflicting theses to coexist?

Table 7.1: Toll Rate Multipliers - Trucks versus Cars

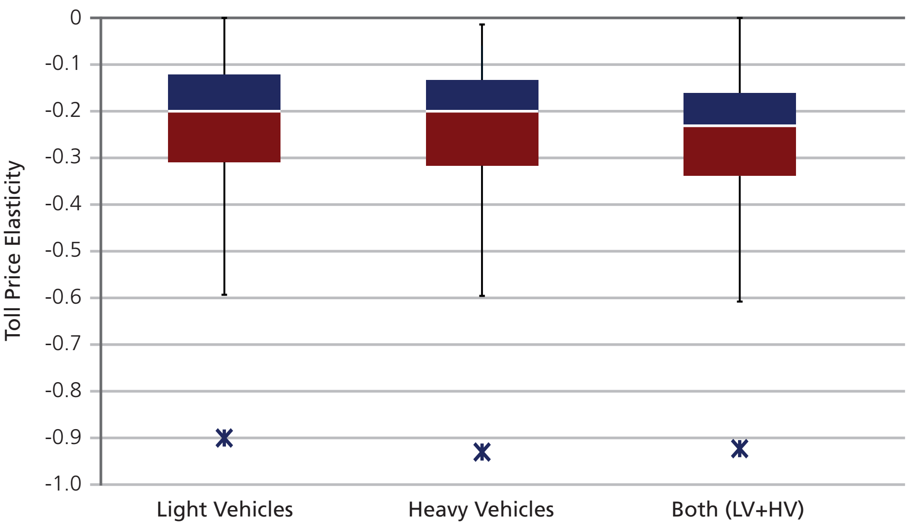
<table>
<tr><th rowspan="2"></th><th rowspan="2">Cars</th><th colspan="5">Trucks</th></tr>
<tr><th>2 Axle</th><th>3 Axle</th><th>4 Axle</th><th>5 Axle</th><th>6 Axle</th></tr>
<tr><td>Dartford (UK)</td><td>1.0x</td><td>1.2x</td><td colspan="4">2.4x</td></tr>
<tr><td>M6Toll (UK)</td><td>1.0x</td><td colspan="4">1.7x</td><td>1.8x</td></tr>
<tr><td>Fréjus (France)</td><td>1.0x</td><td>2.8x</td><td colspan="4">3.5x</td></tr>
<tr><td>RCO (Mexico)</td><td>1.0x</td><td colspan="3">2.0x</td><td colspan="2">3.0x</td></tr>
<tr><td>Brazil/India/Peru</td><td>1.0x</td><td>2.0x</td><td>3.0x</td><td>4.0x</td><td>5.0x</td><td>6.0x</td></tr>
<tr><td>M1 (Ireland)</td><td>1.0x</td><td>1.7x</td><td>2.5x</td><td>3.0x</td><td>3.0x</td><td>3.0x</td></tr>
<tr><td>407ETR (Canada)</td><td>1.0x</td><td colspan="2">2.0x</td><td colspan="3">3.0x</td></tr>
<tr><td>Elizabeth River (US)</td><td colspan="2">1.0x</td><td colspan="4">4.0x</td></tr>
<tr><td>Halifax Bridges (Canada)</td><td>1.0x</td><td>2.9x</td><td>4.4x</td><td>5.8x</td><td>7.3x</td><td>8.7x</td></tr>
</table>

29 Toll price elasticities for trucks can be even lower in developing countries due to the absence of alternative infrastructure for freight.

Data Analysis

As mentioned earlier, we compiled 451 toll price elasticities, 182 for cars (light vehicles), 107 for trucks (heavy vehicles) and 162 for all vehicles combined. The distribution of these elasticities is shown in **Figure 7.1**. Analysis reveals no significant variation across the vehicle classes. Nearly half of the reports reviewed provided both car and truck elasticities. Of those, around 60% reported truck elasticities that were higher than those for cars. The remaining 40% reported car elasticities that were higher than those for trucks. At the aggregate level - with a large dataset - truck toll price elasticities show no signs of lying systematically above or below those derived for cars.

Figure 7.1: Toll Price Elasticities - Light versus Heavy Vehicles



Qualitative Insights

It is tempting to dismiss anecdotal information in a report such as this - with its primary focus on numerical analysis. In the absence of strong quantitative conclusions, however, anecdotes - particularly recurring ones - provide a little more 'colour' and qualitative insight. The following list has been compiled from consultants' reports, discussions with industry participants and our own experience over the years. The points noted are not listed in order of importance and will not be of relevance to every toll road in every situation. Nonetheless, in this under-researched field, they still offer value as contributions to industry understanding.

- **Fleet operations**. Lower price elasticities are generally associated with the larger, more established fleet operations where the company dictates the route and pays the toll. This is particularly true in the case of larger trucks (5-axles or more).

  In some cases, however, the company pays a cash allowance to drivers and drivers, themselves, control the funds. This may encourage the driver to avoid toll roads and retain the allowance for themselves.

- **Owner-operators**. Higher price elasticities are associated with smaller, owner-operator (or owner-driver) operations where the driver pays any toll out of his/her pocket.[30] This is particularly true in the case of smaller trucks (2 or 3-axles).

- **Following instructions**. Some companies instruct their drivers to avoid toll roads unless there is no (practical) alternative route. If the route alternatives are poor, however, truckers' toll price elasticities are reportedly very low.

- **Reliability premium**. Feedback from a number of companies suggests that the main factor dictating route choice is journey time reliability and predictability (more than time savings). This improves the level of certainty associated with the arrival time at a particular destination.

- **Time-saving productivity**. Paying a toll for faster journeys may only make sense if the truck driver can do something economically productive with the saved time (such as another run or delivery).

- **Freight value**. The value of goods being transported by truck varies significantly. The price of a toll is very small - relatively speaking - for a car transporter ('auto carrier') carrying eleven new BMWs worth over $1m.

[30] The American Trucking Association estimates that 65% of trucking operations in the US operate just one truck, and 92% operate fleets of less than six.

- **Roadworks and incidents**. Truckers are reported to be particularly sensitive to (keen to avoid) road maintenance/construction works or incidents on the highway. Truckers speak to each other and are often the first to adjust to changing route conditions.
- **Avoid the peaks**. The peak travel times for trucks seldom coincide with those for cars. Truckers actively exploit off-peak travel times when general traffic volumes are lower. Off-peak tolls may be lower, too.
- **No speed benefits**. Truckers do not necessarily benefit from higher speeds or higher speed limits on tolled facilities (that they cannot or do not want to use). Peak fuel efficiency is generally achieved between 50 and 65 miles per hour (mph), and speed governors often limit trucks to 62-68 mph for safety reasons.
- **Nearby facilities**. Truckers' use of toll roads is sometimes linked to the proximity of origins or destinations such as adjacent warehouses or regional distribution centres (RDCs). In the US, there is a major shortage of designated parking areas which effectively become 'magnets' for larger commercial vehicles.
- **Cost pass-through**. Touched upon earlier, although the extent to which costs can be passed through to their customers is unclear (especially in the short-term), this undoubtedly impacts upon drivers' willingness to pay tolls.
- **No stress**. Truckers (professional drivers) are reportedly less sensitive to congested driving environments that other road users might regard as being intimidating or stressful (reasons often cited by car drivers for choosing tolled routes).

Although certainly not exhaustive, the more qualitative issues listed above can be set aside a toll facility under consideration to determine which factors (if any) are relevant in particular circumstances.

Interpretation & Lessons

There is no doubt that different types of truck respond differently to tolls and toll tariff changes. This is frequently observed. A simple example cited earlier relates to vehicle size. On many tolled facilities, usage by 2 or 3-axle trucks is (relatively) low whereas usage by 5-axle or larger trucks is noticeably higher. This reflects factors such as differences in ownership, commodity type (and value) and length of haul (trip distance). However, insights beyond this require more granular investigation.

In short, it is perfectly possible for the two 'conflicting theses' presented earlier to coexist on particular corridors or roads. At an aggregate level, the resulting toll price elasticity will reflect the underlying blend of trucks. If the fleet mix is weighted towards the less-sensitive owner, vehicle and/or cargo types, the (blended) toll price elasticity will be low - and vice versa.

The challenges associated with understanding a trucking market's particular sensitivities to travel costs were introduced earlier. For these reasons, consultants rarely venture beyond a simple 'cars versus trucks' analysis. Furthermore, the blended elasticity (for all trucks) may serve its purpose in terms of informing a toll operator's pricing decisions. This assumes, of course, that the blend will remain unchanged in the future - something that traffic advisors should be specifically asked about.

8. Client Type

Toll road traffic and revenue studies are commissioned by a number of different parties to support related - but distinct - processes. The reports reviewed as part of this study were compiled for investors, government entities, project owners, lenders and lawyers. The split, by the number of recorded price elasticities, is summarised in **Table 8.1**:

The vast majority (96%) of our elasticity values came from reports written for investors (often as potential buyers), project owners (often as sellers) and government entities (conducting feasibility studies or in support of asset procurement). Four percent of the elasticity values were drawn from reports prepared for debt providers (lenders) or lawyers involved in litigation or arbitration.

In terms of emphasis, each commissioning body sees projects - such as toll roads - through its own lens and the traffic reports tend to be tailored accordingly:

Table 8.1: Number of Elasticities by Client Type

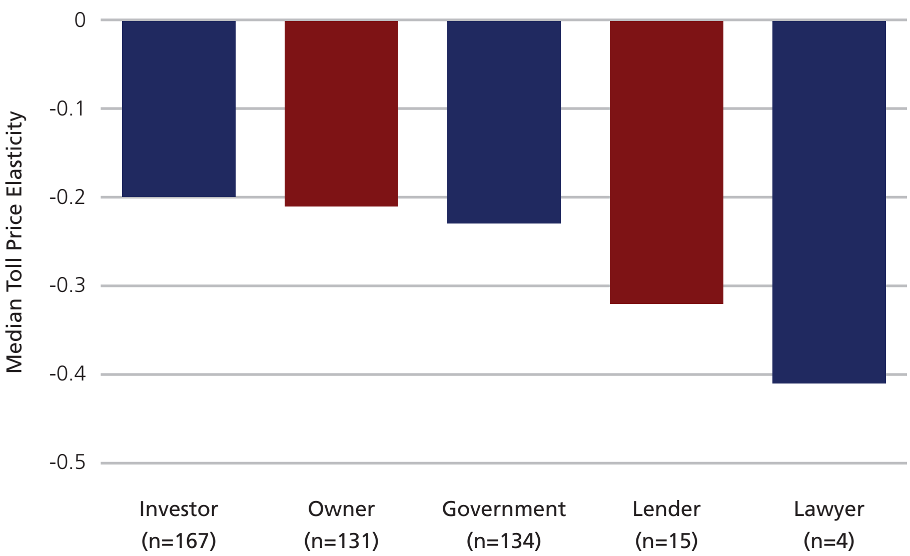
Client Type	Toll Price Elasticities
Investor (equity)	167
Government Agency	134
Facility Owner	131
Lender (debt)	15
Lawyers	4
Total	**451**

- **Equity investors** focus on revenue generation and dependability, using sensitivity tests to evaluate potential investments across various scenarios (upside and downside). They prioritise metrics such as internal rate of return (IRR) and net present value (NPV) and assess competitive positioning to determine the risk-adjusted return profile and the durability of asset value.
- **Government entities** seek to maximise competitive tension during procurement, to strike the best 'deal' with the private sector. Regulatory compliance and the project's alignment with political and policy objectives are key considerations.
- **Toll road owners** may be more focussed on lifecycle performance expectations (including cost-recovery timelines) and long-term profitability. Reports prepared in support of divestment would be expected to showcase and underscore the more attractive project (and market) attributes.

- **Lenders** are looking at revenue resilience and debt repayment capacity - through metrics such as debt service coverage ratios (DSCRs). They also may be focussed on the merits (or otherwise) of financial structuring, collateral arrangements and risk mitigation instruments. Lenders pay limited attention to upside scenarios, instead focussing on downside risks that could compromise debt repayment.

- **Lawyers** tend to be retained in contractual disputes and look closely at professional practice and conduct. They will be keen to contest any specific claims made by project counterparties. A key issue for lawyers is often asset performance against expectations (and the rigour, robustness and reasonableness of these expectations in the first place).

Figure 8.1: Toll Price Elasticities by Client Type



One critical and standout distinction among these commissioning entities is risk appetite. Equity investors and asset owners are generally willing to accept more risk than lenders or lawyers. Does this translate into the elasticity values presented in the respective reports? After all - all things being equal - the use of lower toll price elasticities leads to higher revenue forecasts (more revenue is assumed to be generated following tariff increases).

Figure 8.1 lends some support to this theory. When the median elasticity estimates were analysed by client type, the clients perceived to be more willing to accept risk (at the left of the chart) were associated with lower elasticity estimates. The elasticity estimates were higher for the more risk-averse clients to the right.

There may be no 'theoretical' justification for our findings but, intuitively - and from our own experience - our expectation was that the more conservative stakeholders would favour the use of more conservative assumptions in their toll road studies. Traffic consultants are generally aware of their client's disposition towards market risk and will reflect this (implicitly or explicitly) in the toll price elasticity values being used.

"Although we expect that the [future] *elasticities will be similar to those observed, for the Lender's Case we have assumed that this impact will be higher".*

US Toll Road Traffic Study Report

9. Time of Day

Peak versus Off-Peak

The literature review earlier highlighted the fact that toll price elasticity is frequently associated with the reason for travel (trip purpose), which in turn is often correlated with time of day. The most illustrative example of this relationship is work-related commuting and attending educational institutions, where travel activity is often concentrated during weekday peak hours - generally 6:00–9:00am and 4:00–7:00pm[31] (see **Panel 9.1**). These trips are essential and time-sensitive, occurring during periods of significant network congestion. Such journeys (and the associated time periods) are, therefore, assumed to exhibit relatively low toll price elasticities.[32]

"Estimated toll elasticities for workday midday and off-peak are significantly higher than for either peak or shoulder periods. This is expected to be the case, as the alternative roads are less congested… We also expect that the willingness to pay of the average user will be lower [during the off-peak] *due to the higher proportion of discretionary trips during this period".*

Canadian Toll Road Traffic Study Report

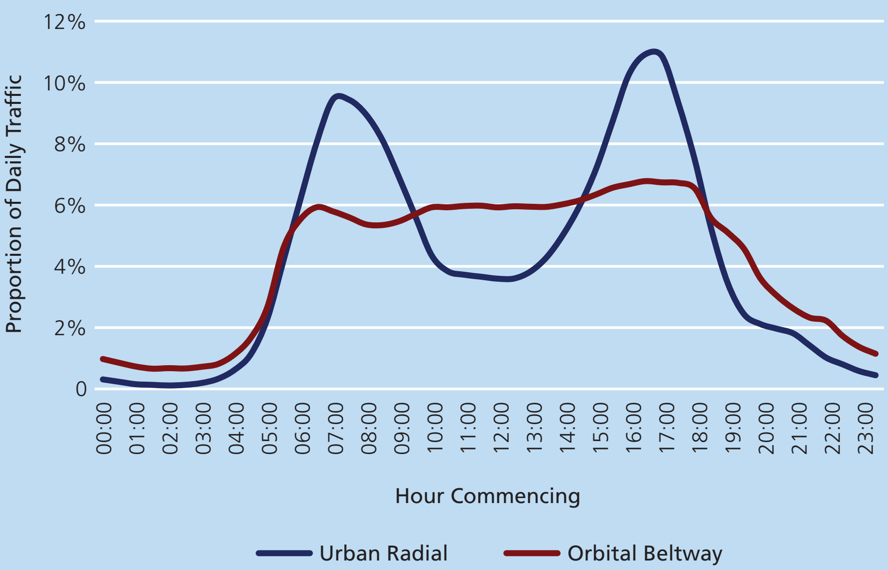
This chapter tests this assumption using the new toll price elasticity data that we have compiled.

Panel 9.1: Hourly Flow Profiles

The chart to the right presents the hourly flow profiles from two, real-world toll roads. An hourly flow profile simply shows the time-series distribution of vehicle flows across a 24-hour period. In the chart, traffic in both directions of travel has been combined.

The blue line was generated by data from an 'urban radial' (a major corridor that extends outwards from a city centre towards the suburbs). It shows the classic, pronounced peaks associated with commuter traffic. The morning peak represents inbound traffic while the afternoon peak corresponds to outbound traffic. The period between the two peaks is labelled the 'interpeak'. Traffic demand is significantly reduced, and elasticities can be significantly higher during the interpeak period.

Figure 9.1: Hourly Flow Profiles by Road Type



The red line was generated by data from an 'orbital' (also called a beltway or a ring road). These encircle urban areas allowing traffic to bypass city centres. As can be seen from the flatter profile, traffic is more evenly distributed across the daytime period. The impact of commuter traffic is moderated by the much broader range of trip purposes being served.

[31] Peak traffic patterns are not universal and can vary significantly across countries and regions, being influenced by factors such as cultural norms, religious observances, climate and labour practices.
[32] This statement refers to peak hour traffic travelling in the peak direction. Toll price elasticities for peak hour traffic travelling in the contra-peak direction are typically higher (and often similar to off-peak values).

Panel 9.1: Hourly Flow Profiles (*Continued*)

Those undertaking toll pricing studies need to understand the temporal distribution of traffic demand as cost sensitivities (price elasticities) - and hence revenue generating capacity - will vary from hour to hour.

One point of note is that many traffic consultants model the weekday peak periods alone. This is largely for convenience. Peak period data tends to be more readily available and dependable. The consultants rely on assumptions about traffic demand and price sensitivity for other (non-modelled) periods.

This poses the risk of misrepresenting the characteristics, sensitivities and preferences of non-peak travellers, leading to biased estimates of future traffic demand and revenue growth.

The Data

Despite having compiled a large sample of toll price elasticities, we were able to identify only 17 cases where toll price elasticities were split between peak and off-peak periods (11 for cars and six for trucks). In 16 of these cases, peak traffic was estimated as being less elastic than off-peak traffic. Aside from the quote highlighted earlier, the authors of the traffic studies talked about drivers being less likely to switch to a toll-free alternative during rush hours (as there is a large time penalty for doing so) and the fact that drivers were unlikely to avoid travel altogether ("…*as peak hour trips are often considered to be essential trips*"). Analysis of the data is summarised in **Figure 9.2**.

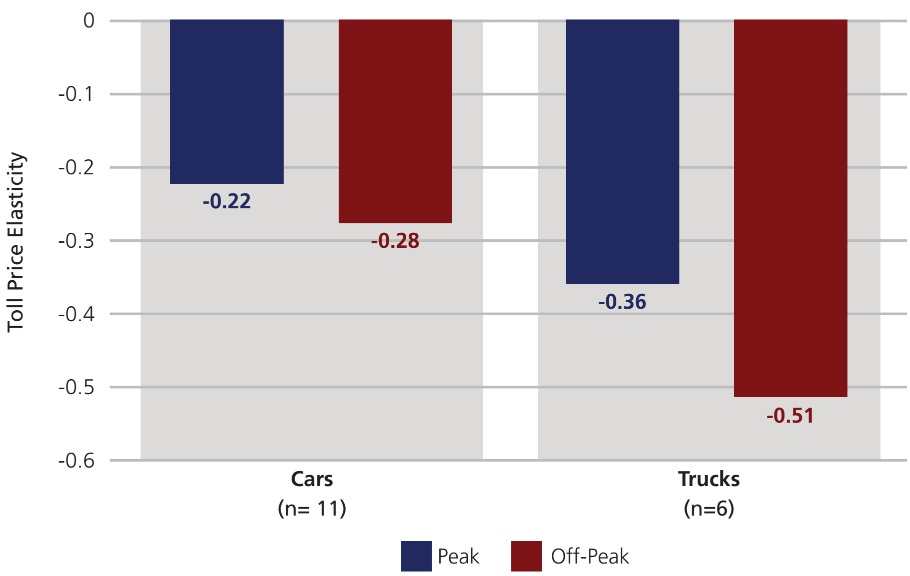
Although care has to be taken because of the small sample sizes involved, it appears that our data validates the premise advanced at the beginning of this chapter. Peak period elasticities are lower than those observed off-peak. The domination of work and school trips during weekday peak periods makes 'captive' drivers less responsive to toll price changes.

As the trip purpose-mix evolves to include more leisure and shopping trips during the off-peak, drivers become more sensitive to tolls. Off-peak drivers are often more price-sensitive than time-sensitive.

These factors have material implications for toll pricing strategies. The most obvious is to increase tolls during peak periods (or, conversely, to reduce them off-peak).

Raising toll prices during peak periods commonly generates more revenue without significantly reducing demand. For the same reason, urban congestion charging initiatives (such as those in London or Singapore) report that peak demand, itself, is more difficult to suppress through pricing interventions alone.

Figure 9.2: Peak versus Off-Peak Elasticities (Cars and Trucks)



10. Electronic Toll Collection

Introduction

Electronic Toll Collection (ETC) refers to the automated process of charging road users without requiring them to stop and pay at toll booths. Using various technologies - summarised below - ETC systems reduce transaction times and increase throughput.[33]

They also hold the potential to improve road safety. Traditional toll plazas require vehicles to decelerate, change lanes and queue - creating conditions conducive to rear-end collisions and lane-changing accidents. By eliminating the need to stop (or even slow down), ETC systems significantly reduce these risks.[34]

ETC is a substantial topic in its own right. A detailed examination lies beyond the scope of this report. The focus here is on the implications of ETC in terms of drivers' sensitivity to tolls and toll tariff changes.

Terminology

With ETC, the automated charging of tolls involves technologies such as radio frequency identification (RFID) or automatic number plate recognition (ANPR). In-vehicle transponders ('tags') or on-board units (OBUs) communicate with roadside equipment to enable payment. System components include a back-office for transaction processing and enforcement mechanisms to address toll evasion. Interoperability allows users to travel across different toll facilities or networks using a single tag and account. Some ETC systems employ congestion pricing - where tolls vary by time of day or by traffic conditions - to manage demand.

A simple typology of ETC systems - based on their operational characteristics - is presented in **Table 10.1**.

In terms of toll price elasticities, a key feature of ETC is that payment is not made at the point (and time) of use. Some systems require pre-payment - funds loaded into a toll account before a tolled facility can be used. Others send out monthly invoices (post-payment). Either way, the use of the facility becomes decoupled from the payment of the toll, reducing salience and encouraging consumption. Our literature review suggested that this reduces drivers' sensitivity to price. Here, we use our elasticity database to test if and how this translates into drivers' sensitivity to price changes (tariff hikes).

Table 10.1: ETC Systems by Technology/Collection Method

Feature	Barrier-Based ETC	Hybrid ETC	Open-Road Tolling (ORT)
Infrastructure	Toll booths and gates	Combination of booths and gates, and free-flow gantries	Overhead gantries, cameras and sensors
Vehicle Movement	Must stop or slow significantly	Some lanes require stopping, others allow free flow	Vehicles maintain highway speeds
Lane Structure	Dedicated lanes with physical separation	Mixed-use: ETC + card/cash and tag-only lanes	Multi-lane free flow
User Identification	Manual payment, tag or ANPR	Tag or ANPR	Tag or ANPR
Enforcement	Physical barrier prevents usage without payment	Mix of physical and electronic enforcement	Video enforcement with database cross-checking[35]
Traffic Flow	Slow - queueing and delays are common	Improved flow in ETC-only lanes	Uninterrupted travel
User Experience	Lowest (slow)	Mixed (varies by lane choice)	Highest (fast and non-intrusive)
Deployment	Older systems	Regions or countries transitioning from manual collection to ETC	Modern systems

[33] In addition, ETC systems allow operators to become much more granular and sophisticated in how they set, adjust and implement toll prices. Cash-based tolls are typically rounded up or down for customer convenience and to simplify change handling. ETC tolls are less constrained in this regard.
[34] For further information, see: https://www.itskrs.its.dot.gov/2019-b01400
[35] Using a photograph of the licence plate, the operator accesses the registered keeper's details (name and address) from the state motor vehicle database.

The Practitioners' Perspective

From our review of traffic consultants' reports, it is clear that the experience of practitioners aligns with the arguments presented above. A couple of report extracts illustrate this point:

"Experience has demonstrated that electronic tolling desensitises motorists to tolling costs (indeed, in surveys of motorists, many have been unable to estimate the tolls they pay)".

Australian Toll Road Traffic Study Report

"Experience with the response of drivers to changes in toll levels on electronic toll roads indicates that price elasticity is lower than 'cash' toll roads. The separation of the time of payment from the point of use leads to a misperception of price. Our market research indicates that this effect equates to an underestimation of the toll price by approximately 15%. Therefore, any future introduction of ETC on [the toll road] *is expected to lead to an effective reduction in elasticity to toll changes".*

US Toll Road Traffic Study Report

Historically, it became almost standard industry practice to discount ETC tolls by 15% in the traffic models used by consultants to prepare toll road forecasts.[36]

Our Data

When we turned to our elasticity database, although a difference in toll price elasticities between cash and ETC systems could be detected (the elasticities relating to cash payments were higher), our findings - by themselves - were unreliable. Our sample size of cash-only toll collection systems was simply too small.

Electronic tolling commenced back in the late 1980s and early 1990s (in the US, Norway and Japan). All-Electronic and Open Road Tolling systems started to appear around 2010 (SunPass in Florida, 407ETR in Toronto, the Massachusetts Turnpike and the UK's Dartford Crossing). The systems and technologies behind ETC are, today, broadly established, mature and time-tested. Globally, the tolling industry has migrated away from cash collection - certainly in developed markets. Many modern toll systems are completely cashless. Where cash-payment options still exist, these tend to have been retained for operational reasons or because of legacy infrastructure (for example, in France and Italy).

Figure 10.1: Open Road Tolling (ORT) Gantry in South Africa

In summary, the perception of ETC as being an innovative technology has diminished over time. It has become widely adopted and, for the consumer, has become familiar and normalised (indeed, expected). The justification for believing that ETC-paying drivers behave differently or respond to toll tariff changes in specific ways has fallen away.

In today's environment, traffic consultants would have to make very strong arguments in support of making adjustments in their forecasting models to take account of a supposed 'ETC effect'. And no adjustments are required when benchmarking against contemporary toll price elasticities observed in other contexts, as most already incorporate the effects associated with ETC.

[36] Some tolling operations offer discounted prices to ETC patrons, to encourage migration from cash. This is different and separate from the 'ETC discount' being discussed here, which is (or, rather, was) an adjustment made in forecasting models to reflect observed driver behaviour.

11. Short Versus Long-Run Elasticities

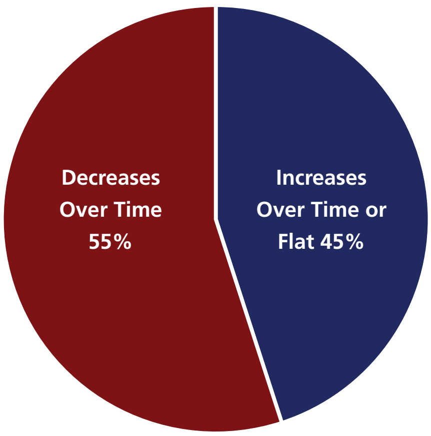
Our earlier review of the literature suggested that price elasticities should increase in the long-term (*the second law of demand*), as the choices available to consumers widen. Academics maintain that long-run elasticities are typically 50-100% higher than their short-run equivalents.[37] But does this align with the observations and experience of practitioners?

In 20 of the 105 traffic and revenue study reports reviewed, the authors specifically addressed the issue of how toll price elasticities would be expected to evolve over time (see **Figure 11.1**):

- In nine reports (45%), the consultants suggested that price elasticities would *increase* in the long-run (or would remain constant).

Reasons provided in support included drivers' inability to adapt immediately (behavioural change happens more gradually) and the fact that, if real tariffs rise faster than real income, the perceived cost of the toll increases, leading to a greater traffic decline.

Figure 11.1: How Do Price Elasticities Evolve Over Time?



- In eleven reports (55%), the consultants suggested that price elasticities would *decrease* over time.

The primary reason given for this was attributed to growing congestion on competing routes. Increasing congestion on the toll-free alternatives causes traffic to slow, magnifying the time-savings - and value - enjoyed by toll road users. A secondary reason cited relates to the values of time. As these generally increase (over time), toll roads become more affordable and attractive as route choice options.[38]

[37] The literature generally defines 'short-run' as being less than one year.
[38] Another reason cited by some consultants in support of decreasing toll price elasticities in the long-run is because of changing collection methods, as drivers migrate from cash to electronic payments.

A key point is that **none** of the practitioner material (traffic studies) that we reviewed attempted to estimate long-run toll price elasticities from historical data. This is unsurprising as they are not observable. As the analytical time period expands, the isolated impact of a price changes becomes difficult (if not impossible) to separate from confounding factors such as economic or development trends, and/or background traffic growth. And, even if it could be isolated, it is difficult to understand how a long-run toll price elasticity would be meaningfully applied in practice.

Recall that only 20 of the reviewed traffic studies touched on the issue of long-run price elasticities. The other 85 reports were silent in this regard. And while a handful of reports discussed the concept of long-run elasticities, *all* of the elasticities presented were short-run elasticities. Where a temporal distinction was made, it tended to be between (a) behavioural differences observed immediately and (b) those observed in the short-term. 'Sticker shock', for example, can lead to an exaggerated initial driver response, with demand rebounding over the following weeks or months.[39] Longer-run toll price elasticities appear to be primarily of academic interest.

Panel 11.1: Practitioners' Views

"As congestion increases…the surrounding roads actually decrease in speed faster than [the toll road] *due to the speed flow relationship… This means that in the future there will be increased travel time savings for users* [of the toll road] *which will result in lower elasticities…"*

US Toll Road Traffic Study Report

"…even when there is no change in the real toll, traffic is assumed to increase due to an increase in purchasing power as tolls are perceived to become relatively cheaper. The change in purchasing power… implies an increase in the value of time and is applied each year…"

Australian Toll Road Traffic Study Report

If toll price elasticities actually decrease in the long-term, this would run counter to economic theory. However, at the heart of that theory lies the assumption that consumer choice expands over time - which may not be the case in a constrained travel market. Demand-side constraints include the common requirement to be at certain places at certain times. And the key supply-side constraint stems from an inability (or unwillingness) to expand the network to meet demand.

In short, the expanding choice set underpinning long-term consumer behaviour in other markets may be of limited applicability to road users.

Instead of maintaining that toll price elasticities are dynamic and increase over time - as much of the academic literature does - a more pragmatic take for practitioners would appear to be that these elasticities are, indeed, dynamic but they are primarily influenced by the evolving quality and viability of the alternatives over time. This highlights the importance for practitioners to understand, not only the competitive landscape today, but how that competitive landscape could change in future years.

[39] Sticker shock refers to the surprise and dismay people feel when they discover the cost of something is higher than expected. It highlights the importance of understanding the psychological impact of pricing rather than simply the monetary aspect.

12. Traditional Traffic Models

Background

When it comes to demand modelling and preparing projections of future asset usage, the road sector sits apart from other classes of infrastructure (energy, water, telecoms, health and education facilities) where custom-built, spreadsheet-based models are typically compiled and used by forecasters. In roads, a modelling approach developed back in the 1950s - requiring the use of specialist knowledge and software - continues to dominate the industry. Known as the '4-step' (or *network assignment*) model, it was originally devised as an engineering tool in the US during the post-war highway boom. Its primary purpose was to predict automobile traffic and plan/design new highway infrastructure accordingly - such as the Interstate Highway System.

Panel 12.1: Alternative to the 4-Step Model

There are two main approaches that can be classified as 'structured travel demand models' (frameworks with a defined architecture where the analyst plugs-in data and assumptions but the steps or behavioural logic are imposed by the model's structure). These are the 4-Step Model (FSM) - discussed here - and the Activity-Based Model (ABM).

Unlike the FSM, which focusses on trips (as independent events), ABMs view travel as a byproduct of people's need to participate in activities and attempt to model the full daily pattern of behaviour at the individual or household level.

ABMs are not a focus here. In terms of data requirements and computational complexity, they are significantly more demanding and expensive than FSMs. ABMs tend to be developed and used by large, well-resourced metropolitan planning departments with richer data and long-term modelling programmes. We have never reviewed a traffic consultant's study for a tolled facility that employed an ABM. The FSM remains the workhorse used by many consulting practices today.

Over the years, the 4-step modelling approach has been adapted in response to a changing policy landscape and, specifically, changing US policy-related legislation. Environmental and social concerns emerged in the 1970s and 80s requiring model developers to incorporate emissions and energy modules. The modelling framework was further adapted in the 1980s and 90s in response to a policy shift towards demand management initiatives and practices. Subsequently, other adaptations have been developed ('bolted on') yet the core modelling framework and principles remain unchanged. This limitation and rigidity have attracted criticism from academics and practitioners[40], some of which surfaced during our literature review.

"The [4-step] *model system was developed for evaluating large scale infrastructure projects and not for more subtle and complex policies involving management and control of existing infrastructure or introduction of policies which directly influence travel behaviour".*

'The Four Step Model', M McNally (University of California)

This is not the place for a detailed critique of the 4-step traffic model or its industry dominance - which some commentators attribute to 'institutionalisation' and deep industry investment rather than technical merit.[41] The distinguishing feature is that no other infrastructure class (other than the highway sector) places such reliance on an approach to demand modelling and forecasting that was developed 75 years ago and is still - with minor tweaks - in use today.

Our Analysis and Findings

As described in Chapter 6, our toll price elasticity database was compiled from different sources: before and after studies, practitioner experience, econometric models, the academic literature and (4-step) traffic models.

The toll price elasticities by source are isolated and summarised in **Figure 12.1** and **Table 12.1**. As can be seen, the toll price elasticities derived from traffic models sit systematically higher than the others.

This finding, that traditional traffic models appear to be oversensitive to toll price, accords with our experience. We have come across a number of examples of projects where 4-step model forecasts - incorporating real tariff increases - have

[40] See, for example, '*The Four Step Model*' by Michael McNally (University of California) at: https://escholarship.org/uc/item/7j0003j0
[41] Industry reliance on the 4-step model is scarcely attributable to strong predictive performance. See, for example: https://www.ibtta.org/sites/default/files/Error%20and%20optimism%20in%20traffic%20predictions.pdf

predicted a certain moderating impact on demand which has not transpired in reality. Managed lanes in the US, employing dynamic pricing, are a good example.[42] On a number of these projects, originally modelled peak-period pricing has failed to manage (suppress) demand as required. To regulate traffic volumes and preserve free-flow conditions, toll prices have had to be adjusted upwards from those originally predicted by the traffic model.[43]

Looking Forward

Despite the continued dominance of the 4-step traffic modelling methodology in highway engineering and government planning, there are signs that other toll road industry stakeholders are warming to alternative approaches that are:

- Customised to reflect specific project or market attributes (rather than a one-size-fits-all modelling approach).
- Non-reliant on specialist software and software-related skills (spreadsheet-based constructs).
- Less data intensive, focussing on project and market-critical information.
- Using the most up-to-date data available, not legacy datasets.
- Streamlined, taking weeks to build and run, not months.
- Transparent, all assumptions being explicit, auditable and able to be flexed (by the client).

Figure 12.1: Toll Price Elasticities by Calculation Method

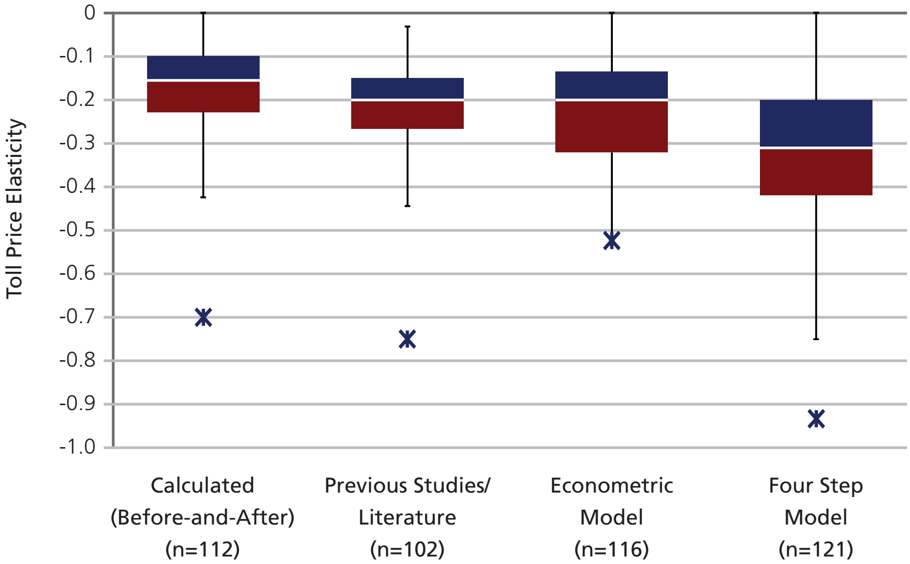


Table 12.1: Toll Price Elasticities by Source

Dataset	Elasticities	
	Median	IQR
Network Models	-0.3	-0.2 to -0.4
Other Sources	-0.2	-0.1 to -0.3

- More granular in terms of their representation of price and price-related behaviour.
- Better supported by cross-comparisons and benchmarking.

Indeed, this emerging consensus - certainly among financial stakeholders - was highlighted at a recent conference for infrastructure professionals devoted to 'exploring the evolving landscape of public-private partnership toll roads and managed lanes'[44]:

"The forecasting model itself is being reimagined. Panelists highlighted a clear shift from static peak-hour-based modelling to more dynamic, empirically driven approaches. Lenders and rating agencies are becoming more comfortable with these improved forecasting methods, especially when supported by robust comparative data from similar assets".

Panel Discussion Summary, IPFA, New York (June 2025)[45]

[42] Dynamic pricing presents a number of challenges to traffic models and modellers. Traditionally, toll demand has been a function of price. On a manage lane project, toll price is a function of demand.
[43] '*Emerging Challenges to Price Managed Lanes: A Synthesis of Highway Practice*', NCHRP Synthesis 559, Transportation Research Board, 2020.
[44] '*Moving on Down the Road: Rethinking Toll Roads and Managed Lane Projects*', International Project Finance Association, 12 June 2025, New York.
[45] See: https://www.nixonpeabody.com/insights/articles/2025/07/21/moving-on-down-the-road-rethinking-toll- roads-and-managed-lane-projects

13. Reflections and Discussion

Context

This report has focussed on toll price elasticity; the responsiveness of travel demand (traffic volumes) to variations in toll charges. Toll price elasticity provides a measure of how driver behaviour adapts to pricing interventions, a consideration of some significance as policymakers and planners increasingly turn to cost-based instruments to influence demand, optimise network capacity, and internalise the wider congestion and environmental externalities of road use.

Our study employed a strategy of methodological triangulation, integrating evidence from a systematic review of the academic literature with practitioner perspectives and experiential knowledge. This approach allowed us to situate theoretical insights within the realities of practice, thereby enhancing both the validity and the practical relevance of our findings.

Despite assembling a substantial database of over 450 toll price elasticity estimates, some of our findings remain tentative, inconclusive or require qualification. In our experience, this is not unusual. It reflects the inherent complexity of behavioural research, where variability across contexts and populations resists overly definitive conclusions. While some academic research and consultants' reports underplay this reality in favour of tidier generalisations, we believe that acknowledging complexity provides more accurate and policy-relevant insights.

Toll price elasticity research faces two major challenges. The first concerns **data availability**. In most situations, an operator's income comes directly from tolls and is, therefore, tightly linked to traffic volumes.

Although some performance data is typically published by publicly operated facilities, it is not always at a level that facilitates the fine-grained 'traffic versus price' analysis required for elasticity estimation.[46] And the detailed data relating to privately operated facilities is generally commercially sensitive and confidential (unavailable).

The second challenge concerns **data extraction** - disentangling the influence of toll charges from the broader set of factors that shape driver behaviour. As noted, travel decisions are conditioned not only by price but by a host of other factors. This becomes messy - but paying careful attention to these interacting influences strengthens the robustness of elasticity estimates and enhances their value to practitioners.

[46] A historical challenge in the industry has been the fact that many tolls have remained unchanged for years - limiting the number of observations available for pricing research.

Academic Research versus Practitioner Experience

Perhaps unsurprisingly, there was strong alignment between academics and practitioners on most of the observations about toll price elasticities.[47] Toll charges were universally found to be price inelastic, increasing with higher tariff levels and larger tariff adjustments. In terms of estimating methodologies, before-and-after studies dominated practice whereas econometric modelling found more favour within the academic community. Reasons for this were suggested earlier.

Strong agreement between academics and practitioners extended to the magnitude and range of the toll price elasticity values themselves, summarised in **Table 13.1**.

Table 13.1: Elasticity Values (Academics versus Practitioners)

Toll Price Elasticities	Academics (Research Papers)	Practitioners (Traffic Studies)
Typical Range	-0.03 to -0.5	92% of reported toll price elasticities fall within this range
Median	-0.2 to -0.3	-0.21
Distribution	n/a	Skewed towards lower values (75% of elasticities lie below -0.33)

Academics and practitioners identified the same set of influencing factors that impact on toll price elasticities, albeit with different parties placing more emphasis on some relationships than others. Notwithstanding, the key determinant was universally acknowledged to be **the availability and perceived attractiveness of substitutes** (variously defined in terms of alternative routes, modes, destinations, trip timing and so forth). All other determinants were comparatively less influential, exhibiting only second-order effects.

Differences in views started to emerge when it came to more disaggregated analysis. To be clear, however, many of these differences were expressed within the academic and practitioner communities - rather than being distinguishing factors between them.

Although not alone, the topic of commercial vehicles illustrates this point well. Both the literature and the consultants' reports were split - almost evenly - on this matter; some maintaining that the evidence suggested that trucks were more sensitive to toll changes than cars with others concluding the opposite. We return to this matter later.

The clearest area of departure between academia and practice concerned the distinction between short and long-run toll price elasticities. The academic literature looked beyond toll roads and considered economic theory more generally. This maintains that, generally, as consumer choice expands in time (for reasons given in Chapter 11), price elasticities would be expected to increase in the long run.

Practitioners appeared to be less constrained by economic theory and more focussed on what the data was suggesting to them. In that context, roughly half concluded that toll price elasticities would increase in time (or remain constant) whereas the other half expected the elasticities to reduce.

And even when increasing elasticities were expected, this was treated primarily as a theoretical observation. None of the consultants attempted to estimate or apply long-run toll price elasticities in practice.[48]

One final distinction between academics and practitioners concerned the use of traditional (4-step) models for travel demand forecasting generally and, more specifically, for toll pricing studies. A number of academics sounded cautions about the ability of these models to represent price and reflect price-related behaviour comprehensively and accurately. Practitioners are either unaware of or unperturbed by such concerns as their reports were notably silent in this regard. Despite this, our analysis suggested that traditional traffic models were unduly sensitive to price, producing elasticities that sat systematically higher than those derived through observation and other sources.

[47] This is unsurprising as many practitioners will be aware of the academic literature - certainly the key research contributions - which they may have studied as part of their formal education.

[48] A number of consultants constructed econometric models for toll price elasticity estimation, but none incorporated a lagged dependent variable which would capture drivers' responses to toll increases over time.

Level of Analysis, Compositional Effects and Aggregation Bias

Having reflected on our research and findings, it is important to highlight and formalise a recurring methodological concern that emerged from the both the literature and the practitioner reports. This theme is often implied but is seldom discussed explicitly - and can be considered under the (related) headings of level-of-analysis misspecification, compositional effects and aggregation bias.

In scientific analysis, the problem of level-of-analysis misspecification can lead to misleading inferences because the analyst is attempting to attribute variation to the incorrect level of observation. Take trucks as a category, for example. As discussed in Chapter 7, trucks are not homogeneous. Instead, they are comprised of various subgroups which differ markedly in their respective sensitivity and responsiveness to tolls.

If the level-of-analysis is trucks, but the underlying variation occurs at a more granular level, inferences become distorted. Trucks may appear to be elastic or inelastic (as our research demonstrated) but this is conceptually flawed as heterogeneous user groups are being amalgamated. And when you combine heterogeneous groups, the aggregate relationship can look different from what exists within the subgroups (aggregation bias) - see **Panel 13.1**.

In short, a number of toll price elasticity 'findings' suffer from what the statistics literature describes as 'compositional effects'. Researchers have reported that, for example, off-peak demand or coastal roads are more elastic whereas these are, in reality, compositional effects.

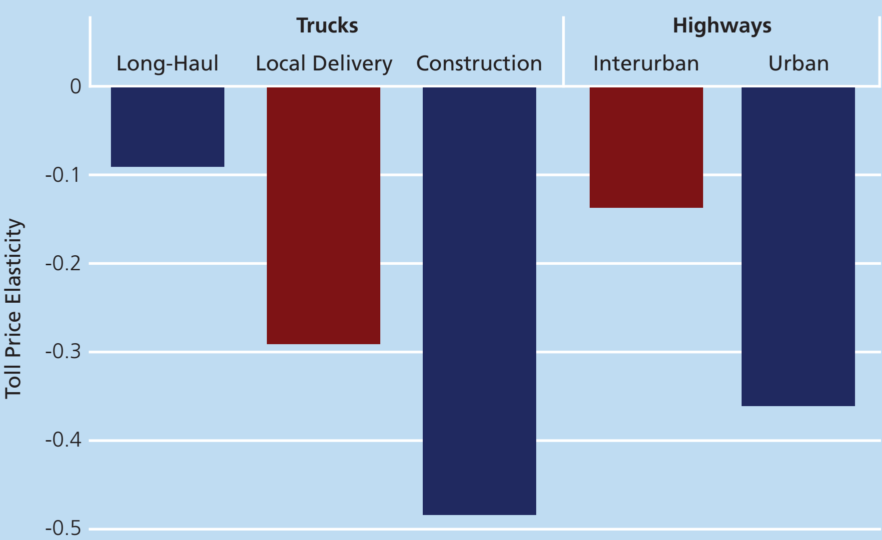
What appears to be a pattern at the aggregate level is simply an artifact of mixing different submarkets. The property (in this case, elasticity) does not stem from the time period or road classification *per se*. Off peak demand is more elastic because of the composition of travellers, tipped in favour of those who are not particularly time sensitive or have scheduling or trip flexibility. Exactly the same effect applies to coastal roads yet is unrelated to the intrinsic properties of the roads themselves.

This causes a mismatch between pricing categories and the behavioural drivers of demand. Toll pricing systems operate using broad categories (car, trucks, peak, off-peak). This is necessary for operational practicality and user convenience. However the underlying behaviours may not be determined at that level, but by the composition of users **within** these categories.

Panel 13.1: Illustration of Aggregation Bias

In this purely illustrative example, long-haul freight is highly inelastic (-0.09), construction-related traffic is relatively elastic (-0.48) and local delivery vehicles sit in between (-0.29). On interurban highways where long-haul dominates, the aggregate 'truck' elasticity looks inelastic (-0.14). In urban areas, however, where local delivery and construction traffic is more prevalent, the aggregate 'truck' elasticity appears to be much higher (-0.36).

Figure 13.1: Trucks by Type and Aggregated by Road



The key issue for practitioners is to recognise this effect and to treat category-level elasticities with caution. More refined segmentation and more granular pricing is the obvious solution (such as shoulder pricing around the peaks) - but opportunities are often limited in practice.

Adaptive pricing that evolves over time with the observed behavioural responses without overcomplicating the system is perhaps a more achievable long-term objective.

All of the evidence that we reviewed as part of this study suggests that the single most important factor in advancing the understanding of toll pricing behaviour generally (and toll price elasticities specifically) is a deeper analytical focus on the specific composition of the market(s) served by each toll facility.

Concluding Comments

The existing literature reports a wide range of toll price elasticity estimates, and our research independently confirms that this range is broadly valid. However, while prior studies have identified individual elasticity values or limited intervals, none have defined the underlying statistical distribution of toll price elasticities.

Our study addresses that gap by empirically characterising the distribution based on a large and diverse sample, providing a representation that is likely to approximate the population distribution. Beyond establishing the distribution, our analysis identifies the principal determinants of toll price elasticity, revealing how factors such as contextual conditions, user characteristics and trip purpose shape the behavioural responses to tolls.

Together, these findings offer both theoretical and practical value. By understanding the relevant determinants for a specific project - its characteristics, context and user base - policy analysts, investors and practitioners can infer where those users are likely to lie within the broader elasticity distribution.

This supports the design of tolling strategies that are both efficient and effective (in terms of satisfying their policy objectives), and should enable more accurate predictions to be made of the likely behavioural response to road pricing under different circumstances.

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Note: Numbers in [squared brackets] are used in Figure 3.1 on page 9.

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