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Measuring Impacts and Risks to the Public of a Privately Operated Toll Road Project by Considering Perspectives in Cost-Benefit Analysis

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Abstract

Decision making about transport infrastructure investment is based on the net impacts and risks to the community. The private sector is often involved in toll road projects, including various schemes to design, build, operate and/or finance the project either in a partnership with a host government, independently, or in some combination. Cost-Benefit Analysis of a privately operated toll road require careful allocations of project impacts, in order to properly reflect the net impacts and risks to the community from the host government's perspective. This study investigates whether alternative assumptions are valid from differing perspectives, when toll roads are delivered and operated privately rather than by a host government. Treatments of tolls and other toll road project related payments are considered from different perspectives. Cost-Benefit Analysis is conducted for a synthesised toll tunnel project case by considering alternating treatments of some impacts. This leads to the exploration of analyses outcomes when the treatment of tolls differ when two perspectives of "toll as a transfer payment" and "toll as an end user cost" are considered. Various scenarios are explored including public versus private operations. The Monte Carlo simulation approach is used to account the risks of variables in the analysis. The synthesised case study revealed that, for privately operated toll roads, treating toll charges as a transfer payment, and alternatively as an end user cost, can both

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be valid approaches but from two perspectives. Moreover, the analysis outcomes under different perspectives are particularly helpful to make decisions on the basis of the impacts and risks solely from the perspective of the host government. The proposed methodology can examine various scenarios other than the ones examined in this study and is extremely useful in the project evaluation of privately operated toll road projects.

KEY WORDS: toll road; cost-benefit analysis; public-private partnership; Monte Carlo simulation; transport planning; transport economics

Introduction

The private sector is often involved in toll road projects, including various schemes to design, build, operate and/or finance the project either in a partnership with a host government, independently, or in some combination. Involvement of the private sector requires careful allocations of project impacts when conducting Cost-Benefit Analysis (CBA) in order to properly reflect the net impacts to the community. The aim of this study is to investigate whether alternative assumptions are valid from differing perspectives, when toll roads are delivered and operated privately rather than by a host government. Treatments of tolls and toll road project related payments are considered from different perspectives. CBA is conducted for a synthesised toll tunnel project case by considering alternating treatments of some impacts. This leads to the exploration of CBA outcomes when the treatment of tolls differ when two perspectives of “toll as a transfer payment” (TTP) and “toll as an end user cost” (TUC) are considered. A toll tunnel project case was synthesised on the basis of the overarching characteristics of recent Australian toll tunnel projects. The Monte Carlo simulation approach is used to allow the risks of various variables to be accounted in the CBA.

There are disagreements and obscurity in the treatment of tolls in CBA. Along with various concession payments, the treatment of tolls are investigated in this study. Additionally, it is important to distinguish CBA for public decision making from financial analysis. A number of studies have considered perspectives in financial analysis, however studying the considerations of perspectives in CBA for public decision making is limited. This study widens the knowledge by conducting CBA for a toll road project, while considering perspectives in the analysis.

This paper first reviews relevant literature and presents the study methodology. It then develops models for CBA calculations. Finally, CBA results, discussions and conclusions are drawn.

Literature Review

Governments are responsible for public decision-making for the good of their constituents. This includes ensuring that public funds are invested wisely and that regulation of private sector activity ensures a net benefit to society. Public decision-making about infrastructure investment is based on the net impacts measured by the host government through project evaluation. Project evaluation is a quantitative process conducted for significant projects to evaluate net impacts to the community and to ensure that public decisions are made in kind.

Cost-Benefit Analysis (CBA) is the most commonly used project evaluation methodology for major road projects (Wee & Rietveld, 2014) and is well-established in literature (Boardman, Greenberg, Vining, & Weimer, 2014; De Rus, 2010). CBA measures the net impacts of a project by monetising and allocating the impacts to benefits and costs (Rogers & Duffy, 2012; Wee & Rietveld, 2014). Broad perspectives including road users and non-road users can be included in CBA (Decorla-Souza, Lee, Timothy, & Mayer, 2013). The outcome of CBA is generally presented using Benefit-Cost Ratio (BCR), which is a representation of a ratio of the monetised benefits to monetised costs. Additionally, the scope of the CBA is limited to economic impacts to the community. The analysis becomes extremely difficult when the scope includes the economic impacts to the whole of state or a country (Australian Transport and Infrastructure Council, 2016b). Currently, the Australian guideline to include wider economic benefits in CBA is in development and Australian Transport and Infrastructure Council advises to exclude the wider economic impacts from CBA (Australian Transport and Infrastructure Council, 2016a). Taxes including income tax revenues from the labor markets and income tax of a privately toll operator are considered as part of the wider economic benefits and it is beyond the scope of this study to include those impacts.

The fundamental difference between public CBA and financial analysis is that the former focuses on impacts to the community. For instance, monetised travel time impacts and travel distance impacts, which are not captured in financial analysis, are considered in the public CBA of a major road project. It is beyond the scope of this study to address financial impacts and risks of a project as this study solely focuses on the impacts and risks to the community using CBA. Consideration of perspectives has been given to investigate financial viability of a project in a number of studies (Mishra, Khasnabis, & Swain, 2013; Pantelias & Zhang, 2010), however they have not been studied for public CBA. Zhang, Bai, Labi and Sinha (2013) found in their financial analysis that the host government is unlikely to gain sufficient benefits from toll road projects unless traffic growth and toll prices are sufficient to provide financial benefit that is equivalent to an upfront capital cost contribution. This study extends this knowledge by widening the scope of the evaluation to the benefits with regard to impacts to the community using public CBA. By using public CBA, various benefits to the community including a number of transport benefits such as travel time saving can be considered in the evaluation.

The private sector can often be involved in a toll road project to design, build, operate, finance and transfer the project. These Public-Private Partnership (PPP) arrangements are commonly referred to in the literature as design-build-finance-operate (DBFO) or build-operate-transfer (BOT) schemes. Involvements of the private sectors raise questions of whether tolls should be considered as a financial transfer. Particularly compelling is when the private operator collects tolls. Toll revenues are generally only included in public CBA by affecting travel behaviours and efficiencies in the transport system (Decorla-Souza et al., 2013). In

Boardman, Vining and Waters's study (1993), toll revenues have been included as benefits to the community in CBA. The guidance on the treatment of tolls in CBA in extant guidelines (Australian Transport and Infrastructure Council, 2016b; Queensland Department of Transport and Main Roads, 2011; Rockliffe, Patrick, & Tsolakis, 2012) is limited. For instance, Queensland CBA manual (Queensland Department of Transport and Main Roads, 2011) advises to only include tolls as one of the factors that influence road demands. These indicate that there are disagreements and obscurity in the treatment of tolls in public CBA.

A number of authors have investigated the traffic forecasting of toll roads and its accuracy. Traffic forecasts play key roles in many studies of toll road projects, because the traffic volume drives the outcomes of both economic and financial assessments. Many studies (Australian Department of Infrastructure and Transport, 2011; Bain, 2009; J M Vassallo & Baeza, 2007) have reported overestimations in toll road traffic forecasts. Rose and Hensher (2014) claim that misestimating value of travel time is the main contributor of errors in traffic forecasting of toll roads.

Toll pricing strategies are well discussed in the literature. A number of strategies exist in toll pricing, such as maximising travel time reliability (Tirachini, Hensher, & Bliemer, 2014), and maximising toll revenue (Joksimovic, Bliemer, & Bovy, 2005). Beck and Hensher (2015) highlighted that a well-designed toll pricing scheme can provide demonstrable time savings in the peak time. Hensher and Bliemer (2014) suggested that to ensure sufficient toll revenues to the host government, registration charges need to be reduced and the distance-based peak time pricing need to be implemented .

Traffic forecasting of toll roads, toll pricing and estimations of value of time largely influence the performance and the level of service of a toll road. However, this study solely focuses on the two perspectives of "toll as a transfer payment" (TTP) and "toll as an end user cost" (TUC) and alternative treatments of tolls and other payments specific to toll road projects in CBA. Traffic modelling that incorporates tolls, and estimations of project costs, effective toll prices, value of time and the appropriate discount rate are beyond the scope of this study.

Table 2 summarises recent literature of public evaluations of toll road projects. Toll road projects have been evaluated in numerous articles, however many focus on traffic and revenue forecasting (Bain, 2009; Li & Hensher, 2010; Welde, 2011), while there is limited study in the literature regarding public CBA for toll road projects.

TABLE 1 Evaluation of toll road projects found in academic literature

[Insert Table 1 here]

Methodology

Examining differing perspectives and model development

Relevant literature including the role of governments in project evaluation and Cost-Benefit Analysis (CBA) are reviewed. Two perspectives of "toll as a transfer payment" (TTP) and "toll as an end user cost" (TUC) are drawn from the findings of literature review. On the basis of these perspectives, the treatments of tolls and other payments that are often used in toll road projects are examined. These payments are examined by observing their flows between various entities such as road users, non-road users, the host government and the private operator. Models of each payment are then developed to reflect these flows. The synthesised case is evaluated using the stochastic CBA and the developed models. Examining the risk profiles of different payment scenarios reveal how shifts of risks can be portrayed in the stochastic CBA. This also determines the treatments of project impacts that best reflect the risk characteristics of a toll road project across scenarios.

Figure 1 presents the methodology of the evaluation of the synthesised toll tunnel project case. It consists of three phases, which are explained in the following section.

[Insert Figure 1 here]

FIGURE 1 Methodology of the stochastic CBA of the synthesised toll tunnel project case

1) Identifying Concession Payments and Costs

The concession payments and costs that are involved in a toll road project need to be first identified. The flows of these payments and costs can then be examined to identify the entity that is responsible for each payment and cost. Costs that the host government and its constituents are responsible for can be determined on the basis of the payment flows. The costs that can be considered as financial transfers would be excluded in this process. Total costs in stochastic forms can be developed using Monte Carlo simulation. Meanwhile, models can be developed for each payment and cost.

2) Estimation of benefits

Input variables of benefits considered in public CBA such as vehicle hours travelled saving (VHTS) need to be determined based on the characteristics of the toll road. Each benefit in a stochastic form can then be developed on the basis of probability distribution forms of input variables using Monte Carlo simulation. The benefits that are generally considered in public CBA of a major road project include travel time saving, vehicle operating cost saving, crash cost saving, environmental and external cost saving, and residual value.

3) Evaluation and decision-making

The stochastic Benefit-Cost Ratio (BCR) distribution can be developed based on the stochastic costs and benefits. The outcome BCR distributions represent the net impacts and risks of the project. Moreover, risk profiles can be developed for the toll road project on the basis of the stochasticity of the outcome BCR distributions.

Monte Carlo Simulation

For the purpose of public CBA, this study presumes that each input variable was undertaken before the end of construction of the toll road. Therefore, risks exist in the variables that are determined from traffic modelling and estimations of project related costs. These variables include annual average daily traffic (AADT), traffic growth, vehicle hours travelled saving

(VHTS), vehicle kilometres travelled saving (VKTS), proportion of heavy vehicles (HV%), capital cost, and O&M cost. The risks of these variables are accounted in CBA using the Monte Carlo approach in this study. For each variable, the form of probability distribution, mean, and coefficient of variation (CV) are defined based on the project characteristics of the synthesised case and inference from a range of literature. Deterministic values of planning horizon and discount rate are incorporated in this study. This study presumes that operation and maintenance (O&M) cost to be ten percent of the whole capital cost, hence O&M cost is stochastic when capital cost is stochastic.

Monte Carlo simulation is a well-established risk analysis tool. Mun (2010) explains the fundamental underpinning of the Monte Carlo simulation methodology in great detail. Monte Carlo simulation has been incorporated in a number of literature studying financial analysis and decision making of public investment (De Rus, 2010; Glasserman, 2003; Lemp & Kockelman, 2009; Mishra, Khasnabis, & Dhingra, 2013; Mishra, Khasnabis, & Swain, 2015). Lemp and Kockleman (2009) argue that Monte Carlo simulation is an effective tool to understand the risk of a project, however also claim that Monte Carlo simulation require more computing time than sensitivity analysis.

Monte Carlo simulation can be used to produce a stochastic Benefit-Cost Ratio (BCR) set on the basis of a sufficiently large number of trials, and hence a comprehensive risk profile of the project on the basis of various combinations of input impacts. In this study, with each trial, the value of each variable was simulated by a Monte Carlo draw from its predefined probability distribution with predefined mean and CV. When 100,000 trials are conducted, a set of 100,000 BCR values will be obtained to ensure a sufficiently representative variation in output. This set represents the outcome stochastic BCR distribution for the project of interest.

Risk Profiling of the Synthesised Project

The BCR distribution that was generated using CBA and Monte Carlo simulation can be analysed using various statistical inferences. The interpretations of various measurements provide a comprehensive representation of the risk of a project. Table 2 shows the statistical inferences that were used in this study, which are particularly useful for comparisons of different scenarios or methodologies. For instance, CV of the outcome BCR distribution can be compared with the predefined CVs of input variables to assess how the risk of each input variable impacts the risk of the outcome BCR.

TABLE 2 Measures of risk profiles and their interpretations

[Insert Table 2 here]

Studying the Synthesised Toll Tunnel Project Case

This study considers a toll tunnel project instead of a toll road project due to the considerable scale of its construction cost. Economic justification of a tunnel project is therefore particularly crucial in project evaluation. A toll tunnel project case is synthesised to demonstrate a stochastic approach to project evaluation on the basis of overarching characteristics of existing toll road projects. The purpose behind studying the synthesised case is so that its project characteristics could be adjusted in a controlled manner to examine various risk scenarios.

Examining Perspectives

Research Hypothesis

Traditionally, when public CBA is used to evaluate toll projects, tolls have been assumed to be, and therefore treated as financial transfers and not counted as societal costs; instead the capital cost and O&M cost are those which are treated as the societal cost impacts. As Decorla-Souza (2013) claimed, toll revenues are generally only included in public CBA by affecting travel behaviours and efficiencies in the transport system. This is rational when the host government obtains the toll revenues, because the end users who pay those tolls are constituents of the host government and therefore enjoy the benefit of that toll revenue through government expenditure, including repayment of project debt. However, depending on the perspective taken within decision-making, the influences of each impact need to be considered carefully in public CBA, especially when the private sector is involved in the project. This is particularly so for cost impacts that are borne by the private sector.

If one takes the perspective that the private operator is an element of an overall economy that bears the costs and reaps the benefits of a project, then the assumption of the toll as a transfer payment is appropriate. However, for public sector decision-making, an alternative perspective can be that the host government, as the decision-maker on behalf of the community, should consider how the end users bear the cost and reap the benefits of a project. Under such an assumption, cost impacts are considered to be recouped in a commercial environment by a private operator charging tolls to the end users, who in the case of a toll road are normally the host government's constituents. Therefore, from this perspective, those end user toll charges should be counted as the societal cost impacts in public CBA. Furthermore, it is reasonable to contend that any capital and/or O&M costs that are borne by the private operator should be excluded from the public CBA, because they are financial impositions that are contained within the private operator's enterprise of offering services to consumers, rather than as an end user societal cost. The effect of this perspective is that the private operator is sequestered from the overall economy, such that the host government can evaluate the project independent of the private operator's financial interests. Notwithstanding, these considerations become more entangled when a toll road project is delivered in some form of Public-Private Partnership (PPP).

The principal rationale of the "toll as an end user cost" (TUC) perspective is that it may enable the public decision-maker to understand how the risk profile to the end user community as expressed by the public CBA might differ from that of the risk profile among the overall economy, including the toll operator, under the "toll as a transfer payment" (TTP) perspective.

The remainder of this chapter uses a case study approach to examine the extent to which public CBA results vary between these two perspectives.

Consideration of Cost Formats of Toll Road Projects

Commonly for a toll road project, concession deeds may include various risk sharing arrangements. For instance, a minimum revenue guarantee arrangement enables the private operator to mitigate its traffic uncertainty risk with its financial obligations, through a mechanism where the host government effectively acts as a guarantor should revenue fall short of the private operator's required debt repayment during a period. Alternatively, the host government may permit the private operator to charge a higher toll price in order to balance its traffic uncertainty risk with its financial obligation of debt repayment. Additionally, an upfront capital cost contribution may be paid by the host government to support the start-up of the project; the amount depending upon its budgetary and political priorities. These arrangements are forms of risk management strategy and need to be considered carefully in project evaluation. Therefore, the public CBA for toll road projects needs to appropriately account for these impacts and their risks.

Figure 2 summarises the payment flow when a toll road project is fully delivered by the host government. The thick line shows the payment that is considered in this study under this scenario. When the host government is designing, building, financing and operating the toll road, including through traditional methods of purchasing from the private sector, they are responsible for capital cost and O&M cost, while the road users, who are its constituents, are paying for tolls. In this scenario, the tolls and any imposed consumption taxation can be considered as a financial transfer between the public toll operator and the users. Moreover, a part of the tolls paid by commercial vehicles can be considered as financial transfers as they are paid back by the end users. However, these are considered as part of the wider economic impacts and not considered in this study, as with other wider economic impacts that are generally excluded from the public CBA of major road projects.

[Insert Figure 2 here]

FIGURE 2 Payment flow of when toll roads are delivered and operated by the host government from the "toll as a transfer payment" (TTP) perspective

Figure 3 summarises the payment flow when a toll road is fully designed, built, financed and operated by a private sector entity or entities. The thick lines show the payments that are considered in this study under this scenario. For purposes of this study, the private sector entities are collectively termed as the private operator. The host government may be responsible for an upfront capital cost contribution and minimum revenue guarantee if included in the concession deed. The private operator is responsible for the balance of capital cost and O&M cost, while collecting tolls and receiving any minimum revenue guarantee payments from the host government. In this scenario, tolls are hypothesised to no longer be a financial transfer under the TUC perspective, because the sum of upfront capital cost contribution and the guarantee would not be equivalent to the capital and O&M costs. Hence, costs to the community that need to be accounted in public CBA in this scenario are the upfront capital cost contribution, any minimum revenue guarantees, and the tolls paid as end users net of any imposed consumption taxation.

[Insert Figure 3 here]

FIGURE 3 Payment flow of when toll roads are delivered and operated privately from the "toll as an end user cost" (TUC) perspective

As introduced in the discussion above, another scenario that could apply to a toll road is that when the private operator charges a premium toll price instead of receiving a minimum revenue guarantee from the host government. In this scenario, the premium tolls paid by the users replaces the minimum revenue guarantee in public CBA. This is summarised in Figure 4. The thick lines show the payments that are considered in this study under this scenario.

[Insert Figure 4 here]

FIGURE 4 Payment flow of when the private operator charges premium tolls from the TUC perspective

Moreover, a number of other risk sharing arrangements can be found with toll road projects, which for brevity are not dealt with in this study. The impacts of the arrangements need to be considered carefully for each project to determine whether they need to be counted as costs to the community in public CBA.

Perspectives Considered for this Study

As has been previously discussed, a toll road project can be delivered under various schemes. Two perspectives are examined in this study that consider all of the scenarios that were previously discussed and highlight the difference in terms of payment flows between the host government and the private operator. The first is the TTP perspective whereby the toll road project is fully delivered and operated by the host government at a baseline toll price, therefore the total cost to the community is the sum of capital cost and O&M cost. Then, three scenarios of the TUC perspective are considered. The first scenario is a “baseline toll with no guarantee” (BNG), whereby the private operator receives no minimum revenue guarantees and charges users the baseline toll price, which is further detailed in later section. The second scenario is a “baseline toll with minimum revenue guarantee” (BRG), whereby the private operator charges users the baseline toll price, however receives a minimum revenue guarantee from the host government where necessary in a given period. The third scenario is a “premium toll with no guarantee” (PNG), whereby the private operator charges a higher toll price than baseline, instead of receiving the minimum revenue guarantee. Table 3 summarises the costs considered in CBA across the perspectives and scenarios.

TABLE 3 Costs to the community that are considered in CBA for this study

[Insert Table 3 here]

Model Development

Traffic Volume and Growth

For purposes of clarity of the synthesised case study, traffic volume is calculated yearly based on the initial annual average daily traffic (AADT) and traffic growth rate. The traffic growth rate is presumed to be constant over the whole planning horizon. The AADT at year y for Monte Carlo trial j is given as follows:

$$AADT_{y,j} = AADT_{i,j} \times \left(1 + g_j\right)^{(y-1)} \tag{1}$$

Where:

$AADT_{i,j}$ = initial average annual daily traffic for Monte Carlo trial j (veh)

g_j = traffic growth rate for Monte Carlo trial j (%)

y = corresponding year, $y \in (0, 1, \ldots, n)$

It is noted that this synthesised case study does not expressly consider a ramp-up period, which often occurs post opening of a toll road. During the ramp-up period, the traffic growth rate can be different from, and typically less than, the annual growth rate as the road matures as a component of the greater road network. However, a ramp-up period may also be readily incorporated in future research.

Baseline Toll Price

The baseline toll price is determined on the basis of the expected traffic volume, while the project cost contains risks as the baseline toll price is determined before the completion of the construction. This study presumes that this baseline toll price would be incorporated into traffic modelling to estimate AADT, traffic growth, VHTS, VKTS and HV%, therefore the risks of these variables are not accounted in the baseline toll price model.

The baseline toll price is that which equates the sum of the net capital cost after upfront capital cost contribution is deducted and the operating and maintenance (O&M) cost, to the expected value of all collected tolls when brought to net present value. It is important to note that this is not a financial analysis and does not ensure that the private operator will recover its cost and yield a profit during the planning horizon. Rather, it is that particular toll price which, under the expected opening year AADT and the expected traffic growth rate, would yield the same project cost to the community as a public road with the same total capital plus O&M cost. That is, under the "toll as an end user cost" (TUC) perspective, the present value of its expected cost would the same as that under the "toll as a transfer payment" (TTP) perspective. It is a starting point for consideration of various payments considered in the scenarios, which are detailed later. The baseline toll price is calculated as follows:

$$\sum_{y=1}^{n}\left[TP_{base,j}\times AADT_{y,exp}\times 365\times(1+d)^{(1-y)}\right] = \left(Cap_j + O\&M_j - UP\right) \tag{2}$$

$$TP_{base,j} = \frac{\left(Cap_j + O\&M_j - UP\right)}{\sum_{y=1}^{n}\left[AADT_{y,exp}\times 365\times(1+d)^{(1-y)}\right]} \tag{3}$$

$$TP_{base} = \frac{\sum_{j=1}^{l}\left(TP_{base,j}\right)}{l} \tag{4}$$

Where:

n = number of years in planning horizon

$TP_{base,j}$ = baseline toll price for Monte Carlo trial j ($)

$AADT_{y,exp}$ = expected AADT with expected traffic growth at year y (veh)

d = discount rate applicable to the project format (%)

Cap_j = total capital cost in present value for Monte Carlo trial j ($)

$O\&M_j$= total O&M cost over the whole planning horizon for Monte Carlo trial j as a present year cost ($)

UP = upfront payment to capital cost ($)

l = number of Monte Carlo trials

When the host government contributes a set upfront capital cost contribution towards the gross capital cost, the risk of capital cost is borne by the private operator through the net capital cost that it contributes after the upfront capital cost contribution is deducted. This study presumes the upfront capital cost contribution to be deterministic. Notwithstanding, the public CBA presented here could be modified to allow for a variable upfront capital cost contribution to be made by the host government.

Minimum Revenue Guarantee

For purposes of this synthesised case study, the minimum revenue guarantee is defined as a payment paid by the host government to the private operator in any year of the planning horizon, when the toll revenue of that year is less than the payment which is required of the private operator to meet its obligations to its financier, which for illustrative purposes of this study are limited to its principal plus interest repayments. The following annual finance repayment by the private operator for Monte Carlo trial j is assumed:

$$P_{annual,j} = \frac{r\left(Cap_j + O\&M_j - UP\right)}{1 - (1 + r)^{-n}} \tag{5}$$

Where:

r = financier's interest rate on the private entity's loan (%)

Under the minimum revenue guarantee scenario, any necessary amount of guarantee payment is calculated uniquely for each period (year) of a Monte Carlo trial of traffic volume to incorporate the risk of the guarantee payment and the traffic uncertainty risk in its CBA. This allows the development of a stochastic distribution of the guarantee payment. The guarantee payment at year y for Monte Carlo trial j is given as follows:

$$G_{y,j} = min\begin{cases}\left(AADT_{y,j}\times 365\times TP_{base}\right) - \dfrac{P_{annual,j}}{(1+i)^{(y-1)}} \\ 0\end{cases} \quad (6)$$

Where:

i = annual rate of inflation in the economy (%)

Under the minimum revenue guarantee scenario, the baseline toll price is not necessarily that which the private operator would wish to charge, or which the host government would want it to charge. Rather, it is an optimal toll price under the assumptions of this study for the purposes of CBA. Sensitivity analysis could readily be performed on the impact of different baseline toll prices on the stochastic Benefit-Cost Ratio (BCR) distribution.

Premium Toll

The premium toll price is defined in this study as that which the host government permits the private operator to charge, such that it is expected to earn sufficient revenue that a minimum revenue guarantee by the host government is not warranted during any year of the planning horizon, irrespective of traffic uncertainty risk. In this scenario, stochastically simulated traffic volumes of each Monte Carlo trial that were produced under the minimum revenue guarantee scenario are unknown, as evaluation of these two scenarios are conducted independently. Although, the expected guarantee payment amount is known, because this can easily be estimated before the completion of construction of the road. A number of approaches exist to estimate the expected guarantee payment. For purposes of this study, the expected of the stochastic guarantee payment distribution that was developed under the minimum revenue guarantee scenario was implemented as the expected guarantee payment. The price of premium toll is therefore determined on the basis of the expected guarantee payment amount, while incorporating the traffic uncertainty risk.

It is first necessary to calculate the premium toll coefficient. This is the ratio of the cost that is borne by both the host government and the private operator, to that which is borne by the private operator alone, under the minimum revenue guarantee scenario. The premium toll coefficient for Monte Carlo trial j is given as follows:

$$R_j = \frac{TP_{base}\sum_{y=1}^{n}\left[AADT_{y,j}\times 365\times(1+d)^{(1-y)}\right] + \sum_{y=1}^{n}\left[G_{y,exp}\times(1+d)^{(1-y)}\right]}{TP_{base}\sum_{y=1}^{n}\left[AADT_{y,j}\times 365\times(1+d)^{(1-y)}\right]} \quad (7)$$

Where:

$G_{y,exp}$ = expected guarantee payment at year y in present value ($)

Using this premium toll coefficient, the premium toll price for Monte Carlo trial j that would compensate for the absence of minimum revenue guarantee, is therefore given as follows:

$$TP_{p,j} = TP_{base}\times R_j \quad (8)$$

Literature (Poole, 2011) has identified that toll price may influence traffic volume and growth, as some users may avoid the toll road as toll price increases. For clarity, this study does not address this micro-economic behaviour, however elasticity between toll price and traffic volume may also be considered in future research.

Further, the premium toll is not necessarily that which the private operator would wish to charge, or which the host government would regulate as a cap. Rather, it is an optimal toll price that raises an equal revenue to when the baseline toll is collected and the minimum revenue guarantee is paid, under the assumptions of this study, for the purposes of public CBA. Sensitivity analysis could also readily be performed on the impact of different toll prices on the stochastic BCR distribution.

Synthesising a Toll Tunnel Project Case

The overarching characteristics of recently built toll tunnel projects in Australia were incorporated to synthesise a toll tunnel project case for the purpose of demonstrating the analysis of risks within public CBA. The project parameters that are needed to conduct CBA for this type of major road project include; capital cost, AAD), traffic growth, HV%, VKTS, VHTS, various transport costs, O&M cost, planning horizon and discount rate. Table 4 presents these values for the Australian recent urban toll tunnel facilities of Legacy Way, Clem Jones Tunnel and Airport Link. The amount of capital cost depends on the size and the type of the infrastructure. For instance, the construction cost of a tunnel project is usually relatively high. The capital cost of Airport Link was significantly high, given the fact that its construction was combined with two other projects, the Northern Busway and the Airport Roundabout Upgrade (BrisConnections, 2011).

TABLE 4 Characteristics of Australian toll tunnels

[Insert Table 4 here]

Table 5 summarises the assumptions that were made in order to conduct public CBA of the synthesised case. According to Australian Bureau of Infrastructure Transport and Regional Economics (2012), traffic in Queensland, Australia was estimated to grow by 2.8 percent annually until 2020. In Queensland, Australia, the discount rate that was used to evaluate major road projects varies between 6.0 and 7.6 percent (Connell Wagner, 2004; GHD, 2013; Queensland Government, 2008; SKM & Connell Wagner, 2006, 2008). Therefore, the discount rate of 7.0 percent was used in this study. All prices were converted to 2015 Australian dollar values using the Reserve Bank of Australia's method (Reserve Bank of Australia, 2017).

TABLE 5 Assumptions made in public CBA calculation of the synthesised toll tunnel project case

[Insert Table 5 here]

Probability Distributions Used in this Study

The Monte Carlo simulation requires a careful selection of the form of probability distribution chosen for each impact, along with nuanced postulation of the distribution parameters. The distribution for an input variable must be selected with sound reasoning. Investigating the impacts of applying alternative forms of probability distribution by variable is beyond the scope of this study. Salling (2008) further discusses the use of various probability distributions. CV needs to be carefully defined as it is a measure of the level of risk in the variable. The magnitude of risks of various variables have been reviewed previously (Salling & Leleur, 2011) so are not readdressed here. It is important to note that CV does not indicate the variety of the variable. For instance, the CV of VHTS does not reflect how VHTS may vary between peak-time and off-peak time. The mean needs to be carefully defined as it indicates the expected value. The characteristics, including the form of probability distribution, its mean and CV, predefine the risk profile of each variable. Therefore, the risk profiles of input variables are inherent within the risk profile of the outcome Benefit-Cost Ratio (BCR) distribution.

Capital Cost of a Toll Road Project

It is reasonable that a threshold capital cost exists, below which a project's development would not be possible, but that higher cost is plausible due to risks. For this purpose the Cowan's M3 distribution (Cowan, 1975) was applied. This dichotomised distribution contains a set proportion of values equal to the minimum, and the remaining proportion distributed negative-exponentially. It has been incorporated previously in various transport applications (Bunker & Troutbeck, 2003; Troutbeck, 1992). Capital cost can be modelled using the Cowan's M3 distribution in cumulative form by:

$$F(Cap_j) = \begin{cases} 1 - \phi e^{-\frac{\phi(Cap_j - Cap_{min})}{(Cap_{av} - Cap_{min})}} & Cap_j > Cap_{min} \\ 1 - \phi & Cap_j = Cap_{min} \\ 0 & Cap_j < Cap_{min} \end{cases} \quad (9)$$

Where:

Cap_j = capital cost in present value for trial j ($)

ϕ = probability that capital cost exceeds Cap_{min} (%)

Cap_{min} = minimum feasible capital cost ($)

Cap_{av} = expected capital cost ($)

Case Dependent Input Variables

There is a scarcity with regard to identifying the forms of probability distributions of various traffic modelling outputs. In the Salling and Leleur's methodology (2011), a probability distribution was applied to travel time saving as a whole and each risk of input variables needed to determine the travel time saving was not modelled in their study. For the purpose of this study, the normal distribution and the CV of 10 percent were applied to those input variables, because the normal distribution can be used to describe uncertain variables (Mun, 2010). Table 6 summarises the characteristics of the probability distributions used for AADT, yearly traffic growth rate, HV%, VKTS and VHTS in this study.

Table 6 Probability distribution forms and CV of the case depend input variables

[Insert Table 6 here]

Results

Evaluation of and Decision-Making for the Synthesised Tunnel Project

Table 7 summarises the calculation of deterministic impacts of the synthesised case when all variables were equal to the expected values of their stochastic distributions. The impact that most contributed to the overall benefit was the travel time saving, which are impacted by the risks of AADT, traffic growth, travel time unit price and VHTS.

TABLE 7 Impacts of the synthesised toll tunnel case when all variables were deterministically equal to their expected values in present value

[Insert Table 7 here]

Table 8 summarises the risk profiles of the synthesised case. The perspectives of “toll as a transfer payment” (TTP) and “toll as an end user cost” (TUC), and the scenarios of “baseline toll with no guarantee” (BNG), “baseline toll with minimum revenue guarantee” (BRG) and “premium toll with no guarantee” (PNG) were considered. All perspectives and scenarios showed similar results of the expected BCR between 1.06 and 1.03. This similarity can be explained by the assumptions used in the model development in this study. The outcome BCR may differ when different assumptions are applied. The expected and medians of BCR across perspectives and scenarios showed great similarities, which indicate that sufficient Monte Carlo trials were conducted for each scenario. The TTP perspective showed the highest CV and the scenario BNG showed the highest probability of BCR being greater than 1.0.

TABLE 8 Risk profiles of the synthesised toll tunnel project case across perspectives and scenarios

[Insert Table 8 here]

Figure 5 shows the cumulative stochastic BCR distributions of the synthesised case. The cumulative graph clearly illustrates the wider spread in the BCR distribution under the TTP perspective.

[Insert Figure 5 here]

FIGURE 5 Cumulative stochastic BCR distributions of the synthesised toll tunnel project case

Figure 6 shows box and whisker plots of the stochastic BCR distributions of the synthesised case. The 9th and 91st percentiles were used as the minimum and the maximum of the whiskers to effectively highlight the characteristics of each distributions.

[Insert Figure 6 here]

FIGURE 6 Box and whisker plots of stochastic BCR distributions of the synthesised toll tunnel project case

Examination of Perspectives

Comparison of the perspectives of TTP and TUC under the scenario BNG reveals nearly identical expected values of BCR. However, from the perspective of the TUC, the CV is noticeably lower. This is also evident in Figure 5 and Figure 6. This indicates that by sequestering the toll operator from the overall economy, there is less volatility in BCR, and therefore less risk borne by the remainder of the community. It follows that the risk represented by the difference in CV is borne by the toll operator.

Comparison of the perspectives of TTP and TUC under the scenario BRG reveals a slightly lower expected value of BCR. This is because of the additional payments made by the host government to guarantee the minimum revenue. Again, from the perspective of the TUC, the CV is noticeably lower. This is also evident in Figure 5 and Figure 6. This indicates that by sequestering the toll operator from the overall economy, there is less volatility in BCR, and therefore less risk borne by the remainder of the community. While it follows that the risk represented by the difference in CV is borne by the toll operator, the minimum revenue guarantee payments to some extent mitigate the toll operator's risk. On the other hand, the reduction in the expected BCR indicates that the project is less attractive to the remainder of the community than if there were no minimum revenue guarantee.

Comparison of the perspectives of TTP and TUC under the scenario PNG also reveals a slightly lower expected value of BCR. This is also because of the higher tolls paid by the end users. Again, from the perspective of the TUC, the CV is noticeably lower. This is also evident in Figure 5 and Figure 6. This indicates that by sequestering the toll operator from the overall economy, there is less volatility in BCR, and therefore less risk borne by the remainder of the community. While it follows that the risk represented by the difference in CV is borne by the toll operator, the premium toll to some extent mitigate the toll operator's risk. On the other hand, the reduction in the expected BCR indicates that the project is less attractive to the remainder of the community than if there were no premium toll.

Discussion

The results suggested that treating tolls as an end user cost in public CBA of a privately operated toll road project is a reasonable and valid approach under the TUC perspective. Notwithstanding, the treatment of other payments of the toll road project need to be considered carefully.

As previously discussed, the risk profile developed in this study does not represent financial viability and financial risks of the project. It is important to distinguish public CBA and financial analysis, and to note that BCR does not represent the risk of the project. The expected BCR indicate the net impacts to the community and CV indicates the quantified net risks to the community. The box and whisker plots effectively represented the outcome of the analysis. For instance, the shorter boxes and whiskers indicate less risks associated and higher positioned boxes indicate higher net impacts.

When a toll road project is fully delivered by the host government, the public is bearing the whole project risk. In contrast, when a toll road project is designed, built, operated and/or financed by a private operator, some risk that is borne by the host government is shifted to the private operator. When evaluating a toll road project with respect to a public good, the impacts and their risks that are borne by the host government on behalf of its constituents should be considered in the evaluation. In this regard, the risk that is borne by the private operator can effectively be sequestered from the evaluation under the TUC perspective. Therefore, the evaluation of a privately operated toll road project can reflect this shift of the risk between the host government and the private operator under the TUC perspective. Risk profiles of TTP and TUC perspectives appropriately reflected the shift of risk in two scenarios. CV was lowered in the TUC risk profile, which indicates the shift of the risk.

Due to the assumptions applied in the models used in this study, the risk profiles of three scenarios of TUC perspective did not show significant variations with respect to the risk. Applications of various assumptions in order to model toll road project specific payments would further extend the knowledge in terms of how the risk varies with each assumption.

The synthesised case was found to benefit the community between 57% and 61% of trials, depending on perspectives and scenarios. The decision-maker may consider it risky to proceed due to the risk that is quantified by the CV in BCR, and the reasonably high probability of BCR being less than 1.0.

The calculated baseline toll price for this synthesised case was $ 4.89. This is slightly lower than the car toll prices of existing toll roads and toll tunnels in Australia, Clem Jones Tunnel and Legacy Way, which are $ 4.93 to $ 4.94 including goods and services tax (Australian Department of Infrastructure and Regional Development, 2013). This difference can be explained by the difference between the theoretical assumptions and the higher complexities of the real toll roads.

Conclusion

This study examined alternative treatments of tolls and other toll road project related payments in public Cost-Benefit Analysis (CBA) for a privately operated toll road project when two perspectives of “toll as a financial transfer” (TTP) and “toll as an end user cost” (TUC) were considered. The synthesised toll tunnel project case was evaluated using CBA across various scenarios. In those scenarios, various payments were considered and their treatments were explored under the two perspectives. The risk of the synthesised case was quantified by incorporating the Monte Carlo simulation approach.

Many past studies evaluated toll road projects from different points of view other than public CBA. Various studies exist with regard to financial analysis and traffic forecasting studies of toll road projects. In comparison, public CBA evaluates a project with respect to transport benefits and costs. This allows to assess whether the project is beneficial to the community, instead of evaluating projects solely based on financial impacts. This study extended the knowledge of evaluation of a toll road project by considering transport impacts using CBA.

Considering TTP and TUC perspectives in public CBA has not been studied, although different perspectives have been examined in financial analysis in a number of previous studies. Treatments of some project impacts in public CBA were altered by considering these perspectives in this study. This allowed to explore whether the TUC perspective is a valid approach. The outcomes of the evaluation confirmed that the shift of risk of a privately delivered project can be observed using the proposed methodology under the TUC perspective. How public CBA can be conducted by solely evaluating the project from the public perspective was examined by considering the TTP and TUC perspectives. This is a significant contribution to the academic study, which can suggest a number of future studies on incorporating different perspectives into CBA of various infrastructure types.

This study found that by incorporating stochastic approach into public CBA of a toll road project, the shift of risk can be analysed empirically, which demonstrated applications of the stochastic CBA. This study also examined the effectiveness of various measures to evaluate toll road projects. Coefficient of variation (CV) was found to be an effective measure of risk of projects with any Benefit-Cost Ratio (BCR). Percentiles and cumulative probability distribution graphs can also represent the spread of the outcome stochastic BCR, while CV quantifies the level of risk in an empirical manner, which can easily be compared across scenarios.

The assumptions used in this study to develop the models of the toll road project related payments can differ between projects in practice. One of the key contributions of the methodology presented in this study is that it can incorporate various strategies and approaches to model the payments. Additionally, the risks of input variables including traffic forecasts and toll price can be quantified in the methodology. These risks tend to reduce towards the opening of the toll road. As has been previously discussed, the risk that is borne by the host government varies between projects. These changes and shifts of risks can also be quantified using the methodology. The quantified risk is one of the key pieces of information that assists in decision-making for a major project. The contributions of this study are not limited to academic contributions but also to provide a useful evaluation tool that can readily be used in practice.

Additionally, this study demonstrated graphical representations of the net impacts and risks of the project using cumulative probability distributions, and box and whisker plots. Visually representing the analysis outcome is particularly useful for the decision-maker. For instance, the length and the position of each box in a box and whisker plot represents the net impacts and risks of the project across various scenarios. The decision-makers can efficiently make a well-informed decision without having to have to read and interpret numerously represented outcomes when the outcomes are represented visually.

The risk of discount rate was not considered in this study. Discount rate depends on the risk shared between public and private sectors for any Public-Private and Partnership (PPP) projects. This is because the systematic risk premium is adjusted to reflect the proportion of risks that the public sector is bearing (Australian Department of Infrastructure and Regional

Development, 2013). The impact of the risk of discount rate can be explored in the future study. Detailed case studies of existing toll road projects can also be conducted to further explore the impacts of the ramp-up period, discount rates and various payment arrangements.

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Tables

TABLE 1 Evaluation of toll road projects found in academic literature

Author	Study purpose	Item evaluated
Aldrete, Bujanda and Valdez (2012)	The study evaluated public revenue financial risk exposure when transport infrastructure is delivered through PPP.	Revenue risk exposure
Anas and Lindsey (2011)	The study reviewed urban road pricing theory on the basis of a toll road project.	Benefits and costs, public transport, public acceptance
Bain (2009)	The study reported the results from the study of toll road forecasting performance.	Traffic forecasts
Bel and Foote (2009)	The study explored the implications with respect to the public interest.	Impacts of toll road concessions on the public interest
Carpintero (2010)	The study examined the gap between the expected outcomes and the actual results of toll roads.	Traffic forecasts, contract management, government’s role
Li and Hensher (2010)	The study compared and discussed actual traffic levels and forecasts.	Traffic forecasts

Author	Study purpose	Item evaluated
Liyanage and Villalba-Romero (2015)	The study measured overall success of PPP toll road projects.	Qualitative measures from project management, stakeholder and contract management perspectives.
Lombard, Sinha, & Brown (1992)	The study investigated the relationship between change in employment or wages and the length of major roads.	Employment, wages, road conditions, and lengths and capital costs of major roads
Mishra, Khasnabis and Swain (2013)	The study proposed a framework to analyse measures of effectiveness of each entity involved in a toll road project.	Capital cost, operation and maintenance cost, toll revenues and other payments to the toll operator
Odeck (2008)	The study evaluated the technical efficiency of toll companies.	Payments to governors, operational costs, traffic volume, number of lanes, and other productivity measures.
Oh, Labi and Sinha (2007)	The study investigates road pricing options and financial viability of a toll road project.	Road pricing, toll revenues and financial costs
Vassallo, Ortega and de los Ángeles Baeza (2012)	The study analysed the impact that the economic recession had on the performance of toll highway concessions in Spain and the actions that the government adopted to avoid the bankruptcy of the concessionaires.	Risk allocations and traffic growth
Welde (2011)	The study examined demand and operating cost forecasting accuracy for Norwegian toll projects by comparing the forecasted and actual levels of traffic and operating costs.	Traffic forecasts and operating costs
Zhang (2008)	The study developed models of market entry, price, and capacity choices on mixed-ownership networks to address these research needs.	Market entry, price, and capacity choices
Zhang, Bai, Labi and Sinha (2013)	The study investigated in the decision-making process: economic efficiency of privatization and the protection of public interest.	Financial transactions and public interest

TABLE 2 Measures of risk profiles and their interpretations

Risk profile	Measures used in this study	Interpretation
Central tendency	Mean, reflecting the expected Benefit-Cost Ratio (BCR)	A higher value reflects a lower risk profile.
	Median, reflecting the middle BCR	A higher median than mean reflects a lower risk profile.
Spread	Coefficient of variation (CV)	CV is a normalised measure of spread. A higher CV implies a wider distribution, for a higher risk profile.

Risk profile	Measures used in this study	Interpretation
Percentile	The probability of a specific BCR	The proportion of BCR trials greater than 1.0 represents the probability of the project being beneficial. A higher probability reflects a lower risk profile.

TABLE 3 Costs to the community that are considered in public CBA for this study

Perspective	Scenario	Costs considered
Toll as a transfer payment (TTP)		Capital and O&M costs
Toll as an end user cost (TUC)	Baseline toll, no guarantee (BNG)	Baseline tolls paid by end users and upfront capital cost contribution
	Baseline toll, minimum revenue guarantee (BRG)	Guarantee payment, baseline tolls paid by end users and upfront capital cost contribution
	Premium toll, no guarantee (PNG)	Premium tolls paid by end users and upfront capital cost contribution

TABLE 4 Characteristics of Australian toll tunnels

Characteristic	Legacy Way	Clem Jones Tunnel	Airport Link
Opening year	2015 (Transurban, 2016b)	2010 (Transurban, 2015)	2012 (Transurban, 2016a)
Capital cost	AU$ 1.5 billion (ACCIONA Australia, 2015)	AU$ 3 billion (Go VIA, 2015)	AU$ 5.6 billion (BrisConnections, 2011)
Annual average daily traffic (AADT)	18,000 (2016 estimate) (Morgans Financial, 2016)	27,000 (2015 actual) (Morgans Financial, 2016)	30,757 (2012 actual) (BrisConnections, 2012)
Proportion of heavy vehicles (HV%)	Unknown	17 % (Transurban, 2014)	Unknown
Vehicle kilometres travelled saving (VKTS) (Google, 2016)	0.7 km	1.2 km	1.0 km
Vehicle hours travelled saving (VHTS)	Between 3 and 18 minutes depending on the time of the day (Google, 2016)	Between 8 and 17 minutes depending on the time of the day (Go VIA, 2016)	Between 10 and 14 minutes depending on the time of the day (Google, 2016)
Planning horizon	40 years (SKM & Connell Wagner, 2008)	Unknown	45 years (SKM & Connell Wagner, 2006)
Discount rate	6.0 % (SKM & Connell Wagner, 2008)	Unknown	6.8 % (SKM & Connell Wagner, 2006)

TABLE 5 Assumptions made in the public CBA calculation of the synthesised toll tunnel project case

Item	Assumption and the expected value
Capital cost	Cowan's M3 distribution with Cap_{min} = AU$ 1.4 billion and probability of actual cost being greater than the minimum, ϕ = 63 %, while maintaining an expected value of AU$ 1.5 billion and a CV of 10 %.
AADT at year 1	30,000
Yearly traffic growth in percentage	2.8 %, the same rate as traffic growth rate in Queensland, Australia
HV%	10 %
VKTS	1.0 km
VHTS	15 min (0.25 h)
Type of project	A toll tunnel project in the greater South East Queensland region, Australia.
Age of facility	A newly constructed facility that has never been used before opening.
The expected economic life of a tunnel	100 years (Australian Transport Council, 2006)
Facility type	Acts as part of the motorway (freeway) network in Australia and is connected to other major roads.
Residual value	The value of an asset is assumed to depreciate linearly over its expected economic life.
Opening year	Opening year is assumed to be year 1 and therefore daily traffic volume of the first year is equal to AADT before applying any growth. Traffic volume will then be increased yearly with the traffic growth rate defined.
User benefits	User benefits will be accrued from year 1.
Capital cost and, operation and maintenance (O&M) cost values	Total cost of the whole of planning horizon in present value. Capital cost was applied as a lump sum at year 1. O&M cost was distributed equally over the planning horizon. The proportions of O&M and capital cost are 10 % and 90 % respectively over the whole planning horizon.
Maximum AADT	Absolute maximum AADT for four lane tunnel is 100,000 (based upon 2,250 pc/h/ln according to the Highway Capacity Manual (Transportation Research Board, 2010) with two lanes per direction, peak hour directional split of 55 %, peak hour to daily ratio of 12 %).
Planning horizon	50 years
Discount rate	7.0 %

Table 6 Probability distribution forms and CV of the case depend input variables

Variable	Source	Probability distribution form	CV
Annual average daily traffic (AADT)	NA	Normal distribution	10 %

Variable	Source	Probability distribution form	CV
Traffic growth	NA	Normal distribution	10 %
Proportion of heavy vehicles (HV%)	NA	Normal distribution	10 %
Vehicle kilometres travelled saving (VKTS)	NA	Normal distribution	10 %
Vehicle hours travelled saving (VHTS)	Salling and Leleur (2011)	Normal distribution	20 %

TABLE 7 Impacts of the synthesised toll tunnel case when all variables were deterministically equal to their expected values in present value

Project impact	Amount	Proportion
Travel time saving	AU$ 1,553,975,403	83.9 %
Vehicle operating cost (VOC) saving	AU$ 209,578,588	11.3 %
Crash cost (CC) saving	AU$ 5,927,046	0.3 %
Environmental and external cost (EEC) saving	AU$ 55,623,491	3.0 %
Residual value	AU$ 27,243,077	1.5 %
Total saving of transport costs	AU$ 1,852,347,605	
Capital cost	AU$ 1,500,000,000	90.9 %
Operation and maintenance (O&M) cost	AU$ 150,000,000	9.1 %
Total cost	AU$ 1,650,000,000	
Net present value	AU$ 202,347,605	
BCR	1.12	

TABLE 8 Risk profiles of the synthesised toll tunnel project case across perspectives and scenarios

Perspective	Scenario	Expected BCR	Median	CV	Proportion of BCR trials greater than 1.0
Toll as a transfer payment (TTP)		1.06	1.05	21%	59%
Toll as an end user cost (TUC)	Baseline toll, no guarantee (BNG)	1.05	1.05	17%	61%
	Baseline toll, minimum revenue guarantee (BRG)	1.03	1.03	18%	57%
	Premium toll, no guarantee (PNG)	1.03	1.03	17%	57%