Key to a low-carbon energy future: an overview of the Economics of IPT*

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Outline

INTRODUCTION

1. Public-private partnership (PPP) overview
2. Economics of the DIPT roadway infrastructure: assumptions and simulation
3. Empirical results & environmental benefits
4. Sensitivity analysis on vehicle uptake and toll fee
5. Challenges and opportunities of DIPT roadway infrastructure through PPP

PPP Overview

RESEAR H PURPOSE

- **PPP: a form of collaboration between public and private bodies to enter into a contract**
  - Involves undertaking specified roles for constructing and operating the infrastructure, while sharing any potential risks
  - Main challenge: forming the contract to uncover the optimal balance
    - Public sector: offer the highest level of community service, ensure the achievement of maximised social welfare
    - Private sector: adequate cash flows to achieve the agreed return on investment
  - To tackle uncertainties:
    - Minimum Return Guarantee
    - Flexible contract structure
    - Build-Transfer-Operate (BTO) - public sector owning the infrastructure after completion and leasing it to the private sector for operation during the contract period.

PPP Previous literature

RESEAR H PURPOSE

1. Chen, Liu and Yin (2017)

- Mathematical model “Charge Facility Choice Equilibrium”: Compare charging lanes and charging stations
- Different scenarios for drivers with varying or indifferent VOT
- Charging lanes are competitive – however, Govt would not be able to fund it.

2. Yang, Long,Li and Rehman (2016)

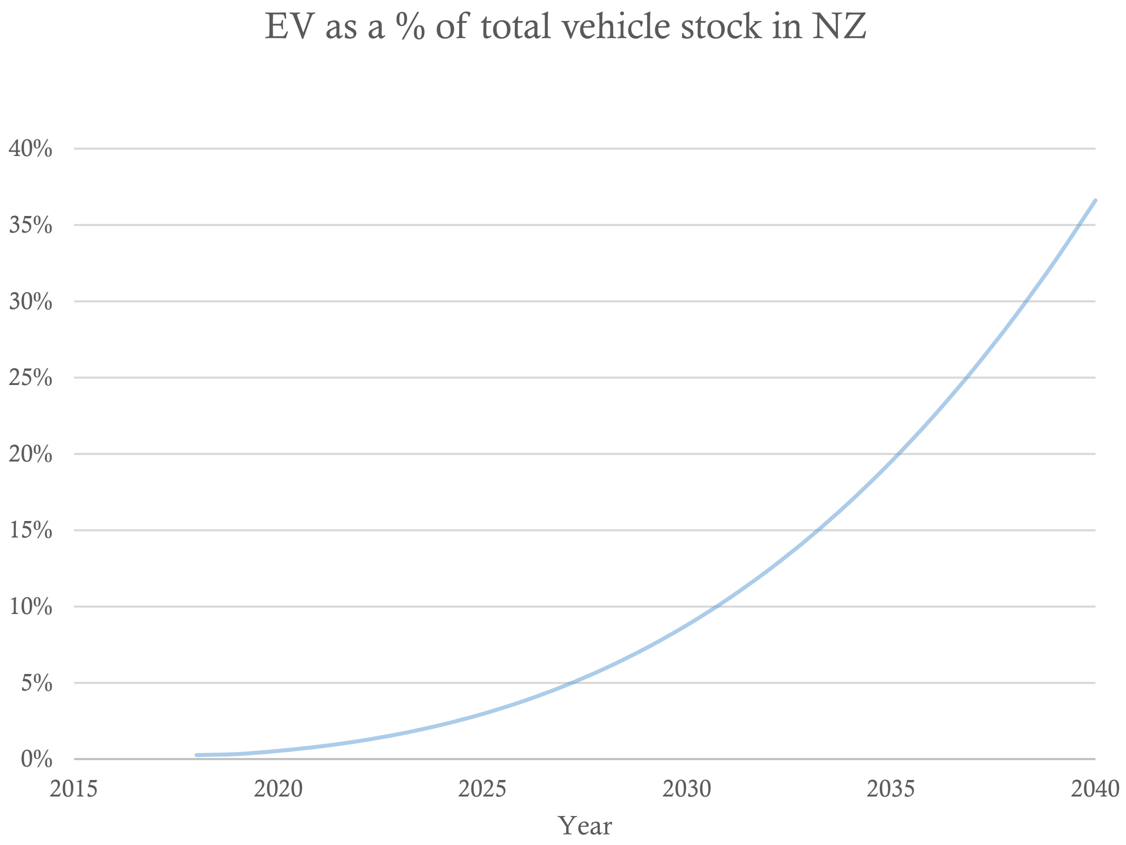
- PPP model for EV static charging infrastructure
- Win-win situation based on long-term cooperation
- Government sectors are enthusiastic but private investors’ willingness still needs to be stimulated
- Requires collaboration between public and private body: capital participation; business involvement in management and operation, and the role of the market in resource allocation

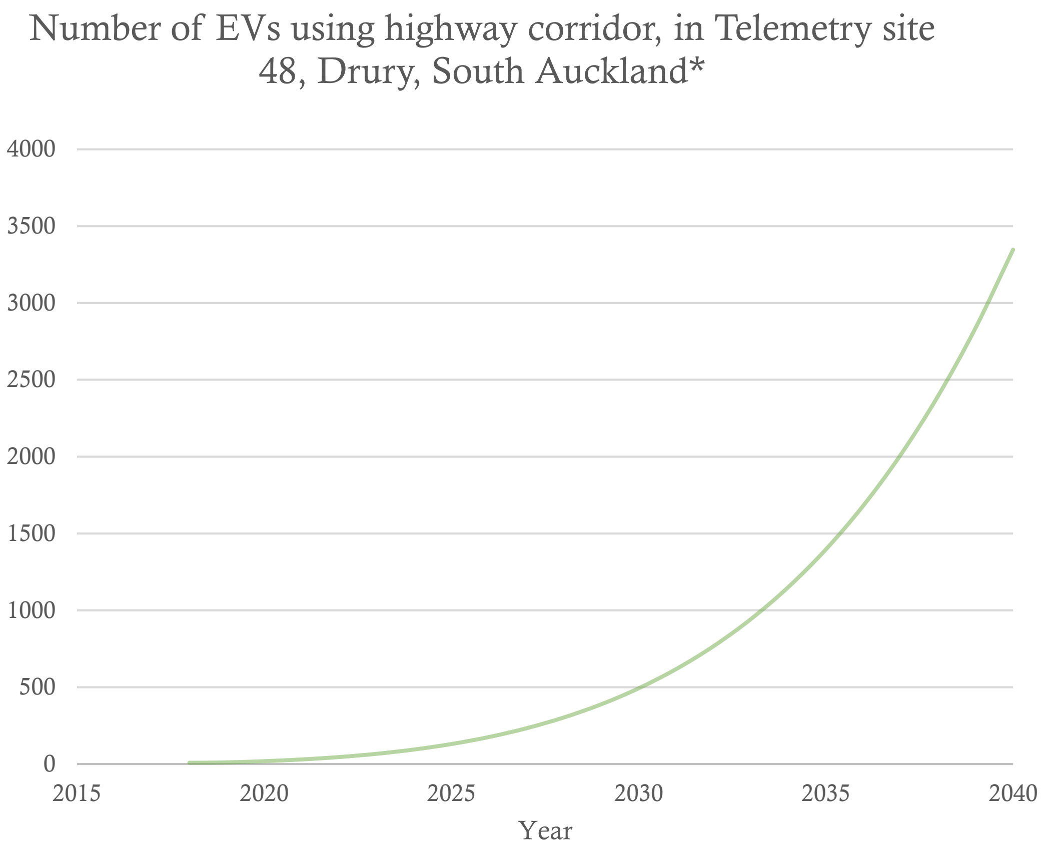
3. Objectives:

- Evaluate the economic feasibility of the IPT technology
- Address the challenges of large-scale investment needed through partnership
- Contribute towards a low-carbon energy future using NZ as a case study

Electric Vehicle uptake

ASSUMPTIONS AND SIMULATION





EVs: 36.6% of the total vehicle fleet (buses, trucks, passenger vehicles and utility vehicles) by 2040.
Ministry of Transport's estimate: 40% of the total vehicle fleet by 2040

*Based on the total # of vehicles in Auckland and the daily # of vehicles using the motorway, the average # of vehicles using the motorway was calculated at 51,570 per day in 2017. The % increase in the total vehicle fleet in Auckland is constant at 3.4% - the # of EVs using the motorway/hour is obtained based on our estimate of EV growth rate

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ASSUMPTIONS AND SIMULATION

- A traffic corridor of a specified length of *l (km)* equipped with DIPT system
- The DIPT roadway infrastructure is assumed to have a power of *P (kW)* for charging the EVs with a recharging efficiency (ε).
- The total # of EVs using the lane is given by *f* as calculated in the previous section.
- EVs have a battery capacity of *E (kWh)* with an efficiency of η.
- Constant speed of EVs travelling at *v (kmph)* all along the corridor.
- The facilities are provided in such a way that no vehicle can finish the trip without recharging and the charging provided is sufficient to complete the trip.
- The EV drivers are assumed to have a range anxiety factor of (1-*x*). Therefore, the driver can be assured with a confidence level *x*.

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Cost

$$C = Civil\ Cost + Cost\ of\ Electronics + Charging\ Cost$$

$$C = C_d\left(\frac{l}{\eta} - xE\right)\left(\frac{v}{\varepsilon P}\right) + C_p P + C_e \sum_{n=1}^{T} \frac{f\,\frac{\left(\frac{l}{\eta} - xE\right)}{\varepsilon}}{(1+i)^n}$$

* It is important to note that the model does not attempt to provide the optimal location of the charging facility. Rather, the model only calculates the length of the transmitter required for a vehicle to finish the trip. The total charge required to complete the trip is $\frac{l}{\eta}$ and the range anxiety factor is $\frac{l}{\eta} - xE$.

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ASSUMPTIONS AND SIMULATION

Revenue

$R = Revenue\ collected\ for\ use = \#\ of\ vehicles \times RT\ (\$/kWh)$

$$f \times \sum_{n=1}^{T_c} \frac{f\left(\frac{l}{\eta} - xE\right)}{(1+i)^n}$$

Net Cash Flow

$$NPV = \sum_{n=1}^{T_c} \frac{R - C}{(1+i)^n}$$

Investment

ASSUMPTIONS AND SIMULATION

- Optimal initial investment ratio between public and private sectors
- Government Investment ratio k

$$k = 1 - \frac{\bar{R} - R(1-\lambda)\omega_s}{R\lambda}$$

A private enterprise expecting a rate of return of r will only consider investing in the project iff: $NPV \geq rI$

Data for computation

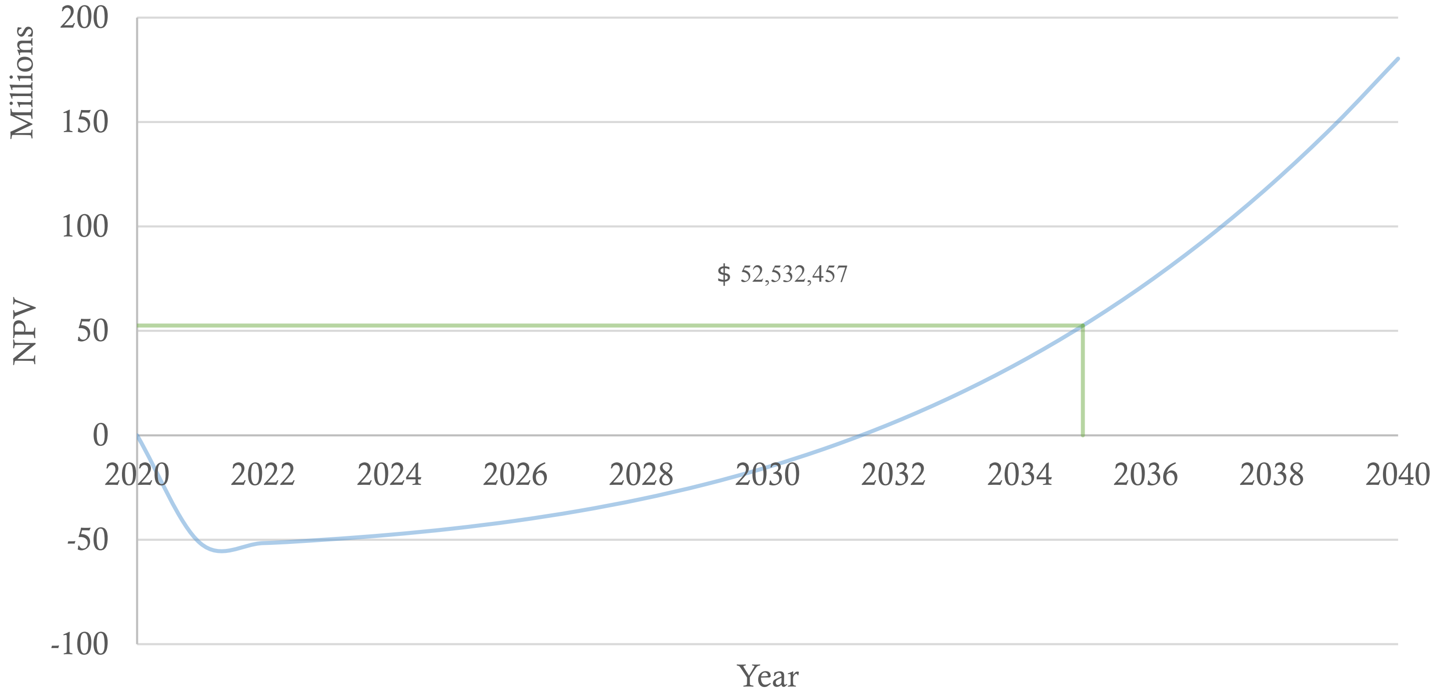
ASSUMPTIONS AND SIMULATION

Symbol	Parameter	Value	Source
l	Length of the corridor	300 km	-
E	Battery size	30 kWh	-
η	Battery efficiency	4 km/kWh	Chen, Liu and Yin (2017)
x	Range anxiety factor	0.7	-
v	Speed	80 km/hr	-
P	Power of charging infrastructure	100 kW	Jang, Suh and Kim (2016); Chen, Liu and Yin (2017)
ε	Recharging efficiency of IPT	0.75	Chen, Liu and Yin (2017)
C_d	Construction cost per unit length of transmitter	$732,957.50/km	Chen, Liu and Yin (2017)
$C_p{}^*$	Cost per unit power	$814/kW	Chen, Liu and Yin (2017) and (Nie and Ghamami, 2013)
C_e	Cost for charging EV including electricity cost	$0.29 $/kWh	MBIE (2018)
i	Discount rate	6%	Public Sector Discount Rates for Cost Benefit Analysis (2008)
T_C	Concession period	15 years	-
λ	Importance of profit maximising	0.5	Weightage given
ω_s	Risk ratio the private sector takes	0.6395	-
R	Expected profit	$68,000,000.00	Calculated at the end of concession period
r	Expected rate of return for private investor	12.5%	-
	Project construction year/duration	2020/3 years	

Note: All currency used is in NZD; * - Assuming two inverter units per km (Shin *et al.,* 2014)

Net Cash Flow

EMPIRICAL RESULTS



Concession period = 15 years

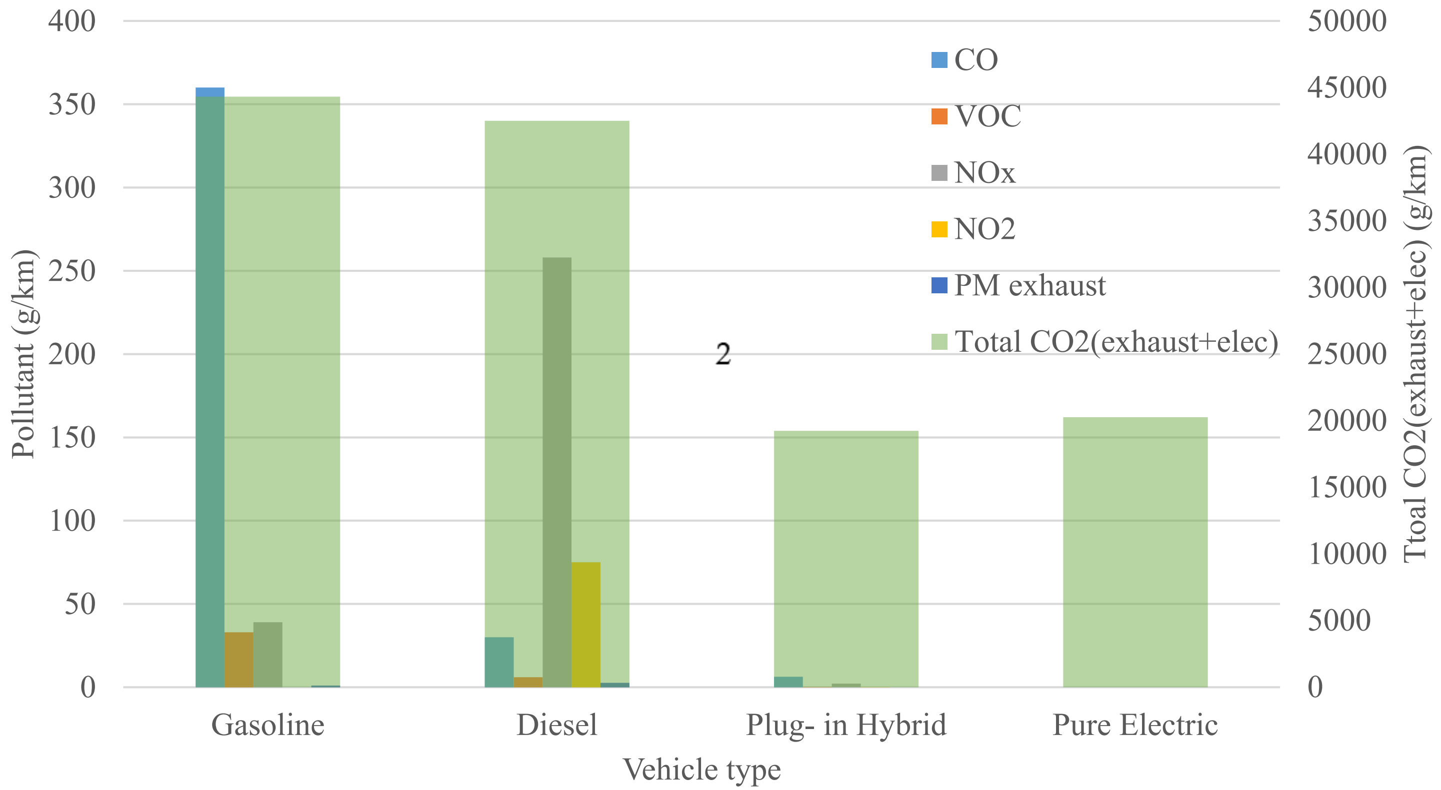
Government Investment = 9.46%

Toll fee = $0.37/kWh

Emissions

ENVIRONMENTAL BENEFITS

Emission from each vehicular category for one vehicle per trip

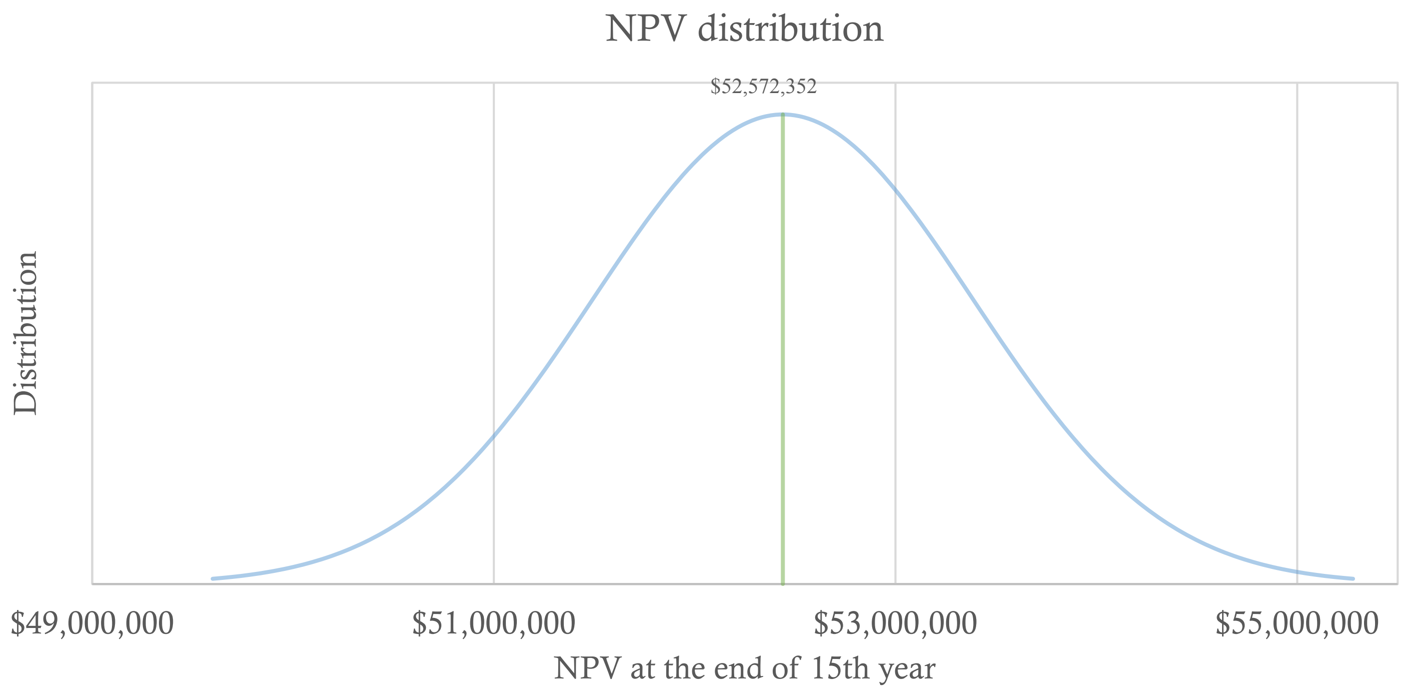


- Pure EVs can reduce CO_2 emissions by 54.27% compared to petrol vehicles, and 52.33% when compared to diesel engines.
- CO_2 emissions from pure EVs is higher than PHEVs: higher demand for electricity; non-renewable power sources

Vehicle Uptake

SENSITIVITY ANALYSIS

Vehicles using the facility ±5%



Mean	**$52,572,352**
Std Dev	$1,067,208
Min	$50,407,156
Max	$54,942,943

- The average value of the net cash flow at the end of 15 years is higher than the expected rate of return for the private industry.
- DIPT infrastructure for EVs is a better investment opportunity.

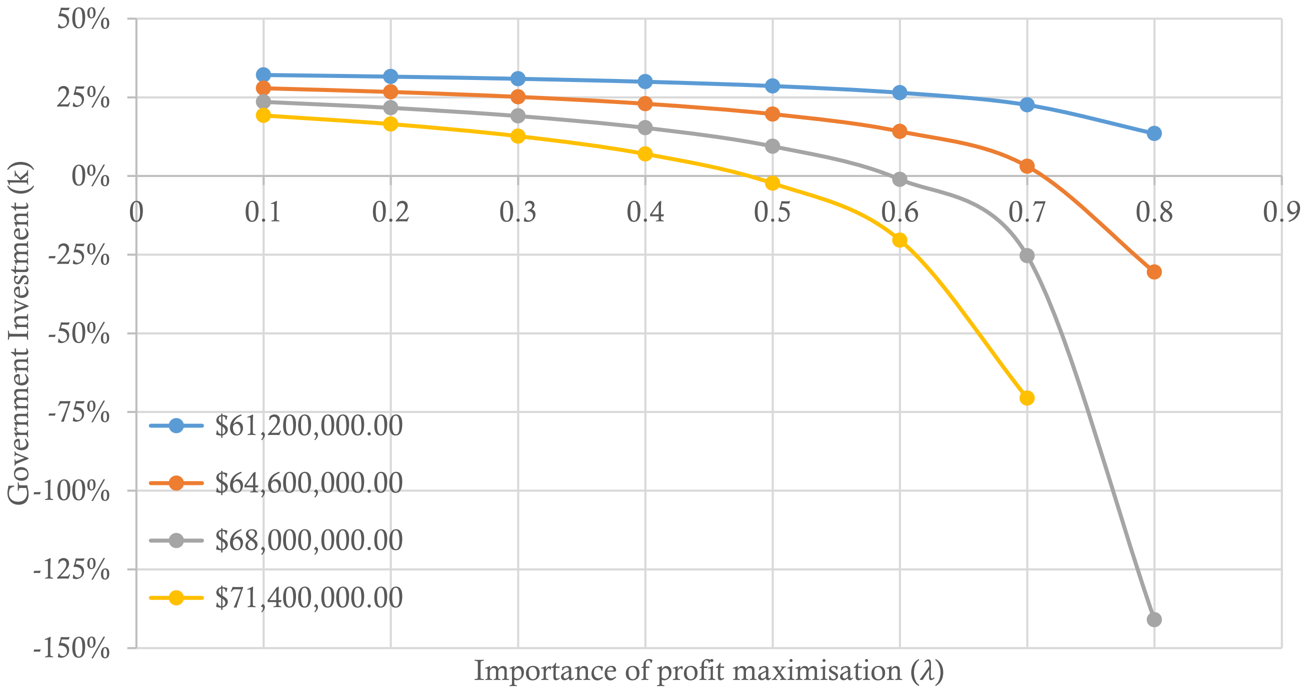
Toll Fee

SENSITIVITY ANALYSIS

Change in toll fee ±5%

Toll Fee	NPV in 15 years
$0.37	$52,532,398
$0.36	$43,521,240
$0.35	$29,937,767
$0.34	$16,354,294

Change in initial investment



- A lower toll fee will provide a higher social benefit favouring consumers, however the Govt will need to bear the burden of the reduced social cost in the form of guarantee to the private industry for the concession period.
- As the importance of profit maximisation and allocation decreases, the value of risk-taking increases and hence the Govt. must invest more to compensate for the risk taken by the private industry, and *vice versa.*
- As the expected profit increases, the Govt. can initially invest less in the project as the rate of return for the private sector will be guaranteed.

Challenges and opportunities of DIPT roadway infrastructure through PPP

- Economically viable option; capital intensive but possible
- Key takeaway message: Govt. formulates policies that could facilitate private sector participation
- Future research:

1) Integration with real-world traffic conditions, i.e. constant speed assumption
2) Partial charging of the vehicle as they enter and exit the lane
3) Electricity demand and grid load etc.