Case Studies on Transport Policy

Political and technical complexities of Electronic Toll Collection: Lessons from Taiwan

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Highlights

1. Taiwan’s experience is analyzed politically, technologically, and practically.
2. Expert interview data reveal policy complexities and their implications.
3. Lessons are drawn for policy making around ETC.

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Abstract

Traditional manual toll collection (MTC) imposes a significant queue length near toll plazas and results in road users delay (travel time loss), administration, fuel consumption, accidents, and other societal costs. Many countries (e.g. the U.S., Japan, Taiwan) have introduced and are continually upgrading Electronic Toll Collection (ETC) systems, thereby achieving key efficiencies and reduction in social costs. ETC systems worldwide have different toll collections technologies, for example, by road usage or Vignette, by peak or non-peak travel, or by distance travelled. Consequently, countries are faced with many technical and political complexities both at the initial consideration of whether to introduce ETC, and in any subsequent development. Taiwan has much experience of both toll collection and also ETC and has a long history in relation to its introduction. This paper presents historical and qualitative interview data with highly experienced ETC operators and government officials in Taiwan. Results are presented and discussed along four major axes: practical applicability, technological development, political variation and publicity and marketing. It also provides a retrospective and current consideration along these axes of technical and political complexities involved with introducing ETC. The paper is intended to inform transportation agencies considering introducing or developing their own ETC systems. Areas of future research for ETC are also suggested.

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1. Introduction

The aim of this paper is to present and discuss the experience of Taiwan's introduction and development of road tolling systems from Manual Toll Collection (MTC) through to Electronic Toll Collection (ETC). The complexities of this process are presented and discussed by drawing on the experience and reflections of key personnel involved and contextualizing these with quantitative data on the impacts of different systems. This is done with the underlying aim of presenting Taiwan's experience in order to help transportation agencies with any decisions in relation to road tolling and ETC.

Previous literature provides a range of lessons for the development complexity around

ETC. Before the 1990s, most freeway tolls were MTC using tollbooths, a labor intensive approach with significant time delay costs for road users (Iseki and Demisch, 2012). MTC increased fuel consumption, emissions, related public health and medical external costs (Tseng et al., 2014), and had negative social welfare impacts (Levinson and Chang, 2003). In contrast, ETC, using radio-frequency identification (RFID) technology (Dias et al., 2014) is far quicker with much reduced traffic related social costs (Komada, Masukura and Nagatani, 2009), and even if drivers need to slow down for ETC recognition (Dell'Asin and Monzon, 2011), they do not need to stop and start.

ETC development is reflected in the many aspects researched, such as engineering, management, road pricing, service performance, consumer behavior, environment, and law (e.g., Chen et al., 2007; Holguin-Veras and Preziosi, 2011; Iseki and Demisch, 2012). ETC has been found to save time for road users (Li et al., 1999), save energy, reduce emissions, and improve services. ETC is also considered advantageous in shifting the risk and cost of building new roads to private companies through privately financed toll road projects (e.g. Bain, 2009), often through Public Private Partnerships (PPPs) (Davidson, 2011).

Table 1 below provides an example of a number of different countries' approaches to ETC. It should be noted that ETC is employed worldwide, and Table 1 only provides an example with 20 countries, and not a full list of all countries employing and developing ETC. It is also the case that ETC is continually being developed, and as the examples in Table 1 show, many countries still employ a hybrid of MTC and ETC, and many are now moving to Global Positioning Systems (GPS) of Global Navigation Satellite Systems (GNSS). The examples in Table 1 also show a range of approaches to Road User Charging (RUC) and that technologically, some countries expect users to have an On Board Unit (OBU) that is recognized using Dedicated Short Range Communications (DSRC) with infrared or more commonly with Radio Frequency Identification Devices (RFID). The approach to charging is often 'Vignette', meaning users are charged per usage of the road; alternatively, users are charged by distance travelled. Often, peak or non-peak hours also affect charges with both Vignette and distance based approaches. Countries use Automatic Number Plate Recognition (ANPR) if vehicles are not equipped with a tag or OBU. The aim in many cases is for a Free Flow Traffic System (FFTS) and in most countries practical application of ETC is through PPP agreements. Countries presented in Table 1 differ in their rationale for introducing tolling, ranging from seeing tolling as a societal good (e.g. Japan), to being a means of funding infrastructure development (e.g. Austria).

Table 1: ETC Systems Worldwide

Country	Toll method (cost)	Vehicle types charged	Charging technology	Comments
1. Australia	Vignette based, peak / non-peak hours	All types	Manual or e-tag with epass initially electronic since 2013. DSRC Radio	PPP initiated to fast track infrastructure development. ETC introduced 1995
2. Austria	Early 20th century move from time-based Vignette to distance based tolls	Trucks and buses	OBUs with radio microwave first, and now	Purpose to generate revenue for infrastructure, charges highest in the EU. PPP used increasingly ETC introduced 2004.
3. Bangladesh	Distance travelled	Vehicle type	ETC and MTC - both need personnel. Advanced systems proposed	Tolls used for road construction, improvement, safety and maintenance, but some feel insufficient quality to charge tolls. ETC introduced 2019.
4. Belgium	Change from Vignette to distance based in 2015 - highways or urban areas only	All types – emission class and weight determines fee	Increasingly moving to GNSS technology	Tolling mainly reduces urban car use; ANPR data can be used to analyse vehicle type movements. EU guided policy. ETC introduced 2013
5. China	Distance based tolls	All types, charge according to vehicle size and increasingly by weight	RFID technology with ETC, moving to 5G technology	Studies suggest most must benefit for charges to be politically viable. Tolls part of government push for intelligent transport system, PPP much used. ETC introduced 2007
6. Hong Kong	Vignette based tolling	All vehicles, charges by vehicle type, weight, size and number of axles	First MTC, ETC in 1992 now FFTS using RFID for toll tags, ANPR for others	Started in the 1980s, and links with China seen as key – public information awareness campaigns used for FFTS. ETC introduced 1992.
7. India	Vignette and peak / non-peak hours based system.	Small, Standard, mid-size, large-size, heavy.	Mostly MTC, also ETC slowly being introduced	Toll roads built using PPPs. Vehicle types assigned specific lanes but often simply choose smallest queue. ETC introduced 2013.

8. Japan	Charges based on distance travelled; peak / non-peak hours, and areas	Small, standard, mid-size, large-size, over-size vehicle.	ETC 2.0 (ETC card) MTC moving to hybrid, ETC introduction.	COVID 19 amongst MTC workers driven call for full ETC. ETC called 'Social Technology'. Built using PPPs. ETC introduced 2001.
9. Morocco	Some highways have tolls, both Vignette and distance travelled.	All vehicles pay, including motorcycles.	Tolls in cash. MTC/machine, moving to ETC	Tolls to reduce congestion. Public Government owned Company. ETC introduced 2014.
10. New Zealand	Vignette and peak / non peak hour based system.	All types, key factor of 3.5 tonne weight.	ETC through ANPR to identify vehicle and charge – no toll booths.	Roads funded through petrol excise duty, sometimes PPPs, tolls used for roads. Now studied for emissions/sustainability. ETC introduced 2009.
11. Norway	Distance based	All types and depends on size of vehicle and number of passengers	Originally MTC but moved to ETC RFID for all	Used since 1982 for funding national road infrastructure. Increases local political influence, run as PPP. Tolls produce 40% of road funding. ETC introduced 1991.
12. Oman	Future plans will be Vignette-based	Mostly aimed at trucks	Will probably use RFID and aim for FFTS	Tried and failed, scrapped in 2008, considering tolls again in a PPP BOT project to fund highway construction, improve road infrastructure, and reduce congestion. ETC not yet introduced.
13. Paraguay	Vignette based, one highway tolled, plans for two.	Unsure what vehicle rates are	Currently MTC, planning smart systems.	Private company owned and US financed PPP. Aim to improve road quality with private finance ETC not yet introduced.
14. Singapore	Vignette based, area charged slowly increased; peak / non-peak hours	All types	Radio	Tolling part of an integrated policy promoting sustainable green transport. PPPs used; publically controlled if failing. ETC introduced 1998.
15. Slovakia	Distance travelled and Vignette based	Toll by vehicle category and weight, motorcycles exempt, key factor is vehicle is over 3.5 tonnes.	Hybrid of RFID, ANPR, and GNSS, from 2010 driver's responsibility to install OBU, now much GPS	EU guided policy.. Managed by Private Company. ETC introduced 2010.
16. South Korea	Combined Vignette and distance based; peak / non-peak hours	Vehicle type and size and weight	RFID and vehicles need OBU and H-Tag	Past policies critiqued for not being integrated. Tolls by principle user benefits so should pay ETC introduced 2000.

17. Sri Lanka	Vignette based.	Charged according to vehicle category and number of axle[s]	Much MTS; moving to ETC - MTC / ETC hybrid. Not FFTS but want this	Late twentieth century PFI projects failed, more recent projects government funded with loans from Asian bank. ETC introduced 2015.
18. The Netherlands	Initially, and still time of day focused.	Freight and trucks, number of axles, emission class, permit length.	First DSRC but now introducing GNSS.	Initial congestion tolling failed - introduced without societal support. Separate pay lanes first proposed. EU guided policy. ETC introduced 1988.
19. United States - California	Distance travelled	All types – number of axles determines charge.	RFID technology.	Pilot scheme on RUC charges undertaken, also focusing on privacy ETC introduced 1993.
20. United States - Florida	Vignette and peak/nonpeak hour based system	All types, according to number of axles.	All Electronic system of ETC through ANPR to identify vehicle and charge – no toll booths.	PPP funded. Private company supplies pass. ANPR issues charges for vehicles with no pass. ETC introduced 1999.
21. United States - Virginia	Vignette based and depending on bridge, road, tunnel used	All types, according to number of axles	Mix of ETC, automatic machines and MTC, moving to GPS	Consideration of auction –based tolling in the future. Operated by PPP, regional and state owned companies. ETC introduced 1996.

As Table 1 shows[1], many countries are introducing ETC, often (but not always) through GNSS and GPS which require no gantries being built to register passing vehicles. This appears the way forward for many countries to ensure FFTS, although others still use gantry check points with RFID, DSRC and ANPR. Some countries are still considering the introduction of ETC (Oman), others are in the early stages of doing so (Sri Lanka, Paraguay) and the ETC of other countries is far more widely used and developed (Norway, the Netherlands, the United States). Florida's All Electronic System is one of the most advanced and a state of the art example of ETC, having first been introduced in 1999 and now fully electronic. Yet, when countries introduce ETC, they face initial and ongoing costs and issues, some of which may be hard to anticipate. Even within a single country, experiences of introducing toll systems can vary greatly with the topology and structure of each city (Börjesson & Kristoffersson, 2015).

Taiwan has over 40 years' experience introducing and developing MTC and ETC. This paper presents and discusses this experience, through a contextual analysis (Iversen, 1991) that draws on both documentary data and also qualitative interview data with highly experienced ETC operators and Government Officials. Key technical and political complexities are identified for transportation agencies introducing or developing ETC (cf. Flyvbjerg, 2006). First, key ETC literature is reviewed, following this, the approach to data collection is detailed, and then results in relation to Taiwan's experience of ETC are presented and analyzed under four axes of: practical application; technological development; political variation and; publicity and marketing. In the discussion section, key complexities are outlined throughout for transportation agencies to consider when introducing or developing their own ETC.

2. Key ETC considerations outlined in the literature to date

Introducing ETC involves many issues (Lee et al., 2008) such as system complexity, construction and maintenance costs, pricing, privacy, and rates of costs (Vats et al., 2014; Gates and Savolainen, 2016; Basar and Cetin, 2017; Heras-Molina et al., 2019; Han et al., 2020). ETC technology is sophisticated, consisting of elements of Dedicated Short Range Communications (DSRC), Global Positioning Systems (GPS); Geographic Information Systems (GIS); Vehicle Positioning Systems (VPS) and; Infrared Short Range Communication (ISRC) based on calm active infrared (Iseki and Demisch, 2012; Vats et al., 2014). Constructing an ETC system that is effectively evaluated and with an ensured quality, requires a complex array of hardware and software (Chu et al., 2013).

[1] We note that it is not possible for reasons of space to include all the sources we consulted (almost 90 in total) which encompassed journal articles, government websites and newspaper articles; but this list can be obtained by emailing the corresponding author.

This technology must combine the measurement of road usage; employ a rate schedule, and; effectively communicate data (Iseki and Demisch, 2012). Such data can help with collecting payment, and it is imperative data are correct to ensure accuracy, help monitor quality, (Chu et al., 2013), and also to ensure security and privacy (Lerouge, 1999; Ogden, 2001; Riley, 2008). Privacy issues encompass data security, enforcement issues, and how records are used (Ogden, 2001).

With such complexity, selecting the optimum technology and deployment of ETC (Levinson and Chang, 2003) is not straightforward, and contextual differences of topology and governmental policy objectives also play a key role. In Singapore, DSRC technology rather than GNSS is used (Kramberger and Curin, 2011). However, in the US, road tolling technology choice can be determined by the geographical scale of road networks and the complexity of calculating fees (Iseki and Demisch, 2012).

Government policy objectives and political variations are also key, with revenue generation for infrastructure development being critical in some countries (e.g. Austria (see Table 1), whereas technology cost can be critical for other countries (e.g. India (Vats et al., 2014)), and optimizing environmental efficiencies key elsewhere (e.g. Norway (Odeck and Welde, 2017). In addition, priorities may change over time, environmental considerations becoming increasingly important for many countries (e.g. in Taiwan (Lai et al., 2021))

Any government's approach to ETC involves publicity and marketing considerations related to road users' travel choice behavior, and many studies (e.g. Chiou et al., 2013) focus on road user's Willingness To Pay (WTP). However, some countries may simply prioritize congestion reduction over road user preferences (e.g. Singapore, see Table 1) or exact higher tolls for infrastructure development (e.g. Austria, see Table 1.). Important to user take up may also be how user-friendly the technology is, and in Taiwan's case this was key (see Section 4 below). Another consideration is possible concerns over privacy and data usage (Lerouge, 1999), and these may be a more pressing priority for some governments (e.g. the US (Ogden, 2001)) than others.

Cost benefit analyses are often considered by policy makers in relation to the practical applicability of ETC and are often in relation to social welfare (Levinson and Chang, 2003). For ETC, 'costs' can encompass initial capital investment, subsequent operating and maintenance, and updating and reconstruction. By comparison, 'benefits' could include time saved (Chang et al., 2004; Chang and Hsueh, 2006), energy saved, emission reductions and service improvements (Li et al., 1999). Cost predicting is highly complex however, and one study (Morgan, 1997) found that 13 of 14 newly implemented road tolls in the US, had lower than predicted levels of traffic flow. This being the case, the PPPs pursued by so many (see Table 1) to fund Toll collection

systems and technology may be overly optimistic, can fail, and may need to be brought back into public government hands if this is possible (See Table 1, Singapore).

Other technology related political issues can be finding alternative employment or compensation for former MTC collectors, and also issues of price discrimination and the time required to ensure accurate charges become law (Tao and Chen, 2016). The importance of user opinions should not be underestimated, and an earlier related polemical paper argues that any government ETC policies will be influenced by political foundations and goals (Chen, 2009).

Thus, introducing and developing road pricing systems presents many complexities for policy makers. Underlying policy aims may differ greatly, from reducing congestion (Singapore), to improving the environment (Holland) or to raising revenue (in Norway's case) for other projects (May, 1992). Governments may face many objections to road-pricing, and whilst technical and political ones can be dealt with (May, 1992) those related to equity may be harder to address (Di Ciommo & Lucas, 2014). In many ways, the use of the revenue from the tolls for other projects, or hypothecation (Santos & Rojey, 2004) has been considered one way to address issues of equity, for example by improving public transport (Di Ciommo & Lucas, 2014), so that users on low incomes can still travel easily (Hensher & Bliemer, 2014). Given such objections, one key issue is how to convince governments of the benefits of introducing road pricing systems for the majority of users, or for all users, that are simultaneously accepted by the public (Hensher & Bliemer, 2014). Much work suggests how to make road pricing acceptable, through the use of financial incentives or by clearly demonstrating environmental improvements, congestion reductions and travel time shortening (Hensher & Bliemer, 2014).

The context of the individual country is also key, and as the examples in Table 1 above show, the range of different approaches worldwide is vast. Research in transition countries, i.e. those moving from a former communist rule to a market based economy and pluralist democracy (Glavić et al., 2017), identifies complexities of both determining and also constructing decision-support frameworks for governments to help them select optimal toll collection systems (Milenković et al, 2018). This is critical, as levels of Willingness to Pay (WTP) are country dependent, even in the same continent, for example Europe (Glavić et al., 2021). Furthermore, impacts of road pricing schemes can even be city dependent, and thus have different outcomes in different cities within the same country (Santos & Rojey, 2004). Notably, optimal pricing is influenced by several indicators that may need careful public discussion before any decisions are made (Glavić et al., 2017). Indeed, it may be the case that users will simply stop paying the toll if it is perceived too high, and thus cease to use the road (Hensher et al., 2016). Vehicle type

and speed are also considerations regarding what to charge, particularly in relation to aims to reduce congestion (Button, 2004). Further, whether to adopt Time Based (TB) vignette systems charging, or Distance Based (DB) charging systems is important, and a decisión that is linked with technical requirements, as DB charging requires greater roadside infrastructure (Glavić et al., 2021). The sourcing of finance is also a complexity for governments, who may or may not have the funding for introducing tolling infrastructure. Where public resources are scarce, Private Finance Initiatives (PFI) and Public Private Partnerships (PPP) are one approach whereby the private sector builds the structures and is paid back over time by the government and the public purse. However, these are commonly more costly than public construction (Acerete et al., 2009).

Regarding environmental benefits, ETC has been said to reduce CO_2 emissions by 61~84% compared to MTC (Coelho et al., 2005), and CO_2 emissions and transaction times can be reduced by switching to ETC (Tseng et al., 2014). In turn, this reduces energy consumption (Pérez-Martínez et al., 2011). One approach to tolling that is used to reduce congestion is to increase charges during peak hours, or to reduce charges during off-peak hours. This approach reduces congestion during peak times and is used widely in the United States. Some literature adds that such approaches should consider user WTP and issues of equity, and suggest revenue could be used to improve public transportation during peak hours (May, 1992; Di Ciommo & Lucas, 2014). Furthermore, it is generally found that ETC, even when hybrid with MTC (Komada et al., 2009), is safer than MTC as drivers pass through an open road without needing to change lanes or stop, although they may need to slow down somewhat for recognition (Dell'Asin and Monzón, 2011).

Thus, governments and transportation agencies are faced with many complexities regarding ETC related to practical application, technological development, political variations and to publicity and marketing of the schemes.

3. **Methodology, Research Design and Sample**

Most studies into ETC are quantitative in nature (Abdel-Aty, 2003; Jou et al., 2011, 2013; Kramberger and Curin, 2011; Wang and Zhang, 2017). Nevertheless, qualitative studies are also undertaken (Ogden, 2001; Lee et al., 2008; Dias et al., 2014). We complement these studies by presenting data based on a contextual analysis (Iversen, 1991) whereby documents and in-depth qualitative interview data with field experts are analyzed to depict Taiwan's approach to introducing and developing ETC. The documents consist of newspapers, public government and ETC private company websites sometimes verified for reliability with officials in Taiwan, and secondary sources similar to those reviewed above. Interviewees were selected by snowball

sampling and on the basis of whether had a thorough knowledge and related working experience (defined as being 15 years at least) of ETC. The backgrounds of these interviewees were consciously chosen for their variety (e.g. engineering, marketing, traffic management, etc.) to avoid potential sampling bias and expand the depth and breadth of information collection (see Table 2). The qualitative in-depth interviews were undertaken with ETC operators (n = 3) with an average of 18 years' experience, and government officials (n = 4) with an average of 24 years' experience. ETC operators had Section Chief or Senior Manager roles, and worked in the areas of Engineering, Marketing, and Administration. Government officials had Section chief or Senior Engineer roles and worked in the areas of Administration, Design and Planning, Traffic, and Toll Management.

Importantly, every individual had sufficient experience to have witnessed the introduction of ETC from its inception, and also its subsequent development. The outline of interviews included questions such as "Did you know any problems when implementing the ETC system in Taiwan?", "Do you think the current charge fee of ETC is fair and reasonable for road users? and "Do you have any suggestions for ETC future application and development?" Interviews were undertaken in the individuals' native language for ease of expression (cf. Cortazzi et al., 2011), transcribed and translated by the researchers for analysis (cf. Bird, 2005) and for reasons of anonymity (cf. Christians, 2011), and then analyzed thematically (cf. Braun & Clarke, 2006). The process of thematic analysis revealed four themes of 'practical application'; 'technological development'; 'political variation' and; 'publicity and marketing'. These themes may well be unique to Taiwan's experience. For example, previous studies have focused primarily on financial related implications of road pricing such as PFI (e.g. Acerete et al., 2009), equity (Di Ciommo & Lucas, 2014), or WTP (Glavić et al., 2021), but in the thematic analysis undertaken here, issues of finance arose as being key to the practical application and the publicity and marketing of ETC for interviewees (and hence this is why finance related data is presented in the section on publicity and marketing below). In addition, issues of equity, whilst dealt with seperately in much previous research (e.g. May, 1992; Di Ciommo & Lucas, 2014), were for these interviewees very much related to the practical application of ETC, and so equity is considered below in the section on practical application.

To describe these axes in more detail: the first axis is 'Practical Application', and this relates to aspects such as cost factors and necessity of introducing ETC over MTC. The second axis is 'Technological Development', and this relates to technology selection; historically, currently, and for possible future choices. The third axis is 'Political Variation', and this related to aspects such as the involvement of private companies,

tendering processes, how much control was with the government, and any political aspects surrounding aspects such as technology selection. Finally, the axis of 'Publicity and Marketing' relates to aspects such as how information about ETC was disseminated, how ETC was promoted, and how policies were adjusted when take up was lower than hoped for. Although these axes are dealt with discretely and include content considered most relevant to them, certain data relates to many axes, and this is noted where it is the case. For example, where the adoption of the technology (axis two) of the OBU was low due to policy decisions (axis three) that drivers should pay for them, this policy was adjusted and impacted on marketing approaches (axis four).

The approach to presentation combines both documentary and interview data in a narrative of Taiwan's ETC development along these axes as this is considered a more effective approach (as opposed to presenting the data discretely) to convey the picture comprehensively and effectively for discussion afterwards.

4. ETC: Taiwan Experience

The presentation of results here combines the documentary and interview data under the four axes outlined above of: Practical Application; Technological Development; Political Variation, and; Publicity and Marketing.

4.1. Practical Application

The backdrop to any consideration of the practical application of ETC in Taiwan is the huge increase in vehicles travelling on the freeways (see below Figure 1). There are nine National freeways in Taiwan. Freeway No. 1 and Freeway No. 3 are the two main (Northern-Southern) freeways and started to operate on July 1978 and February 2008, respectively. Currently, an ETC system is implemented in Freeways No.1, No. 3, and No. 5. Compact cars (including passenger car, pickup truck) are the main vehicle types, followed by heavy vehicles (including coach, heavy duty truck) and trailers.

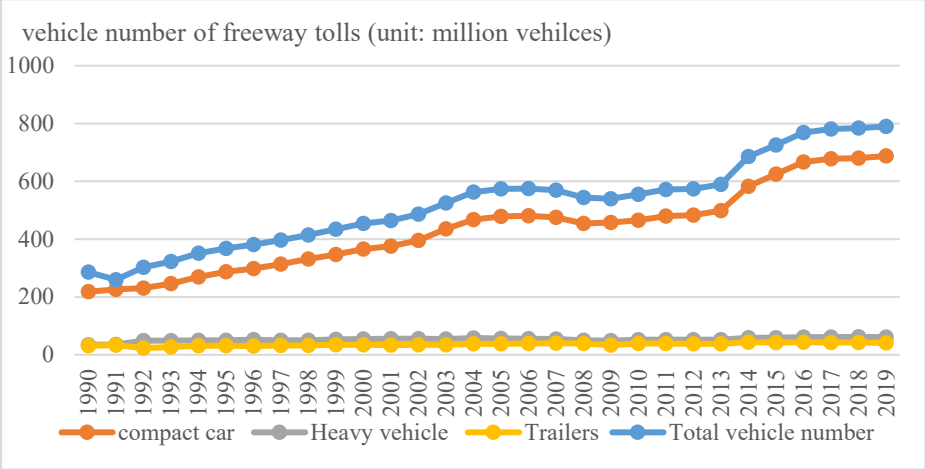

Figure. 1 The total vehicle number of freeway tolls 1990-2019
Source: Freeway Bureau, Ministry of Transportation and Communication, Taiwan. https://www.freeway.gov.tw/english/Default.aspx

Indeed, practically, the old MTC system was highly costly in the need to construct and maintain toll stations and administration costs (e.g. hiring operators of toll stations for dealing with cash (including notes, coins, etc.)), checking tickets, and the danger of theft. Security with MTC was considered problematic by interviewees, one government official observing *"there existed fake tickets"* and also that *"taking care of cash is another problem, someone robbed the cash in certain toll stations in the past."*

For drivers, MTC created time delay costs, fuel consumption, emission external costs, and potential accident risks in toll plaza (cf. Roger et al., 2016; Lin et al., 2020). The inferiority of the old MTC system was highlighted by almost every interviewee. One ETC operator said MTC spent *"lots of human resource, time and costs to deal with toll fee in the traditional manual toll system when comparing the ETC system."* Similarly, government officials felt ETC had helped *"improve the vehicle flow situation"* and remedied the *"congestion situation near toll station."*

Economically, early 21st century scoping predictions showed huge benefits in income compared to cost when introducing ETC (Chang et al., 2004) It was predicted the benefit would increase from 80.76 million to 223.39 million New Taiwan dollars[2] if the combination of freeway lanes transformed from four MTC lanes and one ETC lane to the converse of one MTC lane and four ETC lanes (see Figure. 2 below).

[2] Exchange rate (1 NTD = 0.036 US Dollars)

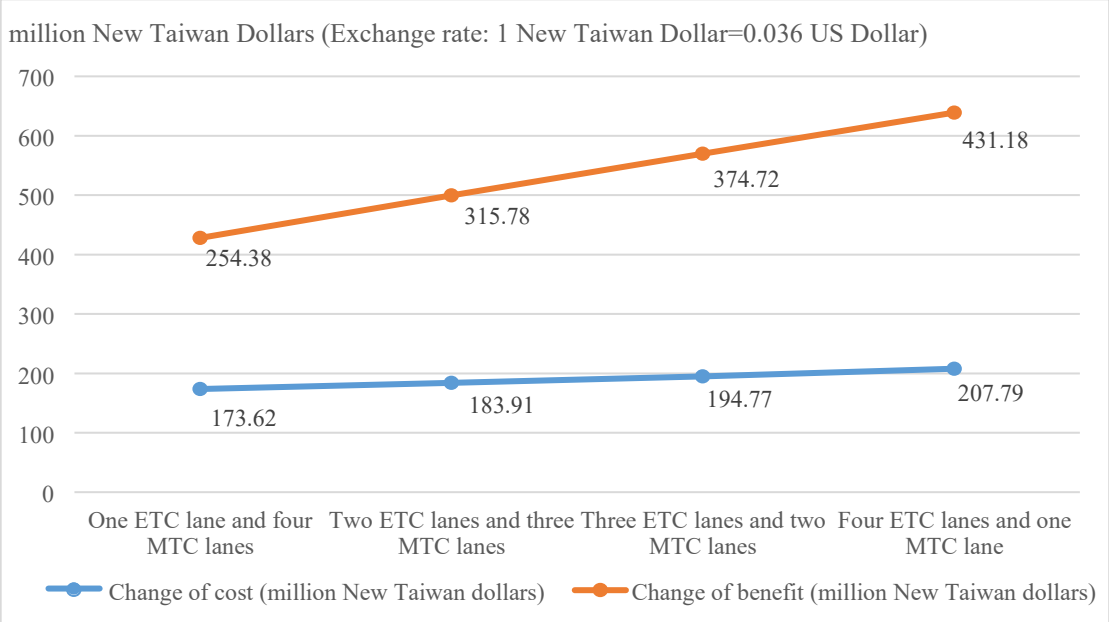

Figure. 2. Benefit and cost analysis for combination of lanes on the freeway in Taiwan
Source: Chang et al. (2004)

Furthermore, practically, from the perspective of country development, other research (Chu et al. 2008) estimated the cost / benefit ratio of ETC in Taiwan was overall 1.29 (0.74 for investors and 3.23 for freeway users, but only 0.40 for government authorities). Indeed, as noted below (4.4) the income from ETC in 2019 in Taiwan was US$ 789.6 million, so the cost benefits did prove to be significant. Admittedly this should be seen in consideration of the fact that this income is Private Company collected, and also that it should be outweighed against the costs of running the schemes, but it nevertheless shows significant amounts. In addition to monetary practical benefits, there were also predicted (Tseng et al., 2014) practical benefits in reduction of external emission costs reductions, and these predictions have also proven correct (Lai et al., 2021). Practically therefore, from 2006-2013, ETC lanes gradually increased; and MTC lanes gradually decreased.

Regarding tolls charged for ETC, currently (see Figure. 3), freeway drivers are charged based on distance traveled, with automated scanners checking each vehicle's ETC tag as vehicles enter and exit.[3]

Gantry sensor on the freeway	E-tag (front side)

Figure. 3 Gantry sensor and E-tag
Source: Taiwan Area National Freeway Bureau
http://www.freeway.gov.tw/english/Default.aspx

In terms of current toll rates (see Figure. 4 below), the first 20 km traveled are free. This policy is based on past research[4] that stated during MTC, the average distance of free charge drivers who travelled a short distance[5] was about 20 km although now, based on the user pay principle, this policy may in future be cancelled (see also below). For compact cars[6], the charge is US$ 0.04 per km for distances between 20~200 km. The toll then drops to $US 0.03 per km for distances of over 200 km. For heavy vehicles and trailers, for travel distances between 20~200 km per day, the charge is $US 0.05/km and $US 0.06/km, respectively. When travel distances exceed 200 km per day, heavy vehicles and trailers are charged $US 0.037/km and $US 0.045/km, respectively.[7]

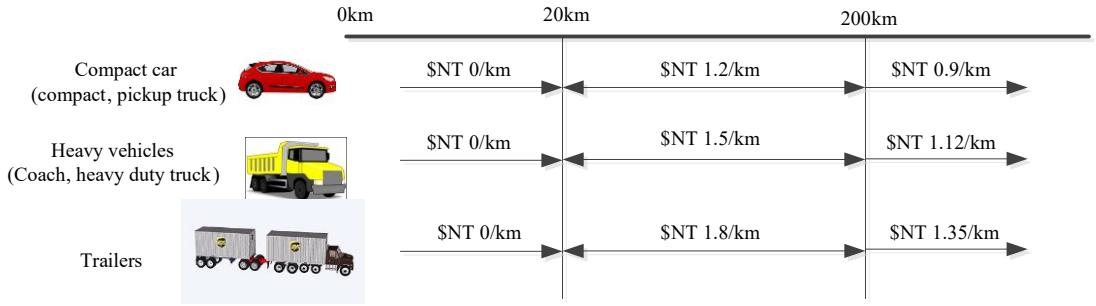

Figure. 4 Toll rate calculation
Source: Taiwan Area National Freeway Bureau
http://www.freeway.gov.tw/english/Default.aspx

The overall feeling amongst operators and officials, despite earlier issues as outlined above, was that current ETC system toll rates are fair. This was considered something that had taken much time to achieve though, one operator noting *"the current charge is formed based on various considerations. I think it is fair now."* Moreover, some considered fairness still required attention, one operator noting that although the current

distance based payment system *"fits the user pay principle"* the charge will be more equitable with future adjustments to a *"unit fee"* and also one to *"stop the discount program"* both for short distances of less than 20km and for some instances of *"long distance…. during the long holiday period"* of over 200km [8] Some government officials considered the charging system equitable on the whole, commenting on the *"fair charging mechanism after the implementation of the ETC."* Nevertheless, one official did note that no need to pay for distances under 20km meant that *"some people think it does not fit the user pay principle,"* although again, another official observed the change to a unit fee will rectify these inequities.

4.2. Technological Development

In Taiwan, a pay-for-use Vignette based MTC was introduced in July 1978. Freeway toll mechanisms have since undergone three stages of technological conversion: traditional MTC (before 10 February, 2006); a hybrid combination of MTC and ETC toll plazas (10 February, 2006 - 29 December, 2013) and; a fully ETC system (after 2 January, 2014). During 10 February, 2006 - 29 December, 2013, the number of ETC lines was gradually increased to replace former MTC lanes, and after 2 January, 2014, Taiwan was fully ETC, using RFID to detect the driver's windshield eTag and deal with toll billing issues based on vehicle types. The first generation adopted infrared ETC and was tested in two toll stations in No.3 Freeway from 1998 to 2001. The second generation also adopted infrared ETC system and was operated by the Far Eastern Electronic Toll Collection Co. (FETC) under a Build Operate Transfer (BOT) contract. Here, freeway users had to pay the fee to install one OBU with a pre-paid account. Technically, this system had some limitations. The OBU failed under low volume battery, and maximum vehicle passing speed was only 50-70 km/hr. Further, the acceptance rate of OBU was only 40% (see also Section 4.4. below). Consequently, in 2011 the third generation ETC system discarded infrared and adopted RFID. It now became free to use an eTag to pay the toll fee and pass the ETC sensor under a higher speed (about 110 km/hr). The function of the eTag was greater (e.g. quick charging with various weather conditions) and the adoption rate has gradually increased.

The decisions regarding which technology to adopt involved much discussion. For example, one government official said there *"existed disputes regarding the system standard, for example, the choice of microwave and Infrared Communication technology."* Other officials commented that the *"development process is difficult"* and

the *"system has faced many problems during the development period."* As one ETC operator noted, technology wise, the *"license plate identification system has spent lots of time to deal with it,"* with the related problem that *"in the past, the ETC company has charged fees twice for one car per time."* For this ETC operator, it was their conviction that the *"ETC company will continuously improve the current system and enhance the service quality."*

For operators, the technical process of introducing ETC *"had faced many disputes and costs and resource waste"* with many unknown outcomes, but that *"if we find something wrong, we correct it immediately in order to reduce potential damages."* Notably, this process required *"10 -20 years to deal"* with and even today *"some highway users are still not satisfied with the current system."* As an official also observed, even today the *"toll charging is not 100% correct"* and also that *"not every highway user uses an eTag"* which subsequently *"wastes administration resources."*

Nevertheless, despite the arduous nature of the technical process and the remaining issues, interviewees considered these alongside both the past and the future. For example, one ETC operator stressed the past system was highly inefficient as MTC *"needs to set up many camera systems, video facilities, communication systems, signal facilities, toll ticket management, and cash management works."* Regarding future technical opportunities, one operator noted, *"these travel data can be used to help the government conduct analysis regarding transportation management in the future"* and that *"it is expected the government and related research units can cooperate to explore potential application issues, e.g. Big Data analysis and blockchain application in the highway."* Government officials also considered such potential, one commenting that *"Big Data is an important development direction in the future"* as *"management units can analyze the vehicle data and conduct value-adding applications."*

4.3. Political Variation

Politically, the goals of ETC introduction in Taiwan were to improve travel efficiency, safety, environmental protection, administration related operation costs, and; to be focused on highway users themselves to achieve the user pay principle (mileage-based toll scheme). The idea of learning from other countries' ETC experiences was also noted by both operators and officials.

Many political tensions were connected with ETC being operated and implemented by a private company under a BOT system, yet remaining overseen by the government (cf Chang and Hsueh, 2006). These revolved around how much control should be with the company (private) and how much with the government (public), and

incorporated the discussions and debates over which technology to adopt (infrared or RFID). There was a strong theme of the government needing to be in control even though ETC was being coordinated and managed by a private company. This was encapsulated by the comments of one official who said "*I hope the government must effectively supervise the ETC operators and achieve a win win situation between the government, operators and highway users."* Nevertheless, it was also felt dangerous for the government to have too much power; one official commenting that *"I hope the political power does not affect decision makers' professional abilities."*

Another issue has been that MTC operators have struggled to protect their job rights after their jobs were rendered unnecessary by ETC.[9] Further, it has been difficult for former MTC employees to find new work, one operator commenting that *"it is difficult to find a good job since some operators are old or lack professional skills."* Politically, this issue was considered the responsibility of both the government and the ETC operating company. Related compensation plans for these toll operators are currently under continuous negotiation.

4.4. Publicity and Marketing

Taiwan has had mostly positive experiences and results of publicity and marketing of ETC. However, one negative experience was the low uptake of ETC in its early stages. This was due to four reasons. First, ETC users had to purchase the infrared based OBU and many people did not do so perhaps because the price (about 39 US$[10]) was too high. As one operator commented, *"some highway users… did not want to pay the fee to install the OBU."* Similarly, one official said *"highway users did not like to use the OBU due to… the… cost of installing it."*

Second, the OBU was large and battery power was short, meaning users had to regularly charge the OBU and considered it awkward. As one operator noted *"sometimes the OBU"* did not function due to a *"low or empty battery"* meaning that *"the highway sensor will take a picture and ask the highway user to pay the fee later."* Thirdly, MTC and ETC tolls were the same, thereby giving no financial incentive to use ETC, particularly as users had to buy the OBU themselves. Finally, some people were not familiar with the technology and consequently had no intention to adopt ETC. Another negative aspect related to equity and fairness. This was because before 2006 toll plazas

were located at toll stations and not at interchanges. Consequently, some users could enter the Freeway at one interchange and leave another without needing to pay a toll, if the distance was under 50km (Jou and Yeh, 2013).

However, despite these negative experiences, Taiwan has had many positive experiences, often as a result of resolving the negative issues. For example, as one government official noted, currently, the *"eTag is developed and can improve the weakness of OBU,"* and as the government has supported and subsidized this it has helped to *"reduce the burden of paying the toll"* for users and increased uptake. This change occurred in May 2012 and, *"when the government announced that users can use a free eTag to use the ETC system the utilization of use has become high (about 99% now)."* ETC quickly achieved over 93% in 2014, and the number of vehicles rapidly increased 16.9% (from 498.9 million to 583.1 million) during 2013-2014. This was directly linked to government marketing strategies, as the installment of an eTag was subsidised by the government to encourage uptake of ETC, and was thus free to users during 2014. After this initial marketing however, in 2015, eTag users were charged US3.6 - US7.0. Thus, the usage rate of ETC in year 2014 peaked due to the government subsidy at that time. Non-eTag users were nevertheless still able to use the ETC service since these users could pay the toll online or in a convenience store. In 2019, ETC usage was 92.57% (see Figure. 5). Resolving these technological issues, combined with subsidization of e-Tags, and also introducing a 10% discount for ETC compared to MTC, both related to increased uptake and also increased revenue.

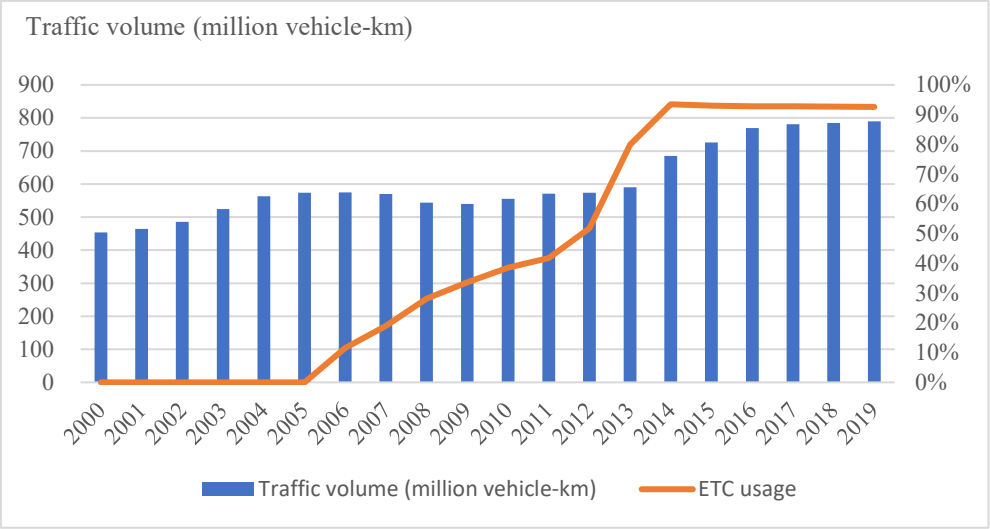

Figure. 5 Freeway traffic volume and ETC usage during year 2000-2019

Regarding efficiencies, the evolution of tolling methods significantly improved freeway traffic flow, as shown in Figure. 6, and these developments are used in publicity and promotion of the benefits of ETC in Taiwan (FETC, 2021). The Taiwan Area National Freeway Bureau estimated travel time can be reduced by 20-30 minutes from Taipei city to Kaohsiung city (about 350 km) with distance-based ETC.

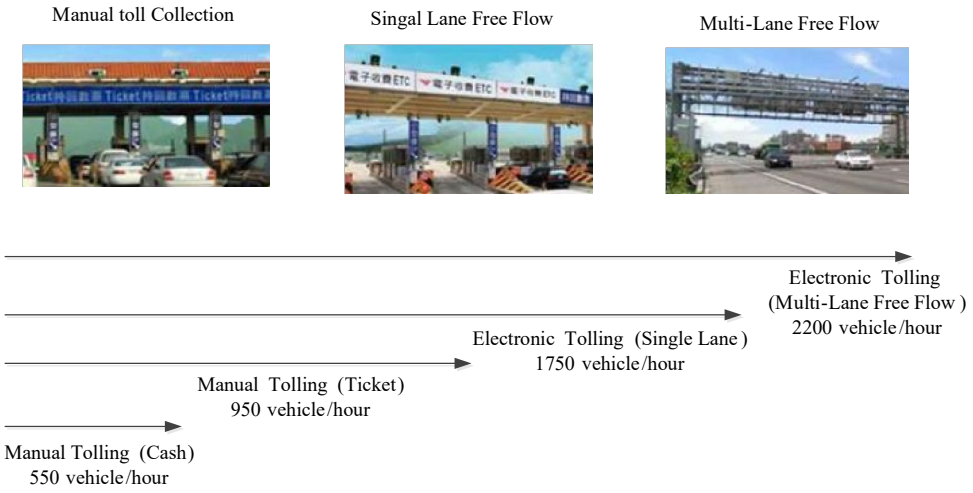

Figure. 6 Evolution Process from pay-at-toll station to distance-based electronic toll
Source: Taiwan Area National Freeway Bureau
http://www.freeway.gov.tw/english/Default.aspx

All such efficiencies can be used to publicize ETC. ETC operators commented that *"when introducing ETC system, human resource, time and related costs can be effectively reduced"* and this meant that *"consequently it will reduce fuel consumption and improve operation efficiency."* For government officials, ETC has enhanced the *"convenience of transportation and administration efficiency"* whereas the previous MTC required *"much time and human resource to deal with ticket and cash transaction problems in the traditional manual toll system."* The broader implications of such efficiencies were also noted, for example one operator observing frankly that, *"basically, ETC brings significant benefits for economic development in the country."* Another observing how the toll rate could be adjusted to achieve environmental efficiencies through the use of *"discrimination pricing in order to balance the traffic flow and reduce the air pollution and external costs."* Indeed, it was estimated that CO_2 reductions and fuel consumption were 29 thousand tons and 1.2 million liters, respectively[15] and recent research shows the environmental benefits of ETC over MTC (Lai et al., 2021). All these aspects help promote ETC.

Interestingly, in promoting ETC, although privacy was not critical in Taiwan, one operator commented that *"some drivers might worry if their personal data and privacy will be well protected."* Also, a government official stressed that it was key that any

data management *"must avoid violation of privacy rights."* The importance of ensuring ETC worked well were stressed, one official saying *"if the ETC system has problems, it might affect the justification of the policy and public reliance of the government."*

Also key to publicity and marketing is safety. In Taiwan, after ETC was implemented in 2014, freeway accidents actually increased 3.7% (from 18,713 (in 2013) to 19,404 (in 2014)).[11] However, A1 accidents decreased 9.2% (from 65 (in 2013) to 59 (in 2014)), and accidents within toll plazas decreased by 17.9% (from 1,568 (in 2013) to 1,299 (in 2014)).[12] As one government official noted, ETC has been able to *"reduce fuel consumption and accident issues."* Whilst there may be many possible reasons why accidents decreased around toll plazas, such as an improvement in driver safety, one possible reason is the ability of users to continue at the same speed without needing to slow down or stop at toll plazas as they may need to with MTC.

Another positive factor in Taiwan's ETC implementation was closely monitoring user experience, government/manufacturers/academic units have continuously implemented surveys (e.g. toll fare acceptance, use preference, etc.) tested works (including technique validation and verification problems) and obtained feedback and suggestions from freeway ETC users (Jou and Yeh, 2013; Jou et al., 2013; Chiou et al., 2013). For the future as well, ETC can make user's experience more beneficial, 4G and 5G mobile systems can improve vehicle communications, the internet of vehicles, and smart transportation. The current function of the e-Tag can be applied in freeway distanced-base tolling, smart parking (including smart guidance, enquiry and security) (Huang et al., 2019). Users can easily download the APP software to check their bank account balances, tolling calculation process, detail list for paths taken. The APP software is compatible with cell phone Android and iSO system and can be applied in customer relations management. Also, freeway authorities can use data mining to extract real-time traffic information on public transportation to help manage traffic flow, reduce congestion and emissions, and improve the overall user experience. All these facets can help promote and market ETC's benefits.

5. Discussion

The contextual analysis of Taiwan's experience to date with introducing ETC along the four axes of practical application, technological development, political variation,

and publicity and marketing reveals much about Taiwan's experience for governments and transportation agencies elsewhere when developing or introducing ETC. In line with many countries, such as Singapore and the Netherlands (Table 1), Taiwan has used PPP approaches and BOT to initiate ETC. In Taiwan's case, this has been linked with technological development and improvement. Although Taiwan did not take back control of failing PPP as for example Singapore has done (Table 1), it has switched technology from infrared to radio on the basis of a selected PPP approach that was not successful and in order to attain the optimum technology (cf. Iseki and Demisch, 2012; Vats et al., 2014). Notably, in Taiwan's case there is the political tension between awarding PPP BOT contracts but retaining governmental power to intervene and retain control. Indeed, Taiwan's government intervened to subsidize the e-Tag when it realized that uptake using the infrared OBU had been unsuccessful. This in turn helped to distinguish between the benefits of ETC compared to MTC for users, and had a dramatically positive effect on uptake of ETC. Here then, the axes of publicity and marketing, political variation, technological development and practical application all aligned. Perhaps uniquely in Taiwan's case, the issue of whether PFI would cost more (Acerete et al., 2009) was not mentioned, the issue of WTP (Glavić et al., 2021) was considered to be related to the practical application of ETC rather than one of user choice, most notably with the move to subsidize the OBU. Neither was there any mention of users simply deciding to stop using the road if a toll was considered too high (Hensher et al., 2016). Ability to pay was not considered as an issue of equity in Taiwan. Rather, issues of equity were considered to relate to the an equity interpreted whereby some roads charged tolls for certain distances whereas others did not, This may be simply due to Taiwan's economic position being relatively strong, and thus not something considered by the interviewees. This is a very different picture to that in other countries that are transitioning to a market based economy from a former communist one (Glavić et al., 2017; Milenković et al, 2018). Whatever the case, it is arguable that when governments and transportation agencies are considering introducing and developing ETC, carefully scrutinizing the contractual claims and responsbilities of any private companies tendering ETC contracts is critical. Arguably, evidence of previous experience, and evidence of contingency plans should the development of ETC not transpire as initially claimed should be insisted upon. Governments and transportation agencies might enlist the help of expert legal advice here, and also want to consider whether they would, as in the case of Singapore, wish to take back control of the contract, or in the case of Taiwan, retain oversight of the project and guide its direction. Deciding on such strategies in advance could well help with the implementation of ETC, especially if it does not go according to the intended plans.

The social benefits (Levinson and Chang, 2003) of ETC in terms of reduced congestion and emissions compared to MTC (Lai et al., 2021) in Taiwan are also key factors in any publicity and marketing of ETC and interlinked with ETC's technological development. Here, Taiwan is unlike many other countries whose focus may be on generating revenue for infrastructure development such as Austria (Table 1), or Norway (My, 1992), or on implementing ETC for environmental benefits, such as Holland (May, 1992). Undoubtedly this will impact upon any marketing selected. Politically, there were a number of issues in Taiwan's case, many of which are ongoing. The issue of reallocating or compensating former MTC employees is a political issue in Taiwan and would arguably also be so elsewhere in countries such as Japan and India (Table 1). In addition, privacy and data protection are a political issue closely linked to publicity and marketing although these may be accorded more priority in some parts of the world than others (e.g. the difference between the US (Riley, 2008) or the EU (Lerouge, 1999). Whatever the case, on the basis of the results here, it is arguable that the social benefits should be seen as operating synergistically with aspects such as publicity and marketing, in that where environmental benefits accrue from ETC, this can be highlighted in any publicity and marketing. Such benefits will be intrinsically linked to the rationale for the policy, and perhaps market surveys on the reasons why users would want ETC or why they may be opposed could help inform publicity and marketing campaigns and their targets. Also, governments and transportation agencies should carefully consider groups or individuals who may stand to lose from the introduction and development of ETC, and think of approaches to resolve any issues.

Politically as well, Taiwan's experience reveals the importance of continual debate and discussion, and to change policies where necessary. This has the need to switch where particular aspects are unsuccessful (compare with Singapore or Oman (Table 1)), and the clear implicatory need for such abilities to be incorporated in any PFI/PPP contracts made. It is arguable here that governments may want to consider the way such contracts are negotiated and, as noted above, to think about including terms that may help avoid private companies assuming too much power or income (Acerete et al., 2009), possibly through enlisting the help of legal experts. The importance of keeping a close eye on the practical application and reception of the technology through development has also been key in Taiwan's case, as is the need to consider ETC as part of a bigger social, economic and political picture. Improved traffic flow through ETC can in turn help reduce accidents, help drive sectors such as tourism (through incorporated e-Tags and the benefits of ETC technology in rental cars) and, vitally, improve the economy. All such factors could be continually monitored through surveys (Glavić et al., 2017) or focus groups (Di Ciommo & Lucas, 2014). Here, as the data

above show, there is huge potential for the continual collection and use of Big Data to improve traffic flow and ETC efficiencies. For example, Big Data could reveal times when it is advisable to vary the toll rates when suitable in order to help ensure optimum traffic flow and achieve environmental efficiencies. Further, Big Data could be considered and analysed alongside survey data to see the impact of changes on user perceptions and WTP.

What is also notable in Taiwan's experience, as commented on throughout the above but underlined here; is what was *not* said, or what was *not* prioritised by the inetrviewees. For example, the issue of equity being linked with all roads adopting the same policy rather than being linked with some drivers not being able to pay. Also, the issue of privacy being key, but not a major priority and more associated with publicity and marketing. Further, the fact that PFI was a choice rather than a necessity, and the abiility of the government to intervene and provide subsidy where necessary. Arguably these are all key points that others may consider alongside what Taiwan's experience was. In other words, to consider Taiwan's experience in light of their own contexts and possibilities, as well as their own policy goals and aims.

Table 2 draws together pertinent points for discussion by governments and transportation agencies when considering which ETC systems to introduce and how to develop them. We suggest this table could be used alongside other developed tools such as Milenković et al's (2018) Decision Support Framework for selecting an optimal road tolling system. Whilst located on separate axes it is again noted that there may need to be alignment between the axes on certain points. For example, political decisions to subsidize may involve the PPP contract, the type of technology used, and be part of the marketing and publicity. Nevertheless, it is hoped it provides a focal point for others when considering implementing or developing ETC, and perhaps Taiwan also.

Table 2 Discussion points based on Taiwan's experience

Axis:	Practical Application
Considerations:	Cost benefit Analyses; PPP / BOT contracts; what to do if PPP fails; how much government control; Charging type
Axis:	Technological Development
Considerations:	RFID and ANPR or GNSSS and GPS or both; gantry system or satellite tracking. Initial subsidization / discounting schemes; potential applications of developing technologies
Axis:	Political Variation
Considerations:	Reallocation of former staff; Equity in charges; purpose of ETC;

Axis:	Publicity and Marketing
Considerations:	Survey users; Extol benefits; Issue of data usage; Monitor usage; Safety;

6. Conclusion

This paper provides a contextual analysis of Taiwan's experience of introducing ETC and its current and ongoing development based on documentary analysis and qualitative interview data with ETC operators and government officials. Various fields of experts via snowball sampling offered professional opinions and comments regarding the interview questions. Such a picture complements the literature by providing a comprehensive view of the political and technical complexities of introducing and developing ETC that sits alongside existing studies into specific technologies and aspects related to ETC. The picture that emerges is one of the ultimate goal of improving traffic management by reducing journey times, improving environmental and social efficiencies, and, ultimately, strengthening overall economic development.

Taiwan's approach is unique to its own context, but its experiences as outlined here are of value for others considering introducing and developing ETC. The results presented and discussed here are primarily intended for policy and decision makers, but they could also be useful for policy advisors. For countries that are planning ETC systems (e.g. Sir Lanka), or to move from hybrid to full ETC (e.g. Japan) or even those already with a full ETC (e.g. New Zealand), it is hoped that discussing future developments guided by the axes used here and summarized in Table 2 above will be useful, particularly when considered alongside other developed decision making tools such as that in Milenković et al (2018). Critical to any decisions relating to ETC are the need to holistically discuss and consider issues of practical allocation; technological development; political variations in the country, and marketing and publicity.

Future research could focus on considering how to encourage uptake, user perceptions of equity, and on issues such as how toll rates align with average living costs and policy rationales (e.g. to alleviate congestion or to generate funds for infrastructure projects). Also, testing and refining the axes outlined above in Table 2, in Taiwan or in other contexts, could refine and develop it further for practical use.

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