
KTH Architecture and
the Built Environment

# Implementing Road Pricing:
# Standards, Institutions, Costs, and Public Acceptance

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Doctoral Thesis in Transport Science
with specialisation in Transport Analysis
October 2012

TRITA-TSC-PHD 12-002
ISBN 978-91-85539-92-5

Akademisk avhandling som med tillstånd av Kungliga Tekniska Högskolan i Stockholm framlägges till offentlig granskning för avläggande av teknologie doktorsexamen fredagen den 5 oktober 2012 klockan 9.30 i sal F3, Kungliga Tekniska Högskolan, Stockholm.

# Acknowledgements

I owe gratitude to many people for supporting me in the preparation of this doctoral thesis. Especially to my supervisors Jonas Eliasson and Maria Börjesson, for their enthusiasm for this project in particular and for their infinite passion for creating and spreading knowledge in general; to Ulla, Hjördis, and Folke for their love and patience; to all the folks at the Centre for Transport Studies, for adding to the socially inclusive, intellectually honest, and downright brilliant atmosphere there; to Lars Carlsson, Johan Hedin, Steinar Furan, Ulrik Janusson, Gunnar Johansson, Uwe Leinberger, Bern Grush, Jonas Sundberg, and Bernhard Oehry, for industry expertise and advice; to the Arena project for the discussions and ideas leading up to paper II and for access to the Delphi panel of experts used in paper III; to Vinnova and KTH for the financial support.

# Abstract

Much has been researched and written about road pricing, and especially how it affects traffic flow, congestion, the environment, and social welfare in general. This doctoral thesis analyses the *implementation* of road user charges rather than its effects. The dissertation consists of five separate papers, each addressing a subset of the topic. The first paper sheds light on the costs to introduce congestion taxes in Stockholm, and describes how public opinion and political risk lead to a system design that in all likelihood was more expensive than necessary. In the second paper the European regulation on interoperability between road charging system is evaluated from a benefit/cost perspective, which is found to be overly ambitious. Paper three builds upon the second, and suggests a general model for how costs and benefits interact in the case of road charging interoperability. In paper four a potential solution is presented for how the practical problems related to enforcement of road charging in an international context or in countries with weak institutions. The fifth and final paper analyses the public opinion of road charges, and especially urban congestion charges, using a survey conducted simultaneously in three European cities.

# Sammanfattning

Mycket har forskats och skrivits kring vägavgifter, och framför allt hur de påverkar trafikströmmar, trängsel, miljö och samhällsnytta. Denna sammanläggningsavhandling analyserar *införande* av vägavgifter snarare än dess effekter. Avhandlingen består av fem uppsatser som var och en tar sig an en delmängd av området. Den första uppsatsen belyser kostnaderna för införande av trängselskatter i Stockholm, och beskriver hur opinion och politisk risk ledde till en systemdesign som troligen var mer kostsam än nödvändigt. I den andra uppsatsen utvärderas den europeiska lagstiftningen för interoperabilitet mellan vägavgiftssystem ifrån ett nytto/kostnads-perspektiv, och finner den alltför ambitiös. Uppsats tre bygger vidare på den andra och föreslår en generell modell för hur kostnader och nyttor samverkar avseende interoperabilitet mellan vägavgiftssystem. I uppsats fyra presenteras en möjlig lösning på hur de praktiska problemen med beivrande av vägavgifter i ett internationellt sammanhang eller i länder med svaga institutioner kan lösas. Den avslutande femte uppsatsen analyserar allmänhetens attityder till vägavgifter, framför allt urbana trängselavgifter, med hjälp av en enkätundersökning som genomförts samtidigt i tre europeiska städer.

# 1. Introduction

These pages aim to paint a broad picture, showing how the five papers fit theoretically, empirically, and historically. In section 2, the research context is laid out, with an orientation to some key references in the fields touched upon by the papers. Section 3 deals with the models and methods applied in each of the papers, and section 4 summarises the results. Section 5 takes a step back and gives an historical context to how standards, institutions, and costs have interacted up until the situation seen today. This is followed in section 6 by six select cases illustrating how public acceptance has developed and how it interrelates with political acceptance. Section 7 concludes.

# 2. Research context and question

There is a vast amount of research carried out on the subject of the economics of charging for road use. In this body of research, the favoured term is *road pricing,* while the industry more often refer to it as *road user charging.* There is a slight difference in meaning; road pricing refers less to the practical process of measuring, pricing, and billing the use of roads, and more to what happens to road traffic demand when the use of roads is subject to a direct monetary cost in relationship to the quantity of use. Pigou (1920) made early reference to road pricing, although not as much as a policy tool for transport planning, but rather as a case in point when debating the economics of welfare in general, and the merits and shortcomings of private enterprise in particular. Several decades later, Vickrey (1955; 1969) made a more practically orientated description of the idea as a policy tool for actual use. Several authors developed the concept further during the last decades, including its relation to equity (Hau, 1992), how that in turn is affected by value of time (Brownstone and Small, 2005), how to use the revenue (Small, 1992), and the demand elasticity at play (Goodwin, 1992).

In those studies however, the focus is mainly on *congestion* pricing, i.e. the special case of road pricing where the policy aim is to reduce congestion by applying a user fee. For a transportation economist, this is indeed an interesting concept, as it marries together the intricacies of the speed-flow curve from highway engineering with marginal external cost theory from economics. But there are other, more widely used, forms of road user charging, also worthy of attention. Mohring and Harwitz (1962), De Palma and Lindsey (2000), and Verhoef (2009) all address the industrial organisation of toll financed road construction and ownership. By ways of modelling they show under what circumstances toll financed road construction is a profitable operation for the firm, and when it is a desirable solution for society. In their models however, the process of measuring the road use and issue the charges is almost ignored, and the friction caused by the act of charging is approximated to zero.

With a more empirical approach, studying eight completed toll road projects, Fishbein and Babbar (1996) sets out to answer a similar set of questions; When to toll and when not to, and when to use private concessionaires and when government construction is preferable. By studying real implemented systems, they notice the non-negligible cost and friction caused by the act of tolling. They conclude, (among other things) that;

> *[t]he primary economic disadvantages of tolling are the time and cost required to implement toll systems and the potential delays and excessive traffic diversions associated with toll collection. On purely economic grounds, therefore, tolls should be used when the benefits of toll revenues and traffic management exceed the costs of implementation and any delays and excessive diversions caused by the system.*
>
> *Fishbein & Babbar, 1996, p 20*

This is the starting point for my work with this thesis. I wish to address the challenge of actually putting a road user charging policy in place, and to do so from the perspective of the city, region or other road owner perspective. By describing the market for road user charging systems, who its actors are, their incentives, and challenges in terms of operation, enforcement, and acceptance I hope to be able to assist legislators, policy makers and government offices getting the regulation and contracting right, so that costs are low and quality and performance is high.

Clearly, it matters how one designs and carries out the charging process. Odeck (2008) addresses the efficiency of toll operating companies in Norway, and finds a few remarkable things, including an apparent disutility from using electronic vehicle identification, and that the studied firms operate under increasing returns to scale as soon as they cover 20 tolled lanes or more. Odeck and Bråthen (2002) look at the successes and failures of three Norwegian city toll rings, given the political context in which they were constructed. System cost is linked to public acceptability by some authors, including Odeck and Bråthen (1997), while others, such as Jones (1995), Schade and Schlag (2000, 2003) and Winslott-Hiselius et al (2009), leave it out of their analysis of reasons to accept or dismiss a road-charging scheme.

In the first paper of this thesis, I address the cost of the Stockholm congestion tax system. It has been cited to show how expensive it is to implement congestion pricing in general, and that Stockholm in particular was extremely expensive. After interviewing some of the key project participants and going through the project documentation, I come to a different conclusion, and find that political risk, public acceptability, system performance, and cost all play important and deeply interconnected roles, in a way previously not addressed.

One way of reducing cost and improving performance, favoured at least by legislators at the EU level, is to increase the level of interoperability, i.e. the ability to use on-board equipment from one charging system when travelling in other systems. Viegas (2003) takes on the subject of interoperability, and states that although important, it is still a feature largely lacking in the lorry charging schemes in Europe today. He pinpoints standards as the key enabler to interoperability. In an industry-generic analysis, Economides and White (1994) and Economides (2003) come to the same conclusion, by connecting compatibility, standards, and network economies. However, Economides' arguments are partly refuted by paper II and III, where I analyse the interoperability of road user charging systems in Europe.

In paper II, a recently passed EU legislation is critically examined by subjecting it to a benefit/cost analysis, where I model the costs of establishing interoperability and the potential benefits that may come from its introduction. Among other things, it is shown that the contracting side of interoperability can be equally critical as the standards involved, and offers a range of policy recommendations.

Paper III takes up on one of the policy recommendations from paper II, and suggests a vertical separation of the toll charger role, which is by necessity a local monopoly, and the service provider role, which may very well be opened for competition, possibly by firms in other industries. As with paper II, the argument is made in relation to the recent EU legislation on the subject.

Unlike paper I-III, which presume a strong institutional framework, paper IV focuses instead on what happens when a road pricing scheme has no legal enforcement infrastructure to fall back on. While a tollbooth with a physical barrier is a simple solution that mostly works, the toll plaza can itself become a source of congestion (see e.g. Times of India, 2012; Guardian, 2012; This Day Live, 2012). The transition to a free flow tolling architecture however, typically rests on an assumption that a picture of a vehicle's license plate means that its owner can be looked up and an invoice can be sent, and that if it is not paid, an effective mechanism for legal collection can be activated. There are two environments where none of this is true. First, there are all the countries and regions where the vehicle database and citizen register are incomplete, incorrect, or even non existent; or where the institutions maintaining them are too ineffective to support the large number of small transactions required to operate a road

user charging scheme. This is typically the case for poor countries or those undergoing very rapid change. Second, there are situations where a significant share of the traffic comes from other countries. There too, the enforcement process lacks the ability to effectively look up owners and fine them, unless there are deeply integrated legal systems on both sides of the border.

In both those cases, it may be possible to implement a free flow architecture anyway, skip the invoices, and instead rely on the fact that most people will eventually come back to the charging system. And when they do, the operator can charge them for all the outstanding debt. Paper IV presents in detail how such a charging scheme could operate, and simulate the behaviour of both the operator and the vehicle owners, in order to get an order of magnitude estimate of the effort required.

In paper V finally, I return to the very first step of getting a scheme deployed, namely the public acceptance. Together with colleagues at the Centre for Transport Studies and a team of researchers from Finland and France, I developed a survey, which was issued to 4500 people in Stockholm, Helsinki, and Lyon. The survey included a wide range of questions on political sentiments, the perceived fairness of a number of hypothetical situations, and of course a few detailed questions about attitude to congestion charging.

# 3. Models and methods

The thesis put forward here is taking a multi-disciplinary approach in its quest to answer the overarching question of how to implement road user charging effectively. The papers it consists of use different methods, and deal with quantification in different ways.

In paper I, the method is qualitative – a case study. Although I try to quantify the effect of each of the cost driver discussed, I deliberately avoid attempting to model them, or even sum them up. This is partly because the figures are uncertain, and it would be dubious to draw any far-reaching quantitative conclusions from them, but most of all it would draw the attention away from the purpose of the study. What I try to uncover is the causes and effects of the cost structure, to establish a systematic understanding of the project, not to determine a counterfactual total cost for the project.

In paper II, I develop and use a model, calibrated in real monetary terms. The model is developed as a simplified representation of the major forces at work when establishing road user charging interoperability. Empirical observations as well as expert judgment are then used to calibrate the model and calculate the results.

Paper III is also a modelling exercise, but where the model is not explicitly quantified. Still, it is built on assumptions that can be mathematically represented. In the model, I argue by examples and logic, to show the principal characteristics of the functions involved, and by doing so indicating the functional form, but not the values of any parameters. By reasoning about the slope of the curves, and what must follow, I deduce my result in diagrammatic form.

The charging scheme invented in paper IV is formalised and declared mathematically, and then implemented as a simulation in Matlab. It builds loosely on previous studies in the fields of criminology and economics of crime. The agents in the model are assumed to be driven by rational choice (with some limited flaws, including hyperbolic discounting, imperfect foresight, and a slight delay in observing the real risk of cheating a road toll). In the simulation environment, a large number of actors are allowed to play out their strategies under different environmental parameters, and resulting equilibria are observed.

In paper V finally I stick mostly to recognised methods. The bulk of the survey analysis is done using proportional odds logistic regression, with the answer to the question “How would you vote if there was a referendum on congestion charging today?” as the dependent variable. There is some method invention in this paper as well, including an attempt to project the voting behaviour of the three

populations and some sub samples, given combinations of multiple questions. This is used to measure the effect of committing revenue to specific purposes, such as public transportation or new roads.

# 4. Results

In paper I, the main conclusion is illustrated by a schematic picture of how cost, risk, redundancy, performance, and acceptability interact. It shows how critical the bad start, with a broken election promise, was for the Stockholm congestion tax. It fuelled low acceptability, which increased the political risk. Anticipating the risk, redundancies were built into the system and its operation, redundancies which led to two things; costs went up, but so did system performance. Very few errors and outages were recorded during the trial period, which likely had a positive effect on acceptability. Hence, ironically, the high risk, high redundancy and high cost environment may have been, as a net effect, beneficial for the project's overall outcome.

The results of paper II, to some surprise, showed that harmonized technical standards were only capable of bridging some of the cost gap. Contractual issues and a heavy weight from cost of the installed base, as well as a small total potential benefit, make it likely that long-range interoperability for anything other than dense transit corridors will not appear by itself any time soon.

Paper III concludes that the policy of vertical separation of the tolling industry is likely to have beneficial effects on the level of interoperability. In addition, it may also contribute to innovation and lower overall cost in the industry, by enabling competition in a larger share of the market.

From the results of paper IV it can be made likely that a well designed enforcement strategy can enable free flow tolling even in a weak institutional environment. By carefully selecting whom to target, the enforcement can be done using as little as one seventh of that required with random selection. It is also observed that the initially expected probability of being enforced has a fundamental effect on the enforcement effort required to keep a scheme in a low-cheat equilibrium.

In paper V finally, I capture some aspects of public acceptance of congestion charging in particular, and to some extent other forms of road user charging. Most of the observations that can be drawn from this study have been shown in part previously, including the importance of having experience from a scheme, the costs one expect to be paying, and how the toll paid is spent. It also confirms that socio-demographic variables like income and gender have very little influence on attitude, with the notable exception of families with children being significantly more negative. It is also shown, beyond what previous studies have been able to establish, that self reported value of time has a strong explanatory potential, and that is true also for populations with no own experience from congestion charging. This would reduce some of the credibility in the notion that people can foresee the costs but not the benefits, as an explanation of support typically being lower prior to introduction than after having experienced a scheme. These findings are fairly consistent across the three population, and are suggested as being universal.

From the questions of political and philosophical nature, including the issue of fairness, the environment, and the role of government, it is noted that although each of them has strong explanatory power in at least one population, they differ substantially across populations. As an explanation here I suggest that these are issues more loosely related to congestion charging, and much more dependent on the existing frame inside which one already thinks of things like cars, the environment, government, and fairness. Thus, they are powerful influencing factors, but there is no reason to believe them to be universal, neither in time nor in space.

# 5. The story so far

In Johan August Malmström's painting *The Gate Coin* (Grindslanten), five children are seen, in various positions to a coin, probably tossed from the horse carriage disappearing in the distant, as a gratitude for the service of opening the gate. Paying local young ones for this kind of assistance was commonplace in the 19th century agricultural Sweden, when roads went straight through cattle pastures. Similar in appearance though, most road tolls work the other way around – the money is paid for the right to pass, and the gate is opened in response to the payment. With a wide range of motives, the institution of paying a small fee for passing a gate on the road has been seen in various forms throughout history.

Aristotle makes brief mentions of tolls, regarding the roads in India and Arabia, and some of the roads of the Holy Roman Empire may have been tolled, as early as during the 14th century. (Munroe, Schmidt, & Westwind, 2006) For purposes of lending legitimacy from history, it is tempting to treat such instances as evidence of road user charging being something natural, historically inevitable. Early and poorly documented references like these are however dubious. The toll charged may just as easily be an example of extortion – or excessive use of scarcity power – by whomever it was that could control the access of a road, bridge, or mountain pass, rather than an example of what is today recognised as a legitimate toll road.

## 5.1. First generation road user charging: The turnpikes

The first legally supported wide adoption of a pay-per-use principle for roads was the turnpikes established in England during the 18th century. Development of new road building techniques made it possible for groups of investors to band together and have roads built, which were then made available to the public for a charge. The first such turnpike trust registered in 1709. A gate with pikes prevented unauthorised access, and only after a toll had been paid, the gate was opened (turned). Thus, the term 'turnpike' came to be the contemporary name for toll roads. Turnpikes quickly became an important

type of roads in England, and by 1829 more than 3,500 turnpike companies were in operation there (Sponholtz, 2008).

The concept spread to the United States, and in the late 1790:s, the Lancaster Turnpike was opened. Nevada was among the first and most significant states to adopt this early form of toll roads, and hosted more than 100 private roads in the late 19th century (Munroe et al., 2006). By that time, private toll roads outnumbered public roads in the USA, totalling more than 1,000 companies and 16,000 km (Klein and Fielding, 1991; Fishbain and Babbar, 1996).

Just like today, not everybody enjoyed having to pay for the use of the roads, especially not in cases where the turnpikes were built on top of already established paths. In fact, only a small share of turnpikes cleared new way and established routes previously not available to travel. In the United States the term 'shunpikes' was coined to describe the phenomena of finding and exploiting toll-evading routes through the bush, passing the gatekeeper's booth, and then again accessing the road. Meanwhile in England, the hatred towards the turnpikes sometimes led to violence, and after several turnpike riots, King George II introduced the death penalty for burning or destroying turnpike gates (Lay, 1992).

During the 19th century, several contributing changes in technology and society lead to the end of the great era, and most of the turnpike trusts faced financial catastrophe, bankruptcy, or overtaking by the government. At first, the construction of railroads and improved canals increased the modal competition to road transport. Additional pressure on the turnpikes came from several technological advances, coinciding roughly in time: The introduction of the rubber wheel, the use of macadam, and later asphalt, gasoline powered internal combustion engines, and the popular adoption of bicycles. These inventions jointly increased both the capacity of the vehicles and the quality requirements on the roads, to a level where turnpike trusts were not capable of assembling sufficient capital.

Possibly an even more important reason for the end of the turnpike trusts though, was a shift in political culture during the early 20th century, when fewer public figures argued for individually owned capitalist solutions, instead favouring progressive ideals, scientific policies, and experts rule. This trend too, first took root in Europe and then gradually spread to the United States. After the era of the turnpikes, toll as a way of financing roads became less frequent, and general taxation, and later fuel and vehicle tax, overtook as the main source of capital. During this period, toll roads where less in vogue, being the exception rather than the rule (Klein and Majewski, undated; Lay, 1992; Sponholtz, 2008).

## 5.2. Second generation road user charging: Toll plazas and the advent of transponders

It was not until the second half of the 20th century that toll roads started to play an important role in countries' infrastructure strategies again, with France, Argentine, and South Korea among the pioneers. Just as during the turnpike era, the main purpose of these road user charges was the direct financing of the particular road system where the charge was levied. Concessions for road construction were issued, bundled with the right to charge for road use, and the firms competing for such contracts developed skills for toll collection and financing, in parallel to their expertise in road construction. (Lay, 1992; Estasch et. al., 2000)

The architecture of those second-generation toll roads is still visible today, with their characteristic toll plazas and wide ranges of tollbooths. The methods of payment offered at the toll booths have evolved since the early implementations, from manual payment, via automatic cash baskets and credit card machines, to the use of transponders, automatically informing the toll plaza equipment what account to charge the toll to. With the gradual adoption of transponder-based payments, an increasing share of tollbooths was converted to be for transponder users only. In those lanes, vehicles typically need only to slow down, without coming to a full stop. The maximum speed has gradually increased and is no longer of any concern for most systems' ability to read a transponder. This feature leads to shorter and

less frequent queues, to the benefit of the driver, and takes away the need to staff the tollbooth, to the benefit of the operator of the charging system.

With the introduction of transponders as method of payment, the charging process became more complex and technology intensive, and a new breed of firms appeared on the stage – the toll collection equipment providers. In Europe, the toll system departments of motorway concessionaires, like Sanef of France and Autostrade of Italy, suddenly saw competition from new offerings from some of the large electronics companies, like Bosch and Siemens of Germany, and from new stand-alone tolling technology innovators, like Kapsch of Austria and Q-Free of Norway.

A struggle between competing standards emerged, with each firm putting forward its own proprietary specification as functionally superior, hoping that it would become the de facto standard in Europe. This typical aspect of a war of standards, as described by Shapiro and Varian (1999) among others, was further intensified by the fact that motorway concessions and procurement of systems were controlled by national governments, which have an interest in promoting domestic firms. The war of standards was however only partly strategic, as a typical road charging project was a small side order of a major road construction project. Supported by nationalistic industry politics, there was initially a significant overlap between a map showing the location of tolling systems and a map showing the country of origin of its equipment providers.

In Europe, three firms – Bosch, Combitech (later acquired by Kapsch) and Thales – were the first to leave the strategy of proprietary specifications, and jointly presented an open specification in 1996, dubbed GSS. At the same time, the European Committee for Standardization (CEN) had already a working group (TC278/WG1) on the subject, and EU had initiated a series of projects, with CARDME directly aimed at interoperability. These initiatives served as a basis for the following interoperability projects in Europe during the late 1990:s, including the A1 and A1+ projects. In 1998 the technical committee dedicated to transponder-based road user charging at CEN and the International Organization for Standardisation (ISO), managed to define a standard, dubbed ISO EN 14906, with broad enough definitions, and with a sufficient number of options, so that a majority of equipment providers could agree upon it (Hedin, 2008; Pickford and Blythe, 2006). This was an improvement, in that the total number of possible designs was now limited to a predictable and well documented finite list of alternatives. The downside of reaching an agreement this way, by allowing different options and settings inside the standard, is that adhering to the *standard* still does not mean adhering to the same *specification*. Thereby standard compliance does not equal immediate potential for interoperability.

It was not until 2007 that a more precise specification, the profile standard EN 15509, was agreed upon, with the explicit purpose of being used to enable interoperability (Hedin, 2008). Today, when Norway's Autopass is gradually joining the European consensus, the Autostrade's Telepass system, ubiquitous in Italy but practically unseen elsewhere, is the only case in Europe where a national proprietary specification is still thriving. (Hedin, 2008; EU, 2009; Furan, 2010).

Interoperability is promoted by harmonisation, and on the technical level this has been to a large extent successful. However, the largest and most successful European example of international interoperability, the Scandinavian EasyGo framework, still relies on the roadside equipment being capable of recognising two different transaction formats, thus hiding the remaining heterogeneity from the end users. Although the technology would allow interoperability in Europe to go further, customer demand is limited, and it has not been a top priority of the owners of other systems (Hedin, 2008; Furan, 2010).

Governments and road concessionaires in Australia, South America, and a few countries in South East Asia including Thailand and Malaysia, have chosen to follow the European standards path – or rather, chosen to source their equipment and services from providers in Europe, with the related standards following. In those places there is no or only limited competition from local equipment manufacturers, and the network effects at play are thus only working out on the system customer side, i.e. there is some benefit in selecting the same technology as one's neighbour.

The North American market developed largely independent of that in Europe. There, another war of standards played out with different proprietary technologies competing for domination. A lower level of government intervention in that market, combined with a larger number of open standards adopted, have contributed to a market characterised by regional de facto standards, some open and some proprietary, just as the idea of a war of standards would predict (see Shapiro and Varian, 1999).

Any state or city comparing different systems on offer will be influenced not only by the features and performance available, but also by the system choices already made by their neighbours. If the surrounding road systems use transponders of type X, some share of the locals will already subscribe to those systems, offering a cost and convenience premium for local governments choosing the same supplier as already in place in the neighbouring areas. This is what Katz and Shapiro (1994) calls indirect network effects, and Economides (2003) models as one-way networks, which is one of the fundamental characteristics firms have to address when crafting their strategy. Firms supplying systems in a market dominated by proprietary standards and network effects have the choice of keeping their technologies proprietary and closed, leading to a winner-takes-all market, or to opt for open interfaces, thereby making intermediate market shares feasible as well.

In the North East of the United States lies the by far largest continuous region using the same tolling equipment, the *E-ZPass* branded transponders, used by some 24 highway agencies in 14 states. The technical specifications are proprietary, owned by the Austrian company *Kapsch* through its newly acquired US subsidiary *Mark IV*, who also source the transponders (IAG, 2012). The patents protecting the technology have however started to expire, and competitors have recently begun offering multi-capacity transponders (Tollroadsnews, 2010).

Further South, in Texas and Florida, it is instead *Super eGo* sticker tags, based on ISO:s *18000 6B* standard, that are used. Georgia, Colorado, Washington, and Utah recently opted for the similar but incompatible *6C* variant of the ISO standard, also based on RFID as used in retail and logistics. Parts of Dallas and Oklahoma use an older read-only tag, based on the *ATA* standard. In California and Denver, Colorado, another proprietary variant of ATA, dubbed *Title 21*, is used. Toronto and Minneapolis both use the *ASTMv6* open standard as their protocol for tolling, although this is a technology normally used for other services, such as weight control of trucks and border control (ISO, 2010; Transcore, 2010; Tollroadsnews, 2010 and 2012).

With this vast number of standards around, interoperability may appear as a distant dream. At the same time, being a deeply integrated economy, with car travel representing a large modal share also for long distance travel, North America ought to have stronger incentives for establishing interoperability between systems for road user charging than any other place. It may therefore be a good place to look for examples, when considering interoperability elsewhere. Up until now, interoperability has largely been achieved by gradual regional harmonisation, which is the result when each system buyer selects the same technology as its closest neighbours.

Although this strategy is capable of reaping quick benefits, two consequential problems are pushed to the future. First, if the technology chosen is proprietary and patented, the monopoly power of the supplier grows stronger for every new system added to the interoperable framework. Second, when such islands of monopolistic interoperability grow larger, they touch borders with other regions, based on different technologies and standards.

The promise of interoperability is now being offered from two directions, based on fundamentally different strategies. From the government's side, the US Department of Transportation has assigned a new frequency band to road transport and telematics, in the 5.9 GHz range. On top of the carrier, protocols and services are being developed, including the overlapping initiatives *CALM*, *VII*, and *IEEE 801.11p*. These services are aiming at enabling much more than tolling applications, offering bandwidth sufficient for multimedia streaming, compared to the miniscule data rates offered by traditional transponder based technologies (US DoT, 2010).

From the industry's side, there is so much money is invested in existing infrastructure and installed base of transponders, that a complete replacement of the existing 915 MHz systems is unlikely to happen any time soon. To see what is going on in this particular phase in the war of standards, the places to monitor are those where the borders of the growing islands of monopoly-harmonised interoperability meet, as in the case of where the South end of E-ZPass-land meets the Southern regions where sticker tags dominate – a standards fault line that happens to be located in North Carolina. In a recent procurement, the highway authority there opted for a solution where the road side is equipped with multi-protocol capacity, and the road users are offered to choose between a simple, low-cost tag that works only in the local system, and a multi-protocol transponder that can be made to work with almost any system in the country. Although being offered a system capable of the new government sponsored 5.9 GHz band, this was not chosen, as its benefits are still to be proven, while its costs are certain and substantial (Tollroadsnews, 2010).

Herein lies an important lesson: Creating interoperability by duplicating the capability of roadside infrastructure and transponders is more costly per unit compared to a hypothetical situation where everybody used one and the same specifications everywhere. But there is an installed base to consider. The choices made today are influenced by earlier decisions, and two end states cannot be compared without understanding the available paths to get there. If the 5.9 GHz initiative is to succeed, policy makers and advocates of open standards must ensure that each step on the way towards the goal is beneficial for the ones making the decisions, i.e. the highway agencies choosing technologies, and not just an attractive island with no bridge to get there.

Asia is a much larger geography, with less international road transport crossing national borders compared to Europe, so the demand for international interoperability is likely to be even smaller there. Additionally, China, Japan, Korea, and Taiwan all have built their road charging systems upon their own national and proprietary standards. All of them are likely to have been chosen in the hope of establishing future export products, with a little help from an initial government protected monopoly. However, none of these standards have made any footprint in the international market. This may serve as a harsh reminder of how difficult it is to dictate a winner in a global war of standards, even if one can beat the domestic market of the world's second largest economy. Failure to profit from reference installations is however not unique to national governments. Mitsubishi, who built the Singapore system, has also failed to reuse this early success story in international sales, and Singapore is now the lone user of its 2.4 GHz technology, and that too, is about to be replaced.

By tradition, many Asian countries are cash based economies, relying less on credit cards and online account withdrawals, compared to Europe and the US. Therefore the road charging systems there commonly features transponders where the user inserts an integrated circuit card, or *smart card*, from which the toll is deducted directly. By using an electronic purse this way, a different range of business processes are required, compared to the European and North American solutions, where the issuer of the transponder is also keeping an account, with a transaction history, a balance, and possibly some credit availability, for each of its subscribers. This too may have influenced the lack of overlap between Asian systems and those in Europe and the US.

## 5.3. Third generation road user charging: Multilane free flow, number plate reading and congestion charging

Once the transponder technologies were deployed, and the no-stop-lanes at the toll plazas became ubiquitous, it was tempting for anyone establishing a new charging system to go for an all-transponder solution to begin with. Ideally, one would want to get rid of the barrier that opens upon detecting a recognised transponder, as well the physical lane separators. Systems with such capabilities were demonstrated by various equipment providers during the 1990:s, with the Austrian Ökopunkte and Singapore's ERP project among the first full scale commercial installations, both completed in 1998.

This development defined a new category of road charging architectures, dubbed "multilane free flow", which has since become the architecture of choice for the majority of new installations.

To make the multilane free flow possible, two related challenges had to be overcome: First, to allow traffic to flow freely one needs to get rid of the physical barrier, which creates the need for some other method of enforcement. As vehicles are not physically prevented from passing without a valid transponder, cameras are installed, to capture the number plate of toll evaders, for later identification and collection. Armed with the ability to look up the registered owner for each vehicle, and a process for legal collection, the barrier is no longer a necessary feature. By these means, free flow was enabled in many installations, but only available in the physically separated transponder-only lanes of traditional toll plazas.

Second, to lose the lane separators, and enable tolling at a cross section of any multi lane road segment, a more advanced technical invention was required. With cameras taking pictures of vehicles passing, and radio receivers registering the identity of their transponders, there must be some way of securely matching each image to its associated radio signal. If several vehicles pass a multi lane free flow charging point side by side, the time of passage alone is not sufficient to do the matching; lateral positioning is required as well. Different suppliers of technology have solved this in slightly different ways, but a typical installation uses a combination of lasers, cameras, and radio transmitters and receivers, all connected to a road side computer, processing the data and creating combined passage transactions of sufficient accuracy. With both technologies in place, multilane free flow quickly became the norm for new systems.

Up until this point in the road charging history – about the year 2000 – the main purpose of road charges has been financing of the roads, in most cases also with a match between the road where the charge is levied and the road being financed. However, in parallel to the development of the multilane free flow systems, new road-charging imperatives evolved as well. With Norway as the early adopter, new charging systems were added to infrastructure already built and paid for, as opposed to being part of a new piece of infrastructure. Among the often multiple and overlapping reasons to introduce a toll on an existing road, at least four categories can be discerned during this period:

- Charging for the use of an old road to finance building a new road.
- Charging foreign vehicles as a means of levelling the competition between domestic and foreign haulier firms and capture tax revenue otherwise unavailable.
- Charging separately for the use heavy goods vehicles, as they generate disproportional wear and tear on the roads, and to some extent other external effects.
- Charging congested areas and routes and during rush hours to manage demand and improve traffic flow.

Different as these policy objectives may appear, they have all been enabled by the multilane free flow systems, as it is generally difficult or impossible to retrofit large toll plazas on roads in urban environments or where such facilities were not planned already from the beginning. In contrast, adding a simple gantry, with radio equipment and cameras mounted on the overhead beam, is much simpler as it requires less interference with the existing architecture on and by the road.

When road user charging became a tool useful for a new set of policies, one of the consequences was that the system providers had a new and more complex customer segment. No longer was it enough to communicate with highway authorities and motorway concession operators. Suddenly, ministers of finance, trade, and the environment were equally likely to be the sponsor of a road-charging project, as was previously the minister of transport.

Examples of road charging projects where these new policy objectives played a role include the Austrian lorry charge, dubbed GoMaut, opened in 2004; Singapore's congestion charging system, which went from a manual sticker system to being fully electronic in 1998; the London congestion

charge, opened in 2003; Stockholm's congestion tax system, trialled in 2006 and made permanent in 2007; and the Czech lorry charging opened in 2007.

In parallel to the suppliers' development of new solutions, national governments and the EU kept pushing the interoperability agenda by financing a continued series of projects; MÅNS, VIKING, CESARE, PISTA, MOVE-IT and more. In 2001, to the surprise of many, the European Commission announced that they were no longer going wait for the market and standardization organizations to reach interoperability agreements. Instead they were going to initiate new legislation, and started drafting the first version of what was to become the Directive on interoperability in for electronic fee collection, "the EFC-Directive".

In the United States, a special variant of the third generation systems has emerged, where one or a few lanes on a multi lane motorway are tolled, leaving the remaining lanes free of charge. The first such Express Toll Lanes (ETL), widening the I95 in Maryland, is under construction and expected to be operational in 2014 (MTA, 2012). That project however, is only the latest step in an evolutionary development going on for at least three decades. In 1973, a bus-only lane in Northern Virginia was converted to become the first High Occupancy Vehicle (HOV) lane in the United States, where only cars with a minimum number of passengers are allowed to drive. This was at a time when congestion started to become unbearable, and it made sense to give priority to vehicles with a higher utilization. During the late 1970:s and 1980:s many more HOV lane projects were completed (BTS, 2012). The effectiveness of a HOV lane is however very sensitive to the level of demand. With too few vehicles, it leads to under utilization of the road, and with too many, it too becomes congested, losing the desired incentive of car-pooling.

As a solution to the inefficiencies of the HOV lane, the High Occupancy and Toll (HOT) lane was introduced, with the first instance on a 15 km section of the SR91 in Orange County, California in October 1995 (GAO, 2012). On a HOT lane, the excess capacity in the HOV lane is made available at fee, which varies with the congestion level (or is approximating congestion level by varying with time). Today there are twelve such HOT lanes in operation (in California, Colorado, Florida, Georgia, Minnesota, Texas, Utah, Virginia, and Washington) and several more under construction or in planning (in Michigan, New York, North Carolina, Oregon, South Carolina, Washington DC), making this particular solution appear to fit the US transport system and political system well.

## 5.4. Fourth generation road user charging: Autonomous on-board equipment

As multilane free flow systems became ubiquitous, and policy design continued to evolve, national governments demanded even larger and more capable charging schemes. Pushing the geographical boundaries of the charging schemes exposed a critical characteristic in the transponder-based systems; while the cost per vehicle is low (sticker tags are approaching one dollar per piece, and transponders are sold in the range of $10-20), the road side infrastructure is expensive (a fully equipped gantry across a four lane road cost in the neighbourhood of $500,000 to put in place). Thus, the cost structure of multilane free flow systems is well suited for covering a limited number of road segments and a large number of vehicles.

But as policy makers and economists saw new opportunities for road user charging, some of the schemes they dreamt up had the opposite characteristics: Covering a very large road network, but only valid for a limited number of vehicles. To meet this challenge, a new breed of systems was developed. In these, the on-board equipment was made more complex than a simple transponder, and thereby could detect, measure, record, and report the road usage with only limited assistance from fixed road side equipment. The first road user charging system with such autonomous on-board equipment was the Swiss Leistungsabhängige Schwerverkehrsabgabe (LSVA) system, charging a fee per kilometre for vehicles of 3.5 tonnes and above, when driving on any road in Switzerland. The system uses a combination of odometer for distance measurement, short range radio signals for switching on and off

the equipment when passing a border station, GPS for calibration and control, and smart cards for data output and reporting (Pickford and Blythe, 2006). This wide range of technologies obviously makes each piece of equipment in the vehicles much more expensive than a simple transponder, but on the other hand, establishing gantries and road side equipment on every road in the country would be prohibitively expensive.

In 2005 a similar system was deployed in Germany, to replace the previously used paper based vignette system. Unlike the Swiss system, covering all roads, the German system charges only for the Autobahn network. To keep track of what road is being used, the system therefore relies on GPS rather than the odometer as its primary source of road usage data. The measurements have to be precise, as in some places there are local non-charged roads running in parallel with the autobahn. This precision requirement was one of several tough challenges for the system provider, a joint venture between Deutsche Telecom and DaimlerChrysler, contributing to significant delays before launching the system. During the delay, the German state suffered painful losses of tax revenue, parts of which the system supplier had to pay reparations for (Deutsche Telekom, 2008).

Here, the industry history of the transponder based systems starts to repeat itself. The German lorry charging system was built on proprietary technology, procured by the national government from domestic firms. It is not far fetched to assume that nationalistic industry policy was at play, banking on the hope of creating the next technology export success. Trusting that the lorry charging trend would catch on in Europe, the German system provider would be in a good spot to take a leading role in this new market, based on its hard earned experience and installed capacity. After all, they were now in possession of the worlds largest and most advanced tolling system ever in operation – a reference hard to beat. And the closed technology effectively prevented competitors from building their systems based on the same specifications, thereby protecting both the economies of network and their learning curve.

Just as in the case of transponder-based systems however, the trophy of being the de facto standard monopolist is not easily given away, neither by customers nor by the competition. Also, the spread of autonomous road user charging was slower than many had anticipated. It was not until 2010 that the third European country launched a road charging system based on autonomous on-board equipment, Slovakia beating France to the bronze. The system providers there were Siemens and Q-Free in cooperation (NDSAS, 2010).

In France, a new system based on autonomous on-board equipment, is planned to extend its existing transponder based lorry tolling scheme, Télépéage Inter Sociétés Poids Lourds (TIS-PL). Even though there are three previous installations based on the autonomous architecture he operational, costs are still expected to be high. The French scheme is estimated by one analyst to spend 20% of the 1.24 Billion Euros it will take in annually on operations, and another 5% in capital costs (Roadpricing, 2012). It was originally planned to be launched in 2011, but after some legal issues with the procurement process it is now delayed to 2013. At the time of launch it will allow for several independent service providers to issue on-board equipment and payment service subscriptions (EcoMouve, 2012; ASECAP, 2009). A similar multi provider approach was planned for the all-vehicles all-roads systems planned in the Netherlands, although after a crisis of government in 2010 that project was put in the freezer, together with several previous Dutch attempts to launch road user charging on a large scale.

By allowing multiple service providers to operate in the same charging system, at least local multi-vendor interoperability is ensured from the beginning. This prevents the bidding firms from using closed systems with proprietary interfaces, and thereby makes international interoperability easier in the future. In that respect, the French procurement strategy makes a positive contribution to the development of interoperable services. Additionally, transponders will be issued capable of interoperating with the Italian Ecopass and CEN DSRC, thereby providing hardware for taking a large step towards pan European interoperability (Autostrade, 2011).

Outside of Europe the interest in the fourth generation, autonomous, road user charging has been more limited. In New Zealand, heavy vehicles are charged for by distance, and drivers of such vehicles may since 2010 on a volunteer basis make use of electronic equipment to record road usage (NZTA, 2010). Being an island nation, without the need to detect border crossings, and applying a flat fee per kilometre, a simple hub odometer is capable of collecting the data required, so there is only limited use of sharing a standard in this case.

In Oregon, USA, a technology pilot was carried out for a distance-based replacement of the fuel tax, aimed at passenger cars. Although the tariff was to be differentiated by zones, odometer was still planned to be the prime data source, only recording accumulated distance by zone, for privacy reason (ODoT, 2007). The project developed a complete concept and functional prototypes, but never got the policy approval to continue (Whitty, 2008). Since then, a range of additional projects has been launched to analyse, and some to pilot similar types of schemes on state or federal level, first under the name of TDP (Time, Distance, Place) or VMT (Vehicle Miles Travelled), and later dubbed MBUF (Mileage Based User Fee).

The development in both Europe and the US is also reflected in the emerging technical standards. Stakeholders on both sides of the Atlantic have increased their interest in supporting the development of standards for the fourth generation of road user charging. This time around, work in Europe and the USA is more synchronised, with more widespread active participation in the working groups developing the relevant standards. If autonomous road user charging ever takes off on a grand scale in the global market, the initial, broad tool-box standards are available already, and there is some chance that the more specific standards, required to enable interoperability, will be too. However, there is much more freedom in the design of autonomous systems, so the challenge facing standardisation is greater than for transponder based systems.

## 6. Paths to public and political acceptance

Many countries have successfully built new motorways and applied a per-use charge to finance them. Introducing road user charging on a network of roads that is already in place is however a much more difficult decision. Not that it is difficult in the sense that it requires a particularly complex analysis – the business case is often straightforward. Nor does the technology have to be prohibitively complicated – much of it is available off the shelf at reasonable cost in competitive markets. Rather, the difficulty to introduce road pricing comes from two other sources: institutional weakness and public resistance. *Institutional weakness* is a challenge because charging cars for when and where they travel means generating a very large number of small charging events, which need to be recorded, processed, priced, collected, and enforced. Well functioning institutions are needed as a basis for implementing cost effective processes to deal with each of those steps. (Enforcement is addressed in paper IV.) *Public resistance,* and by extension political resistance, is a challenge because the proposal of adding a fee for using a road that has traditionally been free of charge invariably leads to fierce negative reactions by the car driving population, which is typically also by comparison a resourceful and well connected population. (Public acceptance is addressed in paper V.)

In this context, it is worth noting that Singapore was for decades the only place employing congestion pricing, although transportation economists had proclaimed its efficiency since the 1920:s. Singapore is a country lead by technocrats. It is stable and rationalistic, with strong institutions but limited influence by the electorate. Even the smallest crimes are strictly enforced, including littering, jaywalking, and spitting (US DoS, 2012). When the Economist Intelligence Unit (EIU, 2011) ranks democracies, Singapore comes in 81$^{st}$ of 167 countries and is labelled a "flawed democracy", with its limited political participation and electoral process and pluralisms as its main deficits.

More than 20 years after Singapore's introduction, London, Stockholm, and Milan followed suit and implemented congestion charging. All of these have strong institutions just like Singapore, but also

political systems that differ. UK is number 19 in the Economist's ranking of democracies, Italy 31st, and Sweden 4th (EIU, 2011), so the possibility to implement congestion charging is apparently not limited to places with a combination of strong institutions and weak democracy.

After the introduction of congestion charging in London, it has been widely claimed that a "determined political champion" is a requirement (see e.g. Peirson and Vickerman, 2008), since that seemed to be an ample description of then mayor Ken Livingstone and his political campaign. That however, is a unique case, in which a politician has come out in favour of congestion pricing prior to an election, won the election, and then succeeded in implemented the charges. In Stockholm for example, the process was entirely different. The social democrat mayor-to-become in Stockholm, Annika Billström, instead campaigned explicitly on *not* to introduce them, and in Milan, the charges were first introduced distinctly as an environmental fee, and then gradually transformed into a congestion charge. So the conclusion that a strong champion is a requirement cannot be the full story.

## 6.1. Stockholm

The introduction of congestion pricing in Stockholm is worth considering in more detail, as it followed an unusual decision-making process. After the general election in 2002, the Green Party came out with the balance of power in both the national and the Stockholm municipal assembly. They chose to use their power on the national level by conceding on their requirement for seats in the cabinet, and in return requiring that the Social Democrats in Stockholm backed off their election promise not to introduce road tolls. (See Gullberg and Isaksson, 2009, for a detailed account of the process.)

This has been challenged as an undemocratic way of decision-making. But politicians make promises all the time, only to break them after winning the election. That alone cannot have been the cause of the deep anger felt by so many. Possibly it was the issue itself – congestion charging – that, in combination with the broken election promise, triggered the additional anger. Some frustration may also have its source in the way the Greens managed to short circuit the national and municipal levels of administration. Additionally, some of the perception of democracy lost could be associated with the fact that such a small party, representing less than five per cent of the population at the time, managed to trump the establishment like that and got to implement their policy.

With an interpretation of democracy that is limited to the casting of votes on election day, aggregating the predefined interest of each citizen, it is difficult to argue against that line of thinking. The decision to introduce congestion charging in Stockholm was indeed out of the ordinary when it comes to democratic decision-making in Sweden.

The interpretation does however become a bit more nuanced if seen in the tradition of *deliberative democracy*, where the decision making process is not regarded a simple aggregation of predefined interests, but rather a collective forming of opinion and norms (see e.g. Dryzek, 2000). In this sense, the use of a trial period in Stockholm can be defended as democratic, precisely because it did make possible a post-implementation discourse, where citizens could debate the issue as equals based on their own experiences from the trial. This would mean emphasizing the social learning process that went on during the seven months of testing the system, during which politicians and media lost their privileged positions as interpreters and mediators of opinions.

For this line of reasoning to be valid, it must thus be clear that the referendum following the trial is binding, i.e. that the politicians truly put the decision in the hand of the voters once the deliberation is allowed to happen. If not, the trial is no more than an expensive gimmick, to hide the fact that voters had been dealt a decision fait accompli. Additionally, one would need to consider the cost of the trial, to understand the different position the decision is taken from pre versus post trial. With the costs and uncertainty already sunk in construction of the system, it may make sense to let it remain, while that would not have been the case had the question been asked up front. There are however no indications

in any of the many attitude surveys made that sunk costs were an influential factor in people's voting behaviour.

There is a distinction to be made here; deliberation does not equate consensus. Mouffe (2005) stresses the importance of clashes of opinions, and the potential oppression built into consensus, by dispossessing the minority of their voice and their right to demur. Here too, the referendum following on the trial period is critical. Knowing that the referendum was coming up, people and organisations with a strong opinion had a focal point and a forum for their discontent, which did not presuppose the reaching of a unanimous agreement.

This emphasis on disagreement contrasts with Innes and Booher (2003), who accentuate consensus and consensus building as an ideal form of democratic decision making, and offers several illustrating examples how groups of individuals representing competing interests have been able to reach a better agreement by engaging in a long term authentic dialogue, which is not limited to ritualistic or rhetoric concessions. Key in this form or consensus building is not to identify a compromise, or even a synergistic third way – then enigmatic "win-win solution". Rather, the process is changing its participants, their view of reality, and by extension their preference functions. Thereby a solution can be obtained which has *become* desirable, without having been among the potential desirable outcomes to begin with.

For this consensus building process to function, there must be an established set of people who faithfully and credibly represent all the major interests in the field. But in the case of introducing congestion charging, there is reason to question the existence of any well functioning such representatives. There may be organisations who *believe* themselves to be fit to the job, such as an Automobile Association, a Chamber of Commerce, or a nearby municipality. But since the understanding of the true nature of congestion charging, what is its full set of consequences, and how that relates to previous beliefs and values, is shown to change on the individual level with experience of the policy in place, it would be puerile to believe that an adequate representation of interests could be arranged ex ante, and negotiated among such groups of representatives.

## 6.2. Copenhagen

The number of cities having managed to introduce congestion charging is widely exceeded by those having proposed it, and then retreated on their ambitions. In the recent case of Copenhagen, the defeat came later than in most cases. Even the social democratic prime minister was dedicated to the introduction, a high level design and a tariff structure was developed, and a time line presented, and still the process made a 180 degree turn and the policy was binned in February 2012, following sharp criticism by party fellows in the surrounding municipalities.

The policy makers in Copenhagen had been careful to fit the entire process of the planned project inside one election cycle (See paper I for more on why this is important.). This is probably a good advice, as public acceptance of congestion charging is generally at its lowest at the time of the decision and detailed planning, and then increases once people experience the effects first hand (see paper V for more on this process). But what they had not anticipated was the effect of staggered elections. Municipal elections in the towns and suburbs surrounding Copenhagen were scheduled less than two years after the national election, which meant renewed electoral pressure on the Social Democrats, at the precise moment when theory would predict support for the charges was the lowest. This, combined with the revelation that the planned charges would only bring in half as much revenue as planned, lead the party comrades of the prime minister to push her to recede on the plans (Copenhagen Post, 2012; private correspondence with Danish Members of Parliament).

This summary of the Copenhagen case illustrates three points relevant for understanding the political decision making process: First, *the influence of the electoral cycle* and the timing of the election in relation to the announcement and implementation of congestion charging cannot be exaggerated. Second, *the order of priority between revenue and congestion mitigation* is important. It is true that

congestion pricing designed to mimic optimal conditions will deliver both congestion relief and tax revenue. But if municipal politicians are only weakly interested in mitigating congestion, while actively seeking to maximise tax revenue, that will influence the design of the scheme further away from what is optimal from a societal point of view, which will then affect acceptance as well. This leads to the third observation; *political acceptance is different from public acceptance*, even in a well functioning democracy; Denmark ranks third in Economist's ranking of democracies. Still the process must be seen as a failure both of Mouffe's (2005) deliberative conflict and Innes' and Booher's (2003) deliberative compromise.

## 6.3. Göteborg

The second and third of the observations made for Copenhagen are also applicable when comparing the process of deciding to implement congestion charging in Stockholm and in Sweden's second city, Göteborg. When the charges were up for debate in Stockholm, the Yes/No fault line followed the traditional Left/Right divide of political parties. Thereby, in addition to voting in the referendum on congestion charging, there were also at least three parties to choose from on each side on the issue of congestion charging. This forced the politicians in Stockholm to tune in to voters' preferences and listen to their arguments on the subject.

In Göteborg, the process was very different. Unlike the case of Stockholm, all of the established parties in the local assembly in Göteborg were for congestion pricing to be introduced, although a majority of the population would vote against it (65% of those stating an opinion in September 2010; GP, 2010). Lacking an electoral way of communicating discontent with the proposal, a new party was soon formed, *Vägvalet* ("the route choice"), which immediately won 5.3% of the votes in the following municipal election. Without being overly cynical about the differences in decision-making situations in Stockholm and Göteborg, it can be noted that in Göteborg politicians could add a new source of tax revenue without fear of losing any real power, while in Stockholm the balance of power determining if a coalition would be formed on the left or on the right was at stake, thereby channelling voters' preferences directly in a way it did not in Göteborg. Additionally, no public referendum is being held in Göteborg, further strengthening this difference in connectedness between public and political acceptance.

To understand why political parties across the board would be in favour of the charges when there was evidently a large amount of electoral support to gain from coming out against, one needs to review the stated purposes for the charges. Since its early days, congestion charges in Göteborg were presented with three aims: combat congestion, improve the environment, and funding of a new infrastructure package. While the financing aspect is always stated as a third-and-last when the project is described officially, the decisions made in the process of the introduction reveal it to be of higher priority. As an example, when the Göteborg scheme was decided by the Parliament in 2009, the system covered an area including several non-congested areas, which would qualify as over charging from an economist's point of view. In a later amendment to that decision, the charging cordon was reduced for efficiency reasons and the tariff structure was reshaped for equity reasons. At that time it was also decided to increase the per-passage fee, in order to "compensate for the loss of revenue caused by the changes" (Riksdagen, 2009, 2010; Transportstyrelsen, 2010). Note that these "losses" are only losses compared to projected revenues from a system that is in the process of being redesigned because it has been found both inefficient and unjust. But the projected revenue numbers happen to be critical, since the decision to introduce congestion pricing in Göteborg was tightly coupled with a list of specifically named regional infrastructure investments (Riksdagen, 2009).

This leads to a forth observation of things important to understanding the decision making process: *It matters who has the power to decide over how revenues are spent.* If the revenue in Göteborg had been passed off to the national government coffers, as was the case in Stockholm, and reallocated to the region only based on a loose agreement that can be (and in the case of Stockholm has been) amended, then it is unlikely that the municipal politicians in Göteborg in support of congestion charging would have been in such overwhelming majority. The difference between Stockholm and

Göteborg thereby summarises some fundamental aspects of the political economy of road pricing in general.

## 6.4. Milan

Milan in Italy is interesting case of introduction of congestion pricing for it illustrates yet another path to acceptance. The scheme itself, dubbed *Area C*, has evolved into its current form in a series of amendments to what was in the beginning an environmental fee, *EcoPass*. This initial focus on the environment has probably helped gaining the necessary public acceptance in the public consultations carried out along the way, and in the 2011 referendum, where more than 79% voted to increase the scope of the scheme (Comune de Milano, 2011A). In its first incarnation, the scheme only charged for the dirtiest vehicles to enter the city; even a diesel with PM filter or a low emission petrol car was then considered sufficient to drive inside the eight square kilometer EcoPass area (Comune de Milano, 2008). The current scheme, in service since January 2012, gives this benefit only to electric vehicles and hybrids, while the dirtiest petrol and diesel cars are banned entirely (Corriere dela Sera, 2012A). In paper V the relationship between environmental concerns and acceptance of congestion charging is discussed in more detail.

In hindsight, it appears as the introduction of congestion pricing in Milan amass each of the key learning from previous attempts; the first step was introduced as a trial, with first a public consultation and later a referendum, to ensure a credible connection to public opinion throughout the process, but timed such that people get to witness the results first hand before making up their mind. By targeting only the dirtiest vehicles first, the issue of charging for roads already built was probably made less sensitive. Once the concept of buying a ticket to be allowed to pollute was normalized, the step from there to also treating congestion as a form of pollution was smaller than it would have been if proposed already at the outset. Additionally, the scheme was part of a package, clearly stating how the revenue is to be spent on public transportation and other local improvements (Comune di Milano, 2011B). However, none of these measures has been able to make congestion pricing a completely non-controversial issue. Criticism has been sharp especially from the political right, and at one occasion the Mayor received a letter sharply condemning the scheme, with a bullet case enclosed (Corriere della Sera, 2012B). With noticeable results though, both in terms of air quality improvement and congestion relief, most Milanese seem to have come to accept the charges.

## 6.5. Lorry charges in Europe

While city road user charging levied on passenger cars is a contagious issue, only to deal with for the very brave or politically suicidal, lorry charges is an easier matter. After all, most voters do not drive a lorry or make a living directly out of the road hauling industry. Additionally, there is an easy to grasp fairness issue working to the advantage of this type of road charges; if lorries from my country have to pay for driving on my neighbour's land, their lorries should have to pay for driving here as well. This too works well at the national political level – charging a tax where a large share of those liable are non voting visitors from other countries is easy to accept.

These simple observations can be generalised in the predictions that countries with a large share of transit traffic, and countries with neighbours employing lorry charging both would be early adaptors of such systems. This prediction fits well with an observation of the countries having introduced distance based road user charges for heavy goods vehicles, and the sequence in which they have implemented it. First came a country with a strategic position and a large share of transit: Switzerland, in 2001. Then followed three neighbours, Austria in 2004, Germany in 2005, the Czech Republic in 2006, and then the neighbours' neighbours, Slovakia 2010, Poland 2011. France is expecting to launch in 2013, Denmark is in a late planning phase, Belgium and the Netherlands are both planning but with a more difficult to predict time line.

While the argument of fairness in the hauling industry is sufficient to predict the sequence of countries to employ the charge, that is not the main policy driver underlying lorry charging. Without its positive

effects on government revenue, it is hard to believe that any of the lorry charging projects would have seen the light of day. Although the cost for collection is higher under a distance based scheme than with a traditional flat rate vignette system, the specifically tailored tariff structure and an effective enforcement can more than make up for more the difference. As an example, Germany made an annual revenue of approximately 0.5 billion Euros from its membership in the Euro-Vignette (which it abolished prematurely in September 2003, when the new autonomous Toll Collect system was supposed to be launched). At launch of Toll Collect, revenue was estimated to fivefold, reaching 2.5 billion Euros (OECD, 2005). After a series of tariff increases, annual revenues were up to 3.4 bn Euros in 2007 (Toll Collect, 2008), and a accumulated total of 24 bn Euros is reported to have been collected from 2005 to the end of the fiscal year 2010/2011, with operational costs down to 12.5% of revenue (TollCollect, 2011).

Given these strong incentives to move from a vignette to distance based lorry charging, combined with the limited political leverage available to opponents in most countries, it ought to be a fair guess that a wide majority European countries will have deployed such charges in one form or another within the next two decades.

## 6.6. United States

Cities in the United States are typically very different from their counterparts in Europe. Congestion is often found on motorways and arterials across the entire metropolitan area, rather than limited to a central core. Therefore European style congestion pricing is probably not the best short-term solution for US cities other than perhaps Boston, New York, Philadelphia, and San Francisco.

Instead, the almost unique US concept (there is one in Israel as well) of ETL and HOT lanes has emerged to be rather successful, as discussed above, (see section *5.3 Third generation road user charging*). Similar to the case of congestion charging in Milan, the HOT lanes evolved following a path that avoids the most sensitive issues associated with congestion charging. First came the HOV lanes, in which no monetary transaction is involved. Although those at times had no positive net effect on traffic flow, they made drivers familiar with multiple types of lanes, a priority system to reduce congestion, and the act of making a sacrifice (e.g. coordinating one's trip planning and share one car) for gaining the desirable right to drive in the fast lane.

Only after decades of being used to HOV lanes, the first HOT lanes appeared in the 1990:s, and in most cases they were introduced in conjunction with adding new capacity, either by widening the road or by repainting the road to fit more lanes on the same width of asphalt. This effectively circumvented the sensitive issue of pricing what was previously available for free. Only now, with HOT lanes being increasingly commonplace, the first ETL with no connection to old an HOV is being built, and even then it is done as an extension of capacity rather than pricing of what is already there (MTA, 2012).

This gradual introduction of congestion pricing over three decades has not made road user charging go by completely unnoticed. It is especially concerns about equity that has been raised against the policy, perhaps surprisingly given the political rhetoric of the United States otherwise being quick to put a socialist label on that kind of arguments. (See e.g. LA Times, 2012 for a comment on the 520 toll bridge in Seattle.) In response to criticism like this, Los Angeles' two new HOT lanes on I10 and I110 have been forced to implement an extraordinarily complicated tariff structure, to get past the legislature, including different HOV limits at off and on peak, and with a special discount for low-income residents (Metro, 2012).

If the development from HOV via HOT to ETL is seen as being steadily on-going, the same cannot be said about the charges used to finance roads. A substantial share of motorways is financed by the federal petrol tax, which is set at ₵4 per litre ($0.184/gallon) and has not been changed since 1993 (FHWA, 2010). Over the years, a combination of improved fuel efficiency and inflation has reduced the tax amount collected in real terms, making it very difficult to maintain the public roads. What may appear as the obvious solution, to increase the fuel duty and index it to inflation, is apparently close to politically impossible. This is the main driver behind the pilot and analysis projects related to MBUF

schemes over the last years. From the outside, this can only be seen as absurd policy; shift from an already existing tax collection mechanism that costs only a small fraction of the amount collected, to one that will consume 12-30% (which is the range European autonomous systems cost), mainly to be able to say "no more taxes". While the situation with funding of federal motorways is surely precarious, a national MBUF scheme for passenger cars is not without its limitations either.

# 7. Discussion and conclusions

The combination of the five papers put forward in this thesis sheds light on some systemic aspects of a policy tool and the industry enabled by its deployment. They illustrate a few not so often discussed characteristics of the industrial organisation in the market for road user charging systems, as well as the institutional and political environment in which it exists. The market for road user charging systems is one where buyers either are public organisations themselves, or as road concessionaires, heavily influenced by regulation. Those buyers exist in a dynamic political context, and even in the most stable countries, public attitude affect their manoeuvrability. As buyers they are also subject to indirect network effects, if their neighbours are already invested in some tolling technology. But they are also themselves sometimes the cause of market imperfection, by taking employment and future exports into consideration, when offering advantages to domestic firms.

Road owners are at the same time active buyers in the markets and part of the policy making entity, making it critical for the sellers in the market to influence policy. Just like defence contractors influence military policy, tolling companies do their best at influencing how governments think about pricing the use of roads. Sometimes this is done simply by lobbying, but the most interesting form of influence is when the service providers change the boundary for what is possible. By inventions leading to lower operational costs, schemes that otherwise would have been unfeasibly expensive become realistic alternative. By inventing the equipment and services required for free flow tolling, congestion pricing is effectively enabled. Similarly, when the autonomous on-board equipment is made small, cheap, and privacy-friendly enough to allow large scale deployment in passenger cars, it is possible that we will fundamentally change how we pay for using roads. The ideas presented in paper V related to enforcement, could potentially be yet another nudge on this frontier of the possible.

While inventing to service and to develop this market, tolling providers play a game of standards – open or proprietary, which has been seen in similar forms in many industries before. Firms may compete against each other in one tendering process, while cooperate in a consortium in another. Some firms focus only on hardware technology, central software systems, integration and implementation, or the operation of the complete business. While most cover at least a few of those, only few claim to master it all. The papers presented in this thesis may offer some input to the operational decisions made in the firms supplying the services, as well as to the government agencies and other road owners who purchase the services.

The end users, i.e. the ones paying the charges, have traditionally been largely left outside of the market interaction. A road user can rarely make any choice of provider or service level, other than possibly the selection of a manual or an automatic lane when approaching a toll plaza. In other networked electronic services, such as credit card payment and mobile telephony subscriptions, there is more choice available to the consumers, with several providers operating parallel networks in most places. Interestingly, these markets also enjoy widespread seamless and transparent interoperability. It is my belief that this kind of service diversity will be available to road users as well in a not too distant future. And when it does, it may have an influence on how road user charging is perceived by users, so that paying for the use of roads becomes no more controversial than paying for a bus ticket, and that paying more for driving in rush hour is no more out of the ordinary than airline tickets being sold at different prices depending on the attractiveness of the departure time.

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