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Next Generations of Road Pricing: Social Welfare Enhancing

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Abstract: This paper offers a broad overview of road pricing from a social welfare perspective. I first examine two common objectives of road pricing: congestion management and profit making. My goal is to provide a guideline explaining how to promote a social-welfare-enhancing road pricing scheme. To this end, we should: (i) consider and improve public transportation systems by providing more environment-friendly transport options; (ii) include tolling profits in our welfare analysis (as opposed to what economists suggest) since residents are the real owners of roads not users, and since some users are from outside the region and so might not be excluded from analysis; and (iii) search for a holistic approach that takes into account system-wide impacts, disutility to users who change their travel behavior (*i.e.*, switch to public transportation, shift their travel, or do not travel at all), and the impacts on land use, employment, and residents.

Keywords: road pricing; congestion pricing; social welfare; profit maximization; optimal tolls

1. Introduction

There is broad agreement among transportation practitioners that under certain conditions, road pricing (RP) can effectively provide a better transportation service, in particular to mitigate traffic congestion impacts [1,2]. Road pricing designed based on the value pricing concept could reduce congestion and/or improve system operation and therefore offer other co-benefits to drivers [3]. RP schemes imply adoption of a fee for the provision of road services, usually taking into consideration social and/or private costs of driving. They could thus provide the appropriate price signal to drivers. Ideally, drivers would pay directly for the operating (and sometimes the capital and land-use) costs of the facility use, the traffic congestion they impose on others, the environmental impact of their travel, *etc.* None of those costs can be addressed adequately with a gas tax or other indirect fees.

Despite clear needs for direct user charges, the actual adoption of RPs has been very limited [4]. Several barriers constrain their implementation. The most important is politics. A strong and devoted political champion is required for such new policies. Politicians are often not willing to risk their election prospects for a system where success is not guaranteed. In addition, organizational loopholes make politicians even more reluctant to pursue RPs. In fact, to include RP schemes as part of their project funding packages, the responsible RP agency must be approved by many levels of government [5].

Public opinion poses another major challenge. Many see road pricing as "double taxation" [6], so users resist RPs. This challenge is also reflected in the so-called "free rider problem" for any un-priced service; users are not willing to pay for a service that has been traditionally free [7]. Therefore, to promote successful road pricing schemes, researchers, policy makers, and public officials should offer a clear vision for the public. Otherwise, RP schemes would constantly face public resistance. As a prominent example, users of e-toll roads in South Africa collectively decided to evade toll payments, and as a result, the pricing system is not functional [8].

As in the case of many other public policy options, road pricing should perceivably improve quality of life for a society as a whole. Accordingly, a detailed welfare analysis takes different aspects (goals) into account in a connected framework. In addition, it accounts for future consequences (with a discount factor) of any action. In fact, a social welfare analysis provides one index to measure sustainability, *i.e.*, one simple but effective approach to have a unified index to measure different aspects of sustainability (especially to complement what various distinct indices offer) is to monetize various aspects. For instance, in the case of road pricing schemes, a welfare analysis should include users' travel costs (time and money), profitability of the scheme, transaction and administration costs, disutility of users (since they have to change their travel modes or even not to travel because of pricing), economic impact on businesses/employment/land-use, and travel-related emissions (health-related costs) together without double counting the effects.

In accordance with the welfare analysis approach, we should combine the two commonly- and (generally) separately-applied goals of road pricing: (1) profit making; and (2) congestion management. The road pricing schemes that are only profitable might not be sustainable since they might significantly increase travel costs and diminish transport system performance. Likewise, pricing systems that only manage congestion can become unsustainable because they can be very costly to society. However, to promote a sustainable path for road pricing systems, we should note that all the above-mentioned aspects are connected and a social welfare analysis can address these connections, using an integrated framework.

To promote successful and welfare-enhancing RP schemes, we should learn that their success is very case-specific, and a successful scheme for one region might not succeed elsewhere [9]. A clear and formal policy, which builds public trust, should be provided to support RP schemes. In addition, several other steps should be taken to create a social-welfare enhancing RP: (i) development of detailed models that can estimate the outcomes of various design parameters such as toll rates and tollbooth locations; (ii) inclusion of flexibility in pricing as an effective tool in managing congestion; (iii) application of a systems approach, not considering only a road (segment) or an area; (iv) investment in environmental-friendly public transport systems which incur less social costs on the society, especially since RP increases costs of driving and could incentivize public transport use; and (v) identification of an all-inclusive goal (rather than simply maximizing revenue or minimizing congestion effects, the goal should be maximizing social welfare). The major focus of this paper is on the last step.

The rest of the paper is organized as follows. I first explore the major objectives of road pricing, then introduce the various types of pricing, briefly discussing various modeling employed to estimate the benefits and costs of each RP design. Finally, I provide a detailed guideline for how future generations of road pricing schemes should be implemented to improve social welfare.

2. Goals of Road Pricing

Victoria Transport Institute states that "Road pricing means that motorists pay directly for driving on a particular road way or in a particular area" [6]. Jones and Hervik define road pricing as "policies that impose direct charges on road use", regardless of the goals of the scheme or the targeted user groups [10]. In fact, a clear difference between gas tax and road pricing is related to the fact that gas tax is not a direct fee; when idling their engines (before start moving), drivers are still paying for gas taxes, while RP is a direct fee for road usage.

Two major goals drive the road pricing decision: revenue generation and congestion management [6]. However, several other objectives are pursued as well, including transportation-related emissions reduction (especially to meet conformity obligations) [11], public transportation use or mode shift encouragement [12], land use management [13], and social welfare maximization [14].

In practice, policy makers typically pursue the revenue generation objective for rural roads, roads that are not heavily congested, or roads with available travel alternatives. Nevertheless, in practice, profit-making RPs have been implemented on congested urban roads as well [15]. To follow the revenue-generation objective, operators/owners generally set high toll rates to maximize their profits (revenues minus costs) [16]. Revenues from this sort of RPs are usually dedicated to roadway projects, and in many cases should be used only on the same toll road. Opposite of what a social-welfare enhancing RP policy should pursue, mode shift to other un-priced alternatives (even when they are not congested) is not desirable for the purpose of revenue generation. In this regard, many private road toll agreements include a phrase called "non-compete clause", protecting the toll road from new capacity expansion nearby [17]. As a result, in most profit-maximizing cases, the application of high unlimited toll rates on a few roads may deteriorate transportation system performance due to spillover effects onto highly-congested alternative roads [18].

Congestion management is another major goal of RP schemes. To manage congestion, prices are generally set to reduce peak-hour traffic demand, encourage use of public transit, and incentivize better trip scheduling and traffic flow over the entire transportation system. Revenues from congestion tolls (if anything is left after paying the costs of implementing congestion pricing schemes) are usually spent on purposes other than facilitating road services (e.g., on public transport) since the objective is to reduce congestion rather than generating further demand on the priced road.

As noted above, the objective of RP, however, should be much broader than those of congestion management or revenue generation. In general, public agencies should seek RP schemes that can effectively improve social welfare and enhance the quality of life in their jurisdiction [19]. An RP scheme should be implemented when it improves total social welfare relative to the non-pricing alternative [14]. Refer to Börjesson and Kristoffersson [20] for a review on welfare effects of various real-life RP cases.

The objective of an RP can drive the choice among various types of RPs (the scale), various technologies (the method), and various modeling approaches to be employed in order to estimate the resulting impact. Figure 1 illustrates a general framework that determines interactions among the goal, the scale, and the method of road pricing. Note that the welfare improvement goal acts as an overarching objective that includes various goals (revenue generation, congestion management, emissions control, mode shift to more efficient modes, land use management, *etc.*) by monetizing and summing up the potential impacts on each factor/goal (see Section 5).

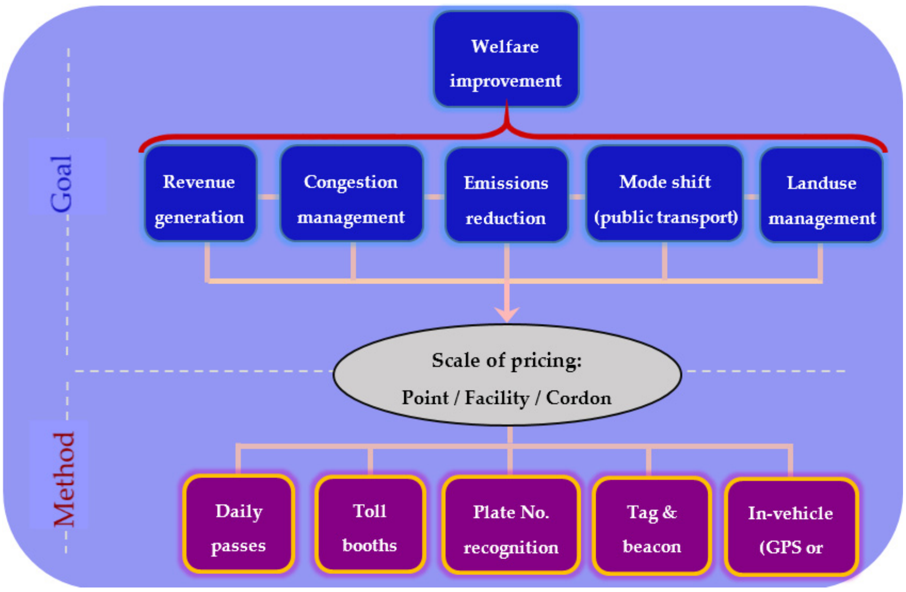

Figure 1. Road pricing general framework.

The scale of pricing (point, facility, or cordon), on the other hand, could impact the preferred method of pricing required to enforce payment. A variety of pricing methods can be used: (daily) passes, tollbooths, electronic tolling, optical vehicle recognition, global positioning system (GPS) devices, video detection, *etc*. Electronic toll collection (ETC) systems are effective tools for RPs, especially since they have proven to offer constantly-decreasing toll collection costs [21].

Examples of ETC include: (i) roadside-only systems using automated number plate recognition like the one used in Toronto 407 (Taylor, 2012 [22]); (ii) dedicated Short Range Communications (a class of tag and beacon systems employed as transponders for E-ZPass in the U.S.); and (iii) in-vehicle-only systems using GPS technology or cellular networks [23]. Note again that the choice among these pricing methods and the corresponding scale of pricing should be made according to the objective of the RP.

However, road tolls are implemented mainly on facilities and corridors, while congestion pricing is generally employed using area-based schemes, although this is not universal.

3. Road Pricing Options

3.1. Area-Based Congestion Pricing

Congestion pricing has been developed based on the notion that drivers (or users in general) should pay for the negative (usually time-related) externalities they produce [4]. Each additional user imposes a time cost burden on other users, not only on him/her self. In fact, while travel costs are largely borne by motorists collectively, there exists an externality; individual motorists increase the travel time for all other motorists by congesting roads [1]. The fundamental idea is to charge users for their social costs (the congestion-related difference between marginal social cost and marginal private cost) to use roads more efficiently [24,25].

Providing a free-of-charge service, as with public roads, leads to relatively higher travel demand, which generally results in wasteful behavior and consumption. It also creates a free-rider problem, where (some) users benefit from consuming goods or services without paying for them. The overuse or degradation of goods and services in turn leads to underinvestment and under provision of the service [26]. To address such challenges, policy makers have implemented several cases of congestion pricing worldwide. Singapore [27], London [28], and Stockholm [29] are some of the most famous examples. The benefits of congestion pricing schemes have been the subject of many studies [27,30,31]. However, these schemes are not necessarily beneficial to society. In a controversial study, Prud'homme and Bocarejo [32] estimated the aggregate demand and supply functions for the London congestion pricing scheme and determined the optimal road usage and optimal congestion toll for the system. They demonstrated that the London congestion pricing was an economic failure despite its political success (Refer to Box 1 for more details on the practical challenges of the London congestion charge zone). The study was the first major analysis showing the key role that transaction costs play in the success of congestion pricing schemes.

Hamilton [33] also indicated that the congestion pricing in the case of Stockholm, Sweden, results in unpredicted and excessive costs. Nevertheless, the study showed that by modifying applied insurance costs, recognizing the election's role, and informing the public, it would be possible to establish a system such as the Stockholm congestion charging system, for a considerably lower cost.

The method of pricing is also an important factor in the success of congestion pricing schemes. Olszewski and Xie [27] modeled the effects of pricing on traffic flows in Singapore. The study found that time-variable road pricing or the "shoulder pricing" method, which increases the charges before the peak and lowers them afterwards, transfers congestion to other periods and other routes and is an effective method of controlling congestion. Xie and Olszewski [34] proposed a methodology for using the traffic data from the Singapore's Electronic Road Pricing (EPR) system to forecast the short-term impacts of peak period traffic volume (trip rate) adjustments. For a general review on methods and technologies available for congestion pricing, refer to de Palma and Lindsey [23]. Despite all efforts to improve congestion pricing schemes, the key question has remained unanswered: Should the objective of a road pricing scheme be the minimization of congestion, or even the management of congestion?

This objective seems to be very limited in its scope. Several questions follow the key question: If only congestion matters, should we charge very high prices on roads, inducing under usage of roads? Even if we aim for the optimal level of congestion, what about the costs of implementing such schemes? Should the congestion pricing analyses include the disutility associated with the inevitable switch to public transport, walking, or not traveling at all since higher driving costs are imposed by congestion pricing schemes? Furthermore, what about other social welfare impacts such as employee surplus, work and residential location choice, and the effects on other parts of the transportation system (not only the facility/area of concern)? Shouldn't these other impacts be included?

Box 1. Panel: The London congestion pricing scheme.

The London congestion pricing scheme was implemented after a long history of research studies and an interesting political process. The report on the review of charging options for London [35] initially recommended two alternatives for charging on the central London area: (1) an area licensing scheme based on video camera enforcement; and (2) a workplace parking levy. Ken Livingstone became the mayor of London in 2000. With his election and after an 18-month period of extensive public consultation, an area licensing congestion pricing scheme was chosen for central London in 2003 [28].

Currently, a constant daily charge of £11.5 (formerly, it was £5, later increased to £8 and then to £10) must be paid for driving or parking within the congestion zone between 7:00 a.m. and 6:30 p.m. on weekdays [36]. With an area of about 22 km^2 (8 square miles), the congestion charge zone covers the financial center, Parliament and the principal government offices [28]. The zone includes the main areas of greater London with the worst congestion. Most studies report better system performance as a result of the application of the congestion pricing scheme [36]. The overall benefit of the scheme, however, has been the subject of hot debate. Transport for London [37,38] has estimated a net annual benefit of 112 million while Prud'homme and Bocarejo [32] estimated a negative net benefit of -£75 million per year. However, the relatively high transaction costs of the London scheme prove that policy makers should be very careful about the use of congestion pricing. In fact, optimizing congestion effects should not be the sole factor driving decisions about social-welfare-oriented road pricing. Employing a more advanced toll collection technology (than the implemented video collection system with its high transaction costs) along with a more careful choice of the geography of the price zone, London congestion charge scheme could have been designed differently so that it does not impose significant burdens on tax payers, which in the long run could even threaten the existence of such schemes because of potential opposing public opinion.

3.2. Road Tolls

Road tolls are commonly used as a method to raise revenue and/or to fund road improvements, as a part of transportation funding packages. The argument for tolling is that a fee should be levied according to the service provided. However, revenue generation is the major motivation for charging tolls, especially in the case of private road operators [39]. Here, mode or path shift is undesirable since the shift decreases road usage and consequently revenues. Road tolls are usually implemented at a point such as a bridge or a tunnel or at an entire (or parts of a) facility based on a per-kilometer (mile) basis. Bay area toll bridges [40] and tunnels and bridges in Hong Kong [41] are examples of point pricing. Tollbooths or electronic pricing are the methods employed in most cases of point pricing. State Route 91 express toll lanes in Orange County, CA [42] and Highway 407 in Toronto [22] are the prominent examples of facility pricing. A facility pricing usually needs electronic pricing that uses transponders, license plate photography, or a combination of the two.

However, the revenue generation as the sole objective of road pricing usually leads to a worse transportation system performance because of traffic spillovers to other parts of the system and to lower travel demand (which itself represents a decrease in social welfare).

3.3. Other Types of Road Pricing

Other types of pricing include :(i) high occupancy toll (HOT) lanes, e.g., Interstate 15 in San Diego [43]; (ii) distance-based charges such as mileage fees, e.g., tolls on trucks in Germany [44] or Oregon's mileage-based user fees [6]; and (iii) road space rationing, e.g., ration peak period vehicle-trips or vehicle-miles using a revenue-neutral credit-based system [45].

Many studies attempt to identify the preferable approaches/methods for an RP. Comparing different methods of RP, May and Milne [46] estimate that time-based pricing provides the greatest social benefits, followed by distance-based, congestion (zonal) pricing, and cordon pricing. However, the choice among the above road pricing types should be made case by case and depends on the following factors: (1) the main purpose of pricing (maximizing revenue, congestion management, or a combination of these); (2) how pricing is structured; and (3) the transport and geographic conditions in which RP is implemented. For instance, a road toll may do little to reduce congestion if alternative routes and modes perform poorly, but it may provide significant congestion reductions if transportation alternatives (such as public transportation, ridesharing, transit and telecommuting) are relatively attractive.

4. General Modeling Approaches

RP schemes usually need strong public support, can be very expensive, and might induce an important social, economic, and environmental impact. Therefore, a thorough evaluation of an RP scheme requires a comprehensive impact analysis both before and after their implementation. The impact of RP depends on: (i) the type and magnitude of fees; (ii) the flexibility of pricing; (iii) where and when it is applied; (iv) potential alternatives to driving; and (v) no-pricing (natural) conditions.

However, the success of an RP is highly dependent on the characteristics of the case under study; the results from one study cannot be generalized to another. For example, the value of travel time [47] and reliability, user group variations, and demand risk calculations, among many others, are case specific. Reviewing six RP real case studies, Vonk Noordegraaf *et al.* [9] found that only 26 percent of factors affecting implementation of RPs are generic, and that dominant factors are those factors, such as public acceptability [48] and equity [49], that result from particular features of the case study. This is the major reason why various models are required for predicting the outcomes of a scheme both before and after its implementation.

Considering the two major RP types (congestion charges or road tolls), I briefly discuss the two general modeling approaches that researchers have used: (i) the aggregate market equilibrium approach; and (ii) network analysis. The corresponding models could act as an optimization problem that usually attempts to find the rate, timing, and flexibility of tolls. The optimization problem is based on the objective functions I discussed in the *Goals of Road Pricing* section. Note that social welfare maximization is one version of the optimization problem.

4.1. Optimal Road Usage Analysis (Aggregate Supply and Demand)

Studies analyzing real-life congestion pricing schemes usually offer aggregate modeling frameworks due to the complex nature of practical studies. Pigou [50] sets up the theory of congestion pricing. The theory shows that to maximize the social net benefit, a marginal cost pricing should be charged from all links (roads) of a transportation network, or what is called "first-based pricing". Imposing the optimal congestion tax (adding to the individual cost) will induce the socially-optimal road usage. The gap between marginal social cost and individual cost could be filled by the congestion charge.

The standard analysis considers the effects of charges usually only on the charge zone(s) [51]. However, we should take the spillover effects to all other parts of the system into account as well. Another common setback of the optimal road usage analysis is that travel demand and congestion charge are usually estimated daily instead of breaking the analysis into shorter periods with different demand characteristics.

4.2. Network Analysis

Although many studies have shown the validity of marginal cost pricing theory (last section) under various conditions (e.g., Yang [52]), charging prices on all links are not practically possible because toll collection costs from all road segments (the entire network) could be very high and there could be political resistance to a widespread pricing scheme. Therefore, optimal road usage analysis is used only for zonal congestion pricing, and many researchers turned their attention to second-best pricing, where toll charges are levied only on a subset of roads [3,53]. This problem is also called toll design problem [54]. The toll design or network design problems are usually simulated by a bi-level or multi-level programming model: the road owners' decision to charge a toll rate(s) (on a subset of roads) at the upper level and the travel behavior of transportation network users at the lower level.

The objective of road pricing through a network analysis could be different from congestion management. When private entities or even public authorities pursue RP as a method to maximize profit (revenue) and because of the important impact of alternative roads/modes on profit, a network modeling approach could be preferred. The literature about private road pricing is very slight relative to that of congestion pricing, although the practice of private road pricing is no less prevalent than that of congestion pricing, especially in the U.S. Theoretical network modeling of private road pricing has analyzed the effects of duopoly and monopoly structures [16,55,56], the effects of traffic diversion to secondary roads [57], the interrelationships between pricing, capacity, and financing/investment [56,58], and impacts of alternative privatization structures and regulations [59–61].

One major benefit of a network analysis is that it can capture the spatial feature of pricing. For further information on optimization models and their corresponding categories for RP refer to Zhang [62]. Nevertheless, the analysis is usually erroneous because of the major flaws of travel demand models [63].

However, although the two modeling approaches discussed above can provide basic insights into the design of an RP scheme, the design should go beyond the traditional modeling approaches. The following section provides details about how a social welfare-oriented road pricing should be modeled, designed, and implemented.

5. Social-Welfare-Oriented Pricing

To appraise different road pricing options/approaches, we need to measure the potential advantages and disadvantages of those options. The appropriate criterion for the evaluation should determine whether or not the approach serves the overall public interest. Benefit/cost analysis, with emphasis usually on net profits or sometimes on congestion management, is one common criterion that has been employed extensively. However, the most appropriate evaluation criterion should be based on overall social welfare impact. In addition, benefit/cost analyses generally lack the details required to examine impacts on various stakeholder groups and the sensitivity analysis to determine the impacts under various scenarios [64]. To promote sustainable road (pricing) systems, we need to consider short-term and long-term social, environmental, and economic impacts of any new scheme altogether. A detailed social welfare analysis can provide a framework that examines all the above discussed factors.

Before starting the discussion about social welfare-oriented road pricing and how to pursue such pricing, I define the general notion of social welfare. Suppose government evaluates whether or not to employ a road pricing scheme (or option). In general, the change in total social welfare is the summation of the change in consumer surplus (*i.e.*, net transport user costs in the case of road pricing), producer surplus (*i.e.*, toll collection agency's net profits or impacts on businesses), government surplus (*i.e.*, transaction costs and political implications), and employee surplus (*i.e.*, employment consequences of applying road pricing). The summation is usually considered with a welfare weight assigned to each component (weights might not be equal). All components could be measured (monetized) in present value; the future effects are considered from a sustainability perspective. Major stakeholders' gains and losses from a road pricing should be compared to the gains and losses from the do-nothing alternative to providing the same infrastructure or service. Previous welfare studies about road pricing have developed a crude knowledge about the design and implementation of road pricing, in a very limited scope [14,20].

Policy makers should take several key factors into account in their social welfare analyses. In the following, I provide a guide about the issues and challenges that should be addressed in order to promote a successful social welfare-enhancing RP system. I categorize these factors into three major areas to examine: (1) modeling; (2) design; and (3) implementation.

5.1. Modeling

5.1.1. Taking Profit into Account

One of the most important issues surrounding RP analysis is that economists generally assume that toll revenues to the government or toll costs to users are economic transfers. Users pay, but government receives the revenue. Therefore, user payments could be exactly offset by the government's revenue. This assumption is not valid for several reasons. First, the transaction costs of toll collection should be taken into account; *i.e.*, user payments and toll profits do not match because of transaction costs. One very interesting example is the London congestion pricing scheme. Prud'homme and Bocarejo [32] showed that the scheme is an economic failure due to its high transaction costs. Even without the inclusion of transaction costs, this simplified assumption does no hold for social welfare analysis because of two more reasons: (i) the weights of different stakeholders might be assumed to be different, e.g., the benefits to residents (through redistributing the toll revenue in the area) might be assigned a greater welfare weight relative to the costs to users. The major rationale is that residents are the real owners of roads. Thus, their welfare weight could be assumed higher than other stakeholders; and (ii) the benefits and costs (e.g., the amount of tolls paid) of users from outside the region (or foreigners) should not be counted since the project funding is generally from local or state sources, and the benefits/costs should be assumed locally [64]. The exclusion of outside users results in a relatively lower welfare weight for users and leads to a relatively higher weight for toll collection revenues (relative to the costs paid by users). In fact, the economists' assumption of excluding revenues from welfare analysis (revenues being transfers between two groups) is plain wrong for road pricing case studies.

5.1.2. System-Wide Analysis

Transportation modelers should analyze the effects of an RP scheme on all parts of the transportation system of concern. In fact, modelers should avoid examining/modeling a toll road or a congestion zone individually. Even analyzing a toll road and its major competing roads is insufficient. The system-wide performance should be the goal of the analysis, especially for a large metropolitan area, where only the total environmental and fuel costs of congestion could easily reach over $400 million [65], and traffic spillovers to un-tolled alternative routes could increase system-wide travel time by millions of dollars [18,66]. Network analysis is also required to examine the micro impact of pricing on several links, zones, or travel modes of a transportation system.

5.1.3. Demand Risk Modeling

When calculating revenues and costs of a pricing scheme, both the government and the private toll collection agencies should fully consider travel demand risk [67]. The calculation is more relevant for the privately operated toll roads. However, demand estimation is the central issue in determining benefits of any pricing scheme. Perhaps the highest risk associated with toll facilities stems from uncertain future demand/revenue streams. The financial failure of several major public-private partnerships (P3s) [68] demonstrates the importance of employing an appropriate risk analysis and risk allocation strategy. To include demand risk into social welfare analysis, we can provide several scenarios (through a sensitivity analysis) on travel demand parameters (variables).

5.1.4. Travel Disutility

Transportation practitioners should be aware of the social welfare decrease of RPs when some users decide not to travel because of higher travel costs associated with charging tolls [16]. Note that the social welfare change should be calculated based on the net effects on users (considering both those users who decide not to travel and the new users who decide to travel after pricing). The loss in social welfare is lower when users decide to travel by switching to public transportation or when they reschedule their trip (than when they decide not to travel), but these changes in travel choices to avoid tolls also convey a reduction in social welfare for those users and consequently for society [4,69]. The social welfare decrease is very important since without such calculations, the analysis might lead to very high toll rates with minimal travel accommodations. In order to calculate the decrease, researchers have implemented the rule of half concept. Refer to Rouhani and Niemeier [12] for more information about how to calculate the corresponding social welfare loss, especially when using network analysis.

5.2. Implementation

5.2.1. Alternative Modes

To support a more sustainable and welfare-enhancing transportation system, RP schemes should be implemented where high quality travel alternatives such as public transportation, biking lanes, walking facilities, ridesharing and other services are available. Travel alternatives should be improved to ensure that people (especially poor or medium-income users) could travel even when roads are expensive to use [12]. An RP system usually increases costs of driving, which in turn will offer incentives for the use of less costly and environmental-friendly travel modes. However, with poor public transit, the alternative choice to pay and use the toll road would be very limited [47].

5.2.2. Public Opinion

Policy makers should provide the information necessary to help shape the public's vision, to insure that RP decisions are transparent and built on trust, and to make prices as predictable as possible [5,6]. It is important to understand that the idea of tracking vehicles/people, an idea considered by many vehicle-miles traveled programs, is very unpopular. Even if a jurisdiction decides to implement it, a thorough public consultation should be conducted.

Another important issue related to gaining public support is the establishment of a redistribution policy that returns partial profits back to the public, directly or indirectly. For instance, Geddes and Nentchev [70] propose an investment public–private partnership (IP3) scheme, where residents receive a direct financial gain from road pricing. Such schemes could be effective in creating the vision for residents as the real owners of roads. The question that the public must answer is: If they are the true owners of roads, would users be allowed to use those roads (partially) free of charge? Alternatively, would they price their roads, provide a better service, reduce congestion, and raise money out of their highly-valued assets?

5.2.3. Equity Challenges

A major legitimate concern for RP schemes is related to their potential equity impacts. The primary question is who will lose and who will gain. If RPs can make our systems more efficient and reduce their environmental/social footprints, the solutions to providing more equitable systems will not be out of reach. By considering distributional effects [71], we can redistribute toll revenues and compensate for the loss of some user/resident groups [72]. Analysis of an RP scheme should also identify the potential spatial and social equity impacts of the proposed scheme on different social/geographical stakeholders.

5.3. Design

5.3.1. Flexible Pricing

To increase profits and reduce congestion, policy makers could provide the responsible toll collection agencies with a flexible (temporal and spatial) tolling scheme, especially if the road is operated by the private sector. The toll rates should be allowed to vary spatially (geographically) and temporally. Flexible tolls could be significantly effective in increasing profits and specifically in improving system performance [73]. Toll rates can vary based on time-of-day schedules [42,44,74] (as in the case of Singapore), based on responsive tolls adjusted according to actual travel conditions [75], and from one road segment to another for road pricing [73]. If regulations permit, a flexible pricing system is preferable since operators can easily switch to a fixed charge, and in most cases, variable pricing can increase profits and manage congestion better.

5.3.2. Toll Ceilings

For private RP arrangements where toll rates should be regulated, policy makers should set toll limits within a range between profit-maximizing rates and system-optimal (congestion-optimizing) rates, to meet a combination of these two goals. Tolls on few roads, especially with unlimited (high) profit-maximizing rates, could increase total travel costs for a transportation system as a whole because of spillover effects to un-tolled sections [51,66]. This is the major reason why Vickrey [24] suggests creating and applying congestion pricing on existing roads, not only on (limited) new facilities. On the other hand, existence of alternative modes to private cars, however, may justify implementing high profit-maximizing toll rates on major corridors in order to encourage and promote a more efficient and sustainable transportation system (e.g., the observed increase in the public transport mode in London, Leape [28]).

For cases in which the private sector is operating the toll collection system and receives the revenue, as with concession privateroads, public officials should implement a lower limit(s) along with an upper limit(s) on toll rates to ensure system-optimal or any system-improving rates by a private operator [66]. The lower limit prevents the private sector from undercutting the applied upper toll limit(s) at social-optimal rate(s).

5.3.3. Outside-Transportation Welfare Implications

The impact of road pricing is beyond immediate (or even mid-term) effects on transportation systems. The implementation of RPs can have long-run consequences surrounding businesses [76], employment [77], and residential and work location choices [78]. Although most of these factors are directly related to the corresponding improvements on the transportation system, a complete social welfare analysis should take these into account. One important finding by Eliasson and Mattson [79] is that road pricing schemes can result in high-density housing only when they increase the costs of driving. In fact, congestion pricing schemes that could reduce travel costs might even result in lower density. Therefore, road pricing in urban areas should be employed with careful consideration about their residential/work location impact. Otherwise, we might end up with a system that incentivizes longer commute trips for non-urban residents. With similar arguments, policy makers should take the employment and business-related impacts of RP schemes into account.

Table 1 summarizes the discussed key modeling, implementation, and design factors that should be taken into account for a social-welfare-oriented road pricing system. Final note is that although the inclusion of these factors are vital for a social-welfare-oriented road pricing, the actual quantification of some of these factors are very complex, if not impossible, to accomplish. For instance, the impact of a road pricing system on businesses or employment depends on many parameters and is very hard to estimate precisely, especially before the implementation of RPs. However, a comprehensive social welfare analysis needs to examine all welfare aspects, even though the analysis could not provide estimates of exact impacts for some aspects.

Table 1. Summary of key social welfare considerations.

Major Areas	Factors	Welfare Consideration
Modeling	Including profit	*Contrary to common perception, profits matter*: since high sunk transaction costs and residents' stake > users' stake
	System-wide analysis	*Analyze all parts of the transportation system*: impact analysis beyond only charge zone or priced road(s)
	Demand risk	*Fully consider travel demand risk*: risk calculations could reveal future challenges/solutions
	Travel disutility	*Estimate the disutility from travel discomfort*: after pricing, users may reschedule/avoid trips or change mode
Implementation	Alternative modes	*Provide high-quality (public transport) travel alternatives*: not only to make travel easier, but to promote further mode shift
	Public opinion	*Shape the public's vision*: ensure transparency/make prices predictable/provide redistribution
	Equity challenges	*Carefully examine losers and winners (equity)*: spatial/social impacts for different social/geographical stakeholders
Design	Flexible pricing	*Provide flexible or responsible (temporal/spatial) tolling scheme*: varying tolls → increase profits and improve system performance
	Toll ceilings	*Avoid high prices (for private toll roads):* high tolls → spillovers to un-tolled roads → increase system travel costs
	Outside transportation	*Include long-run consequences beyond impacts on transportation*: businesses, employment, and residential and work location choices

6. Conclusions

Opposition and distrust from the public pose major challenges for RP schemes. Residents fear that RPs are being implemented to increase government revenue, seeing it as "double taxation", and users do not want to pay for a system that has been unpriced, what is called a "free rider" problem. In fact, average users might be worse off without any redistribution policy since with an RP, they are usually forced to pay more in order to use formerly free-of-charge roads. Facing these difficult challenges means that radical policies like introducing new RP schemes will require detailed and well-thought-out analyses far beyond what has been usually employed in the past.

Generally, road pricing systems are designed (employed) either to raise profits or to manage congestion. These two goals are very narrow in their scopes. In this paper, I proposed a new approach, well beyond what the two commonly-used goals imply. Not only should we combine these goals together, but we also need to add many other factors/goals into our analysis. Social welfare analysis (a commonly-used method in economics) provides a framework that can combine these factors and account for future effects from a sustainability perspective. In addition, I explained how a social welfare improvement goal should be pursued for road pricing systems from the modeling, implementation, and design aspects.

The important factors to be considered in the welfare analysis procedure are: (*i*) take profits from road pricing into account, contrary to economists' approach (profits/revenues are transfers from one group to another and should not be considered); (*ii*) examine the impacts of pricing on transport systems as a whole not only the priced facility or the charge zone; (*iii*) consider the demand risk (uncertain future demand) in the analysis, using a scenario analysis; (*iv*) include the disutility resulting from travel discomfort (the induced change in travel behavior, e.g., not to travel) because of road pricing; (*v*) improve public transport systems to provide/encourage an environmentally-friendly alternative to driving (which becomes more expensive as a result of pricing); (*vi*) provide the vision to users and residents why road pricing increases welfare; (*vii*) explore equity implications (which stakeholders are losers and winners and how to address their gains/losses); (*viii*) offer a flexible, but capped, tolling/pricing system that allows tolls to vary temporally (from time to time) and spatially (from one region to another); and (*ix*) include impacts on sectors outside transportation (businesses, employment, and residential and work location choices). In this paper, I explained the basic foundations about how these factors should be included. However, this is the first major step in developing/promoting the idea of social-welfare-oriented pricing systems. Future work can develop detailed modeling steps required to ensure (or even maximize) welfare improvements from road pricing, e.g., how to separate/categorize various stakeholders, how to measure environmental and equity impacts in monetary terms, what types of models required for the analysis, *etc*. In addition, I will model and design social-welfare-oriented road pricing schemes for real case studies. Finally, I will examine the fundamental changes/benefits social-welfare-enhancing RP schemes would induce, relative to congestion pricing and profit-oriented pricing schemes.

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