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Abstract

People who anticipate the introduction of a policy can adapt their behavior, perhaps in ways that make the policy ineffective and exacerbate the problem to be addressed. This paper develops a political economy model to study strategic behavior related to the introduction of congestion policies, focusing on tradeable driving permits and congestion tolls. We have the following results. First, anticipatory behavior after the policies are announced but prior to their introduction may make both congestion policies welfare-reducing. Second, drivers will oppose the policies even when they receive all permits for free, or toll revenues are distributed to drivers only. As a consequence, strategic behavior makes it more difficult to get a political majority to support both congestion policies. Third, in an infinite horizon setting, tradable permits are superior to congestion tolls in that they avoid strategic behavior once the system is implemented. In contrast, with congestion tolls the steady-state equilibrium implies continuing strategic behavior. Drivers will always strictly prefer a permit system over congestion tolls as long as they receive a sufficient share of the permits for free.

JEL-Codes: H230, R410, R480, P160.

Keywords: anticipatory behaviour, political economy, congestion tolls, tradeable driving permits, strategic behavior.

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1. Introduction

Economic agents who anticipate a policy may adapt their behavior in ways that make the policy less effective. The literature offers many examples of such strategic behavior.[1] For example, landowners in the US prematurely harvested timber before costly land use restrictions became effective (Lueck and Michael 2003). Studying the effect of a program in Mexico City that restricted the number of days each car could be driven, Davis (2007) finds virtually no effect on pollution, because of an increase in the registered vehicle stock in anticipation of the policy. Coglianese et al. (2016) report that gasoline purchases increase by 1.3% in the month preceding an increase in the gasoline tax, followed by a drop of 3.1% in the month of the tax increase. The environmental economics literature offers additional examples. Tougher environmental standards over time induce firms to increase baseline emissions (Damon et al. 2019). The expectation of repeated grandfathering of environmental pollution permits may delay abatement investments so as to receive more permits; moreover, firms may expand output via new plants that claim additional free permits (Sterner and Muller 2008).

This paper develops a political economy model to analyze strategic behavior related to the introduction of congestion policies, focusing on two policies: tradeable driving permits and congestion tolls. We study the welfare implications of strategic behavior and consider whether and to what extent such behavior would affect the popular support of voters for the introduction of the policies.

Congestion pricing has been intensively studied, and the first cases of successful implementation are available; for an early comparison of the economic implications in London, Stockholm and Milan, see Anas and Lindsey (2011). Technological developments suggest that obstacles to congestion pricing in the future will be more of a political than of a technical nature. Tradable driving permits have often been proposed as a politically preferable alternative to congestion tolls (see Wu et al. 2012, Fan and Jiang 2013). If the permits are grandfathered drivers incur no extra monetary cost, unlike under congestion tolls; moreover, they benefit immediately, not having to wait until the toll revenues are redistributed or used to improve road infrastructure or public transport supply (de Palma and Lindsey 2019). Both for congestion tolls and tradeable permits, the transaction costs have strongly decreased by the availability of new technologies for monitoring of cars (ANPR cameras) and by the appearance of new platforms for transactions (de Palma et al. 2018).

[1] See the literature review in Section 2 for more examples.

Congestion tolls are rare and, as far as we know, there are no cases at all of tradeable driving permits. In the few cases where tolls were implemented, there is no documented evidence of strategic behavior prior to the introduction of congestion tolls (see the review by Anas and Lindsey 2011). One of the results of this paper is that it offers a convincing explanation why this is the case. Not surprisingly, therefore, with one exception, strategic behavior has not been studied in the context of congestion policies.[2] However, we would expect such strategic behavior to occur, especially for tradeable driving permits. Analogous to what has been observed with the introduction of tradeable emission permits and to gain political support, it is likely that tradeable driving permits would to some extent be grandfathered to drivers; that is, given for free to people who drove prior to introduction of the policy. Competition for permits may then induce extra driving prior to introduction of the policy to obtain more of the permits made available. Similarly, to the extent that toll revenues are partly redistributed to drivers one way or another (for example, in the form of better infrastructure), competition to get more of the revenues may strategically be exploited by drivers.[3]

We present a simple political economy model to investigate the implications of strategic behavior when policies to reduce congestion are decided upon and implemented. We consider two types of strategic behavior. First, in line with the examples given above, there may be anticipatory behavior after the announcement of the policies and prior to their implementation. We study such anticipatory behavior in a two-period model. Second, when the allocation of permits or distribution of toll revenues is based on behavior in the previous period, there may also be continued strategic behavior once the policies have been implemented. We investigate the importance of this type of permanent strategic behavior by analyzing the steady state equilibrium of an infinite horizon model.

Strategic behavior raises several questions. Does strategic behavior make policies to reduce congestion ineffective? Might these policies reduce rather than increase welfare, so that it is better not to introduce them (or introduce them in a form that avoids strategic behavior, if possible at all)? Does strategic behavior make it easier or more difficult to get congestion policies politically accepted? Do people behave differently depending on whether congestion tolls or tradable permits are announced and implemented? Is one policy preferable over the other? Is it easier to get political support for permits than for congestion tolls?

[2] One exception is the air transport literature where both pricing and slot allocation have been studied in a strategic context, see Brueckner (2009). An important difference with our context is that the airlines are non-atomistic agents so that market power and size of airplanes play a role.

[3], see below.

To fairly compare toll and tradeable permit systems, and to emphasize strategic behavior, the two-period model we use implies that both congestion policies can be implemented such that they are equivalent both in terms of efficiency and political acceptability whenever there is neither uncertainty nor strategic behavior. We then show that both policies are politically acceptable only (i) if a large enough fraction of toll revenues or grandfathered permits are allocated to drivers, or (ii) if many voters are non-drivers. Second, allowing for anticipatory behavior between announcing and implementing the policies, we show that both for tolls and permits the welfare cost of strategic behavior may be so large as to eliminate the benefits of the policy altogether. Third, we find that strategic behavior makes it more difficult, and in some cases impossible, to find a political majority in favor of the policies to reduce congestion. Fourth, looking at strategic behavior once the congestion policies are implemented, we show in an infinite horizon model that tolls and permits are no longer equivalent. We show that the efficient number of permits can sustain an efficient congestion solution, whereas tolls lead to excessive driving even if the toll is set at the efficient level. Permits do not give incentives for strategic behavior once the policy has been implemented; on the contrary, under road pricing the steady-state equilibrium implies continued strategic behavior. On this account, strategic behavior makes permits preferable to road tolls. Lastly, we find that drivers will never politically support congestion tolls, but they will support permits if a sufficient fraction is grandfathered to those driving in the previous period.

The paper unfolds as follows. As we build upon earlier literature, the second section is devoted to a literature review. Section three presents a simple model to study the efficiency and political acceptability of tradable driving permits and compares the results with those under congestion tolls. The fourth section introduces strategic behavior in a two-period model, focusing on anticipatory behavior after the announcement but prior to the introduction of the policies. Section five considers an infinite horizon model to study persistent strategic behavior once the congestion policy has been introduced. The final section concludes.

2. Literature review

This paper relates to different strands of literature, drawing on papers from the environmental and transport economics literature, the political economy literature, and the literature on anticipatory and strategic behavior.

First, despite a large literature on the relative merits of pricing versus permits in environmental economics, tradable mobility permits did not yet gain the same prominence as congestion tolls among transport economists. They believed for a long time that transaction costs of mobility permits would hamper efficient trading (Verhoef et al., 1997), and they focused mainly on price instruments (see de Palma and Lindsey (2011) for a review). Recently, however, monitoring technologies and trading platforms have reduced transaction costs and made permit systems attractive, generating a stream of further research. For example, Nie (2012) derives precise conditions under which transactions costs are prohibitive. The use of permits in road networks is analyzed by, among others, Yang and Wang (2011), Wang et al. (2012), and Akamatsu and Wada (2017). The distributional effects of a permit system are discussed by Wu et al. (2012), and the role of uncertainty is studied in Shirmohammadi et al. (2013) and de Palma et al. (2018). By using a virtual currency to compare routes and times of day, transaction costs can be further reduced (De Palma et al. 2018). Importantly, experiments suggest that individuals understand the permit system and adapt their behavior accordingly when confronted with tradable mobility right options (Brands et al. 2019).

In the most comprehensive analysis to date, de Palma and Lindsey (2019) compare the allocative efficiency of a congestion fee and a permit system for congestible facilities under both demand and cost uncertainty. The number of permits issued and the congestion fee are not allowed to differ depending on the realizations of cost and demand. Which system is preferable depends on the nature and the magnitude of demand and cost shocks, the elasticity of the cost function, and whether the number of permits is sufficient to cover all demand. The permit system is found to perform well when socially optimal usage levels differ little across realizations. In contrast, congestion charges are socially preferable if the first-best fees are similar across realizations.

Second, our paper relates to the literature on the political economy of transport decisions. Political economy models of road pricing try to understand why a seemingly welfare-enhancing policy faces so much resistance and is rarely implemented[4]. De Borger and Proost (2012) summarize this literature and develop a simple majority voting model. They argue that individual and political uncertainty may be a major reason why road pricing is not more often introduced. In line with earlier literature, they emphasize that the use of the revenues is important to get a majority to favor road pricing. Small (1992) as well as Goodwin (1994) prefer a combination of improvements of the road network, improvements of public transport

[4] This phenomenon is of course not restricted to road pricing. Institutional and political failures (Dixit, Grossman and Helpman (1997), Coates and Morris (1999), uncertainty (Fernandez and Rodrik (1991), Jain and Mukand (2003)), and asymmetric information (Mitchell and Miro (2006), Maskin and Tirole (2004)) all have been suggested as plausible explanations.

and a reduction of other taxes. King et al. (2007) think it is best to allocate the revenues of the toll on a freeway to the cities through which the freeway passes. Other models suggest that allocating the revenues to improve or subsidize public transport may be the best option to generate political support (De Borger and Proost 2012, De Borger and Russo 2018).

Note that none of these studies take into account strategic behavior, neither before not after implementation of the congestion policies. Moreover, they do not address the political economy of permits (i.e., under what conditions would a majority of voters favor this policy), nor do they compare congestion permits and tolls from a political perspective. Although some authors argue that it may be easier to get a political majority to favor tradable driving rights than to favor congestion tolls (see Fan and Jiang 2013, and Raux and Souche 2003), their conclusion is not based on a formal political economy analysis.[5]

Third, from a broader perspective, this paper contributes to the literature on anticipatory and strategic behavior. Following the announcement of the implementation of the Endangered Species Act, landowners feared costly land use restrictions in case their forests became inhabited by endangered species. In anticipation, they prematurely harvested their timber to prevent this from happening (Lueck and Michael 2003). In the medical sector, there is evidence that physician labor supply increased with anticipated reform of tort laws. Compared to a model that ignores anticipation, accounting for anticipation could increase effects of caps on punitive damages by a factor of two or more (Malani and Reif 2015). Another example occurred after the announcement of Medicare Part D in the US, the prescription drug benefit that took effect two years after it was signed into law. Evidence shows that it caused a 6% decline in overall drug use by the elderly in the two years between announcement and implementation (Alpert 2016). Strategic behavior was also observed in response to the Energy Independence and Security Act which gradually implemented a ban on the production and import of incandescent light bulbs. Stockpiling in response resulted in a 97% increase in 100-watt incandescent bulbs sold per store per week (Dong and Klaiber 2019). In Columbia, within the framework of the peace negotiations, the government announced in 2014 a policy that would offer payments to farmers who voluntarily reduced cultivation of coca. The policy was first implemented at the end of 2016. In the period between announcement and implementation, cultivation of coca

[5] A major argument is that tolls are often perceived as a tax, even if the revenues are redistributed somewhere; on the contrary, assuming that the permits are distributed for free, tradeable permits avoid having to pay for something that was previously free. However, the higher political support for permits may then just be the result of an unfair comparison. The literature often assumes that the revenues of congestion tolls are redistributed uniformly to all inhabitants, whereas permits are grandfathered to drivers only. Then if drivers have a majority it is no wonder that permits will be easier to get politically accepted. We return to this issue below.

more than tripled, reversing a downward trend from the years before the announcement (Ladino, Saavedra, and Wiesner 2019). As a final example, Mannberg et al. (2014) study anticipated strategic behavior in the case of the Stockholm congestion charge. Ethanol vehicles were initially exempted from paying the charge. Maybe unsurprisingly, the authors find a marked increase in the sale of ethanol vehicles both prior to and after implementation of the toll system.

Lastly, closely related in spirit to our paper is the paper by McKenzie (2017) which has a rent seeking model to study the choice between price and quantity instruments in environmental policies.[6] However, as permits are given to firms, not to individuals, he follows the political economy literature on tradeable permits and largely focuses on rent seeking. Our emphasis differs. As mobility permits are allocated to individuals, we focus on gaining political support of voters. Moreover, pollution permits allocated to firms and mobility permits given to drivers differ in the nature of strategic behavior. As we will show, there is an important difference between a once and for all allocation of free mobility permits and a repeated allocation of free pollution permits where the inefficiency of the lobbying game is repeated.

3. Majority voting on mobility permits: a basic model

This section presents a majority voting model on the introduction of mobility permits by extending the simple model used in De Borger and Proost (2012). Our purpose is to study under what conditions a permit system may be politically supported by a majority of the population. To facilitate the comparison with congestion tolls later in the paper, we set up the model in such a way that, in the absence of strategic behavior, the two transport policies (tolls and tradeable driving permits) can be designed to be perfectly equivalent, both in terms of welfare effects and voting outcomes. Doing so allows us to make sure that, when we introduce strategic behavior in Sections 4 and 5, any differences between the two systems that will be identified there are entirely due to strategic behavior.

3.1. Structure of the model

[6] The literature on rent seeking is huge. Important early papers include Tullock (1967), Krueger (1974), Posner (1975), Buchanan, Tollison, and Tullock (1980), Bhagwati (1982), and Tollison (1982). Under some conditions, competitive rent seekers may spend so much as to dissipate the value of the rents to be distributed (Tullock (1967, 1980)). In a survey of measures of rent-seeking costs, Del Rosal (2011) finds estimates ranging from 0.19% of GNP to 45% of GNP. The estimates of what fraction of the value of rents are dissipated through rent-seeking expenditures range from 0.2% to 31.2%.

We assume that there is only one road and one period of the day where there is congestion. The population consists of $n=1,..,N$ individuals that are all potentially interested in using their car. An individual who does not drive because there is too much congestion can use another transport mode that is priced at marginal social cost.

The value of a trip for household n is

$$\begin{aligned} v(n) &= a - bn \\ v(N) &= 0 \end{aligned} \tag{1}$$

We order individuals according to their willingness to pay from highest ($n=1$) to lowest ($n=N$). We assume that all individuals have the same value of time.[7] The average cost of driving is specified as a linear function of the number of cars on the road:

$$d + cn \tag{2}$$

The parameter c is the slope of the congestion function.

Combining (1) and (2), the equilibrium number of road users is

$$n^{\circ} = \frac{a-d}{b+c}. \tag{3}$$

The efficient number of road users n^* is obtained by taking into account the marginal external congestion cost; this amounts to cn. Setting $(a-bn)=(d+2cn)$ we find

$$n^* = \frac{a-d}{b+2c}. \tag{4}$$

Government distributes the socially optimal number n^* of tradeable driving permits. Drivers can be identified using *ANPR* cameras, so that only those with a permit can make the trip by car. Moreover, we assume a fraction f of the permits is grandfathered to initial drivers. The rest $(1-f)$ is sold in an auction and the revenues are redistributed uniformly over the whole population. In equilibrium, the permit price will equal the marginal external cost cn^*. To see this, denote the permit price by P. Equilibrium requires $a-bn^*=d+cn^*+P$. Solving for the permit price and using the definition of n^* we immediately find $P=cn^*$. The total value of all permits in circulation is $c(n^*)^2$.

The remainder of this section assesses the political feasibility of the permit system as a function of the share parameter f. As mentioned, we assume there is no uncertainty and ignore strategic behavior (but see Sections 4 and 5).

3.2. Political equilibrium

[7] We discuss relaxing this assumption below, but stick to the simplest model first.

This subsection examines the conditions needed for a permit system to receive a political majority. We specify the political game as follows. All N members of the population can vote. The vote is limited to accept or not accept a given proposal (n^*,f), where $0 \le f \le 1$. The proposal consists of the socially optimal number of permits distributed and the share grandfathered to initial drivers.

Our goal is to determine the fraction $0 \le f \le 1$ of the permits that needs to be grandfathered to the initial drivers to obtain a majority supporting the proposal. In the absence of strategic behavior in the period preceding introduction of tradeable permits, the system reduces the number of drivers from $n°$ to n^*, as given in (3) and (4). We analyze the change in utility for three groups of citizens: those that continue to drive, those that stop driving, and those that did not drive before the permits system was implemented.

First, <u>initial drivers who continue to drive</u> (the group of individuals indexed n for which $0<n<n^*$) need a permit to be allowed to make the trip. The market price is cn^*; however, grandfathering implies that a fraction f of the value of the permits (equal to $c(n^*)^2$) is distributed for free among the $n°$ initial drivers. Moreover, continuing drivers enjoy a lower trip cost due to the decline in traffic from $n°$ to n^*, saving $c(n°-n^*)$. Lastly, they share in the auction sales revenues from permits. The total net benefit per continuing driver is

$$c(n^\circ - n^*) - cn^* + f\left(\frac{c(n^*)^2}{n^\circ}\right) + (1-f)\left(\frac{c(n^*)^2}{N}\right) \tag{5}$$

This benefit can be positive or negative, depending on the share f given to initial drivers. To see the role of f, suppose first that $f=0$. This is a regime where there is no grandfathering of permits; all permits are sold at the market price and the revenues are redistributed uniformly to all N individuals. In that case, continuing drivers are necessarily worse off: it is easily shown that for $f=0$ expression (5) reduces to:

$$c(n^\circ - n^*) - cn^* + cn^*\left(\frac{n^*}{N}\right) = -\left[\frac{c(a-d)}{a(b+2c)^2(b+c)}\right]\left(abc + db(b+c)\right) < 0 \tag{6}$$

Continuing drivers are always worse off because the efficiency gain is diluted by sharing it with the whole population. At the other extreme, suppose $f=1$. This is a regime where all permits are grandfathered to initial drivers. Continuing drivers will then necessarily be better off:

$$c(n^\circ - n^*) - cn^* + \left(\frac{c(n^*)^2}{n^\circ}\right) = c\frac{(n^\circ - n^*)^2}{n^\circ} > 0 \tag{7}$$

Noting that (5) increases with *f*, combining (6) and (7) suggests that there is a cutoff value for *f* such that a larger *f* makes continuing drivers better off. It is given by the value of *f* that solves

$$c(n^\circ - n^*) - cn^* + f\left(\frac{c(n^*)^2}{n^\circ}\right) + (1-f)\left(\frac{c(n^*)^2}{N}\right) = 0. \qquad (8)$$

Denote the value of *f* that solves this equation f^L (superscript *L* for the *lowest* value of *f* making drivers better off). We find:

$$f^L = \frac{1}{n^*(\frac{1}{n^\circ} - \frac{1}{N})}\left[2 - \frac{n^\circ}{n^*} - \frac{n^*}{N}\right] \qquad (9)$$

Straightforward algebra shows that $0 < f^L < 1$. If $f > f^L$ then continuing drivers are all better off under the permit system.

Second, consider individuals who <u>initially drive but then stop driving</u> (the group indexed *n* for which ($n^* < n < n^\circ$)). The permit system implies that they lose the value of the trip but save the cost of the trip; moreover, they get part of the grandfathered permits which they can sell on the market, and they share in the redistributed revenues from permit sales. Their net gain is

$$-(a - bn) + (d + cn^\circ) + f\left(\frac{c(n^*)^2}{n^\circ}\right) + (1-f)\left(\frac{c(n^*)^2}{N}\right) \qquad (10)$$

To see the implications of (10), first note that, if all continuing drivers are better off (this holds when $f > f^L$), then initial drivers who give up driving are also necessarily better off. The reason is that, first, for $n = n^*$ expression (10) is equal to (5) and, second, (10) is increasing in *n*. If, however, all continuing drivers are worse off (this happens when $f < f^L$) then there must be a value n' such that all voters for which $n^* < n < n'$ are worse off, whereas all for which $n' < n < n^\circ$ are necessarily better off. The value of n' is the value for *n* such that expression (10) equals zero; we find:

$$n' = n^\circ - f\left(\frac{c(n^*)^2}{bn^\circ}\right) - (1-f)\left(\frac{c(n^*)^2}{bN}\right) \qquad (11)$$

The group (n^*, n') suffers from the permit system because the value of the trip they no longer make is large, compared to the benefits of grandfathered permits and redistributed auction sale revenue. The group (n', n°) gains; they attached a lower value to the trip no longer made; it is more than compensated by the benefits received.[8] Importantly, note that n' is declining in f: giving more permits to initial drivers implies that the size of the group that is better off becomes larger.

Third, the (N-$n°$) people who did not drive before the permit system was introduced (the group for which $n°<n<N$) will gain from the redistributed sales revenues. Per person, members of this group therefore gain an amount

$$(1-f)\left(\frac{c(n^*)^2}{N}\right). \tag{12}$$

What does the above analysis imply for voting behavior? First, for a sufficiently large share f (in essence for $f > f^L$) of the permits distributed for free to the $n°$ initial drivers, both continuing drivers and drivers who stop driving are better off. The latter benefit because their share in the revenues of the system exceeds the loss of the value of the trip. Moreover, as long as $f<1$ initial non-drivers also share in the revenues, so that they too will be better off. In that case, therefore, a majority favoring the tradeable permit system always exists.[9]

Second, if the share of the permits grandfathered to initial drivers is small, in the sense that $f < f^L$, then all continuing drivers n^* oppose the system, together with those who stopped driving but valued a trip highly (the group for which $n^*<n<n'$). Hence, n' voters will oppose permits. If this group has a majority, i.e. $n' > \frac{N}{2}$, the tradeable permit system will be voted down. If this group does not constitute a majority ($n' < \frac{N}{2}$), a majority of voters will favor the system. This majority consists of the group of voters who stop driving but who attach a low value to this loss ($n'<n<n°$), together with the initial non-drivers ($n°<n<N$). Note that whether a majority appears depends on f in a predictable way. Using the definition of n' given above, the condition $n' < \frac{N}{2}$ needed for a majority of mainly non-drivers favoring tradeable permits can be reformulated as

[8] Note that for $f = f^L$ we find $n'=n^*$, confirming that all initial drivers that give up their trip are then better off.

[9] Even if $f=1$ (all toll revenues or permits are allocated to initial drivers) a voting majority is still highly likely: initial non-drivers will now be indifferent (or they may benefit from reduced pollution or accident risks, issues not captured by the current model), but initial drivers are all better off.

$$f > \frac{\frac{b}{cn^*}\left(n^\circ - \frac{N}{2}\right) - \frac{n^*}{N}}{n^*\left(\frac{1}{n^\circ} - \frac{1}{N}\right)} \equiv f^{ND}. \tag{13}$$

Denoting the right-hand side as f^{ND}, a majority consisting of non-drivers and part of the initial drivers no longer making the trip is obtained when[10]

$$f^{ND} < f < f^L.$$

Note that f is restricted to be between 0 and 1, but f^{ND} can be negative. Algebra shows that a negative value appears when $n^\circ < \frac{N}{2}$. In this case initial non-drivers constitute a majority, so that even at $f=0$ a majority favors the permit system. Moreover, f^{ND} can also be larger than f^L. Using the definitions and working out we find that this applies when continuing drivers have a majority, i.e., when $n^* > \frac{N}{2}$. By definition, there is then no majority of non-drivers.

To summarize, if the fraction of permits assigned for free to initial drivers $f > f^L$ both initial drivers and non-drivers favor the permit system. If $f^{ND} < f < f^L$, initial drivers oppose, but the group consisting of non-drivers (n°, N) plus part of those no longer driving (n', n°) favor the system and it has a majority, so the proposal is supported by a majority. If $f < f^{ND}$ then this same group is no longer a majority, so that a majority opposes the system. We bring our findings together in Table 1 and Proposition 1.

Cases considered	**Required condition**	**Share *f* of permits allocated to initial drivers**	**Majority in favor?**	**Composition of the majority in favor**
Continuing drivers have a majority	n*>(N/2)	$f>f^L$ $f<f^L$	**Yes** **No**	All voters No majority
People not driving in initial period have a majority	n°<(N/2)	*f* anywhere between 0 and 1	**Yes**	Non-drivers
Neither continuing drivers nor	n*<(N/2)<n°	$f^{ND} < f < f^L$ $f < f^{ND} < f^L$	**Yes**: *n'<(N/2)*	Non-drivers plus part of those giving up trips

[10] Note the very different interpretation of f^L and f^{ND}. The former determines whether drivers are in favor or not; the latter determines whether non-drivers (who are always in favor) have a majority.

people not driving have a majority			**No**: $n' > (N/2)$	No Majority

Table 1. Voting on tradeable driving permits

Proposition 1. Majority voting on tradeable driving permits.

a. **For a sufficiently large share *f* grandfathered to initial drivers (more precisely, the share satisfies $f > f^L$), all such drivers will be better off. A majority then favors the introduction of the policy.**

b. **If $f < f^L$, all continuing drivers are worse off. However, a majority of non-drivers favors the introduction of tradeable permits as long as $f > f^{ND}$.**

c. **If $f < f^{ND}$ a majority opposes the tradeable permit system.**

Lastly, note a corollary of our results. If there are no constitutional constraints on the value of *f* it follows that, when continuing drivers constitute a majority ($n^* > N/2$), the permit system will be introduced with $f=1$; all permits go to initial drivers. If initial non-drivers constitute a majority ($n° < N/2$), then the permit system will be introduced with $f=0$; initial drivers get nothing. The same holds if there is a majority of initial non-drivers plus part of those giving up their trips; we will then also have $f=0$.

A numerical example illustrates the results so far. Let $a=12$, $d=4$, $b=0.006$, $c=0.004$, and $N=1200$. We then find $n° = 800$ and $n^*=571,5$. This is a case where neither continuing drivers nor the initial non-drivers constitute a majority, because $n^* < \frac{N}{2}, n° > \frac{N}{2}$. As noted above, this implies $0 < f^{ND} < f^L$. Using (9), the value of the cutoff for the share to be grandfathered to initial drivers is $f^L=0.52$. Using (13), for f^{ND} we find $f^{ND}=0.205$.

We illustrate the possible outcomes in Table 2 below. The numerical results imply that one needs to distribute for free at least 52% of the permits to initial drivers to have them support the system. Doing so would guarantee a majority favoring the tradeable permit system. If less than 52% of the permits is grandfathered to initial drivers, continuing drivers and part of those giving up their trip oppose the system. There can still be a majority, now mainly consisting of non-drivers. Whether there is such a majority depends on the value of *n'* (which itself depends on *f*). As long as $f>0.205$ a majority supports the system. Clearly, in the above example tradeable permits without grandfathering a fraction of the permits (case $f=0$) does not get a majority (because for $f=0$ we have $n'=618$, so $n' > \frac{N}{2} (=600)$).

Value of f	Value of n'	Majority in favor?
>f^L=0.52		Yes (continuing drivers + those giving up trips +non-drivers)
0.5	573	Yes (part of those giving up trips + non-drivers)
0.4	582	Yes (part of those giving up trips +non-drivers)
0.3	591	Yes (part of those giving up trips + non-drivers)
0.2	601	No (drivers + part of those giving up trips are against)
0.1	609	No (drivers + part of those giving up trips are against)
0	618	No (drivers + part of those giving up trips are against)

Table 2. Majority voting on congestion policies: results from a numerical example

3.3. Tradeable permits versus congestion tolls

Some argue that it may be easier to find political support for tradeable driving permits than for congestion tolls (see Wu et al. 2012, Fan and Jiang 2013, and Raux and Souche 2003). As noted in the introduction, however, this suggestion is based on an unfair comparison: studies of tolling systems often assume lump sum redistribution of the toll revenues, whereas analyses of tradeable permits typically assume that the permits are partly grandfathered to initial drivers. This clearly puts tolls at a disadvantage. However, toll and permit systems can in principle be designed so as to make the two policies equivalent, both from a welfare perspective and from a political point of view.

Suppose that – instead of the tradeable permit system -- the government implements the social optimum by imposing a toll. The efficient number of road users n^* can be obtained by a toll τ equal to the marginal external cost cn^*; the toll revenues are $c(n^*)^2$.

To make tolls equivalent from a behavioral perspective to the tradeable permits analyzed above, we again assume that initial drivers can be identified using *ANPR* cameras, and we impose a toll $\tau=cn^*$ per trip. A fraction f of the toll revenues is directly reimbursed to the group of initial drivers $n°$, a fraction $(1-f)$ is returned via a uniform lump-sum subsidy to everyone. All expressions for the payoff per category of individuals that we derived above for the tradeable permit system will then be the same for congestion tolls. When $f=1$ the toll revenues go to initial drivers only. The other extreme case where $f=0$ is full lump-sum redistribution of revenues. Under the stated rigid design conditions, Proposition 1 holds for permits and tolls alike.

Of course, if the tolling and tradeable permit systems are introduced under widely different assumptions on the use of the toll revenues and the grandfathering of permits, the comparison between the two systems will strongly depend on design characteristics of the systems. For example, if we compare a tradeable permit system, where part of the permits are grandfathered, with a system of congestion tolls with lump sum redistribution of all toll revenues, it will be politically easier to get a majority in favor of permits than of tolls. By the same argument, however, our model implies that it is much easier to get a majority for a toll system where toll revenues are somehow returned to drivers than for a permit system with zero grandfathering.

3.4. Extensions

Our model only considered car transport; moreover, our assumption on the use of the toll revenues or the allocation of permits was just one of several possibilities. However, including public transport and allocating part of the permits or toll revenues to public transport does not affect the main insight from the model presented above. In an extension, available from the authors, we introduced public transport as an alternative mode, and we considered outcomes when a fraction of toll revenues or tradeable permits are given to the initial drivers, with the remainder allocated to initial public transport users. Although the detailed results obviously differ, the qualitative implications are similar: if the group of initial car users is large, the likelihood of having a political majority increases when more of the revenues or permits are allocated to initial drivers. If the group of initial car users is small, a majority of the population will always favor pricing and permits.

Lastly, one may wonder to what extent the results would differ if we took account of differences in willingness to pay and in time valuation between different groups. In another extension, available from the authors, we considered a two-mode version with two groups (H, L) that differed in their valuation of time and in their maximum willingness to pay. Unsurprisingly, it then turns out that if the value of time of the group H (the group with high time value) is sufficiently high, all initial H-type drivers will be better off, even if they receive no permits at all. For some values of the fraction of the permits grandfathered to initial drivers, H-types are better off whereas L-types are worse off. A voting majority therefore now depends on the relative size of the two groups and on the fraction of permits allocated to drivers.

4. Political equilibrium with strategic behavior: a two-period model

The literature surveyed in Section 2 suggests that people adapt their behavior in anticipation of policies being introduced in the future. For example, much evidence shows that introducing pollution permits leads to strategic behavior prior to its introduction in order to get more of the permits allocated (Sterner 2008). The previous section looked into the behavior of drivers when a share f of the permits or toll revenues is allocated to the $n°$ initial drivers. Of course, this may lead drivers to behave strategically to get more of the toll revenues or of the driving permits. Strategic behavior implies that the number of initial drivers becomes endogenous. This may not only affect the overall efficiency of a tolling or tradeable permit system, but also political decisions based on majority voting.

This section analyzes strategic behavior after the announcement but before the introduction of congestion tolls and tradeable permits. We use a two-period model. Note that no strategic behavior will occur if the congestion policies are introduced unexpectedly. For example, the government could observe driving behavior in period 0 before announcing that a permit or toll system will be introduced in period 1. Given the political process by which such decisions are taken, this is very unlikely to happen. Indeed, the voting assembly has to make three decisions: the level of the toll or the number of permits, the allocation of the revenues or permits, and the observation and registration technique for the drivers in period 0. The experience of the cities that implemented road pricing (London, Stockholm, Milan, etc.), and that of the many cities that did not succeed to implement such a system, shows that this public debate and the implementation of this decision may take several years. In line with the literature on pollution permits, we can safely assume that the introduction of the policy is announced well in advance of its introduction. We therefore assume that drivers in period 0 know the system will be implemented in period 1.

We first consider tradeable permits. The comparison of the results with a system of congestion tolls is discussed in Section 4.3 below.

4.1. Strategic behavior of drivers before permits are introduced

Suppose that the government announces that a system of permits will be introduced in period 1, and that a given number of permits will be grandfathered to those who drove in period 0. In period 0, no permits are required. In period 1, only those having a permit are allowed to use the road. This makes strategic driving possible: a driver in period 0 will receive some free permits in period 1. For simplicity, we assume a zero discount rate; this does not affect the qualitative results.

An important question for the government is how to determine the number of permits to distribute in period 1. There are at least two options. One is to take a naïve stand and fix the number of permits at the optimal level absent strategic behavior (i.e., at n^*). A second option would have the government anticipate strategic behavior and set the number of permits in period 1 taking into account strategic driver behavior in period 0. We focus on the first approach here. The second approach is touched upon in Section 4.4 below.

Therefore, assume that the number of permits n^1 distributed in period 1 is fixed at the efficient level absent strategic behavior, so:

$$n^1 = n^* = \frac{a-d}{b+2c}.$$

We further assume that some permits are grandfathered: the permits are (partly or fully) allocated to people who drive in period 0. Let there be n^{e0} drivers in period 0. We know that, in the absence of any strategic behavior, in period 0 we would have

$$n^{e0} = n^\circ = \frac{a-d}{b+c}.$$

Assume a share f of the socially optimal number of permits is grandfathered in period 1 to people that drove in period 0. This will affect the equilibrium number of drivers in period 0, because by making the trip in period 0 a driver gets free permits the next period. This makes driving in period 0 more valuable and raises the willingness to drive in period 0. The equilibrium number of drivers in period 0 will be determined by the marginal driver n^{e0} for which the willingness to pay equals the generalized cost:

$$a - bn^{e0} + f\ p = d + cn^{e0}. \tag{14}$$

In this expression, p is the value of the permits distributed to a period 0 driver. Note that the equilibrium price associated with n^* permits is cn^* per permit. Therefore, the total value of the n^* permits distributed is $c(n^*)^2$, so that:

$$p = \frac{c(n^*)^2}{n^{e0}}.$$

Using this expression in (14), noting that $(a-d) = (b+c)n^\circ$ and rearranging, the number of period 0 drivers satisfies:

$$n^{e0} = n^\circ + f\frac{1}{(b+c)}\frac{c(n^*)^2}{n^{e0}} \tag{15}$$

Note that (15) is an implicit equation in n^{e0} that can be solved for any given value of *f*. It immediately shows that strategic behavior leads to more driving in period 0 than absent such behavior: $n^{e0} \geq n°$. Equality holds only if *f=0*: strategic behavior disappears when period 0 drivers get no share of the permits. It plays at full force when all permits are allocated to period 0 drivers (*f=1*). Using the implicit function theorem, (15) implies that giving more permits to period 0 drivers increases strategic driving, and therefore congestion, in period 0:

$$\frac{dn^{e0}}{df} = \frac{\frac{c}{b+c}\frac{(n^*)^2}{n^{e0}}}{1+f\frac{c}{b+c}\left(\frac{n^*}{n^{e0}}\right)^2} > 0. \qquad (16)$$

In period 1, strategic behavior is absent because the number of permits has been fixed at the optimal level n^*.

We can compare the efficiency loss due to strategic behavior in period 0 and the welfare gain of optimal pricing in period 1. The efficiency loss of excessive driving in period 0 is:

$$(n^{e0} - n°)\left\{d + 2c\left(\frac{n^{e0}+n°}{2}\right) - \left[a - b\left(\frac{n^{e0}+n°}{2}\right)\right]\right\}.$$

This can be compared to the welfare gain of efficient pricing in period 1, calculated as:

$$0.5cn°(n° - n^*).$$

To illustrate the implications of strategic behavior, consider again the numerical example used before. Let *a=12*, *d=4*, *b=0.006*, *c=0.004*, and *N=1200*. Remember that we had $n°= 800$ and $n^*=571.5$. Solving the nonlinear equation (15) for different values of *f* determines n^{e0}, the number of drivers in the initial period. Using the above expressions, we then calculate the welfare loss of excessive driving in period 0 and compare it with the gain from optimal driving in period 1. The results are given in Table 3.

f	n^{e0}	***Welfare loss from strategic behavior***	***Welfare gain from optimal driving***	***Net welfare gain***
0	800	0	365.6	365.6
0.25	839	135.4	365.6	230.2
0.5	875	279.4	365.6	86.2
0.75	908	427.2	365.6	-61.6
1	939	580.0	365.6	-214.4

Table 3. Strategic behavior and the net welfare gain from tradeable permits

Strategic behavior increases with the share of permits grandfathered to drivers in period 0. If all permits are grandfathered, it increases driving by 17%, from 800 to 939. Importantly, when a large fraction of permits is grandfathered, the welfare loss due to strategic behavior prior to the introduction of the congestion policy is larger than the benefit of efficient road use in period 1: strategic behavior leads to additional driving in period 0, exacerbating congestion. This increases the inefficiency of an already suboptimal allocation in that period. Drivers in period 0 are motivated by the private share ($c(n^*)^2 / n^{e0}$) of the total value of the permits, and not by the social efficiency gains that are only a small fraction of the permit revenues.

We summarize with:

Proposition 2. The welfare effect of strategic behavior by drivers in a two-period model

a. **Allocating a higher proportion of the permits to initial drivers increases strategic behavior. There will be more excessive driving and more congestion prior to the introduction of the system.**
b. **The welfare cost of strategic behavior in period 0 can be large. It may exceed the benefits the optimal permit system has in period 1, so that the congestion policy reduces welfare.**

In practice, the discount rate (here assumed to be 1) also matters. More importantly, the number of periods during which the initial allocation applies is important for several reasons. It increases the benefits of the permit system, because the efficiency gain from reduced driving applies to multiple periods. However, if the initial allocation counts for many future periods, it becomes even more important to drive in the initial period, increasing the cost of strategic behavior in the initial period. Note, however, that this is not how toll or permit systems typically operate: the allocation of revenues and tradeable permits is usually adapted based on behavior in the previous period.

4.2. Majority voting in the presence of strategic behavior

How does strategic behavior affect support for a tradeable permit system? To fix ideas, assume the vote takes place before period 0. Voters in period -1 may or may not support the permit policy, knowing about strategic behavior in period 0. In the absence of strategic behavior, the number of drivers in period 0 is $n°$. Due to strategic behavior, the number of period 0 drivers becomes endogenous: n^{e0} is a function of f. Under our assumptions, the other definitions are the same as in Section 3: the number of continuing drivers is n^*, the number of drivers that would have stopped driving is the interval (n^*, $n°$), and non-drivers are in the interval ($n°$, N).

As the extent of strategic behavior depends on the share of permits allocated to period 0 drivers, we want to find out how this share f affects voting outcomes. To do so, we reconsider consecutively the net utility gains of the permit system for the different groups affected. To keep things simple, we ignore the discount rate.

First, reconsider the net utility gain of the permit system to a continuing driver. Adding the various effects in periods 0 and 1 this is

$$-c(n^{e0}-n°)+c(n°-n^*)-cn^*+fcn^*(\frac{n^*}{n^{e0}})+(1-f)cn^*(\frac{n^*}{N}) \qquad (17)$$

The first term concerns the efficiency loss in period 0 because of excessive driving. It captures the increased congestion cost due to strategic behavior. The other four terms capture effects in period 1. A continuing driver saves time in period 1 due to reduced traffic (second term). Next, to drive in period 1 he needs a permit, but he can use his share of the value of the permits that were distributed to drivers in period 0. Since a fraction f of the permits was grandfathered to period 0 drivers, the net cost of a permit is given by the sum of the third and fourth terms. The last term captures the driver's share of the fraction (1-f) of the permit value that was distributed lump-sum.

Whereas in the absence of strategic behavior the net benefit of a continuing driver increased in f (see (5)), expression (17) suggests that under strategic behavior this no longer necessarily holds. On one hand, receiving more permits reduces the net cost of driving: conditional on a given number of trips n^{e0}, a higher f increases the net benefit for a continuing driver. On the other hand, a higher f increases strategic behavior and increases driving in period 0 ($n^{e0} > n°$). Expression (17) shows that this hurts continuing drivers in two ways: drivers face more congestion in period 0 (see the first term), and the fraction of the permits that is grandfathered to initial drivers has to be shared with more drivers (see the fourth term in (17)). Therefore, providing a larger share of the permits to drivers does not necessarily increase their net benefits from the permit system.[11]

[11] Differentiation (17) makes the effect of increasing f more precise. We find that an increase in f has the following effect on utility of a continuing driver:

$$c(n^*)^2\left(\frac{1}{n^{e0}}-\frac{1}{N}\right)-c\left(1+\frac{f(n^*)^2}{(n^{e0})^2}\right)\frac{\partial n^{e0}}{\partial f}$$

The first term captures the effect of more grandfathered permits, holding the number of drivers in period 0 constant; this term is positive. The second term is negative. It takes into account that a higher f increases strategic

We know from the previous section that the permit system benefits continuing drivers if they receive a sufficiently large share of all permits (specifically, if $f > f^L$). Importantly, this no longer holds under strategic behavior: we show that continuing drivers will always be worse off when there is strategic behavior. This result holds for any positive share f of the permits they receive.

To prove this result, dividing all terms in (17) by c and rearranging, it follows that (17) is positive if and only if:

$$f\left[\frac{(n^*)^2}{n^{e0}} - \frac{(n^*)^2}{N}\right] > (2n^* - n^\circ) + (n^{e0} - n^\circ) - \frac{(n^*)^2}{N} \qquad (18)$$

From (15) we know that $n^{e0} - n^\circ = \frac{fc}{b+c}\frac{(n^*)^2}{n^{e0}}$. Substituting this result in (18) and rearranging, the latter inequality can be rewritten as:

$$f\left[\frac{(n^*)^2}{n^{e0}}\frac{b}{b+c} - \frac{(n^*)^2}{N}\right] > (2n^* - n^\circ) - \frac{(n^*)^2}{N} \qquad (19)$$

Now algebra shows, using earlier definitions, that

$$2n^* - n^\circ = \frac{b}{b+c}n^*. \qquad (20)$$

Substituting this result in (19) and dividing by n^* then shows that condition (17) reduces to:

$$f\left[\frac{n^*}{n^{e0}}\frac{b}{b+c} - \frac{n^*}{N}\right] > \frac{b}{b+c} - \frac{n^*}{N}. \qquad (21)$$

Using earlier definitions of n^* and N, the right-hand side is necessarily positive:

$$\frac{b}{b+c} - \frac{n^*}{N} = \frac{b\left[ac + d(b+c)\right]}{a(b+c)(b+2c)} > 0.$$

Lastly, observing that $n^* < n^{e0}$, the term within brackets in (21) is smaller than the right-hand side, so inequality (21) can never hold for any f, $0 \le f \le 1$.

With strategic behavior, continuing drivers are therefore always hurt by the introduction of tradeable permits. Absent strategic behavior, they were in favor of the system if they received at least $f^L < 1$. However, they will now oppose the system, even if all permits are grandfathered to drivers in period 0 ($f=1$). Giving all permits for free to initial drivers is therefore insufficient to have drivers favor tradeable permits. As a consequence, strategic

driving in period 0. This implies more congestion; moreover, it also means that the grandfathered permits have to be shared with more other drivers.

behavior may easily destroy a majority for the permit system that would have existed absent such behavior.

Second, let us turn to people that stop driving because of the permit system, that is, people in the group (n^*-n°). Their net benefit of the permit system is also reduced due to the higher congestion cost in period 0; it reads:

$$-(a-bn)+(d+cn^\circ)+f\left(\frac{c(n^*)^2}{n^{e0}}\right)+(1-f)\left(\frac{c(n^*)^2}{N}\right)-c(n^{e0}-n^\circ)$$

We showed above that continuing drivers ($0<n<n^*$) are worse off. Given the linearity of the model in n, this implies that some of the initial drivers that stopped driving in period 1 due to the permit system will also be worse off. More specifically, all those for which $n^*<n<<n''$ will be worse off, where n'' solves

$$-(a-bn)+(d+cn^\circ)+f\left(\frac{c(n^*)^2}{n^{e0}}\right)+(1-f)\left(\frac{c(n^*)^2}{N}\right)-c(n^{e0}-n^\circ)=0\,.$$

We find

$$n''=n^\circ+\frac{c}{b}(n^{e0}-n^\circ)-f\left(\frac{c(n^*)^2}{bn^{e0}}\right)-(1-f)\left(\frac{c(n^*)^2}{bN}\right). \qquad (22)$$

Unsurprisingly, this cutoff n'' is larger than the cutoff n' we found when there is no strategic behavior:

$$n''-n'=\frac{c}{b}(n^{e0}-n^\circ)+\left(f\frac{c(n^*)^2}{b}\right)\left(\frac{1}{n^\circ}-\frac{1}{n^{e0}}\right)>0.$$

Strategic behavior implies that a greater number of those who stop driving will also oppose the system than absent such extra driving in period 0.

How does strategic behavior affect voting outcomes? First, if continuing drivers constitute a majority ($n^*>(N/2)$), the proposal to introduce a permit system will not have a majority. Second, if initial non-drivers constitute a majority ($n^\circ<(N/2)$) the proposal to introduce the permit system will be accepted. As the benefit to a non-driver is $(1-f)\left(\frac{c(n^*)^2}{N}\right)$ they will favor the system with as little grandfathering as politically feasible, i.e., they opt for a very low value of f. Third, if neither group constitutes a majority ($n^*<(N/2)<n^\circ$), a majority in favor exists (consisting of people who initially did not drive plus those giving up their relatively low-valued trips) when $n''<(N/2)$.

An important policy implication is that, unless non-drivers constitute a majority, strategic behavior makes it much harder to get majority support for the system. We summarize in Table 4 and Proposition 3 below.

Cases considered	**Required condition**	**Majority in favor?**	**Composition of the majority in favor**
Continuing drivers constitute a majority	n*>(N/2)	**No**	
People not driving in initial period constitute a majority	n°<(N/2)	**Yes**	Non-drivers
Neither continuing drivers nor people not driving constitute a majority	n*<(N/2)<n°	*n"<(N/2):* **Yes** *n">(N/2):* **No**	Non-drivers

Table 4. Voting on tradeable driving permits with strategic behavior

Proposition 3. Strategic behavior by drivers and majority voting in the two-period model

a. **Continuing drivers oppose tradeable permits, even when they receive all allocated permits for free.**
b. **Strategic behavior makes it much more difficult to get a majority supporting tradeable permits.**

Returning to the numerical example, Table 5 compares voting outcomes with and without strategic behavior. In the absence of strategic behavior, a majority supporting the permits was possible, provided at least 20% of the permits were grandfathered to initial drivers. Under strategic behavior, using the parameters of the model we find that, for all values of f between 0 and 1, the inequality $n''>(N/2)=600$ holds. Consequently, for any level of grandfathering f ($0<f<1$), a majority always opposes permits.

f	**Majority in favor? No strategic behavior**	**Majority in favor? Strategic behavior**	n^{e0}	**n"**
1	**Yes**	**No**	939	661
0.9	**Yes**	**No**	927	655
0.8	**Yes**	**No**	914	649
0.7	**Yes**	**No**	901	644
0.6	**Yes**	**No**	888	639
0.5	**Yes**	**No**	875	635
0.4	**Yes**	**No**	861	630
0.3	**Yes**	**No**	846	627
0.2	**No**	**No**	831	623
0.1	**No**	**No**	816	621
0	**No**	**No**	800	618

Table 5. Majority voting on permits under strategic behavior: numerical example

4.3. Equivalence of permits and tolls

The results derived in Sections 4.1 and 4.2 are again identical if we replace the permit system by a system of tolls, whereby a share f of the toll revenues in period 1 is allocated to people who drove in period 0. Setting the toll equal to cn^* (the marginal external cost at traffic level n^*) implies toll revenues $c(n^*)^2$, and all results immediately follow. Again it pays to drive in period 0 (before the introduction of the tolling system) so as to get more of the toll revenues generated in period 1; strategic behavior in the initial period is the same as with permits. In period 1 there is again no reward for strategic behavior, as the toll is set optimally; this implies the number of drivers in this period is n^*. Therefore, in terms of strategic behavior between announcement of the congestion policy and its introduction, tolling and permit systems have the same implications, provided they are designed in a similar way (i.e., introduced with the same value for f). As mentioned before, if the value of f differs between tolls and permits, results will obviously no longer be identical.

4.4. Socially optimal policies given strategic behavior of drivers

So far we assumed that the government sets the number of drivers in period 1 at the socially optimal level *absent* strategic behavior. Suppose, however, that the government anticipates the strategic behavior by drivers in period 0 and optimally adapts the number of trips in period 1 (to be achieved either via a toll or by allocating permits in period 1) to take this into account. For example, to reduce strategic behavior, the government may allocate a number of permits n^{S1} in period 1 that deviates from n^*, the socially efficient number of permits absent strategic behavior. The number of trips allowed in period 1 then directly affects the extent of strategic driving in period 0. Clearly, then, variations in the fraction of permits f grandfathered to initial drivers affect the overall inefficiency of the congestion policies, and also determines the trade-off between two inefficiency components: excessive driving in period 0 and reduced driving in period 1. This trade-off is illustrated in Appendix 1.

5. Strategic behavior in an infinite horizon model

The previous section showed that strategic behavior prior to the introduction of the permit system strongly reduces the welfare benefits of the congestion policy. Moreover, under plausible conditions, road tolls and permits have the same implications for welfare and for voting. This subsection focuses on strategic behavior once the system is operating and is expected to stay in place for many periods. Specifically, we consider an infinite number of periods and study the steady state equilibrium. As will become clear, in an infinite horizon model, strategic behavior has very different implications for tolls and permits. We therefore study the two policies in sequence.

5.1 Congestion tolls with an infinite horizon

First look at congestion tolls. One can imagine at least two different assumptions on the way the toll is determined in each period. First, the government could fix the toll at cn^*, the socially optimal toll absent strategic behavior, in all future periods. In other words, the toll level for future periods is pre-announced and remains constant. Second, alternatively, the government could announce that the toll will be set at the socially optimal level $\tau = cn(t)$ in each period, where *n(t)* is the traffic level in period *t*. This amounts to having the toll respond to traffic levels.[12] In what follows we assume that the government pre-announces a toll cn^* for all future periods. The alternative setup mentioned above yields qualitatively similar results.

Assume that a fraction *f* of the toll revenues in period (*t-1*) is redistributed to drivers the next period. Each driver in year *t* therefore receives an amount $f\frac{c(n^*)(n(t-1))}{n(t)}$. The number of drivers in year *t* is therefore determined by the equilibrium condition:

$$a - b\,n(t) = d + c\,n(t) + c\,n^* - f\,\frac{c(n^*)(n(t-1))}{n(t)}. \qquad (23)$$

The left hand side is the willingness to pay; the right hand side is the net generalized cost. This consists of the average user cost (*d+cn(t)*) plus the toll (cn^*), minus the individual share of the toll revenues received.

We are interested in the steady state of this dynamic system. In a steady state *n(t-1)* must equal *n(t)*. The steady-state number of drivers *n=n(t-1)=n(t)* therefore solves:

$$a - bn = d + cn + (1-f)cn^*.$$

Using the definition of $n°$, the steady-state equilibrium number of drivers under an efficient toll (denoted $n^{sse,toll}$) is:

$$n^{sse,toll} = n° - \frac{(1-f)c}{b+c}n^* = n^*\left(1+\frac{fc}{b+c}\right) \geq n^*. \qquad (24)$$

Expression (24) shows that when the drivers can share in the toll revenues, there is continuous strategic behavior that leads to excessive driving: it systematically exceeds the socially optimal level n^*. The reason is simple: when a driver shares in the toll revenues of the previous period, the marginal car user will consider that, in net terms, she only pays a fraction of the toll in period *t*. Combining this with the observation that there is no absolute limit on the number of drivers leads to excessive driving in all periods.

Persistent strategic behavior increases with *f*. Consider first the extreme case where *f=1*. Expression (24) then immediately shows that the toll has no effect: the steady-state equilibrium number of drivers is the same as without the toll; it is $n°$. When all toll revenues are returned to drivers and they behave strategically, tolls do not reduce driving at all. To have an effective toll system that does permanently reduce driving, the authorities cannot allocate all toll revenues to drivers; it needs to set $f < 1$. At the other extreme, for $f = 0$, there is no

[12] This distinction between pre-announced and responsive dynamic pricing is well known from models in industrial organization (see, for example, Papanasasiou and Savva (2016)).

strategic behavior, and (24) implies that the steady-state equilibrium is the socially optimal outcome n^*.

Table 6 illustrates the relation between the steady state equilibrium number of drivers and *f* (determined according to (24)); the numerical example is the same as before.

Value of *f*	Steady state equilibrium driving $n^{sse,toll}$
0	571.5 *(=n*)*
0.2	617
0.4	663
0.6	709
0.8	754
1	800 *(=n°)*

Table 6. Steady state equilibrium driving with congestion tolls

5.2 Tradeable driving permits with an infinite horizon

Now instead assume that a permit system is permanently implemented. In each period government sets the number of permits that is optimal in the absence of strategic behavior: it announces that the number of permits will be n^* in all future periods.

This has powerful implications. Clearly, the steady-state equilibrium under the permits system (denoted $n^{sse,permit}$) cannot exceed n^*: by definition, one cannot increase driving beyond n^* when there are only n^* permits. Hence we will have $n^{sse,permit} \leq n^*$. However, can it be optimal for a person to drive less in period *t* to increase her share of the distributed permits in period $(t+1)$? No. It would reduce demand for permits below n^*, and then the value of an additional permit would be 0. In other words, this type of strategic behavior would imply that drivers are eliminating desirable trips without any compensation. Therefore, the only steady-state equilibrium is then n^*, the optimal number of permits. Of course, this does not rule out that there is strategic behavior in period 0, as shown in Section 4.

We summarize in Proposition 4.

Proposition 4. **Consider an infinite horizon, and let a fraction *f>0* of the permits or toll revenues collected in each period be allocated to the drivers in the next period.**

a. **There is no strategic behavior when permits are used and the number of permits is fixed ex ante.**

b. **When tolls are used, there is continuous strategic behavior, even when the toll level is fixed ex ante.**
c. **If all toll revenues are allocated to drivers, congestion tolls are totally ineffective in the long-run.**

Why is there systematic strategic behavior under tolls but not under a permit system? With driving permits the number of trips is fixed at n^*; under a toll scheme the toll level can be fixed, but not the revenues to be redistributed, because these depend on the number of drivers in the previous period.

5.3 . Voting outcomes with an infinite horizon

Which voters will prefer tolls over permits and vice versa? Is it easier to generate support for tradeable congestion permits than for tolls, as the literature has suggested based on other arguments?

To anticipate the results of this subsection, we will first show that continuing drivers always prefer tradeable permits over tolls. Next we show that continuing drivers will always oppose tolls, even when they receive all revenues, but they will support a permit system if they receive a sufficient share of the permits.

First, reconsider the generic expression for the change in utility for continuing drivers; it holds for tolls as well as for tradeable permits. Their utility change in the steady-state equilibrium relative to the equilibrium in the absence of congestion policies is

$$c(n^{\circ}-n^{sse})-cn^{sse}+f\frac{c(n^{sse})^2}{n^{sse}}+(1-f)\frac{c(n^{sse})^2}{N} \tag{25}$$

The first term captures the benefit of the time savings, the second term the payment of the toll or permit. The third and fourth terms are the shares in the grandfathered permits or toll revenues (which now have to be shared with the equilibrium number of drivers in the previous period; in the steady state this amounts to n^{sse}) and the share in the lump-sum redistributed revenues in the steady state.

The utility change depends on the steady state number of drivers, which is larger under a toll system than with tradeable permits. Continuing drivers will then prefer permits over tolls. To see this, note than the net utility change declines with the equilibrium number of drivers in the steady state. Differentiating the above expression (25) with respect to n^{sse} and dividing by c yields:

$$-2+f+2(1-f)\frac{n^{sse}}{N}.$$

This derivative is negative for all values of f, $0 \le f \le 1$. As the steady state implies more driving under a toll system than with permits, it follows that continuing drivers prefer the permit system over tolls.

Second, we proceed to show that continuing drivers will always oppose the toll system. It follows from (25) that they benefit from tolls if and only if

$$n^{\circ} - n^{sse,toll}\left[(1-f)(1-\frac{n^{sse,toll}}{N})+1\right] > 0 \tag{26}$$

In this expression, n^{sse} is the steady state number of drivers under tolling (see (24)):

$$n^{sse,toll} = n^*\left(1+\frac{fc}{b+c}\right). \tag{27}$$

Algebra shows that (26) is non-positive for all f, $0 \le f \le 1$. It is negative for *f=0* (then $n^{sse,toll} = n^*$) and converges to zero for *f=1* (because then $n^{sse,toll} = n^{\circ}$)[13].

Third, interestingly, although they oppose tolls, continuing drivers do support the permit system if they receive sufficient permits for free. Under the permit system we have $n^{sse} = n^{sse,permit} = n^*$. Expression (25) then implies that permits benefit continuing drivers provided that:

$$f > 1-\left(\frac{n^{\circ}-n^*}{N-n^*}\right)\frac{N}{n^*}. \tag{28}$$

The right-hand side of this expression can be shown to be positive. It follows that inequality (28) is not satisfied for *f=0*. It always holds when *f=1*.

The fact that continuing drivers will support permits with a sufficient level of grandfathering (as given by (28)) but will always oppose tolls generates a wide variety of possible voting outcomes. The reason is that initial non-drivers will favor exactly the opposite. They only benefit from the congestion policies via the redistribution of toll revenues or the auction sale of permits. As long as some of the revenues are distributed to all voters (as long as *f<1*), they will prefer the toll system, because it yields the highest revenues (due to more

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[13] For *f=0*, using (26)-(27), we find after some algebra that (26) reduces to $-\frac{(a-d)b\left[ac+d(b+c)\right]}{a(b+c)(b+2c)^2} < 0.$ For *f=1*, using $n^{sse} = n^{\circ}$ in (26) immediately implies that the left-hand side of (26) equals zero.

driving in the steady state equilibrium). If they constituted a majority, they would prefer a toll system with $f=0$ for the same reason.

If continuing drivers constitute a majority, we therefore expect support for a permit system if there is sufficient grandfathering. If initial non-drivers constitute a majority, they will favor a toll system with very little redistribution towards drivers. The toll system is then more effective in reducing congestion. Of course, as always neither continuing drivers nor initial non-drivers may constitute a majority. As before, cutoff values then exist for n such that either continuing drivers plus some people giving up their relatively high-valued trips, or initial non-drivers plus people giving up their relatively low-valued trips constitute a majority. In the former case voting outcomes are then more difficult to predict: people who stop driving prefer tolls because of the higher revenues, whereas continuing drivers prefer permits. In the latter case one expects a toll system with low values of f.

Proposition 5. Voting behavior with an infinite horizon

a. **Continuing drivers prefer tradeable permits over congestion tolls.**
b. **Continuing drivers will always oppose tolls, but they will favor a permit system provided drivers receive at least a minimum number of permits for free.**
c. **Voters that do not drive will support both tradeable permits and congestion tolls, but they prefer tolls over permits. They do not want to allocate any of the permits or toll revenues directly to drivers.**

Note the difference between the voting outcomes in the 2-period model and the infinite period voting outcome. In the 2-period setting, the strategic behavior of drivers in the first (pre-policy)period is so costly that it can never compensate the benefits of congestion tolling or congestion permits. In the infinite period setting, there will be costly strategic behavior in the pre-policy period but these costs will become negligible when a permit system is used in all the next periods. When congestion pricing is in place, the strategic behavior remains present in every period, so the costs of excessive driving continue to destroy the benefits of congestion pricing.

6. Conclusion

This paper focused on the strategic behavior of drivers when congestion policies such as congestion tolls or a grandfathered permit schemes are introduced based on observed driving behavior in previous periods. Permits are likely to be partly grandfathered to people observed to be drivers prior to introduction of the system. Similarly, when congestion tolls are introduced, at least a fraction of the toll revenues is typically redistributed to initial drivers.

Strategic behavior appears whenever drivers in the period where tolling is debated but not yet introduced can claim a share of the permits or revenues. Allocating a sufficient part of the toll revenues or permits to initial drivers is key to make the congestion policies acceptable for the drivers. The drawback is that this allocation generates excessive driving in the period before the introduction of the scheme. The efficiency losses of this strategic behavior can destroy part or all of the welfare gains of efficient congestion toll and permit systems.

Although both congestion tolling and permits suffer from strategic behavior of drivers prior to their introduction, once the system is in place sharing tolling revenues with drivers is much more vulnerable to strategic behavior than is sharing permits. The reason is that with an infinite horizon, sticking to the optimal number of permits guarantees an optimal volume of traffic on the road. This fails under an optimal toll because the optimal toll does not stop drivers from excessive driving; they react to the net cost of the toll, that is, the toll after deduction of the share that is returned to them.

What can we conclude in terms of political acceptability of tolls and permit systems? Letting drivers share in the toll revenues helps build a political majority, but sharing should be based on indicators that drivers cannot easily adapt. This can, for instance, be a vehicle registration tax, but this way of returning toll revenues has a price in terms of political acceptability because peak drivers may be poorly compensated.

This paper made a series of simplifying assumptions. For example, we ignored several other differences between tolls and permits. One example is that tolls generate revenues, whereas permits are usually handed out for free and generate no revenues for the road authority or the state. This is an important issue when the difference in revenues has to be raised via additional distortionary taxes (for example, taxes on labor)[14]. Another difference between tolls and permits is that they may have different distributional implications. However, neither of these two assumptions will affect the negative impacts of strategic behavior on the political acceptability of congestion policies.

[14] Both congestion taxes and permits raise the price of going to work and tend to discourage labor supply and labor tax revenue. This negative second-order effect can be compensated by using the toll revenues to reduce the labor tax or by allocating part of the permits for the people working.

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Appendix 1. Socially optimal policies given strategic behavior of drivers

We assumed that the government sets the number of drivers in period 1 at the socially optimal level *absent* strategic behavior. Suppose, however, that the government anticipates strategic behavior in period 0 and optimally adapts the number of trips in period 1 (to be achieved either via a toll or by allocating permits in period 1) to take this into account.[15] This strategic behavior leads to inefficient driving in period 0 because drivers compete for permits or toll revenues in the next period. To reduce strategic behavior, the government may allocate a number of permits n^{S1} in period 1 that deviates from $n*$, the socially efficient number of permits absent strategic behavior. The number of trips in period 1 directly affects the extent of strategic driving in period 0. We are interested to see whether and to what extent strategic behavior induces the government to let n^{S1} (the socially optimal number of trips in period 1, given strategic driving in period 0) differ from $n*$.

Consider how the number of trips is determined in the two periods. First look at period 0. We denote the number of trips in period 0 by n^{S0}. If there is strategic behavior this will exceed $n°$. It is determined by the following equation:

$$a - bn^{S0} + fp = d + cn^{S0}$$

In this expression, p is the value of the permits or toll revenues for which drivers in period 0 compete, expressed per driver. More precisely, we have

$$p = \frac{\tau n^{S1}}{n^{S0}},$$

where τ is the toll (in case of a congestion toll) or the value of a permit (in the permit case). Substituting p and rearranging we immediately have:

$$n^{S0} = n° + \frac{f(\tau n^{S1})}{(b+c)n^{S0}}. \qquad \text{(A1)}$$

Absent strategic behavior ($f=0$) the number of trips in period 0 equals $n°$. More importantly, the above expression links strategic driving in period 0 to the toll revenues in period 1. The implicit function theorem immediately implies $\frac{dn^{S0}}{d(\tau n^{S1})} > 0$: higher toll revenues -- or a higher total value of the permits allocated -- raise strategic driving in period 0.

Next consider period 1. The number of trips n^{S1} will be determined in a socially optimal manner below. At this point, just note that it should satisfy equality between the willingness to pay and the generalized cost, inclusive of the toll or the value of a permit:

$$a - bn^{S1} = d + cn^{S1} + \tau .$$

This equilibrium condition directly links the number of trips in period 1 to the toll or permit value as follows:

$$n^{S1} = n° - \frac{\tau}{b+c} \quad \Leftrightarrow \quad \tau = (n° - n^{S1})(b+c) \qquad \text{(A2)}$$

[15] Note that our setup assumes a Stackelberg leader-follower structure with the government as the leader. The government moves first and the drivers respond. In principle we could also consider a standard Nash game where the government sets the number of permit in period one in function of driving in period zero, and drivers drive in period zero in function of the number of permits available in period 1. The leader-follower structure seems more plausible.

Using the above expressions we can easily link driving behavior in periods 0 and 1. Substituting τ as given by (A2) in (A1) and rearranging immediately yields the equilibrium relation between driving in period 1 and driving in period 0:

$$n^{S0} = n^{\circ} + \frac{f(n^{\circ} - n^{S1})n^{S1}}{n^{S0}}. \tag{A3}$$

Using the implicit function theorem and working out we find the effect of having more trips in period 1 on driving in period 0:

$$\frac{dn^{S0}}{dn^{S1}} = \frac{fn^{S0}(n^{\circ} - 2n^{S1})}{\left(n^{S0}\right)^2 + f(n^{\circ} - n^{S1})n^{S1}}. \tag{A4}$$

If the government allows more trips in period 1 this has no effect on driving in period 0 if there is no strategic behavior; this happens when *f=0*. Given strategic behavior, more trips in period 1 may raise or reduce driving in period 0. As drivers compete for the toll revenues or permit value of period 1, this depends on the sensitivity of total toll revenues or total permit value with respect to the toll or permit price. To see this note that, using (A1) and simple algebra shows that:

$$\frac{d(\tau n^{S1})}{d\tau} = n^{S1} + \tau\frac{dn^{S1}}{d\tau} = n^{S1} - \frac{\tau}{b+c} = 2n^{S1} - n^{\circ}. \tag{A5}$$

This shows that the sign of the numerator of (A4) depends on whether a higher toll raises or reduces toll revenues, i.e., on the elasticity of toll revenues with respect to the toll. It follows that, if a higher toll raises toll revenues, then the term $(n^{\circ} - 2n^{S1})$ in the numerator of (A4) is negative, so that more trips in period 1 in fact reduce strategic driving in period 0.

The above discussion implies that more trips in period 1 can be consistent with more or less strategic driving in period 0. The intuition is simple. Consider a toll system. Drivers in period 0 compete for the toll revenues of period 1: strategic driving in period 0 will therefore increase if toll revenues in period 1 increase. Suppose that a higher toll in period 1 -- reducing the number of trips in period 1 – increases toll revenues, then strategic driving increases in period 0. In other words, if demand for trips is inelastic, fewer trips in period 1 increase strategic trips in period 0. By the same argument, more trips in period 1 reduce strategic driving in period 0. Alternatively, assume that demand is elastic so that a higher toll reduces toll revenues. Then more trips in period 1 will induce more strategic driving in period 0.

We assume that the government determines the socially optimal number of trips n^{S1} in period 1 by minimizing the social cost of strategic behavior in period 0 (i.e., the social cost of the deviation between n° and n^{S0}, where n^{S0} is the equilibrium number of trips in period 0, given strategic behavior) plus the social inefficiency cost in period 1 (the efficiency cost of the deviation between n^* and n^{S1}). Specifically, we assume that the social optimum value n^{S1} of trips in period 1 solves the following problem:

$$\begin{aligned} \underset{n}{Min} \quad & (n^{S0} - n^{\circ})\left\{d + 2c\left(\frac{n^{\circ} + n^{S0}}{2}\right) - \left[a - b\left(\frac{n^{\circ} + n^{S0}}{2}\right)\right]\right\}, \\ & + 0.5(n^* - n)\left\{a - bn - (d + 2cn)\right\} \end{aligned} \tag{A6}$$

The first line captures the efficiency cost of strategic behavior in period 0, the second line measures the efficiency loss due to inefficient pricing in period 1. In solving (A6), we take into account that equilibrium driving in period 0 depends on how many permits are allocated in period 1 (see (A4)).

Taking the first-order condition, using earlier results and rearranging, we find that the solution n^{S1} can be expressed as follows:

$$n^{S1} = n^* - (n^{S0} - n^*)\frac{dn^{S0}}{dn^{S1}}. \tag{A7}$$

This is obviously not a closed-form solution. However, since $n^{S0} > n^*$, it clearly shows that all depends on the sign of the effect of driving in period 1 on driving in period 0, see (A4).

Substituting (A4) in (A7), the latter equation and (A3) form a system of two nonlinear equations that jointly solve for n^{S0}, n^{S1}, the optimal permits in period 1 and driving in period 0, given strategic behavior. Reconsidering our numerical example, we find the results in Table A below. The toll or permit value is determined using (A2). The final three columns give the welfare loss in periods 0 and 1 (first and second components of (A6)), as well as the total welfare loss.

F	***n^S0^***	***n^S1^***	***Toll (permit value) τ***	***Welfare loss period 0***	***Welfare loss period 1***	***Total welfare loss***
0	800	571.5	2.285	0	0	0
0.25	835	602	1.98	123.1	6.5	129.6
0.5	857	649	1.51	205.8	42.30	248.1
0.75	851	721	0.79	178.2	156.2	334.3
1	800	800	0	0	365.5	365.5

Table A. Strategic behavior and the socially optimal number of trips in periods 0 and 1.

If there is no strategic behavior (*f=0*), the number of trips in period 1 is set at the socially optimal level absent strategic behavior (which was n^*=571.5). This is done by setting a toll which is easily shown -- using (A1) and (A5) – to equal the socially optimal toll $cn^*=2.285$. Alternatively, it can be implemented by selling n^* permits in an auction and distributing the proceeds lump-sum to all people, drivers and non-drivers alike. Providing more of the permits or toll revenues to initial drivers in period 0 implies a lower optimal toll and more drivers in period 1. Providing all of the revenues or permits to initial drivers eliminates strategic driving in period 0 again. It is optimal to set the toll or permit value at zero; this leads to much excessive driving in period 1 but zero strategically excessive driving in period 0.

The results in the table illustrate an obvious point. The best the government can do is to set the number of trips optimally at n^* in period 1 and give none of the toll revenues or permits directly to initial drivers but distribute lump sum to all people (*f=0*). However, this socially optimal solution is not politically attractive because there will not be a majority in favor.