Road tolls, diverted traffic and local traffic calming measures: who should be in charge?

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1. Motivation

- There are many examples of drivers trying to avoid a congested ‘main’ road or a local shortcut
  - Highways and parallel roads
  - National or regional road and local roads through a local community
- Traffic diversion towards ‘local’ roads leads to local congestion, pollution and accidents risks for the local population

Motivation II

- Higher level authorities (federal, regional) may have access to the use of tolls to cope with congestion
- Local communities have instruments to reduce diverted traffic and to reduce local externalities
  - Traffic calming: speed bumps, traffic lights, pedestrian bridges, etc.
  - **New technologies** (automatic number plate detection) make (selective) access restrictions feasible and cheaper: a ban on heavy-good vehicles, low emission zones, a ban on through traffic, car-free zones, etc.

Traffic regulation by economists

Traffic regulation by non-economists

Motivation III

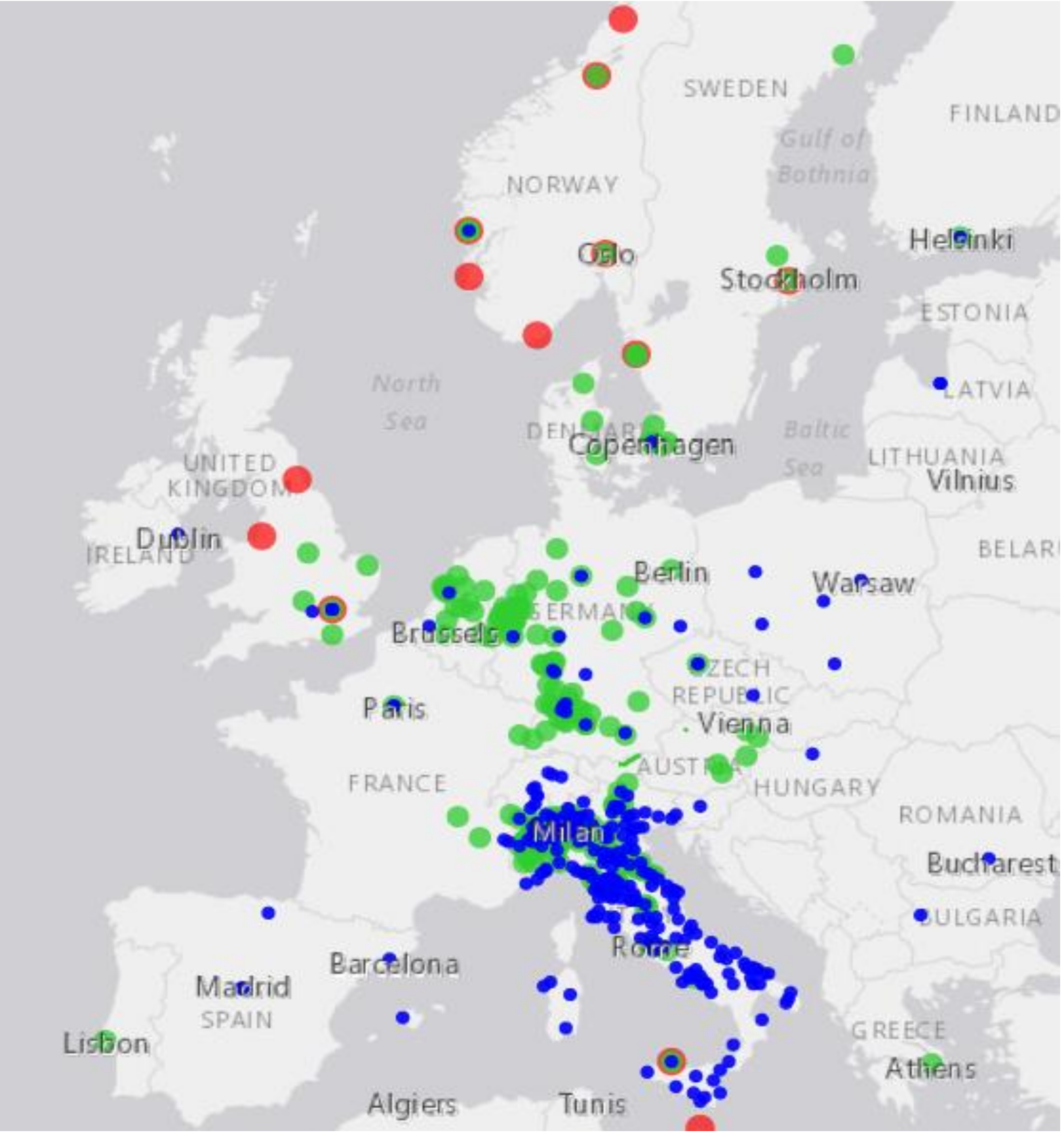
- Economists have focused much more on tolling than traffic calming, although the latter are much more common
- This paper looks at the competition between a higher and a lower level government
  - ‘Federal’ government uses tolls on the main road
  - ‘Local’ government uses traffic calming measures or formal access restrictions on the local road
- Who should be in charge of what?

2 Belgian examples

- Leuven:
  - A suburb parallel to a main access road avoids through traffic using 2 ANPR cameras (traffic flow fell from 1200 to 600 cars/day) – only number plates of residents were allowed (investment cost of 60 000 Euro)
- Ghent – harbour
  - A small village (length of 1.5 km)was used as shortcut for another road by 700 trucks per day
  - Using cameras at the entrance and at the exit of the road, all trucks that pass the stretch of road in less than 4 min were fined – investment cost of 600 000 Euro)

Access restrictions in Europe (very incomplete)

<u>Legend</u>
Green: low emission zone
Blue: key access regulation
Red: toll



Overview of the paper

- 1. Motivation
- 2. Relation with the literature
- 3. Model preliminaries
- 4. Specification of the model
- 5. Access restrictions: results
- 6. Conclusions

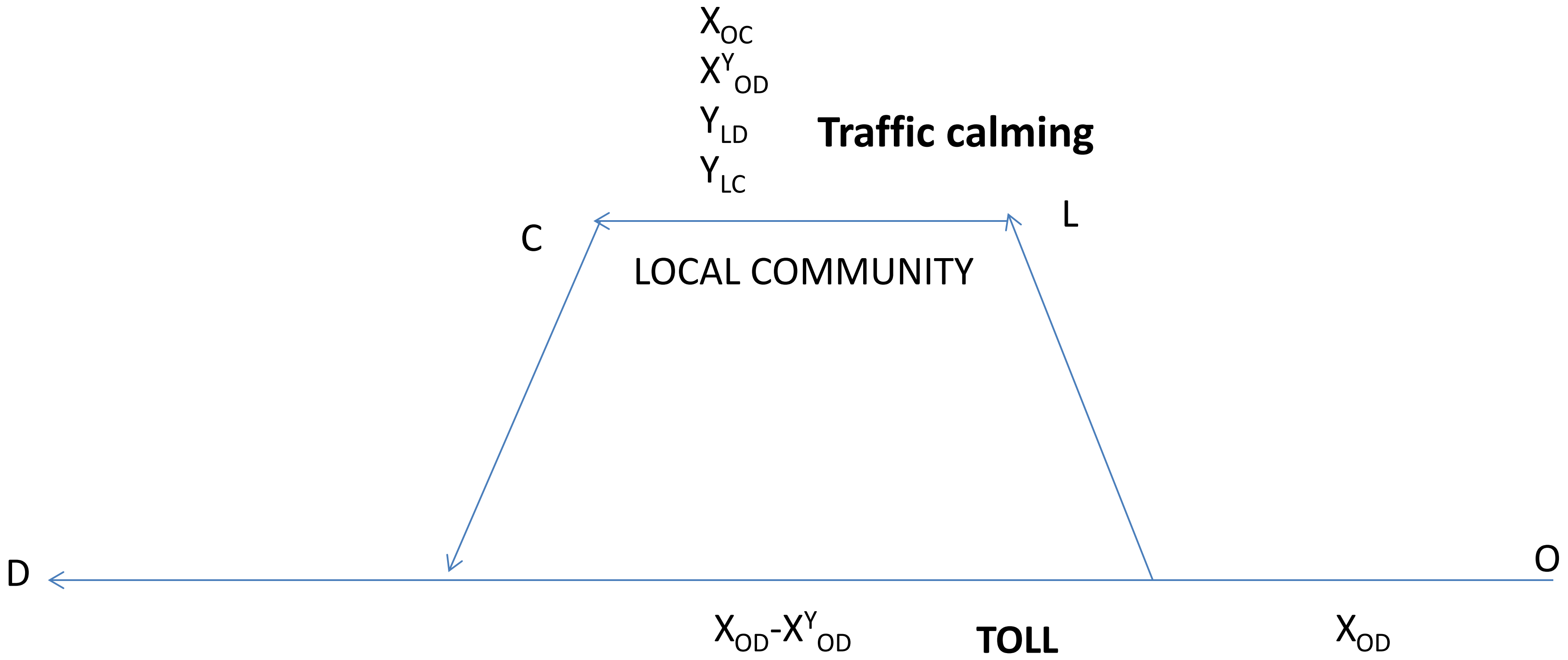
2. Relation with the literature

- Literature on tolling parallel roads to control (mainly congestion) externalities (Verhoef, Nijkamp Rietveld (JUE 1996), De Palma and Lindsey (ARS 2000), De Borger, Proost, Van Dender (EER 2005)
- Literature on accident externalities
- Literature on allocation of pricing of roads between government levels (De Borger&Proost,ITPF,2016)
- Literature on non-price measures: traffic calming De Borger and Proost (JUE 2013), Proost& Westin (PaRegSc 2016),low emission zones (Wolff and Perry (REEP 2010)) , Nitzsche & Tscharaktschiew (TrResA 2013)

3. Model preliminaries

- Simple network setting with different types of trips, commuting and non-commuting (shopping trips, trips to school, etc.)
- The network consists of two congestible roads
  - A main road, intensively used for commuting
  - A parallel secondary road passing through a local community
- Car traffic through the local community causes accident risks to the local population (bikers, pedestrians, children, etc.), local pollution, congestion etc.

The network



X_{OC}
X^{Y}_{OD}
Y_{LD}
Y_{LC}
Traffic calming
C
L
LOCAL COMMUNITY
D
O
$X_{OD}-X^{Y}_{OD}$
TOLL
X_{OD}

Notation

Type of trip	Notation	Remark
Commuting from O to D (outsiders)	$\bar{X}_{OD}$	Fixed
→ Via local community: secondary road y	X_{OD}^{y}	Depends on generalized cost x versus y
→ Via main road x	$\bar{X}_{OD} - X_{OD}^{y}$	Depends on generalized cost x versus y
Commuting from L to D (locals)	$\bar{Y}_{LD}$	Fixed
Non-commuting from O to C (outsiders)	X_{OC}	Price-responsive
Non-commuting from L to C (locals)	$Y_{LC} = \rho X_{OC}$	Price-responsive, proportional

Externalities

- Two types taken into account
- Congestion on main road x and local secondary road y: via generalized costs
- Local nuisance costs for the population of the local community; specified as

$$\lambda\theta(1-\gamma Z)\left(X_{OD}^{y}+(1+\rho)X_{OC}+\overline{Y}_{LD}\right)$$

- For example, θ,λ could be accident probability and accident cost per accident
- Parameter γ captures effectiveness of traffic calming Z in reducing local non-congestion externalities

Effects of local traffic calming measures

- They may or may not slow down traffic
  - Speed bumps, traffic lights, etc. do
  - Pedestrian bridges, seperated bike lanes, etc. do not
- They reduce the local externality imposed by traffic in the local community

Traffic calming measures

Traffic calming measure (Z)	Effect on congestion (δ)	Reduction in local external effect (ϒ)	Implementation cost for local government (c)
Speed limit	High	medium	Low
Speed bumps	High	medium	Medium
Traffic lights	High	medium	Low
Pedestrian bridge-tunnel	None	High (accidents)	High
Cycling paths	None to Low	High (accidents)	High
Low Emission Zone	Medium	High (pollution)	High
No through traffic	High	High	Medium
No access for trucks	Medium	Medium	Medium

Policy instruments studied

	Main road	Local road	Government responsible
Pricing	Toll on the main road		Federal
Local traffic calming		Speed bumps, traffic lights, pedestrian bridges, seperated bike paths, etc. on local road	Local
No through traffic; no through traffic for trucks, etc.		Access local road restricted to local destination	Local

4. Model specification

- Demand
- Generalized costs
- Externalities
- Initial equilibrium
- Welfare
- First- and second-best
- Allocation of authority and Nash equilibrium

Welfare

- Federal Government: Total Welfare
  - Consumer surplus of through traffic and local traffic (including generalized costs)
  - External costs of local inhabitants
- Local welfare: Welfare of inhabitants
  - Consumer surplus of local traffic
  - External costs of local inhabitants

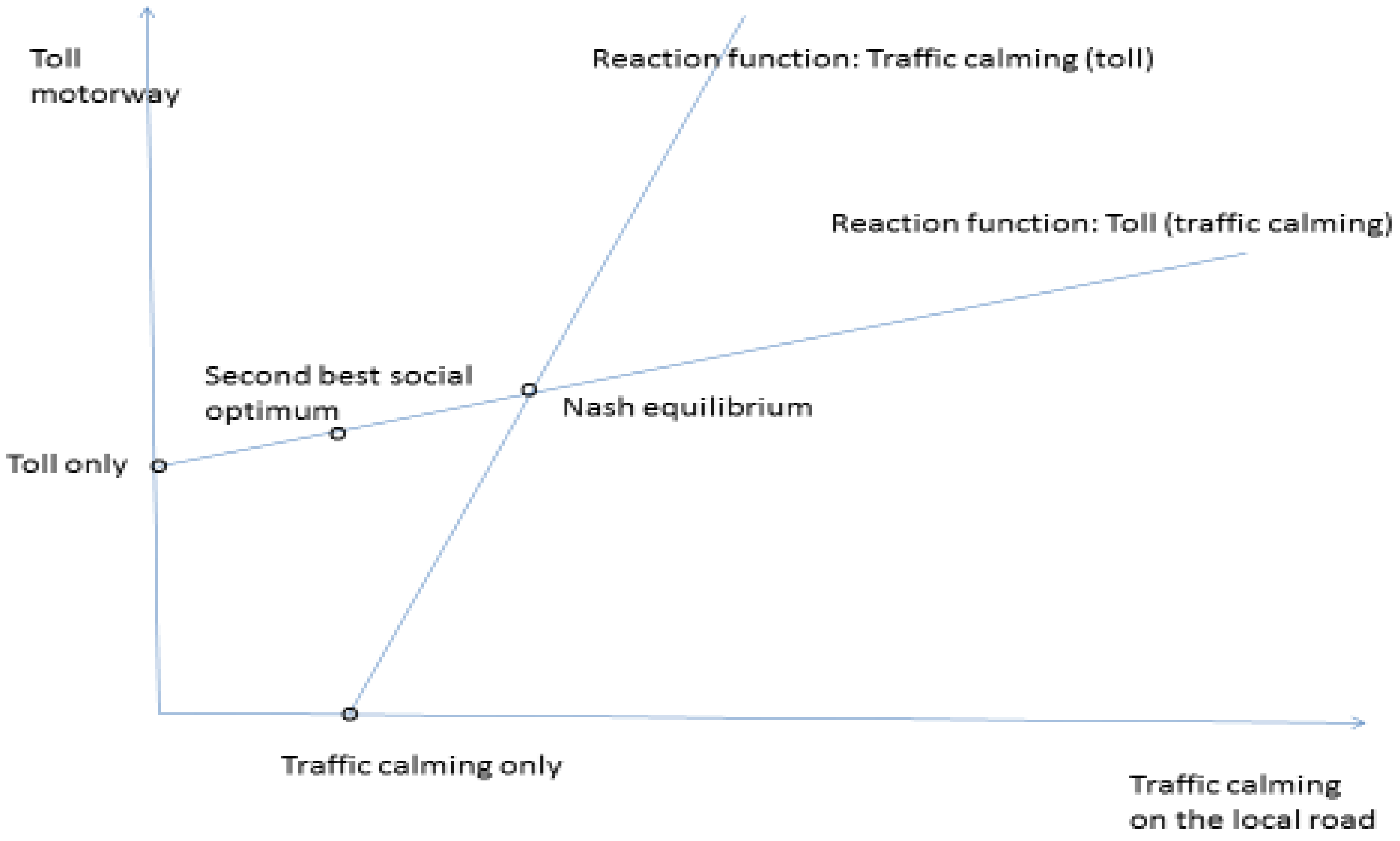
Proposition 1: First and Second Best with only one government level

- The first best requires the use of three instruments: a toll on the use of the main road, a toll on the use of the municipal road, and traffic calming on the local road.

- The inability to toll the local road implies that the second-best optimum yields a lower toll on the main road and more traffic calming on the local road compared to the first-best.

Proposition 2: When the federal government controls a toll on the main road AND the local government controls local traffic calming

- The higher toll on the main road unambiguously raises traffic calming by the local authority.
- More traffic calming in the local community raises the optimal federal toll.
- For traffic calming measures that raise the generalized cost of traffic on the local road (speed bumps, traffic lights), the Nash equilibrium implies too high tolls on the main road and too much traffic calming at the local level compared to the second-best optimum.
- For traffic calming measures that do not raise the generalized cost of using the local road (pedestrian bridges, biking paths, low emission zones), the Nash equilibrium is second-best socially optimal.


Toll
motorway
Reaction function: Traffic calming (toll)
Reaction function: Toll (traffic calming)
Second best social
optimum
Nash equilibrium
Toll only
Traffic calming only
Traffic calming
on the local road

Proposition 3: Who should be in charge?

- If the local authority uses local traffic calming measures, imposing a federal toll on the main road is not necessarily welfare-enhancing.
  - It will only increase federal welfare if toll revenues are high (high congestion on the main road) and traffic calming is quite effective in reducing local accident costs.

- If a federal toll were in place on the main road, then granting authority to the local community over traffic calming measures is unjustified,
  - except when doing so is highly effective in reducing local external costs imposed on the local community.

Proposition 4 Restricting access to through traffic

- From a global welfare perspective it is optimal to keep the road open for through traffic as long as accident risks for the local population are small and congestion on the main road is large.
- The local authority will always close the road for through traffic.
- Leaving authority over traffic restrictions to the local government implies that road access will be denied to through traffic even when it is socially optimal not to do so.

Proposition 5 Resticing access to trucks

- Both the federal and the local government will agree on imposing a ban on trucks through the local community.

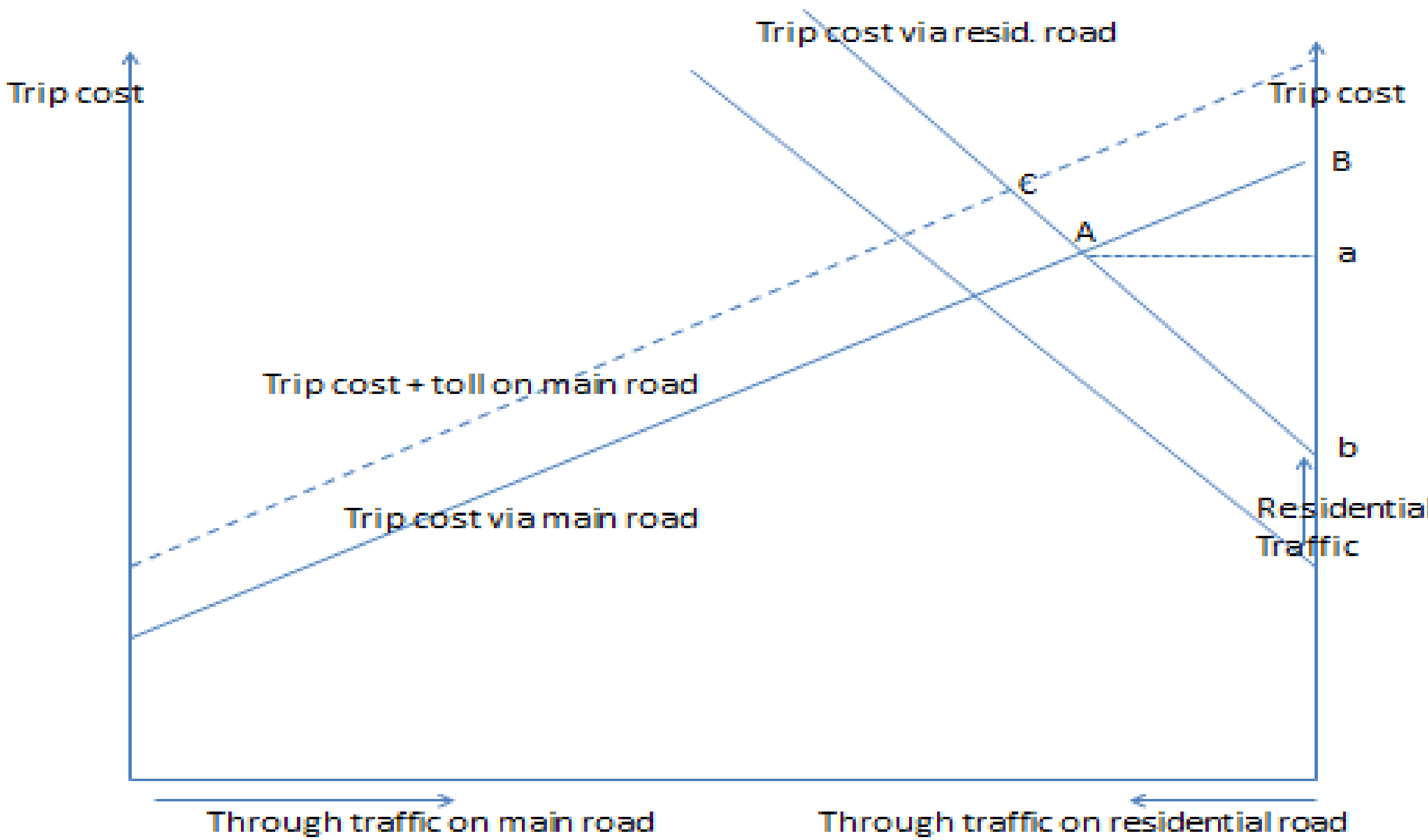
Leuven – suburb

Ghent – harbour suburb

Case studies

Restricted entry had
Negative B- C
because congestion on main road deteriorated
External costs gain small

Restricted entry for trucks
Positive B-C
Because no congestion
Large gains in external costs



Possible extensions

- One main road and two parallel suburbs
  - Race to the top problem persists
- Car free zones within municipalities
  - Requires extra transport options
- Add public transport
  - Supply of public transport may take some cars off the main road – but does not really change the issue
- Add different population groups and study political economy

Concluding comments

- Competition in tolls and traffic calming measures leads to tolls that are too high and too much traffic calming
- Granting authority to local governments over traffic calming may not be justified
- Road access will be denied even when this is socially undesirable – this problem is more severe for cars than for trucks

Welfare

- We distinguish ‘federal’ welfare and ‘local’ welfare
- Federal welfare

$$W^f = \int_0^{(1+\rho)X_{OC}} P(q)dq \quad - GC_x(\bar{X}_{OD} - X_{OD}^y) - GC_y\left(T^y\right) + \tau_x(\bar{X}_{OD} - X_{OD}^y)$$
$$- 0.5cZ^2 - \left(\lambda\theta(1-\gamma Z)\right)\left(T^y\right)$$

- Local welfare

$$W^l = \frac{\rho}{1+\rho}\int_0^{(1+\rho)X_{OC}} P(q)dq - GC_y\left(Y_{LC} + \bar{Y}_{LD}\right) - 0.5cZ^2 - \left(\lambda\theta(1-\gamma Z)\right)\left(T^y\right)$$

5. Competition between governments

- Behavior of the local government

$$-\left[(\beta_y+\delta Z)(Y_{LC}+\overline{Y}_{LD})+\lambda\theta(1-\gamma Z)\right]\left(\frac{\partial T^y}{\partial Z}\right)+\lambda\theta\gamma T^y=cZ+\delta T^y(Y_{LC}+\overline{Y}_{LD})$$

  – Extra benefit compared to first-best rule: traffic calming reduces demand for local road use
  – Lower cost compared to first-best: only effect on local demand taken into account
- Reaction function has positive slope

$$\frac{dZ^R(\tau_x)}{d\tau_x}>0$$

- Higher toll diverts traffic towards local road
- React by more traffic calming, despite more congestion for locals on the local road

Competition between governments II

- Behavior of the <u>federal government</u>

$$\left(\tau_x - \beta_x(\bar{X}_{OD} - X^y_{OD})\right)\frac{\partial X^y_{OD}}{\partial \tau_x} = -\left\{\left[(\beta_y + \delta Z)\left(T^y\right) + \lambda\theta(1-\gamma Z)\right]\left[\frac{\partial T^y}{\partial \tau_x}\right]\right\}$$

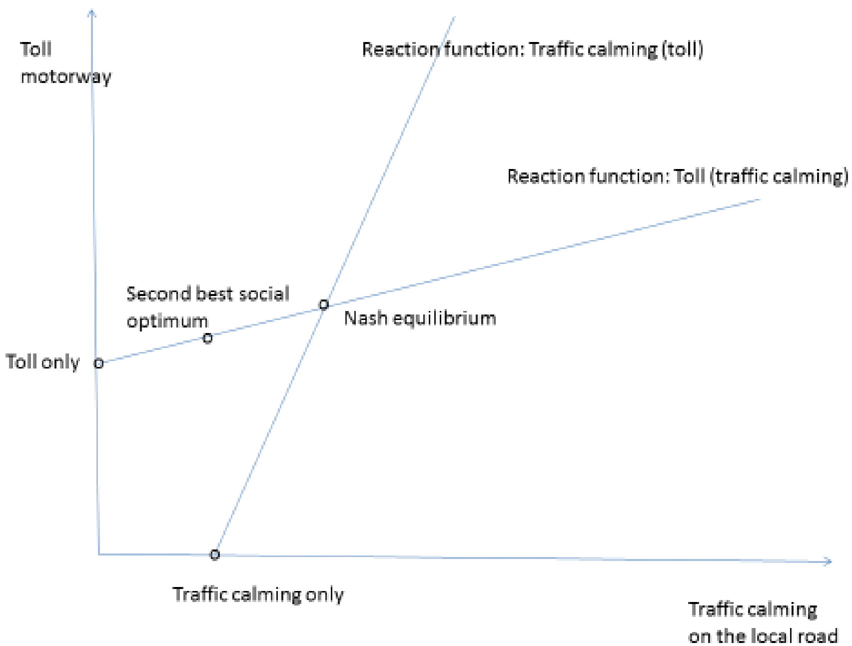
- Toll below marginal external cost
- Reaction function has positive slope

$$\frac{d(\tau_x)^R}{dZ} > 0$$

- Traffic calming reduces diverted traffic and raises congestion on the main road
- React by higher toll

Nash equilibrium

- Compared to the second-best social optimum:
  - NE toll is too high
  - NE has too much traffic calming
- For local measures not affecting local congestion ($\delta = 0$) NE is second-best optimal



6. Division of authority

- Is local control of traffic calming welfare improving?
- Compare federal welfare
  - At Nash equilibrium
  - At equilibrium with a federal toll only
- Use of traffic calming by local authority is welfare improving if
  - Congestion on the main road is important
  - Traffic calming is highly effective in reducing local externalities

Division of authority II

- Is a federal toll welfare improving?
- Compare federal welfare
  - At Nash equilibrium
  - At equilibrium with local traffic calming only
- Tolling the main road is welfare improving
  - Congestion on the main road is severe
  - Traffic calming is highly effective in reducing local externalities

7. Formal access restrictions

- Suppose no toll and no other traffic calming measures
- Is it welfare improving not to allow through traffic?
- Is it welfare improving not to allow through traffic by trucks only?
- Is it desirable to let local governments decide on access restrictions?

No through traffic: federal view

- Difference in federal welfare: no through traffic (restricted 'R') minus unrestricted

$$W^R(f) - W^U(f) = \frac{b}{2}(1+\rho)^2\left[\left(X_{OC}^R\right)^2 - \left(X_{OC}^U\right)^2\right] - \beta_x X_{OD}^y \bar{X}_{OD}$$
$$+ (\beta_y \bar{Y}_{LD} + \lambda\theta)\left[T^{y,U} - T^{y,R}\right]$$

$$X_{OC}^R > X_{OC}^U$$
$$\left[T^{y,U} - T^{y,R}\right] > 0$$

- Imposing zero through traffic is welfare-reducing if congestion on the main road is important and local external costs are limited
-

No through traffic: local view

- Difference in local welfare: no through traffic (restricted ‘R’) minus unrestricted

$$W^{R}(l)-W^{U}(l)=\left(\frac{1+\rho}{\rho}\right)\frac{b}{2}\left[\left(Y_{LC}^{R}\right)^{2}-\left(Y_{LC}^{U}\right)^{2}\right]+(\beta_{y}\bar{Y}_{LD}+\lambda\theta)\left[T^{y,U}-T^{y,R}\right]>0$$

$$Y_{LC}^{R}>Y_{LC}^{U}$$

$$\left[T^{y,U}-T^{y,R}\right]>0$$

- Imposing zero through traffic is always welfare-impriving for the local authority
-

No through traffic for trucks

- Adapt the model
  - Distinguish cars and trucks
  - Assume fixed proportion cars versus trucks
  - Assume Wardrop equilibrium
- Find

$$W^{NT}(f) - W^{0}(f) = \lambda_t \theta_t \left(X_{OD}^{y,t} \right) > 0$$

$$W^{NT}(l) - W^{0}(l) = \lambda_t \theta_t \left(X_{OD}^{y,t} \right) > 0$$

- Both the federal and the local authority will impose a ban on truck through traffic

Demands

- Demand for non-commuting traffic to the local community
  - Demand by outsiders X_{OC}
  - Demand by locals $Y_{LC} = \rho X_{OC}$

- Linear inverse demand function

$$P = a - b(X_{OC} + Y_{LC}) = a - b(1+\rho)X_{OC}$$

Generalized costs

- No congestion outside zones *x, y* considered
- Generalized costs road use via main road and via local community, respectively:

$$GC_x = \alpha_x + \beta_x(\bar{X}_{OD} - X_{OD}^y)$$
$$GC_y = \alpha_y + (\beta_y + \delta Z)(X_{OD}^y + (1+\rho)X_{OC} + \bar{Y}_{LD})$$

Initial user equilibrium

- We assume Wardrop for the allocation of demand $\bar{X}_{OD}$ via *x* and *y*
- Equilibrium conditions

$$\alpha_x + \beta_x(\bar{X}_{OD} - X_{OD}^y) + \tau_x = \alpha_y + (\beta_y + \delta Z)\left(X_{OD}^y + (1+\rho)X_{OC} + \bar{Y}_{LD}\right)$$

$$a - b(1+\rho)X_{OC} = \alpha_y + (\beta_y + \delta Z)\left(X_{OD}^y + (1+\rho)X_{OC} + \bar{Y}_{LD}\right)$$

- Gives equilibrium traffic flows X_{OD}^y, X_{OC}
- Find

$$\frac{\partial X_{OD}^y}{\partial Z} \le 0 \quad (0 \text{ for } \delta = 0) \qquad \frac{\partial X_{OD}^y}{\partial \tau_x} > 0$$

$$\frac{\partial X_{OC}}{\partial Z} \le 0 \quad (0 \text{ for } \delta = 0) \qquad \frac{\partial X_{OC}}{\partial \tau_x} < 0$$

$$\frac{\partial T^y}{\partial Z} = \frac{\partial X_{OD}^y}{\partial Z} + (1+\rho)\frac{\partial X_{OC}}{\partial Z} \le 0 \quad (0 \text{ for } \delta = 0) \qquad \frac{\partial T^y}{\partial \tau_x} = \frac{\partial X_{OD}^y}{\partial \tau_x} + (1+\rho)\frac{\partial X_{OC}}{\partial \tau_x} > 0$$

First-best

- Direct optimal choice of traffic flows and traffic calming

$$\underset{X_{OD}^{y},X_{OC},Z}{Max} \quad \int_0^{(1+\rho)X_{OC}} P(q)dq \quad -GC_x(\bar{X}_{OD}-X_{OD}^{y})-GC_y\left(T^y\right)-0.5cZ^2-\left(\lambda\theta(1-\gamma Z)\right)\left(T^y\right)$$

- First-best can be implemented by user tolls on *x* and *y* equal to marginal external cost, plus traffic calming

$$\tau_x=\beta_x(\bar{X}_{OD}-X_{OD}^{y})$$

$$\tau_y=(\beta_y+\delta Z)\left(T^y\right)+\lambda\theta(1-\gamma Z)$$

$$\lambda\theta\gamma(T^y)=cZ+\delta(T^y)^2$$

Second-best

- Suppose toll on major road plus local traffic calming, no toll on local road.
- Find

$$\left(\tau_x - \beta_x(\bar{X}_{OD} - X_{OD}^y)\right)\frac{\partial X_{OD}^y}{\partial \tau_x} + \left\{\left[(\beta_y + \delta Z)\left(T^y\right) + \lambda\theta(1-\gamma Z)\right]\left[\frac{\partial T^y}{\partial \tau_x}\right]\right\} = 0$$

$$\{\Omega\} + \lambda\theta\gamma T^y = cZ + \delta(T^y)^2; \quad \Omega > 0$$

- Toll below marginal external congestion cost
- If congestion on main road not serious, zero toll
- Too much traffic calming compared to first-best