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The Economic Impact of Tolling in the Era of High Gasoline Prices

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Outline of the presentation

- Initial motivations for road tolling
- The current situation of road tolling: successes and failures
- The impact of inflationary gasoline prices on tolling strategies
- Conclusion

Initial motivations for tolling

- Reduce Congestion
- Reduce Externalities:
  - Pollution
  - Noise
- Reduce Number of Accidents
  - Material damages
  - Mortality rate due to accidents

Initial motivations for tolling

- Later on due to privatization of certain / all links of networks toll revenue served as means of paying for:
  - Fixed Costs: Infrastructure Investments (paid for through bank loans)
  - Variable Costs: Maintenance, and Management
- But toll pricing criteria stayed unchanged:

Initial motivations for tolling

- Each road user should pay for:
  - The use of the road
  - and savings in travel time
- In the context of a road network, both the road and the savings in travel time are considered as commodities that can be purchased. Together they constitute an economic good.
- The main problem in this case is to find an optimal pricing scheme for location based travel time savings.
- A simple formula for tolling is found.

Initial motivations for tolling

- Let (τ) represent a toll, then

Toll is a function of the price of time

$$\tau = f\left(P_{t(r_0)}\right)$$

$P_{t(r_0)}$ = Monetary value per unit of time (t) on the shortest path (r_0)

(r_0) = Shortest path containing several links

t = time

Initial Motivations for Tolling

$$\tau = P_{t(r_0)} * t_{r_0} * (1 + \varepsilon)$$

t_{r_0} = *Travel time on the shortest path*

ε = *increments applied depending on a toll regime or operator considerations*

Toll regime = 1) fixed toll irrespective of time of day; 2) variable tolls depending on time of day

Private operator considerations = adjustments relating to marginal costs

Initial motivations for tolling

- Problem: $P_{t(r_0)}$

  Is chosen in most cases as an arbitrary value.

  Different formulation for tolling are given by researchers, which are either based on a subjective value of time or other considerations such as marginal costs and welfare effects.

- Non of these formulations have offered optimal toll pricing schemes that correspond to increase in consumer surplus.

Initial motivations for tolling

- Rise in gasoline prices has an adverse effect on consumer surplus. Thus it is necessary to find $P_{t(r_0)}$ that corresponds to differentiated consumer characteristics:

  Cars: individual road users (local, transit): are characterized by their income level, cost of living, and taxes they pay.

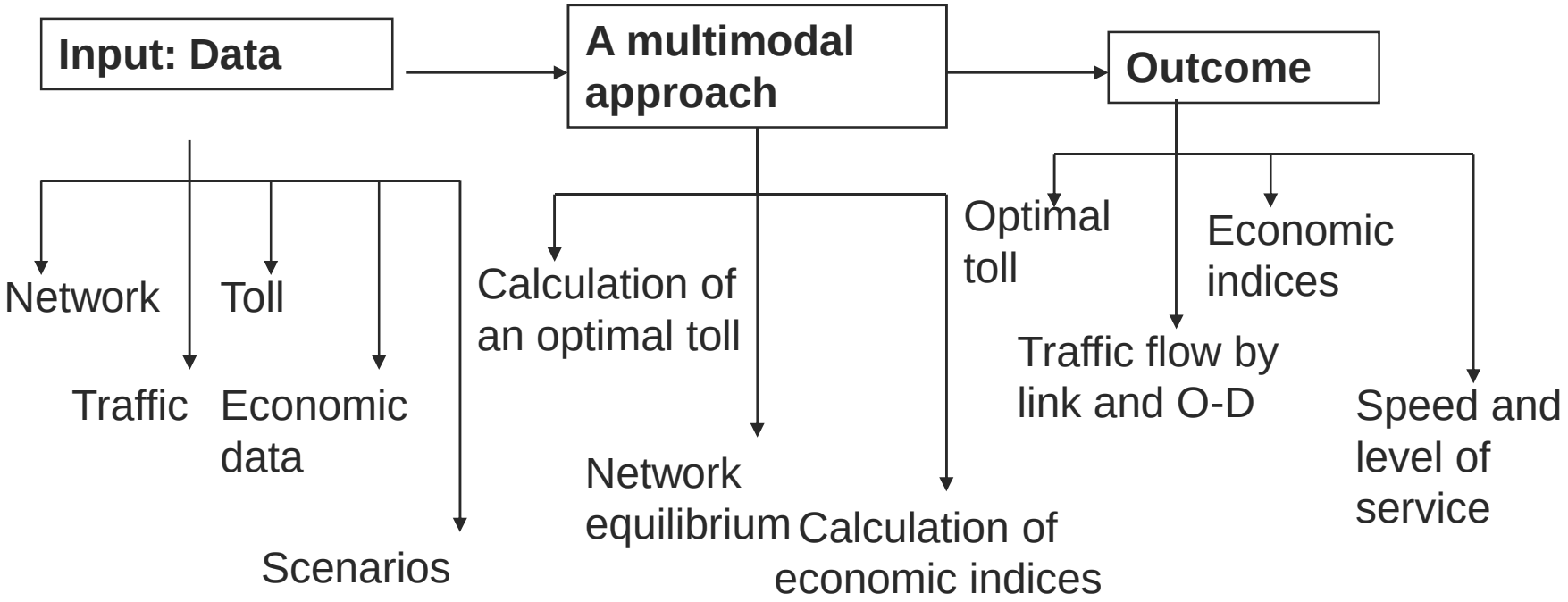
  Freight: (local, transit) is characterized by profit level, operation costs, level of investment, ability to borrow money, and standing in the stock market. But other market elements such as: bank's lending ability, commodity and stock market evolution, play an important role in the life of freight business.

Initial Motivations for Tolling

- A study was conducted in 2001 under the MC-ICAM project following the general transport policies of the European Union. The objective was to:

- Study the effects of tolling on a national scale on Belgian road networks: How tolling affects:
  - Traffic volume freight (local, transit)
  - Traffic volume individual cars (local, transit)
  - Social Welfare (W)
  - Toll Revenue (TR)
  - Consumer Surplus (CS)
  - Environmental costs (EC)

General form of the model used



Model architecture: Bi- level and Multimodal

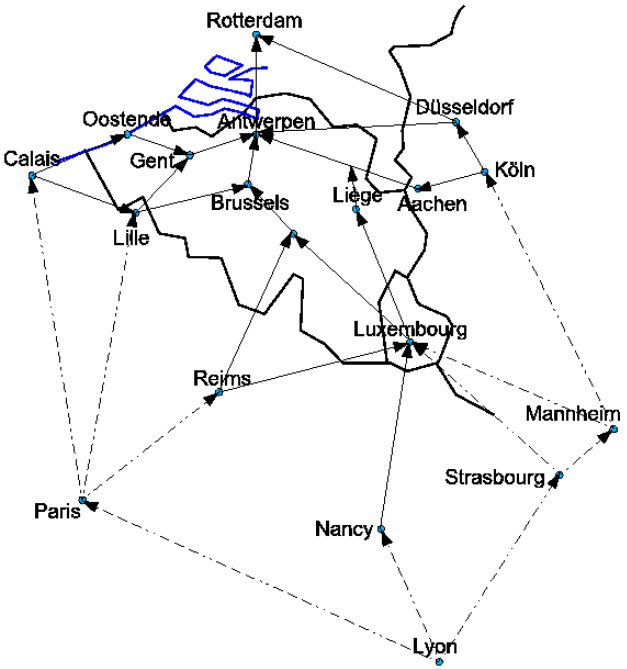
- **First level:** Optimal pricing and network equilibrium using Wardrop, fixed point, variational inequality, and bi-level optimization methods.

- Network flow is optimized for (cars, trucks) for each origin-destination based on an optimal toll.

- **Second level** is the economic analysis of optimal tolling on the network:
  - flow (local, transit),
  - Mode and path choices
- **Economic analysis** of the following economic variables based on traffic flow changes : Calculate change in values of economic indicators from the base scenario to other scenarios
  - Social welfare (W)
  - Toll revenue (TR)
  - Consumer surplus (CS)
  - Environmental costs (EC)

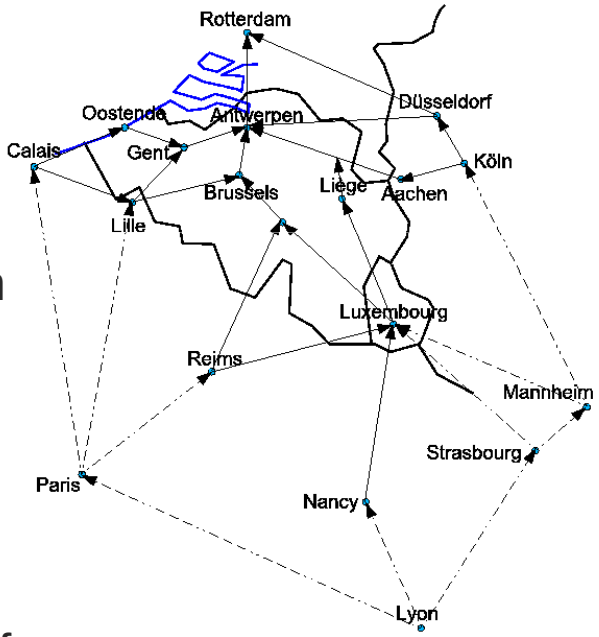
Network 1

- Major highways in Belgium and neighboring countries: France, Germany, The Netherlands.
- Only road traffic is considered. It is assumed that other modes of transport function at optimum and do not have to be taken into consideration
- Focus is on (local and transit) traffic. It is assumed that:
  - Transit traffic changes as a function of transport costs
  - Local traffic changes as a function of transport costs
  - Only uni-directional links are considered



Network 2

- Network has (46 links, and 52 paths) mainly major highways connecting Belgium to it's neighbours.
- There are 5 origins :
  - Calais, Lyon, Paris, Strasbourg, France
  - Köln, Allemagne.
- These origins capture freight traffic from southern Europe and Switzerland.
- Freight traffic from eastern Europe enters the network from: Düsseldorf, et Köln.
- There are 2 destinations:
  - Antwerpen en Belgique
  - Rotterdam aux Pays-Bas
- There is a minimum of 4 paths and a maximum of 17paths between each pair of origin-destination.



Model 1

- The model used has two levels:
  - Network equilibrium and optimal toll pricing
  - Economic analysis
- Data:
  - Reference link flows
  - Reference origin flows
  - Link and origin Inverse demand functions
  - Network attributes
  - Link (arc) characteristics:
    - Free speed
    - length
    - Number of lanes / capacity
    - Link congestion cost functions

Model 2

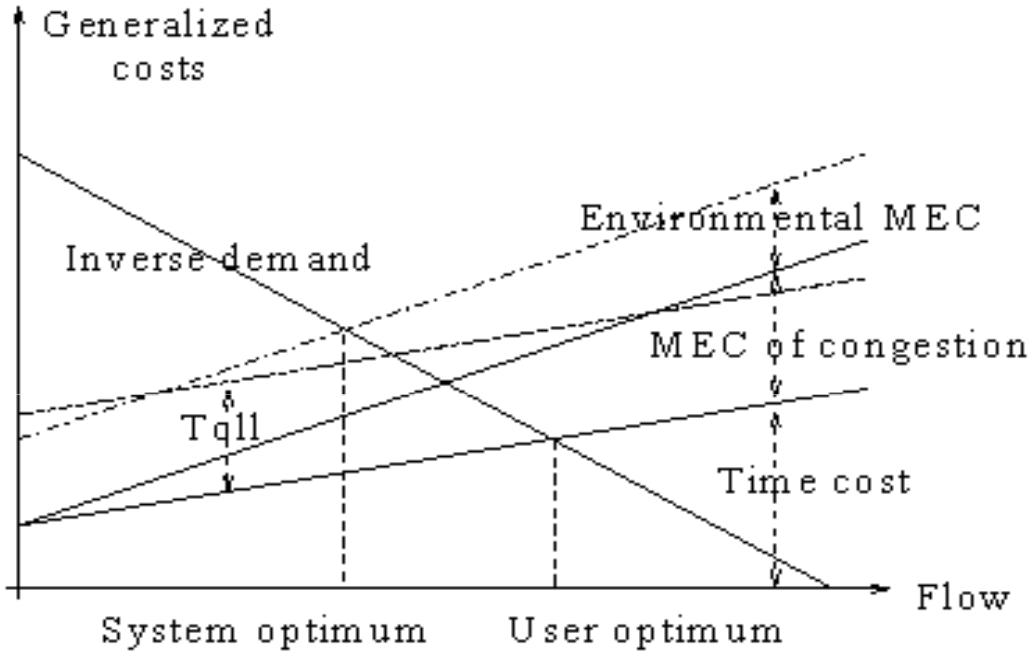
- Link economic data:
  - Fuel tax rate (trucks, cars)
  - Wage and depreciation costs
  - Value of time (VOT), (trucks, cars)
  - MEC of environmental pollution
  - MEC of road accident risk
  - MEC of damage to infrastructure (trucks)
  - Congestion cost
  - Toll
  - Demand elasticity

Model Output

- Traffic per arc:
  - Equilibrium path choice
  - Flows (truck, car), (local, transit) (vh/Pk.hr)
  - Origin and path costs
  - Link costs
  - Average speed (truck, car) (km/hr)
  - Number of trips per origin-destination pair

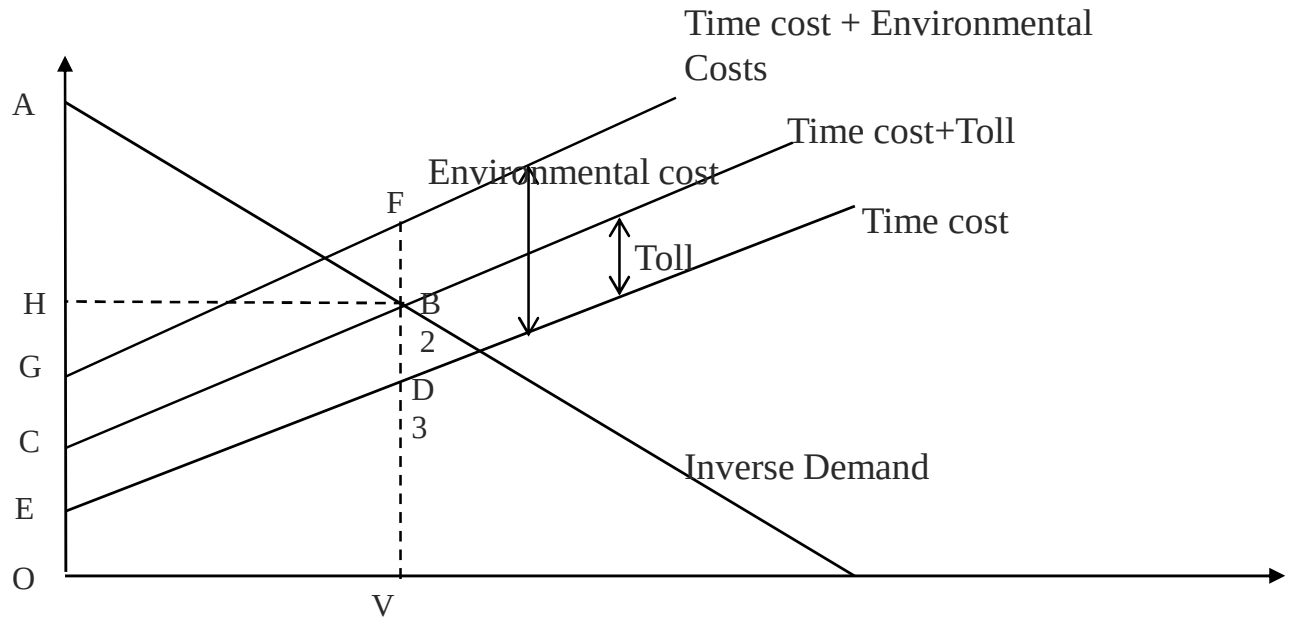
- Economic variables per link:
  - Generalised costs (€/vh)
  - External congestion cost (€ /vh)
    - Welfare (truck, car) (€/hr)
    - Link tolls (€)
    - Environmental costs, (local, transit) (€/hr)
      - Pollution
      - Accidents
      - Road damage
    - Toll revenue (truck, car), (local, transit) (€/hr)
    - Consumer surplus (truck, car), (local) (€/hr)

General Formulation of Economic Indicators 1



- Generalized Costs = Resource Costs
  + Average Time Costs
  +Marginal External Congestion Costs
  + Marginal External Environmental Costs

General Formulation of Economic Indicators 2



- Welfare = Consumer Surplus (ABH) + Toll Revenue (CBDE) – Environmental Costs (GFDE)

- Welfare for a Country = CS (local flow) + TR(local)+ TR(transit) – EC(local) – EC(transit)
  (per link)

Simulating First-Best Tolling Approach per Link

Generalised Social costs	Generalized User Costs
Resource Costs	Resource Costs
Time costs	Time costs
External Congestion Costs	Fuel Tax
External Pollution Costs	Toll
External Accident Costs	
Damage to infrastructure	

- The objective is to set:

  Marginal Generalized Social Cost = Generalized User Costs

- Thus toll per link can be determined by:

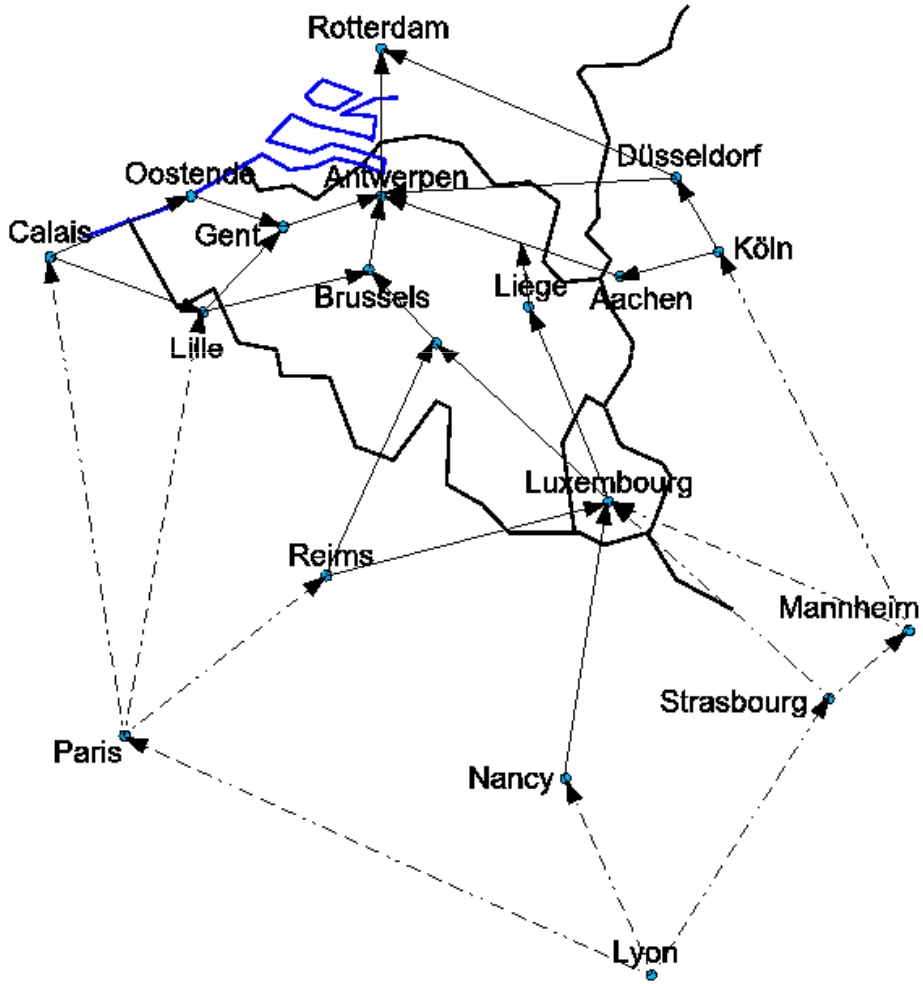
  Toll = $\sum$ (External Environmental Costs) – Fuel Tax

  Fuel Tax = fuel tax coefficient $\times$ road length

- The best reasonable initial toll for a country by (truck, car) is the average of all link tolls (truck, car).

  Uniform Toll = $\sum$ (link tolls in country (a)) / (Number of links in country (a))

Example : Network



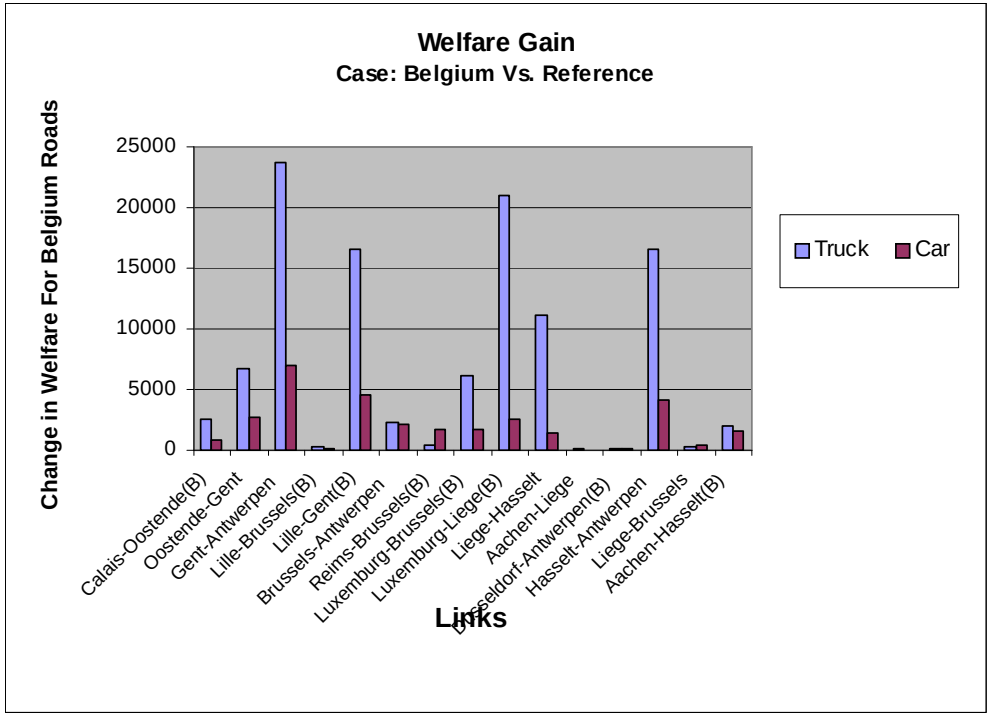
The Analysis of the Results

- The model is tested using a benchmark case. In the benchmark, we include existing fuel excises.
- Only France has tolling policies. Therefore, France is chosen as the benchmark. A uniform toll of
  - 18€ per 100 km per truck, and
  - 5€ per 100 km per car

  is applied to all highways in France. The other three countries do not toll.
- Following the First-Best simulation procedure, a uniform toll of
  - 36€ per 100 km per truck, and
  - 10€ per 100 km per car

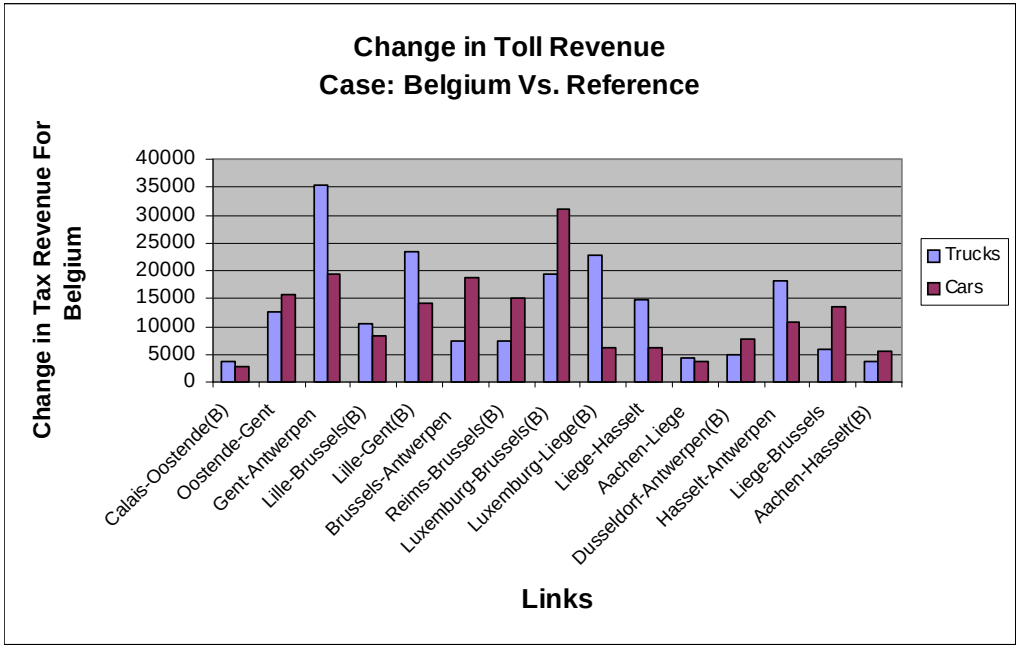
  is applied to all highways in Belgium.
- Welfare, Consumer surplus, and Toll revenue are compared with the benchmark (France).

Welfare (36€, 10€)



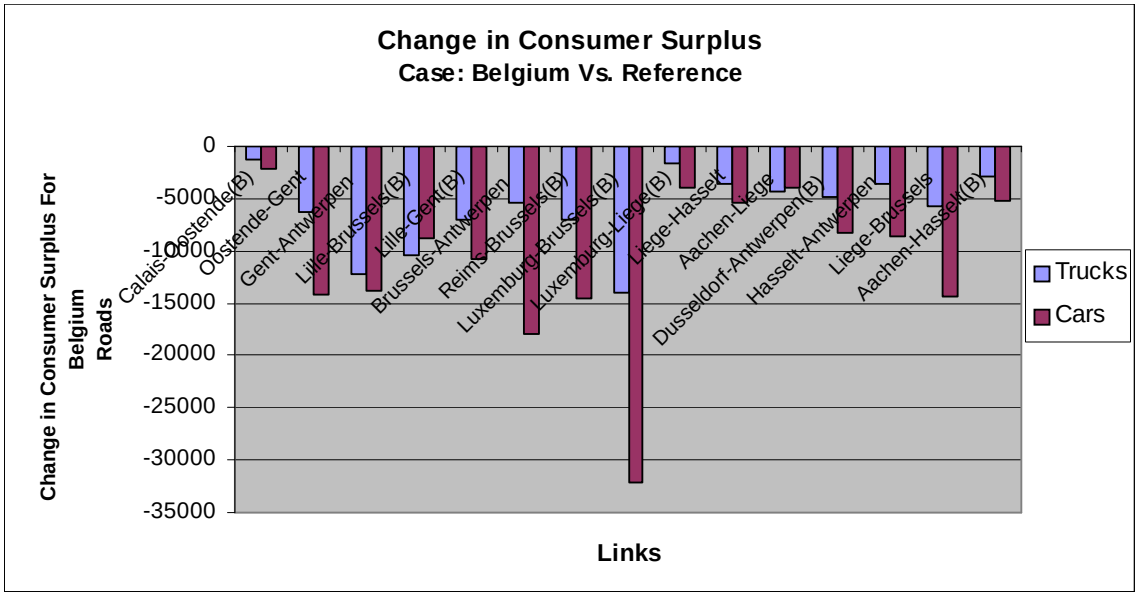
- The welfare gain from tolling trucks is much higher than cars.
- Particularly for links: Gent-Antwerpen, Lille-Gent, Luxemburg-Liège, Liège – Hasselt, and Hasselt-Antwerpen
- Welfare gain from transit trucks is significant.

Toll Revenue (36€, 10€)



- Change in toll revenue is generally high.
- Change in toll revenue is equally distributed between cars and truck.
- On links: Liège-Brussels, Brussels-Antwerpen, Reims-Brussels, Luxemburg-Brussels
  - Change in toll revenue from cars is significantly higher than trucks.
- On links: Düsseldorf-Antwerpen (B) and Aachen-Hasselt
  - Change in toll revenue from cars is somewhat higher

Consumer Surplus (36€, 10€)

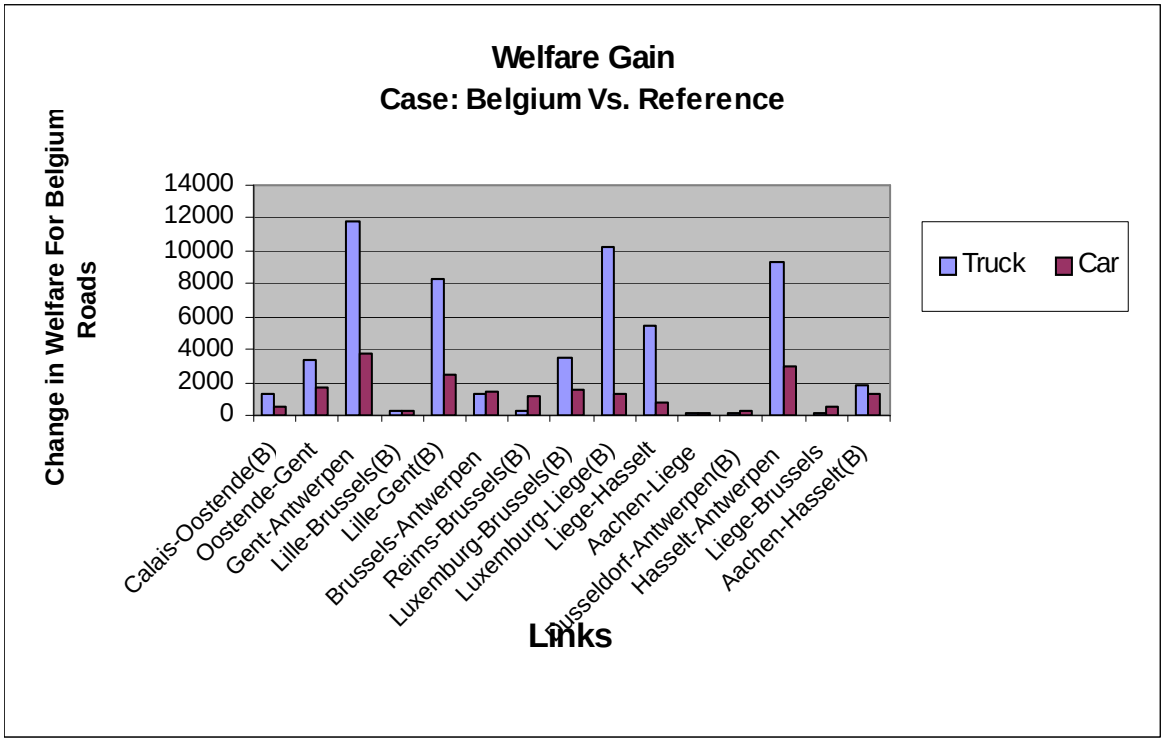


- Change in consumer surplus is negative.
- On average the negative change in consumer surplus for cars is much higher than trucks.
- Link: Luxemburg-Brussels shows a particularly negative change in consumer surplus for cars.

Testing a lower uniform toll

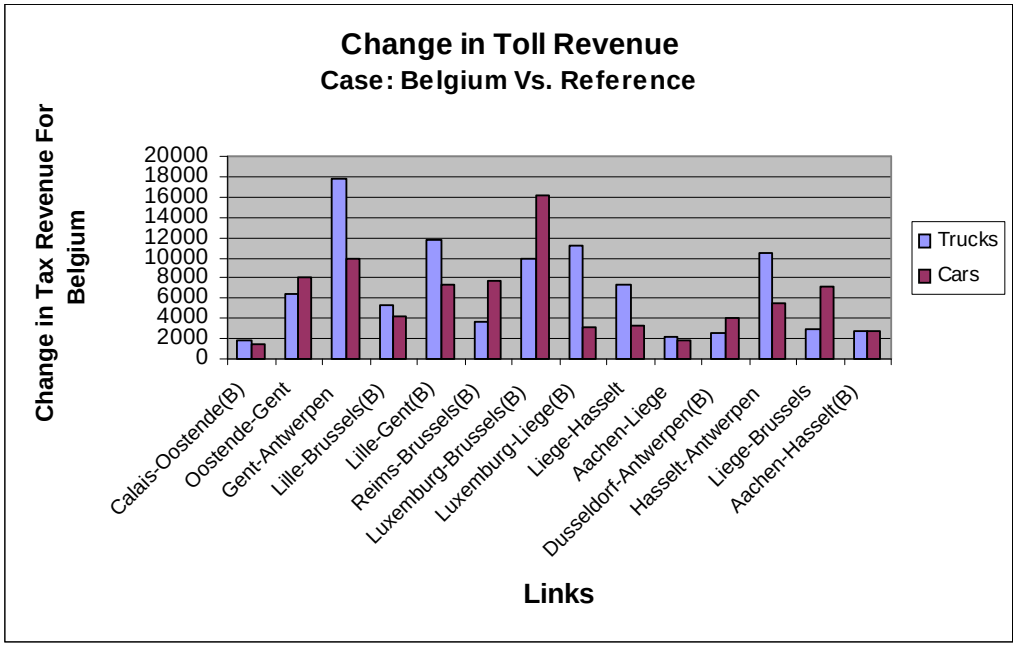
- A lower uniform toll level of 18€ per 100 km per truck, and 5€ per 100 km per car was applied to all highways in Belgium.
- The results were compared with the bench, and the change in the economic indicators is charted.
- Purpose: to check for the benefits of lower tolls

Welfare (18€, 5€)



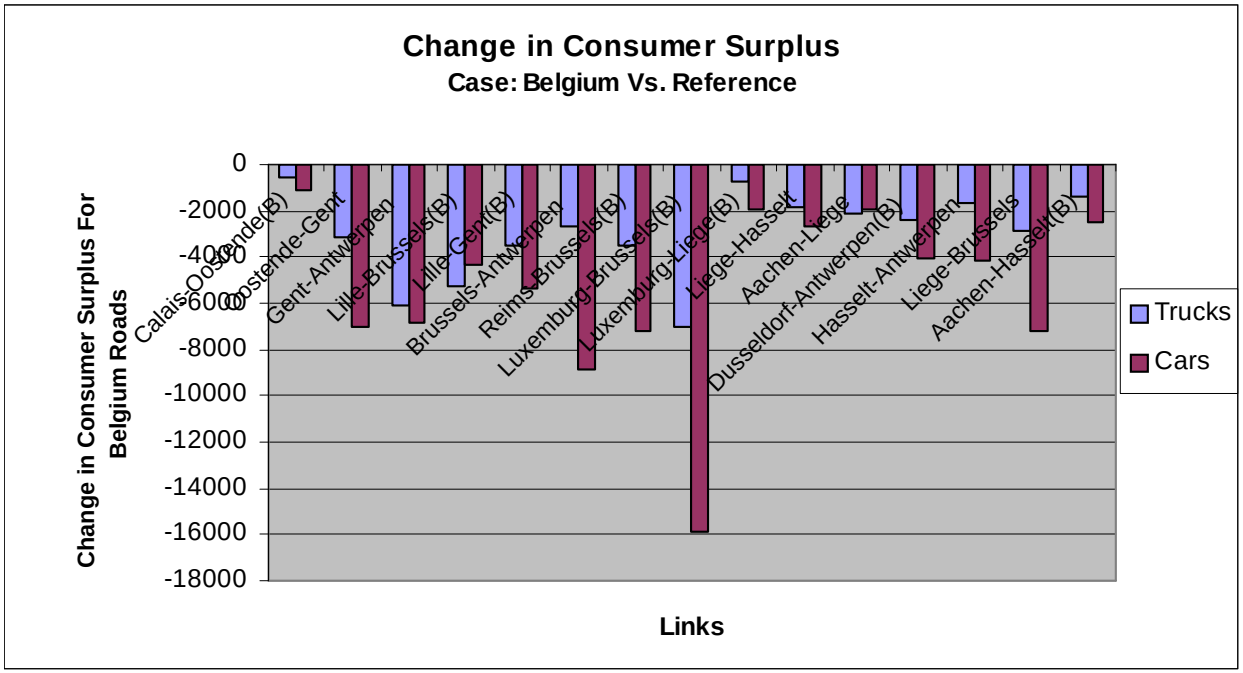
- In general the magnitude of change in welfare gain is small.
- The welfare gain from tolling trucks is much higher than cars.
- Particularly for links : Gent-Antwerpen, Lille-Gent, Luxemburg-Liège, Liège – Hasselt, and Hasselt-Antwerpen

Toll Revenue (18€, 5€)



- In general, change in toll revenue is positive.
- The change in toll revenue is generally high and equally distributed between cars and truck.
- On links: Liège-Brussels, Brussels-Antwerpen, Reims-Brussels, Luxemburg-Brussels
  - Change in toll revenue from cars is significantly higher than trucks.
- On links: Düsseldorf-Antwerpen (B), Aachen-Hasselt
  - Change in toll revenue from cars is somewhat higher.

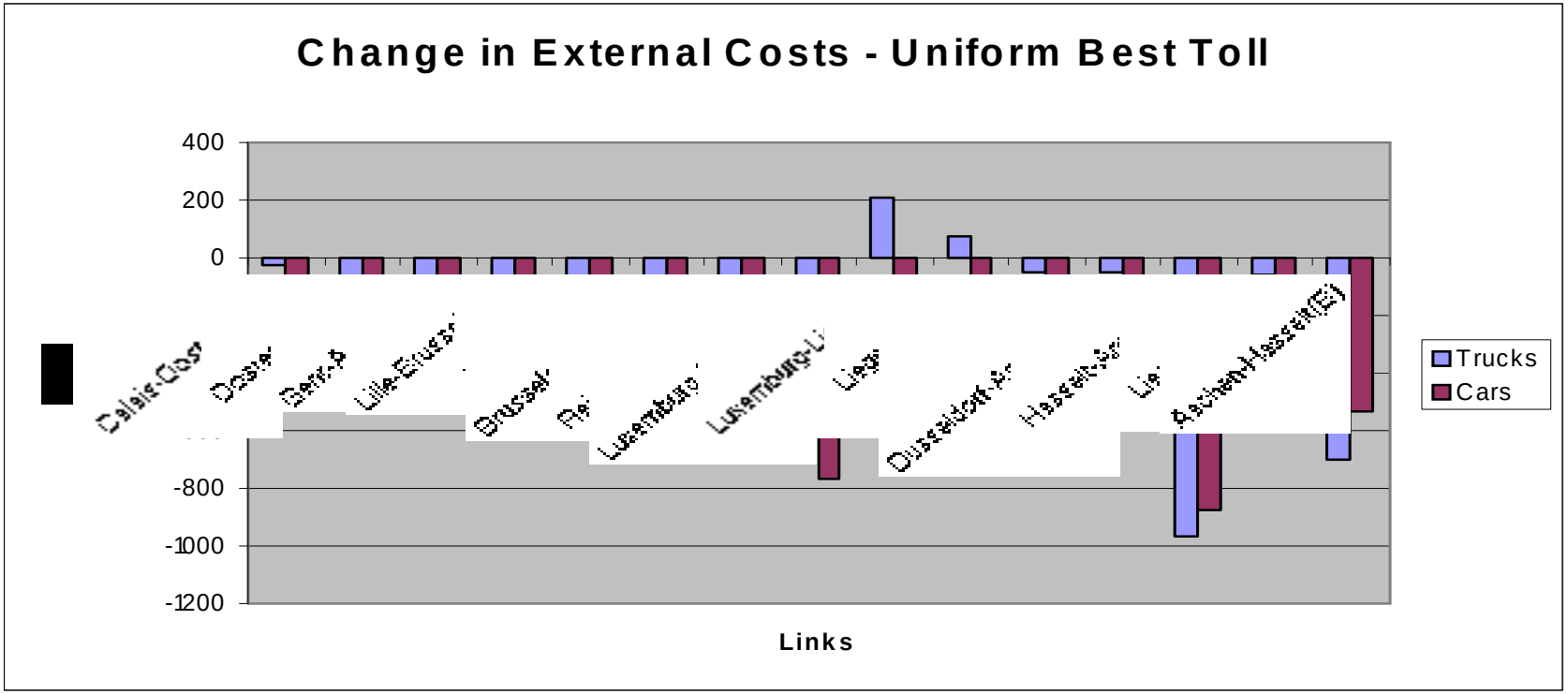
Consumer Surplus (18€, 5€)



- Loss in consumer surplus follows the same trend as the previous case, but the magnitude is smaller.
- Change in consumer surplus is negative.
- On average the negative change in consumer surplus for cars is much higher than trucks.
- Luxemburg-Brussels link shows a particularly negative change in consumer surplus for cars.

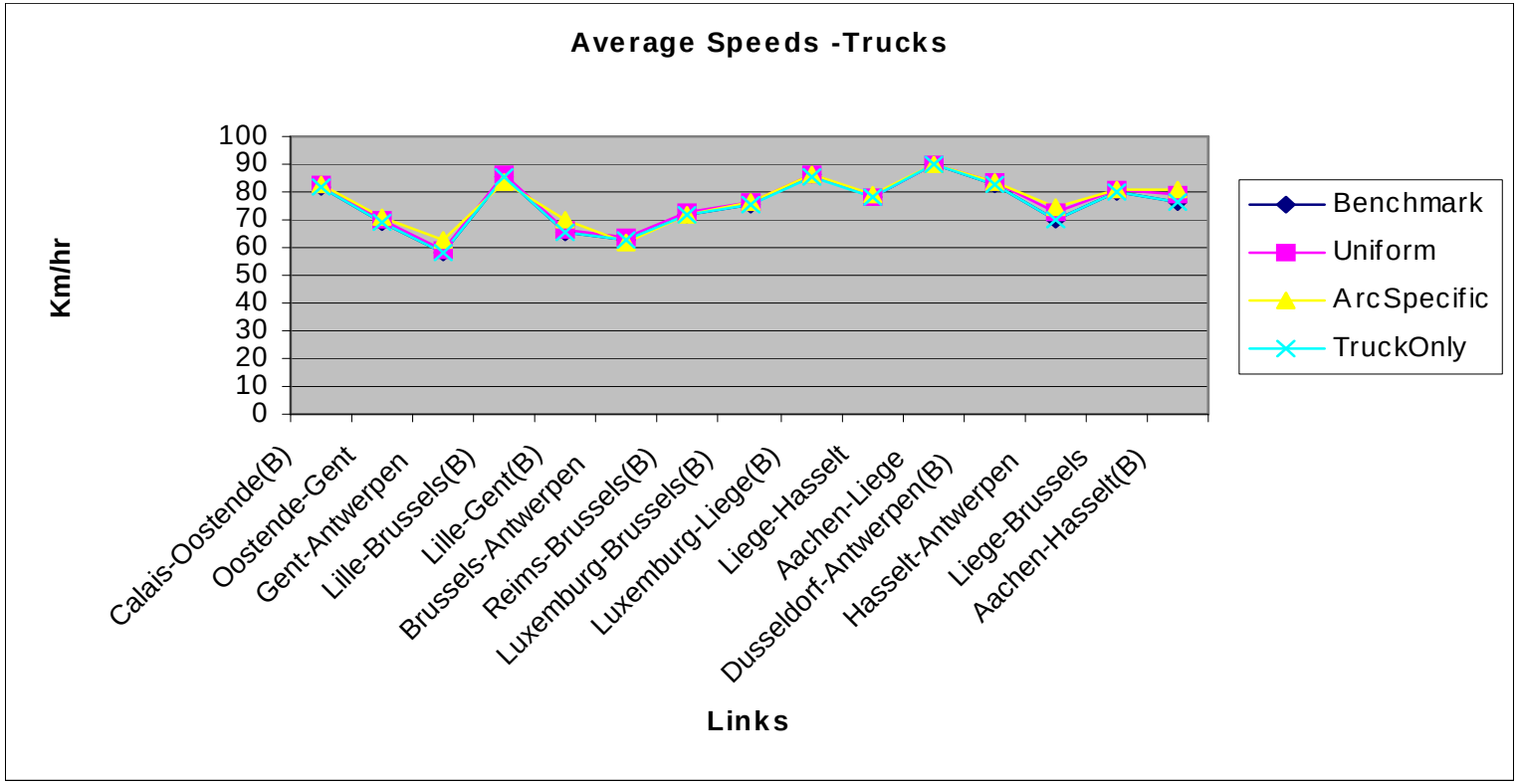
External costs (18€, 5€)

- There is a drop in external costs due to Uniform Tolling as compared to the benchmark. For the majority of links, this drop in external costs is more significant for cars than trucks. On two links “Luxemburg-Liège”, and “Liège-Hasselt” there is an increase in externalities due to trucks. External costs from trucks and cars are significantly lower on three links “Luxemburg-Brussels”, “Hasselt-Antwerpen”, and “Aachen-Hasselt”.



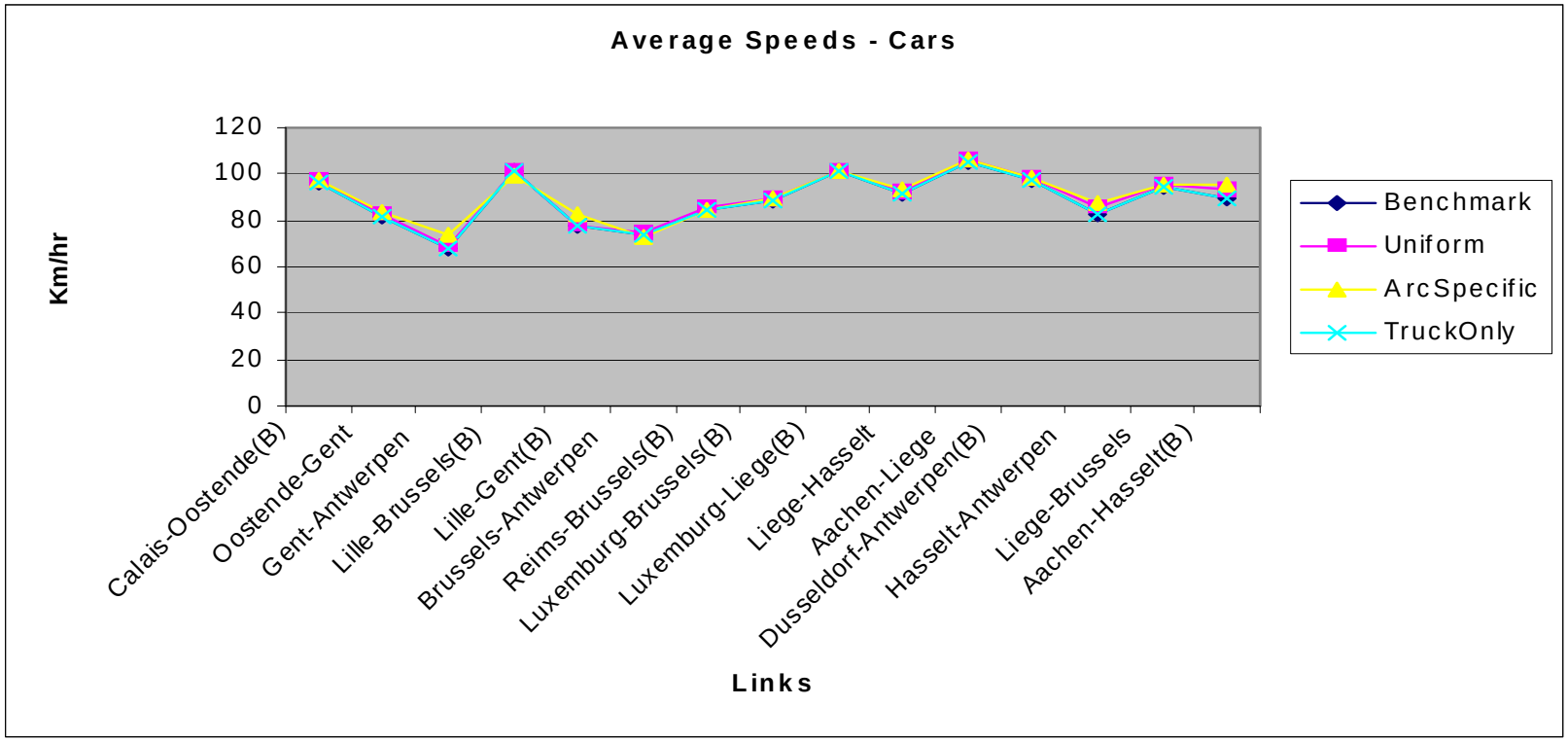
Average Speeds - Trucks

- There is a small change in average speed due to tolling.
- Mainly externalities are lower on links with higher speeds

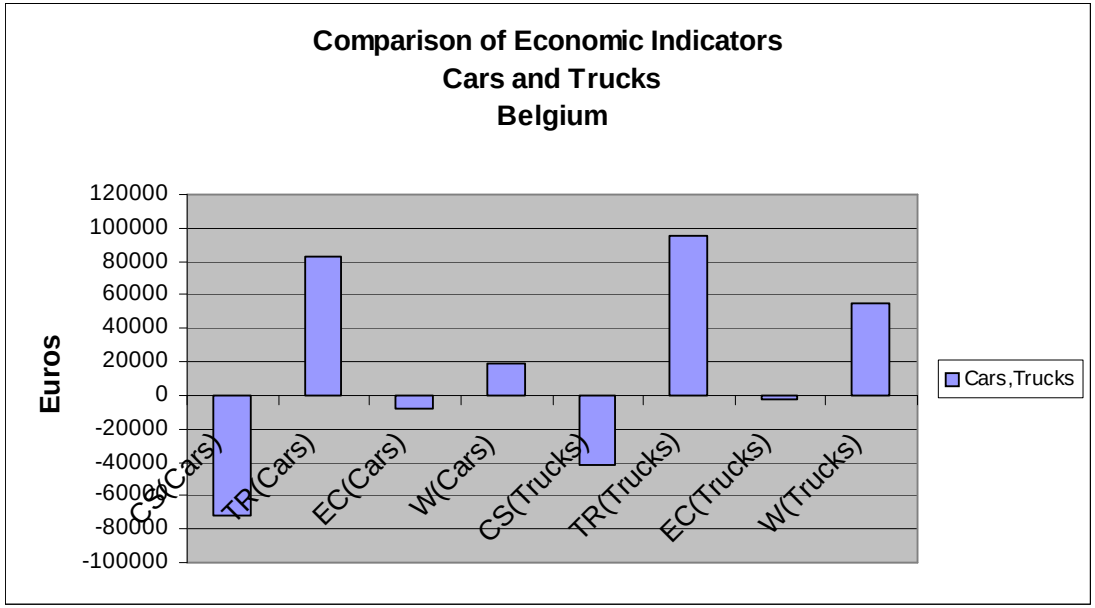


Average Speeds - Cars

- There is a small change in average speed due to tolling.
- Mainly externalities are lower on links with higher speeds



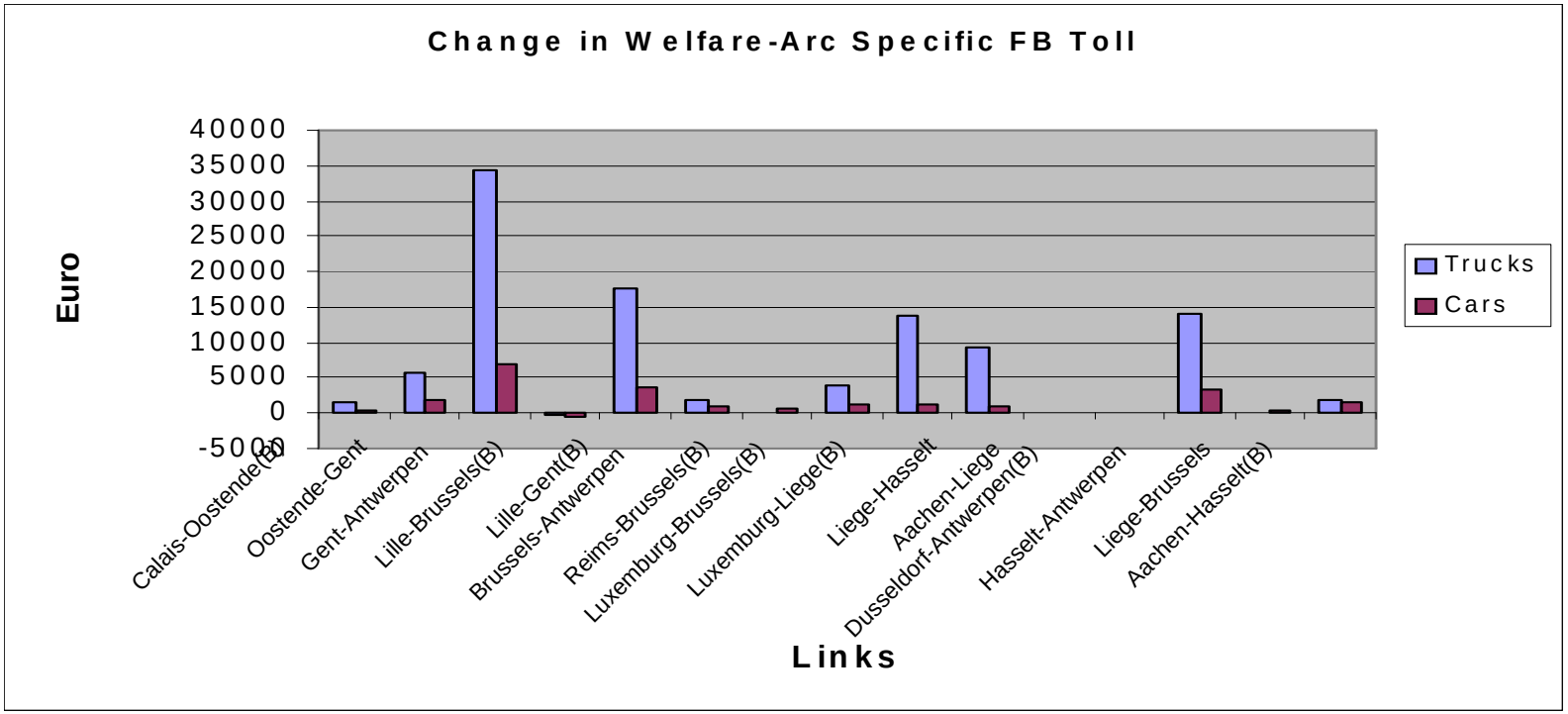
Summary Results (18€,5€)



- Gain in toll revenue is higher for trucks than it is for cars.
- Welfare gain is higher for trucks than it is for cars.
- Trucks cause less environmental costs than cars.
- Loss in Consumer surplus is more significant for cars than for trucks.

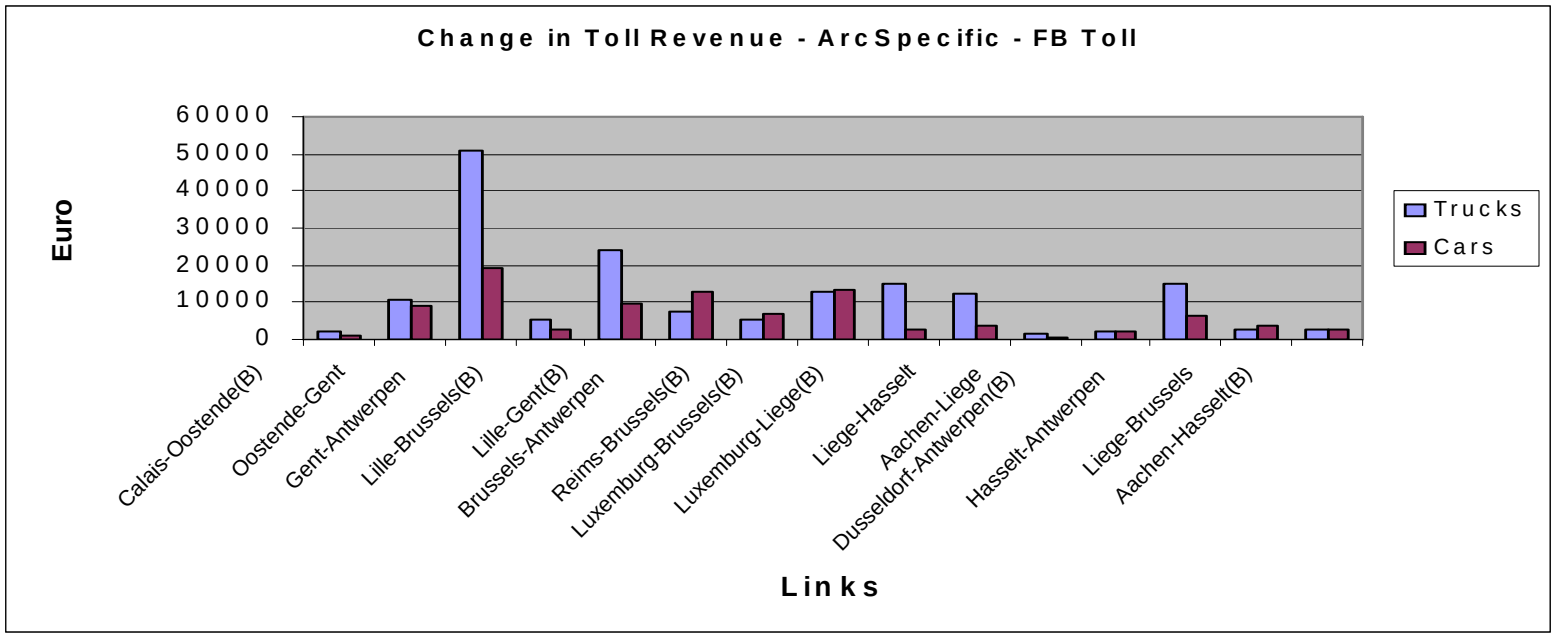
Testing Arc Specific Tolling

- The overall welfare gain is very low for all links with the exception of five links: “Gent-Antwerpen”, “Lille-Gent”, “Luxemburg-Liège”, “Liège-Hasselt”, and “Hasselt-Antwerpen”. The main welfare gain is due to trucks. The welfare gain from cars is low.



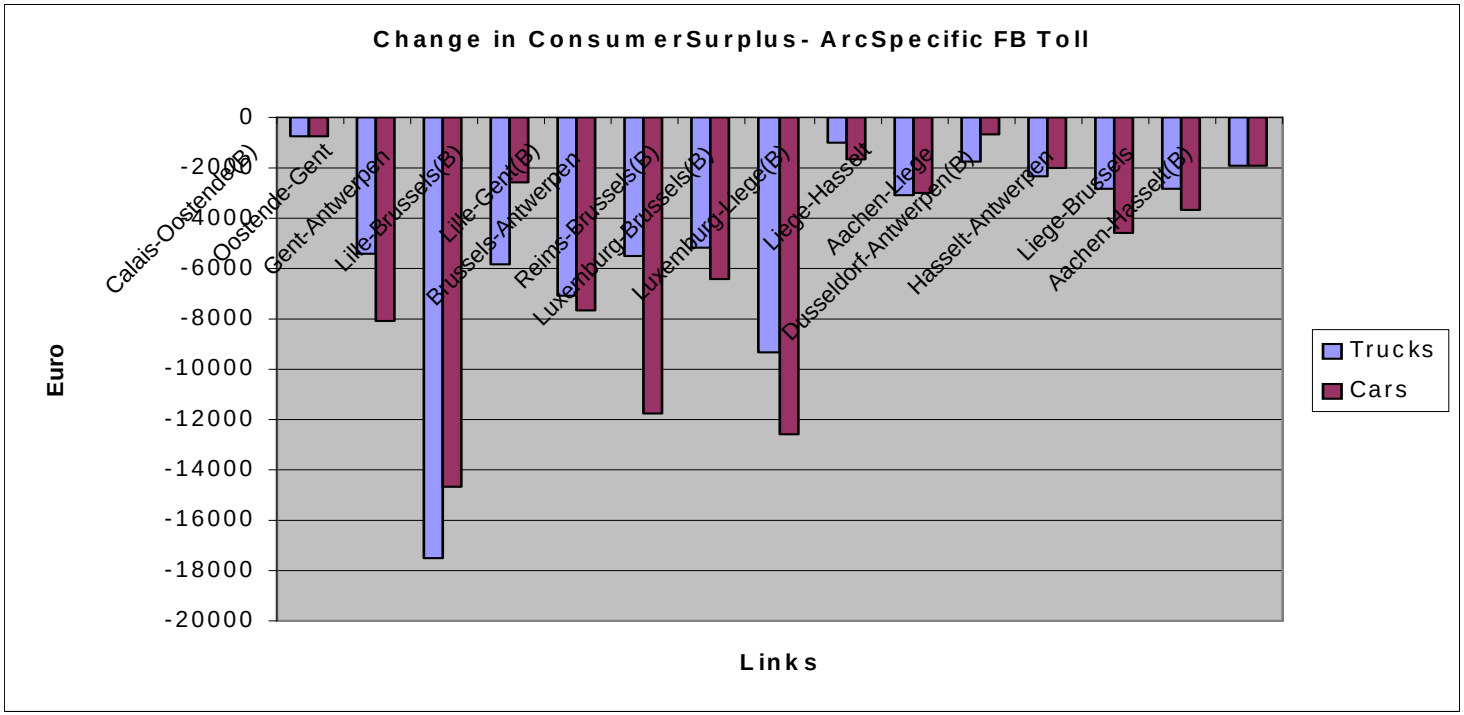
Testing Arc Specific Tolling

- Overall, there is a positive gain in Toll Revenue due to Arc Specific Tolling. However this change is not significant. Only one link “Gent-Antwerpen”, shows a significant gain in the Toll Revenue. The gain in Toll Revenue is mainly from tolling trucks.



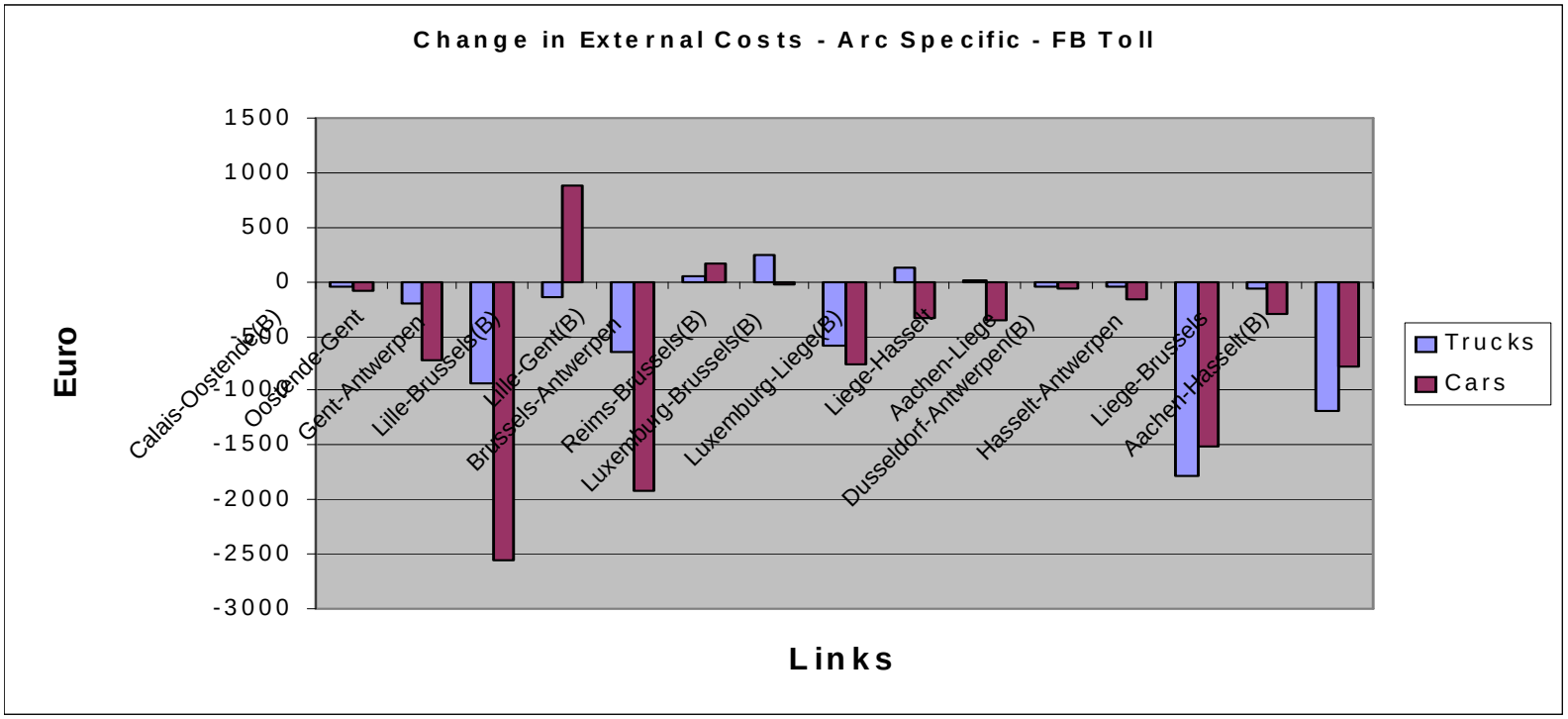
Testing Arc Specific Tolling

- All links show a drop in consumer surplus due to Arc Specific Tolling. On average this drop in consumer surplus is more significant for cars than trucks. On link “Gent-Antwerpen” in particular shows a significant drop in consumer surplus for trucks. Drop in consumer surplus is significantly higher for cars on links: “Brussels-Antwerpen”, and “Luxemburg-Brussels”.



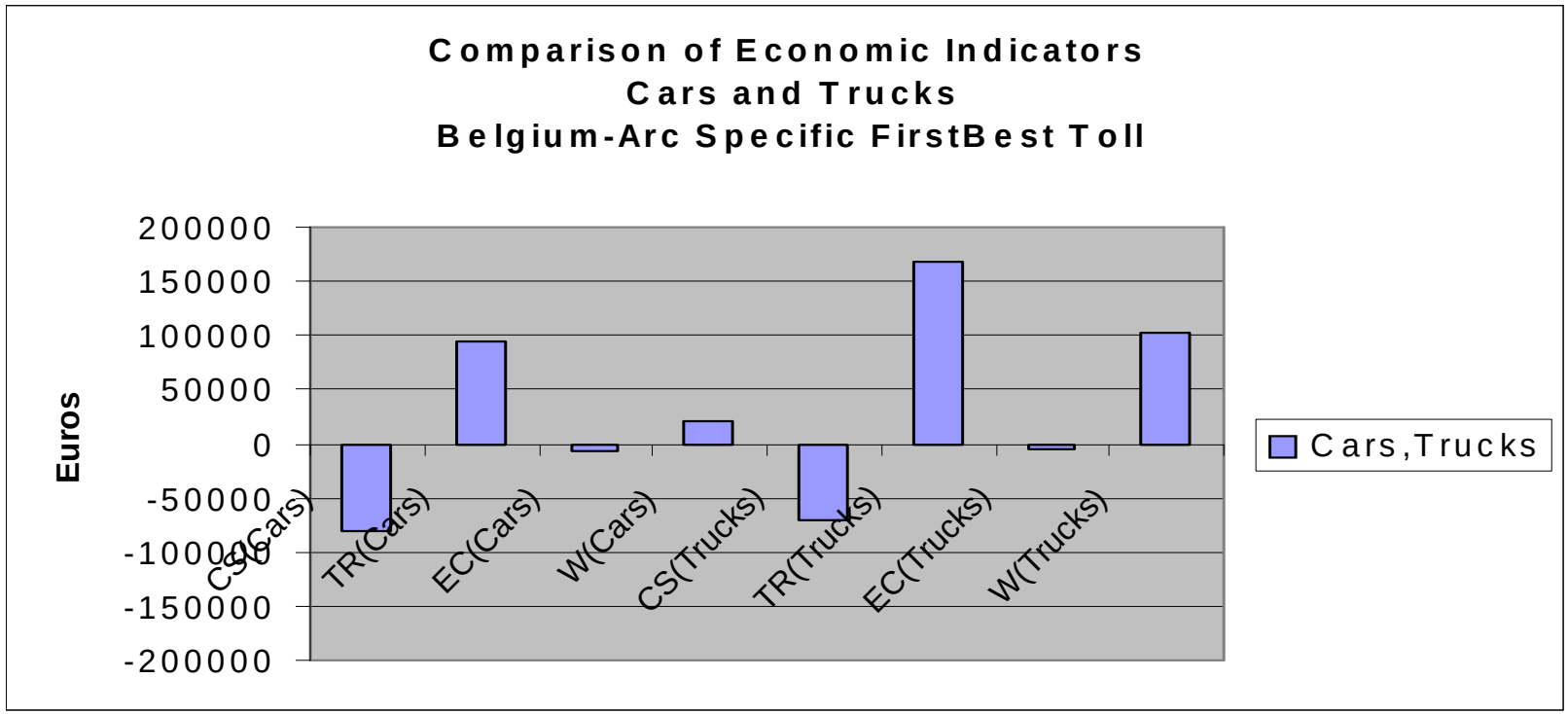
Testing Arc Specific Tolling

There is a decrease in external costs due to Arc Specific Tolling. However, there are exceptions. Five links show positive externalities. On link: "Lille-Brussels", the external costs of cars are positive. On link "Reims-Brussels(B)", link "Luemburg-Liège", "Brussels-Antwerpen", and link "Liège-Hasselt" change in external costs is positive due to trucks. On link "Brussels-Antwerpen" there is a positive externality due to both trucks and cars.



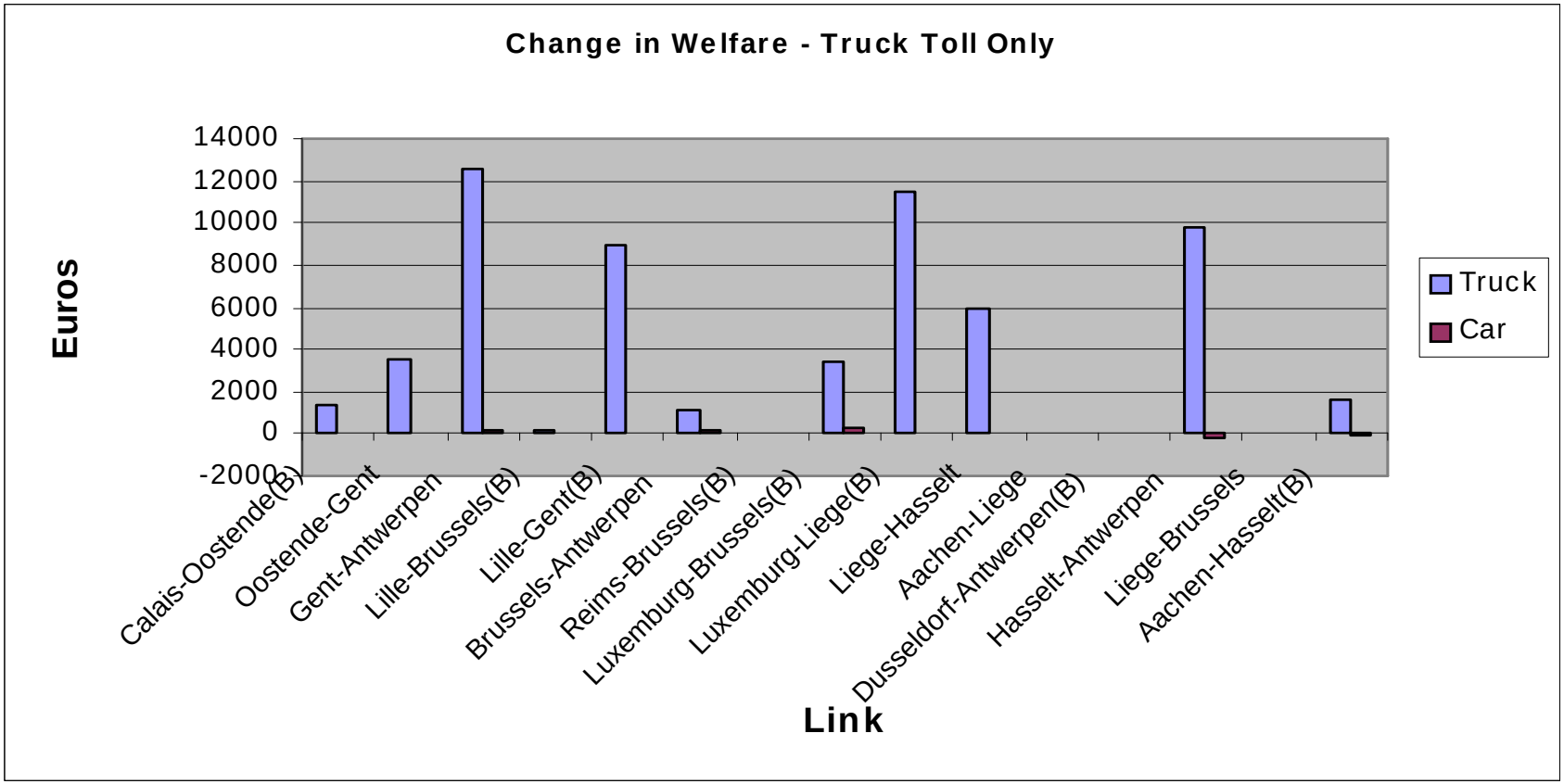
Testing Arc Specific Tolling

The overall impact of Arc Specific Tolling is analyzed The drop in consumer surplus is significant for cars than trucks. Both the Toll revenue, and the Welfare show a significant gain due to trucks. Drop in externalities is not significant neither for cars, nor for trucks.



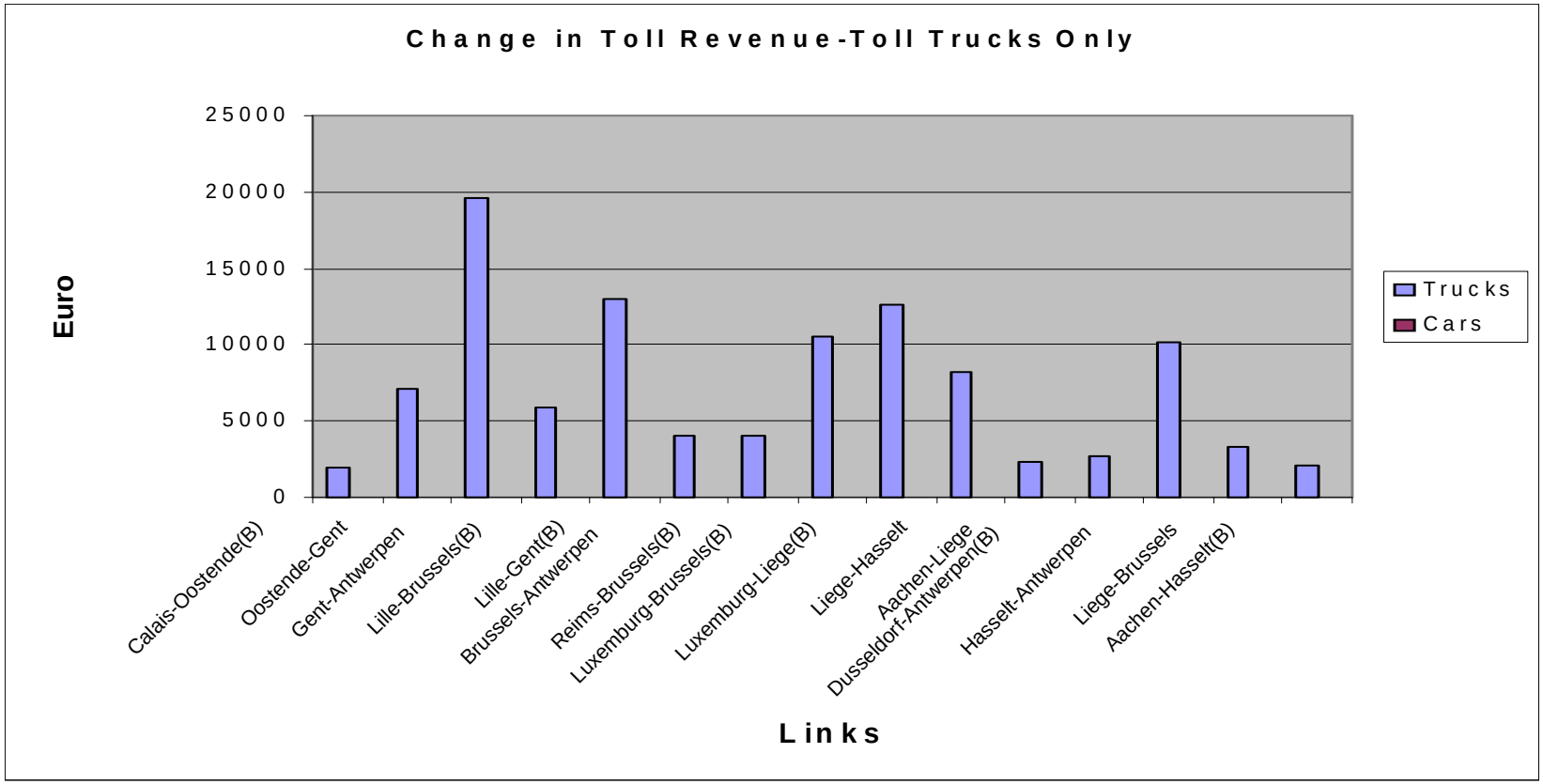
Truck only Tolling

- Shows a gain in Welfare due to truck only optimal uniform tolling.



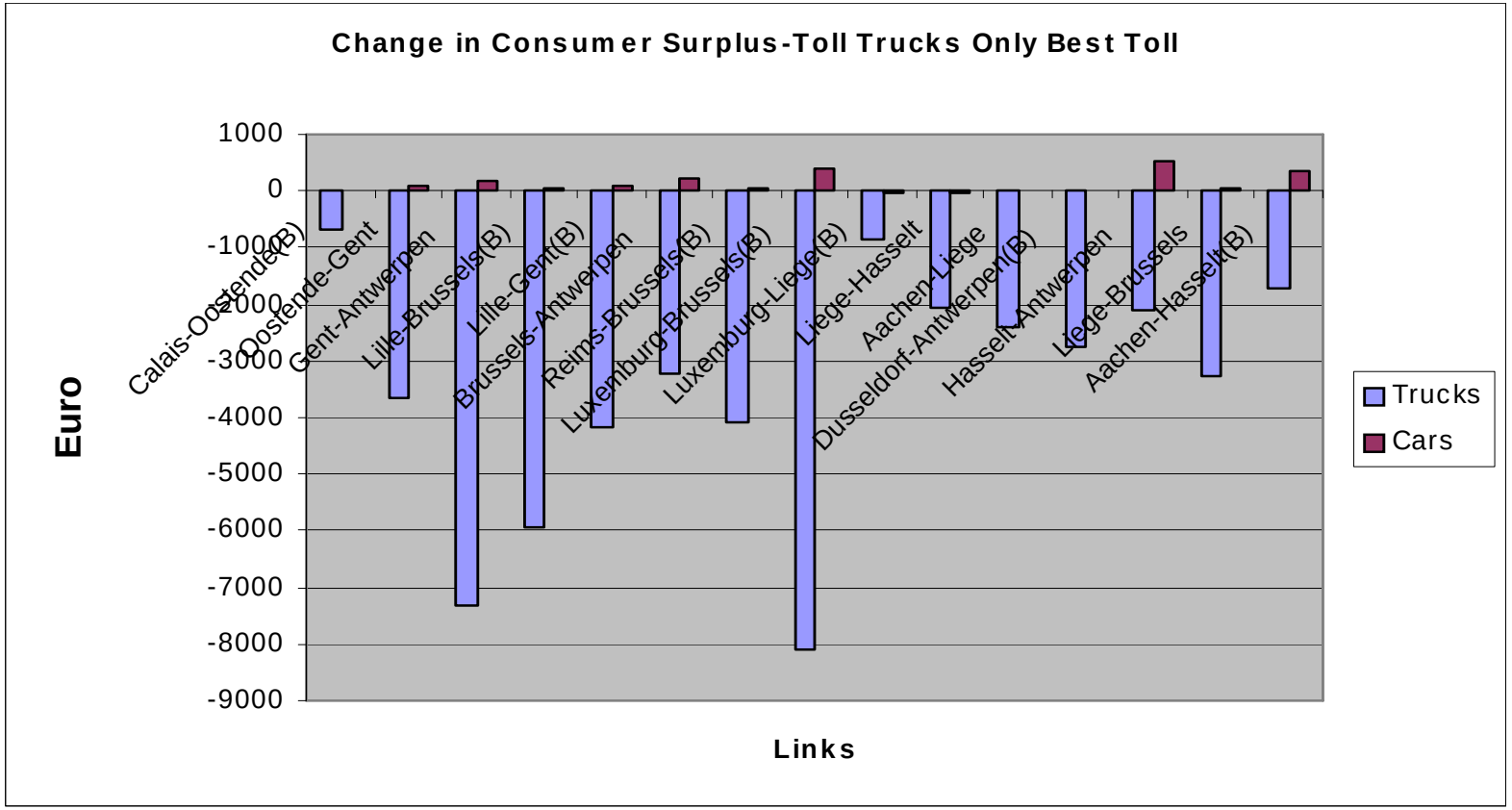
Truck Only Tolling

- A positive change in Toll Revenue due to this type of tolling.



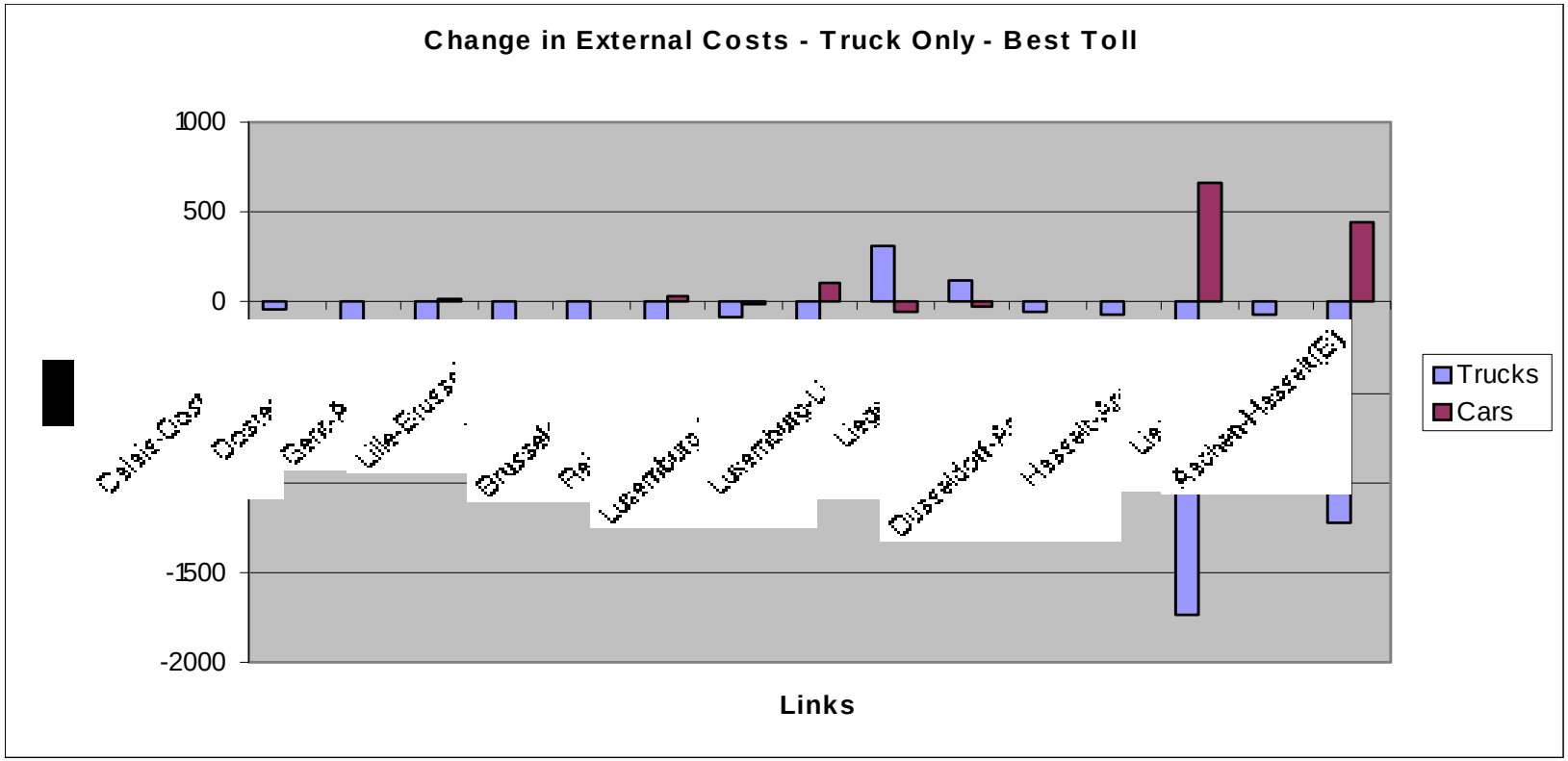
Truck Only Tolling

- shows a drop in consumer surplus for trucks, but the this does not raise the consumer surplus for cars, since it stays low.



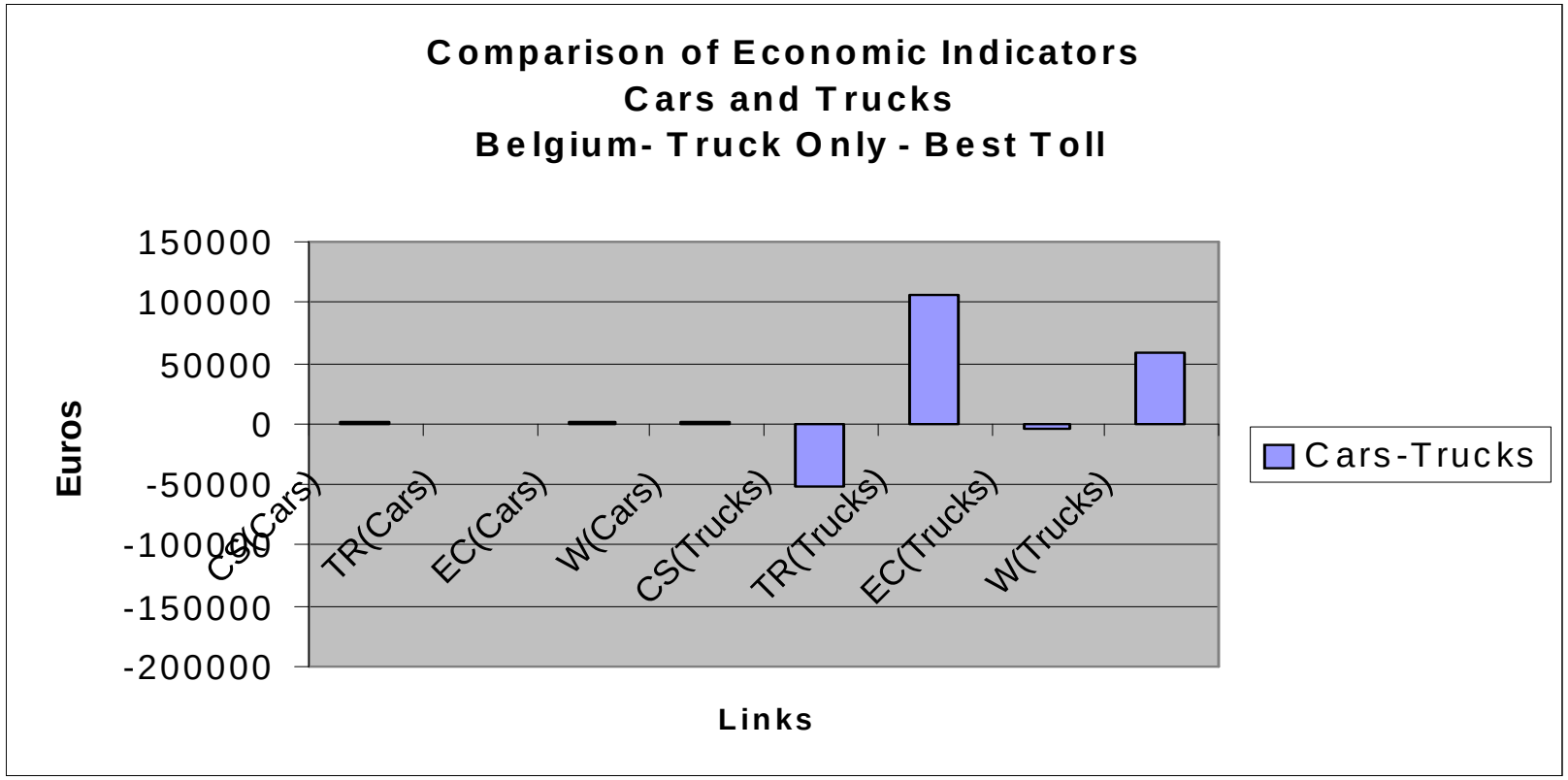
Truck Only Tolling

- A drop in externalities for trucks for the majority of links, except two. Links “Luxemburg-Liège”, and “Liège-Hasselt” show some increase in external costs due to trucks. Two links show positive change in externalities due to cars.



Truck Only Tolling

- The overall impact of truck only tolling shows both changes in toll revenue, and welfare are significantly positive. There is a drop in consumer surplus for trucks.



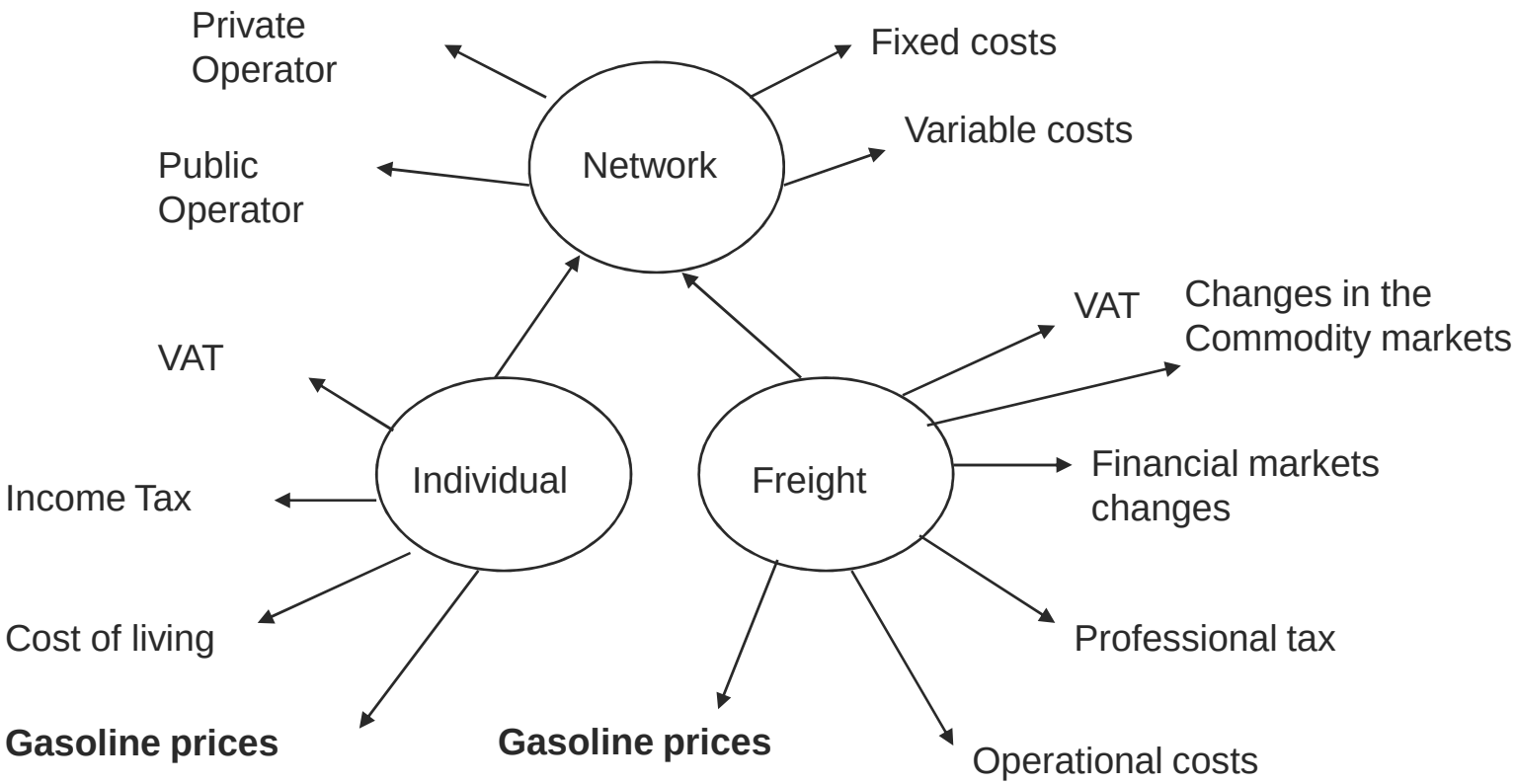
Conclusion 1: Economic aspects

- The economic benefits of uniform first best tolling schemes are clear (*externalities*) and (*welfare increase, concerning mainly trucks*), but limited.
- *Adverse effects*, loss in consumer surplus and reduction in demand, cannot be ignored.
- The *increase of average speed is moderate*, and also of limited social benefit, as excessive speed has been identified as the cause of accidents.
- *The main advantage* of tolling is to generate revenue: we could think of it in terms of welfare economics as a *tax instrument*.

The impact of inflationary gasoline prices on tolling strategies

- Toll as a tax instrument. The implications of this approach are:
  - Network as a public good
  - Toll to be coordinated with other relevant taxes such as VAT, income tax, changes in average annual income, and cost of living for individual road users, and VAT, professional tax, changes in operational costs, and financial markets, for freight traffic.
  - Rise of gasoline prices have changed the outlook for road use. The criteria is no longer to reduce congestion, and environmental externalities. As gasoline prices go up the value of time goes down. Less and less people will consider going on the roads and look for alternative modes. In not so far a future, the objective may become to find ways to attract road use.

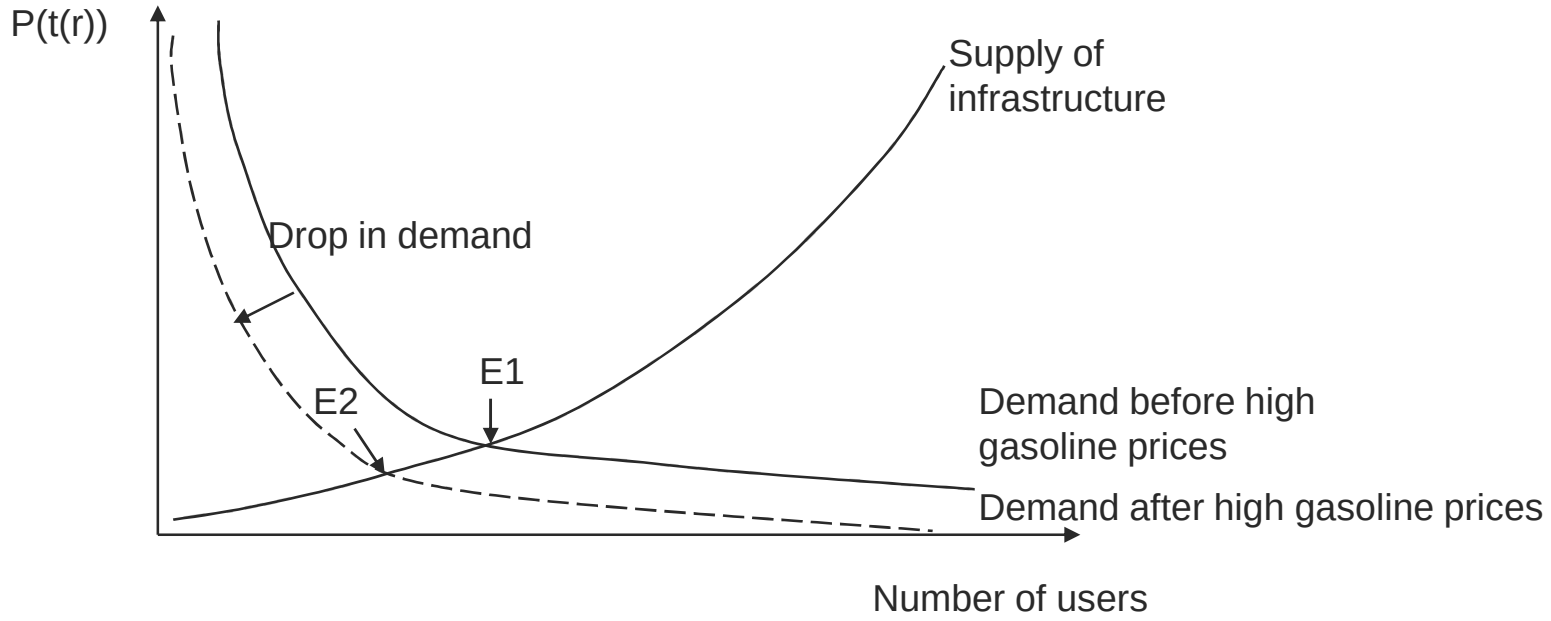
The impact of inflationary gasoline prices on tolling strategies



The impact of inflationary gasoline prices on tolling strategies

- Impact of high gasoline prices on road transport:
  - Reduction in traffic both (car, freight), (local, transit).
  - Reduction in externalities due to high traffic level such as: congestion, pollution, noise, and accidents.
  - As the price of oil goes up, the perception of time saving changes. In this case the price of location dependent time goes up. As the location dependent time is a commodity in the context of a road network, when the price of time goes up, demand for time will go down meanwhile short term supply stays fixed.

The impact of inflationary gasoline prices on tolling strategies



P(t(r))=Price of time on a shortest path

The impact of inflationary gasoline prices on tolling strategies

- Network equilibrium changes from (E1) to (E2). Implications are:
  - As demand goes down the level of service should go down. This conclusion is not realistic, since once a road network is built, it can not be undone. The level of service will stay fixed no matter if there are changes in demand.
- Other consequences of rise in gasoline price:
  - Development of other modes of transport not dependent on oil.

The impact of inflationary gasoline prices on tolling strategies

- Alternative car use schemes: renting a car from train station to a destination in town, weekend rentals, once or twice a week rentals to do shopping and other activities.
- Alternatives to road freight traffic: transport by train or barge traffic.
- New technologies: hybrid cars (lower externalities (pollution, noise)), lower speed (possibly lower congestion levels)

The impact of inflationary gasoline prices on tolling strategies

- High gasoline prices necessitate reformulating tolls:
  - Toll as a function of location dependent value of time.
  - Toll as a tax instrument should take into account other considerations such as other taxes, cost of living (cars), profit levels, level of involvement in financial markets (including banking practices), operation costs (freight), movements in commodity markets (freight).

Conclusion 2

- Toll as a tax instrument
- Location dependent time as a public good.
- Toll pricing for cars should be formulated taking into account factors such as: The VAT, income tax, cost of living .
- Toll pricing for freight should be formulated taking into account factors such as: The VAT, professional tax, operation costs, level of involvement in financial markets, changes in the commodity markets, and annual profit.