The impact of regulated toll highway price policies on the Consumer Price Index

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Introduction

- The presentation suggests a first exploratory analysis of the impact of price policies in regulated toll highways as a specific case of revenue management in transportation services.
- Its aim is twofold
  - Analyse the impact of Revenue Management policies on the Consumer Price Index in Toll Highways with the hypothesis that it brings about adverse consequences as compared to other transportation services.
  - Describe the price behaviour of a highway operator and suggest a formal framework to study it.
- Very few papers exist on this topic and the work is still in progress.

What is Revenue Management?

- A price policy that seeks to optimize the revenue of a company.
- The ordinary objective is to saturate the available capacities by discriminating customers demand.
- It especially works in industries where the output is not storable and customers can be identified = services producing activities.
- Consists usually in offering discount fares to attract new customers.
- New fares are affixed to specific requirements.

What is the likely impact of RM on the Consumer Price Index?

- The presentation refers to standard practice for CPI:
  - Laspeyre's index for two periods (0, 1) and n products

$$\frac{\sum_{i=1}^{n}(p_{i1} \cdot q_{i0})}{\sum_{i=1}^{n}(p_{i0} \cdot q_{i0})}$$

(Prices are evolving but the quantities are held constant)

  - Quantities refer to the constant use which is approximated by the distance covered by a given number of customers.
  - The price is the average price paid for a unit of production (seat)
  - Revenue Management ordinarily intends to bring in new customers that pay less for the same travelled distance, thus the average customers price tends to decrease.

The specificities of the Highway Industry

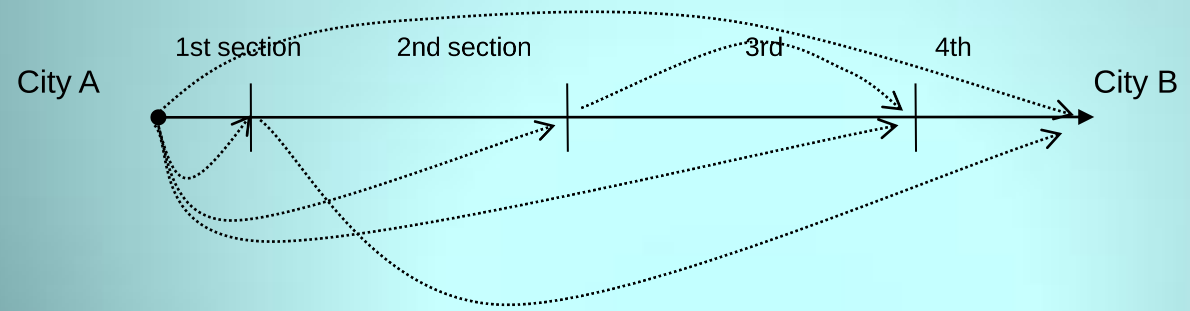
A quasi monopolistic situation, where direct competition is often missing and low intermodal competition.

A high share of fixed costs, mainly due to the building of the network. Economists (Ekelund Jr et al. 2003), commonly view the function of production of the road industry as the one of a natural monopoly.

Competition for the market rather than within the market: public contracts set up for a definite period the requirements that the highway operator should fulfil. The specification requirements ordinary include a price cap.

Revenue Management in Toll Highways: optimising revenue and saturating capacities (?)

- In highways, saturating capacities is not about seats, but kilometres.
- Maximising price per unit of production = price per vehicle/kilometre. Highways are split in several toll sections that determine routes. Operators optimise the kilometric income per route.
- Because of their quasi monopolistic situation, the rise of the average kilometric revenue per route may be reached by increasing the average kilometric price, rather than by attracting new customers using discount fares.



How to measure average kilometric price? Price cap versus CPI rationale

- prices are regulated and must comply with specified formulas (Cour des Comptes 2008; Odeck 2008).
  - In Spain Matas & Raymond (2003 p. 94): in the 1990's "toll increases equal to 95% of annual CPI growth".
  - In France, the approved increase for the APRR company (Autoroutes Paris Rhin Rhône) was for the duration of the last contract (2004-2008): 0.85% of annual CPI growth + 0.845.
- two main concerns:
  - The price cap links motorways prices to the CP Index.
  - The capping scheme may not fit to the Consumer Price Index principles. Companies may raise the actual average consumer toll above the regulated toll level.

the regulated kilometric ratio (T)

$$\frac{\sum_{i=1}^{N} p_{i.0}}{\sum_{1}^{N} k_i}$$

In France the *kilometric ratio*, is used by authorities to regulate highways prices (Cour des Comptes 1992, 2008). Its formula is to be found in the contract that ties the State and the operators. It is defined as the ratio of the sum of all the separate tolls divided by the sum of the length of all the routes.

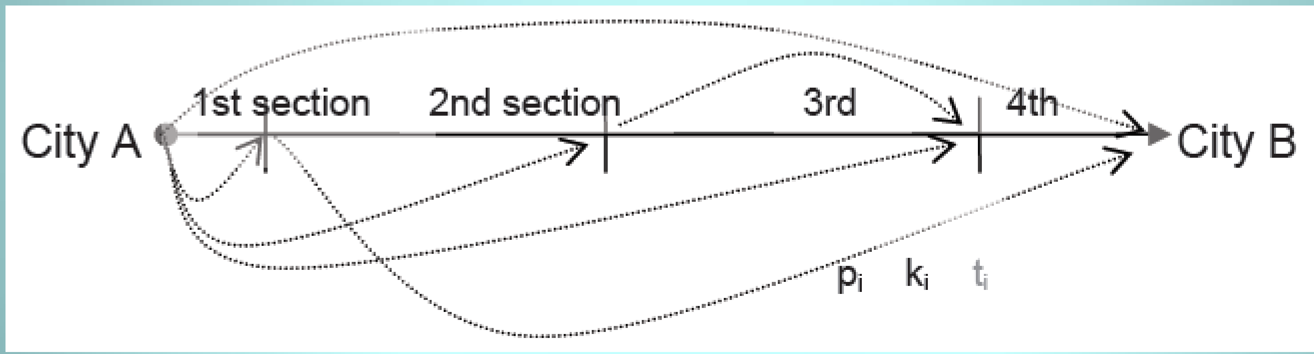


Table 1: Kilometric ratio (kilometric toll) for several highway companies In France in 2006

Highway companies	APRR	ASF	SANEF	ATMB	AREA
Kilometric ratio, class 1 vehicles; cts €/km, (VAT Included)	6.57	6.9	6.74	9.7	9.09

Autoroutes Paris Rhin Rhône (APRR). Autoroutes du Sud de la France (ASF); la Société du Nord et de la France (SANEF); société des Autoroutes Rhône Alpes (AREA); autoroute tunnel du Mont-Blanc concédée à la société (ATMB); (Cour des Comptes 2008 report).

The regulator sets the approved value of the toll increase (price cap) for the kilometric ratio T, let ΔT = c% (price cap in %) or $\frac{T_1}{T_o} = 1 + c$. For instance, the approved increase for the APRR Company (Autoroutes Paris Rhin Rhône) was up to 0.916 in 2007.

The real kilometric toll (T_{KM})

- The latter ratio is quite notional and merely “seeming” since it does not take into account the actual kilometres covered by customers.
- Let us call t_i the traffic related to the i^{th} segment; t_i is the number of times a route is travelled during a reference period.

Let the *real average kilometric toll (or price)* for the period n°0 be $T_{KM\,0} = \dfrac{\sum_{1}^{N} p_{i0} \cdot t_{i0}}{\sum_{1}^{N} k_i \, . \, t_{i0}}$

- This ratio is the one to be used for the computation of the CPI.
- The same ratio called “‘*weighted average toll*” is the kilometric price the 2006 directive Eurovignette asserts that should serve to control the coverage of highway infrastructure costs for lorries.

Under what circumstances these two ratios may be equals?

$$T_0 = \frac{\sum_{i=1}^{N} p_{i.0}}{\sum_{1}^{N} k_i} \qquad T_{KM0} = \frac{\sum_{1}^{N} p_{i.0} \cdot t_{i.0}}{\sum_{1}^{N} k_i . t_{i.0}}$$

The two ratios produce equal results in the following particular circumstances:

1) When there is only one section.

2) When all the kilometric prices $\frac{p_{i.0}}{k_i}$ are equal to T_0. For instance when the price of any route is a multiple (mathematical product) of its length (in kilometres), i.e. when $p_{i.0} = \beta * k_i$; $\beta > 0$.

3) If by chance the linear combination of the tolls by the effective traffic, divided by the traffic kilometres is equal to T_0.

Therefore there are few chances that in ordinary circumstances the two ratios can produce the same result.

- The real kilometric ratio T_{KMo} is more likely to be above or under the legal kilometric ratio T_o, depending on whether the average consumer uses more or less routes with a kilometric price respectively above or under T_o.
- In fact the result of the comparison ultimately depends on the highways price policy.
- However intuitively Revenue Management should tend to drive T_{KMo} above the controlled T_o ratio.

An illustrative example: the A 36 highway

- The A 36 is a rather typical medium traffic size motorway, operated by the APRR Company, one of the major French highway operators. It goes from the south-west German border to the so-called “sun highway” going to the “Côte d’Azur”.
- For practical and statistical reasons the stretch under scrutiny is the west part that goes between Montbéliard to Beaune.
- Several toll segments have been merged in order to keep only four sections and ten routes compatible with available traffic data

Table 2: Length and traffic of sections and routes of the Montbéliard – Beaune stretch of the A 36 highway (light vehicles)

Km	Montbéliard	East Besançon	West Besançon	Dole	Beaune
Montbéliard	0	59	82	115	173
East Besançon			24	57	113
West Besançon				32	89
Dole					53
2006 average daily traffic ↔					
Montbéliard	0	1500	1750	7000	5000
East Besançon		0	350	1000	1500
West Besançon			0	2000	500
Dole				0	1000
Actual overall traffic on each section (figure n°3)	17340	15890		18000	8040

Present highway network in France

The A 36 Highway stretch under scrutiny

HIGHWAYS
States Roads
Local roads

Table 3: Tolls for the routes between Montbéliard and Beaune in Euros

2008 tolls ↔	East Besançon	West Besançon	Dole	Beaune
Montbéliard	6,1	7,3	9,8	13,5
East Besançon		1,6	3,9	7,2
West Besançon			2,7	6,6
Dole				4,1
2009 tolls ↔				
Montbéliard	6,2	7,4	10	13,7
East Besançon		1,6	4	7,3
West Besançon			2,8	6,7
Dole				4,2

Source APRR 2008, 2009 documents

Table 4: Kilometric ratio, HCPI and their deviations between 2008-2009

	2008	2009	Deviation %
Kilometric ratio for merged sections €/km,	0.0788	0.0802	1.75
Real Highway Consumer Price and deviation Index for merged sections €/km	$5.126\ 10^{-05}$	$5.218\ 10^{-05}$	1.79
Full 8 sections kilometric ratio €/km	*0.0776*	*0.0789*	*1.67*

All results are computed VAT included.

Exploratory formal analysis: the Revenue function

The revenue function R (p) depends for each trip i on the toll p_i and the traffic t_i, which in turn also react to the prices.

$$R(p_i) = \sum_{i=1}^{N} (p_i . t_i)$$

Finally, all things being equal (especially the gasoline price and the economic growth), the traffic in t_1 is for the operator basically contingent upon the price deviation of the corresponding trip from period 0. It is thus contingent upon the average short term demand price elasticity of traffic for section i ($\eta_i; \eta_i < 0$) applied to traffic t_0.

$$R(p_i) = \sum_{i=1}^{N} (p_i . \theta_i(p_i)) \text{ with } \theta_i(p_i) = t_{i.0}(1 + (\frac{p_{i.1}}{p_{i.0}} - 1).\eta_i)$$

$$R(p_i) = \sum_{i=1}^{N} (p_i . t_{i.0}((1 - \eta_i) + \frac{p_{i.1}}{p_{i.0}}.\eta_i))$$

Exploratory formal analysis: short term elasticity of demand

The elasticity of demand in highway is noticeably lower than in railway or air transportation. It depends on several factors such as the length of the trip and the potential access to good alternative free roads. It is also conditional on the regularity of the trips.

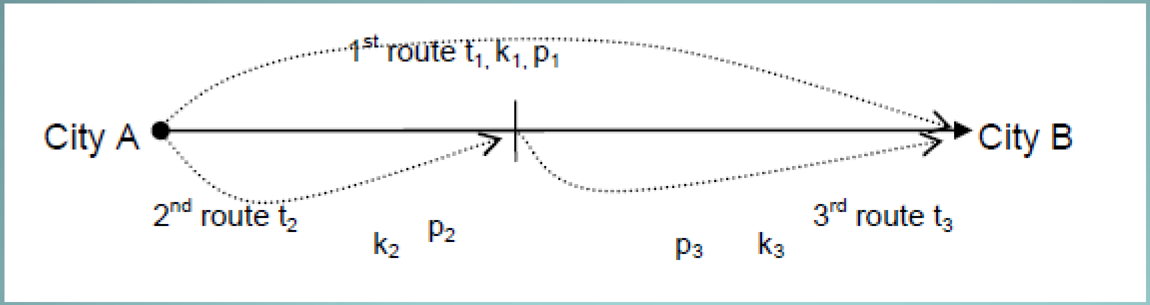
Table 6: Demand consumer price short term elasticity in selected tolled circumstances

Mode of transport		
Highways France (trips > 100km)	-0,22 to – 0.35	(1)
Highways France very long distance trips	~ 0	(2)
Bridges and tunnels	-0,09 to -0,50	(3)
Highways, Spain	-0.21 to -0.83	(4)
Railway passengers, France	*-0,7 to -0,9*	*(5)*
Air transportation	*-0,8 to -2,7*	*(6)*

(1) INRETS 1997 (in Matas 2003)
(2) Conseil de la concurrence (1994)
(3) six bridges and two tunnels, New York city area in Matas 2003
(4) Matas 2003
(5) Services des Etudes et de la Statistique France
(6) OACI

Two sections exploratory analysis case

Three sections already means six unknown variables… A genuine theoretical analysis produces an infinite number of unknown variables.



R(pi.) = $(p_{1.} \,.\, \theta(p_{1.})) + (p_{2.} \,.\, \theta(p_{2.})) + (p_{3.} \,.\, \theta(p_{3.}))$

with $\theta_i(p_i) = t_{i.0}(1 + (\frac{p_{i.1}}{p_{i.0}} - 1).\eta_i)$ or $\theta_i(p_i) = t_{i.0}(1-\eta_i) + t_{i.0}.\eta_i \frac{p_{i.1}}{p_{i.0}}$; $\eta_i \leq 0$

Constraints

Only three constraints are taken into consideration.

1) $\frac{p_{1.1} + p_{2.1} + p_{3.1}}{p_{1.0} + p_{2.0} + p_{3.0}} \leq (1+c)$ (C_1) capping constraint

2) $p_{1.1} \leq p_{2.1} + p_{3.1}$ (C_2) Direct route price constraint

3) Let $\frac{p_{2.0}}{k_2} \geq \frac{p_{3.0}}{k_3} \Rightarrow \frac{p_{2.1} * k_3}{p_{3.1} * k_2} - 1 \leq 0.2$ (C_3) Limitation of the kilometric price deviation between two contiguous sections.

Sometimes a broken (discontinuous) trip is cheaper than a direct one

Table 5: Total tolls and spreads for various Montbéliard - Beaune dotted (discontinuous) routes (2009 tolls)

	Mixed dotted routes			Pure dotted route
€ →	One stop	Two stops		Three stops
Via East Besançon	**13.5 (- 0.2)**	14.5 (+ 0.8)	14.2 (+ 0.5)	14.8 (+ 1.1)
Via West Besançon	14.1 (+ 0.4)	/	14.1 (+ 0.4)	/
Via Dole	14.2 (+ 0.5)	/	14.4 (+ 0.7)	/
nonstop route	13,7 (0.0)			

The spreads between the corresponding route and the direct one are shown between brackets.

We look for the $p_{i.1}$ that maximise

$$\mathcal{L}(p_{i.}, \lambda_1, \lambda_2, \lambda_3) = p_{1.1}\, t_{1.0}(1-\eta_1) + t_{1.0}\frac{p_{1.1}{}^2}{p_{1.0}}\eta_1 + p_{2.1}\,.\,t_{2.0}(1-\eta_2) + t_{2.0}.\eta_2\frac{p_{2.1}{}^2}{p_{2.0}} +$$

$$p_{3.1}\,.\,t_{3.0}(1-\eta_3) + t_{3.0}.\frac{p_{3.1}{}^2}{p_{3.0}}\eta_3 - \lambda_1\left(\frac{p_{1.1}+p_{2.1}+p_{3.1}}{p_{1.0}+p_{2.0}+p_{3.0}} - 1 - c\right) - \lambda_2\,(p_{1.1} - p_{2.1} - p_{3.1}) -$$

$$\lambda_3\left(\frac{p_{2.1} * k_3}{p_{3.1} * k_2} - 1 - 0.2\right)$$

First order conditions:

$$\left\{\begin{array}{l}
\frac{\partial \Lambda}{\partial p_{1.1}} = 0 \Leftrightarrow t_{1.0}(1-\eta_1) + 2\,.t_{1.0}.\eta_1 \frac{p_{1.1}}{p_{1.0}} - \lambda_1 \frac{1}{p_{1.0}+p_{2.0}+p_{3.0}} - \lambda_2 = 0 \\
\frac{\partial \Lambda}{\partial p_{2.1}} = 0 \Leftrightarrow t_{2.0}(1-\eta_2) + 2\,.t_{2.0}.\eta_2 \frac{p_{2.1}}{p_{2.0}} - \lambda_1 \frac{1}{p_{1.0}+p_{2.0}+p_{3.0}} + \lambda_2 - \lambda_3 . \frac{k_3}{p_{3.1} * k_2} = 0 \\
\frac{\partial \Lambda}{\partial p_{3.1}}\ 0 \Leftrightarrow t_{3.0}(1-\eta_3) + 2\,.t_{3.0}.\eta_3 \frac{p_{3.1}}{p_{3.0}} - \lambda_1 \frac{1}{p_{1.0}+p_{2.0}+p_{3.0}} + \lambda_2 + \lambda_3 . \frac{p_{2.1} * k_3}{k_2 . p_{3.1}^{\ 2}} = 0 \\
\lambda_1 \geq 0 \\
\frac{\partial \Lambda}{\partial \lambda_1} \geq 0 \Leftrightarrow \frac{p_{1.1}+p_{2.1}+p_{3.1}}{p_{1.0}+p_{2.0}+p_{3.0}} - 1 - c \leq 0 \\
\lambda_1 \frac{\partial \Lambda}{\partial \lambda_1} \geq 0 \Leftrightarrow \lambda_1 \left(\frac{p_{1.1}+p_{2.1}+p_{3.1}}{p_{1.0}+p_{2.0}+p_{3.0}} - 1 - c \right) = 0 \\
\frac{\partial \Lambda}{\partial \lambda_2} \geq 0 \Leftrightarrow p_{1.1} - p_{2.1} - p_{3.1} \leq 0 \\
\lambda_2 \geq 0 \\
\lambda_3 . \frac{\partial \Lambda}{\partial \lambda_3} = 0 \Leftrightarrow \lambda_3 . \left(\frac{p_{2.1} * k_3}{p_{3.1} * k_2} - 1 - 0.2 \right) = 0 \\
\frac{\partial \Lambda}{\partial \lambda_3} \geq 0 \Leftrightarrow \frac{p_{2.1} * k_3}{p_{3.1} * k_2} - 1 - 0.2 \leq 0 \\
\lambda_3 \geq 0
\end{array}\right.$$

The following computation remains especially strenuous and complex when the parameters are kept unknown. Nevertheless little calculation shows that solutions depend on cross elasticities. As a simplified first exploratory step let us apply the exploratory process to the illustration case already under analysis.

Using the data from the A 36 stretch

The previous maximisation function $\mathcal{L}(p_{i.}, \lambda_1, \lambda_2, \lambda_3)$ Becomes:

$$\mathcal{L}(p_{i.}, \lambda_1, \lambda_2, \lambda_3) = (p_{1.1}.9100 - 2100 * \frac{p_{1.1}^2}{9.8}) + (p_{2.1}.1800 - 300 * \frac{p_{2.1}^2}{6.1}) +$$

$$(p_{3.1}.4900 - 1400 * \frac{p_{3.1}^2}{3.9}) - \lambda_1 (\frac{p_{1.1} + p_{2.1} + p_{3.1}}{19.8} - 1{,}022) - \lambda_2 (p_{1.1} - p_{2.1} - p_{3.1}) -$$

$$\lambda_3 \frac{p_{2.1} * 56}{p_{3.1} * 59} - 1 - 0.2$$

Using the data from the A 36 stretch

First order conditions following Kuhn and Tucker method:

$$
\left\{
\begin{array}{ll}
\dfrac{\partial \Lambda}{\partial p_{1.1}} = 0 \Leftrightarrow 9100 - 4200 * \dfrac{p_{1.1}}{9.8} - \lambda_1 \dfrac{1}{19.8} - \lambda_2 = 0 & \\
\dfrac{\partial \Lambda}{\partial p_{2.1}} = 0 \Leftrightarrow 1800 - 600 * \dfrac{p_{2.1}}{6.1} - \lambda_1 \dfrac{1}{19.8} + \lambda_2 - \lambda_3 * \dfrac{56}{59 * p_{3.1}} = 0 & \\
\dfrac{\partial \Lambda}{\partial p_{3.1}} \; 0 \Leftrightarrow 4900 - 2800 * \dfrac{p_{3.1}}{3.9} - \lambda_1 \dfrac{1}{19.8} + \lambda_2 + \lambda_3 * \dfrac{56 * p_{2.1}}{59 * p_{3.1}^{2}} = 0 & \\
\lambda_1 \geq 0 & \\
\dfrac{\partial \Lambda}{\partial \lambda_1} \geq 0 \Leftrightarrow \left(\dfrac{p_{1.1} + p_{2.1} + p_{3.1}}{19.8} - 1.022\right) \leq 0 & \\
\lambda_1 . \dfrac{\partial \Lambda}{\partial \lambda_1} \geq 0 \Leftrightarrow \lambda_1 \left(\dfrac{p_{1.1} + p_{2.1} + p_{3.1}}{19.8} - 1.022\right) = 0 & (C_1) \\
\dfrac{\partial \Lambda}{\partial \lambda_2} \geq 0 \Leftrightarrow p_{1.1} \leq p_{2.1} + p_{3.1} & (C_2) \\
\lambda_2 \geq 0 & \\
\lambda_2 . \dfrac{\partial \Lambda}{\partial \lambda_2} = 0 \Leftrightarrow \lambda_2 . (p_{2.1} + p_{3.1} - p_{1.1}) = 0 & \\
\lambda_3 . \dfrac{\partial \Lambda}{\partial \lambda_3} = 0 \Leftrightarrow \lambda_3 . \left(\dfrac{p_{2.1} * 56}{p_{3.1} * 59} - 1 - 0.2\right) = 0 & (C_3) \\
\dfrac{\partial \Lambda}{\partial \lambda_3} \geq 0 \Leftrightarrow \dfrac{p_{2.1} * 56}{p_{3.1} * 59} - 1 - 0.2 \leq 0 & \\
\lambda_3 \geq 0 &
\end{array}
\right.
$$

- Given the requirements of the maximisation program and the observed data not all the options have to be analysed. The interesting case is (C_1) and (C_3) saturated, (C_2) not saturated $\Leftrightarrow \lambda_1$ and $\lambda_3 \neq 0$ but $\lambda_2 = 0$ There is no optimal solution that saturates both the three constraints (further research needed).
- Even with the workable results, the CPI amounts to 103.77 while the legal kilometric ratio stands still at 102.2, which ascertain that Revenue Management may push consumer prices above legal toll cap initiating an inflationist drift.

Table 7: Data for the maximisation process and results

KM	East Besançon	Dole
Montbéliard	59	125
East Besançon		56
Traffic t_0		
Montbéliard	1500	7000
East Besançon		3500
2008 actual tolls		
Montbéliard	6,1	9,8
East Besançon		3,9
2009 actual tolls		
Montbéliard	6,2	10
East Besançon		4
Elasticities		
Montbéliard	-0,2	-0,3
East Besançon		-0,4
Adjusted t_1 traffic given 2009 tolls		
Montbéliard	1490,16	6957,14
East Besançon		3464,10
Kilometric ratios 2008		
Montbéliard	0,1034	0,0784
East Besançon		0,0696

RESULTS	East Besançon	Dole
Maximising rounded tolls		
Montbéliard	5,6	10,1
East Besançon		4,5
Adjusted t_1 traffic with maximising tolls		
Montbéliard	1524.59	6935,71
East Besançon		3284,62
New kilometric ratios		
Montbéliard	0,09492	0,08080
East Besançon		0,08036
Revenue in €	**2008**	**2009**
Actual tolls; t_0 traffic	91 400	93 300
Maximised tolls and t_o traffic		94 850
Maximised t_1 tolls and adjusted traffic		*93 369*
Actual t_1 tolls and adjusted traffic		*92 697*

conclusion

- Despite capping formulas, Revenue Management in toll highways may have adverse consequence on Consumer Prices.

- The paper proposes a first simple formal framework to analyse highway pricing behaviour. The model shows that the behaviour depends on crossed elasticities between different tolled sections. However, even in the simplest case, two tolled sections, there is (apparently) no optimal solution to the maximisation problem. Furthermore study is needed to enhance and complete the analysis.

- The quality issue has been discarded, and should deserve some observations. The capping scheme, as well as the consumer price index, should take into account quality enhancement, such as security improvement or better rest area services, or else an increase in daily accessibility… These quality upgrades should be interpreted as a real price decrease. However the valuation of these improvements raises particular strenuous and subtle questions that should be addressed in further research.