Heterogeneity in preferences for transportation modes: Effects on modal split and urban pollution*

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Abstract

We model commuters' decision to drive or use public transit in the presence of heterogeneity regarding the level of discomfort each mode of transportation represents. We consider three groups of commuters, suburban, urban and those living in the city. We take into account aggregate pollution and its effect on welfare to examine policy options susceptible to reduce aggregate pollution. Preliminary results show that the effectiveness of policy instruments is contingent on the spread of the public transit network.

Keywords: Heterogeneity, Transportation, modal split, Pollution
JEL codes: Q50, R44

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1 Introduction

In 2013, among the 989 billion passenger-kilometers counted on the french territory, 819 billion was made by private cars and 103 billion by railway (see Fig. 1)[1].

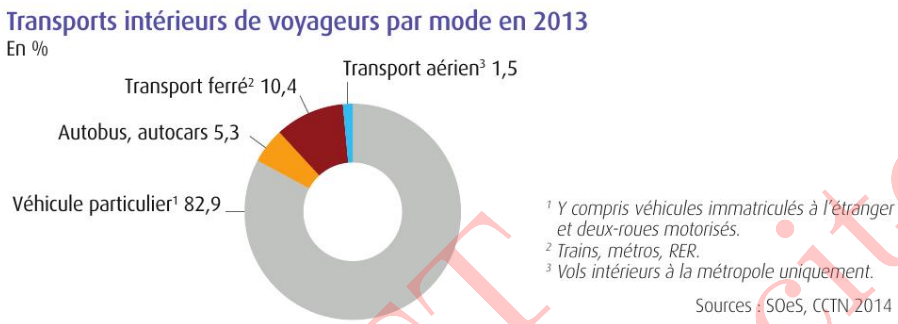


Figure 1: Modal split of passenger traffic in 2013 in France

As Fig. 2 shows, there has been a relative stability in personal vehicle traffic since 2004 but a growth in railway traffic since 2000

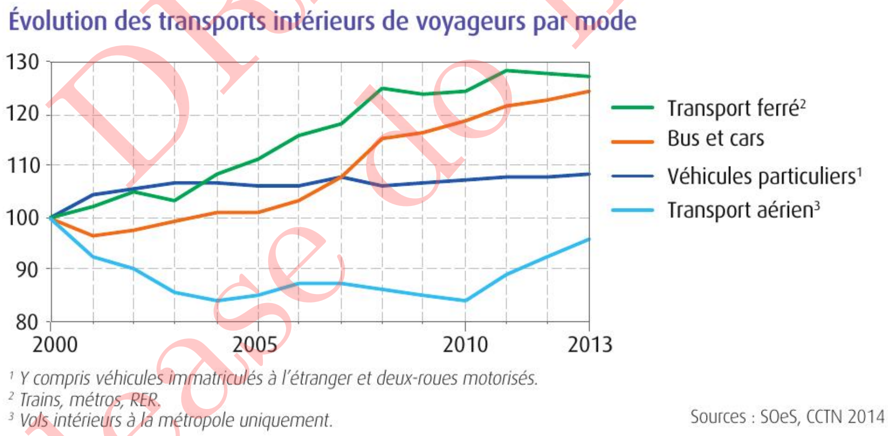


Figure 2: Evolution of passenger transportation modes since 2000

Among public transport, local public transport has shown a growth of 30 % (Fig. 3)

Simultaneously, urban public transportation networks expanded rapidly. This growth was especially strong for tramways: 15 % of annual growth in the number lines in service in Île-de-France between 2009 and 2013 and 19 % in the number of kilometers (respectively 12 % and 10 % in the rest

[1] All figures are from Commissariat Général du Développement Durable (CGDD), 2015, Repères - Chiffres clés du transport, édition 2015

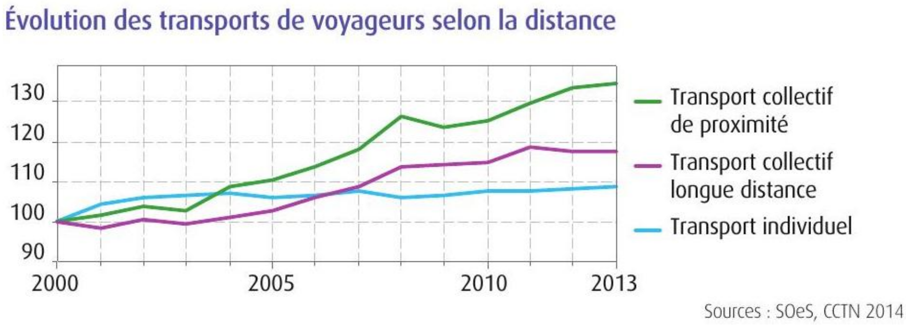


Figure 3: Evolution of passenger transportation by distance

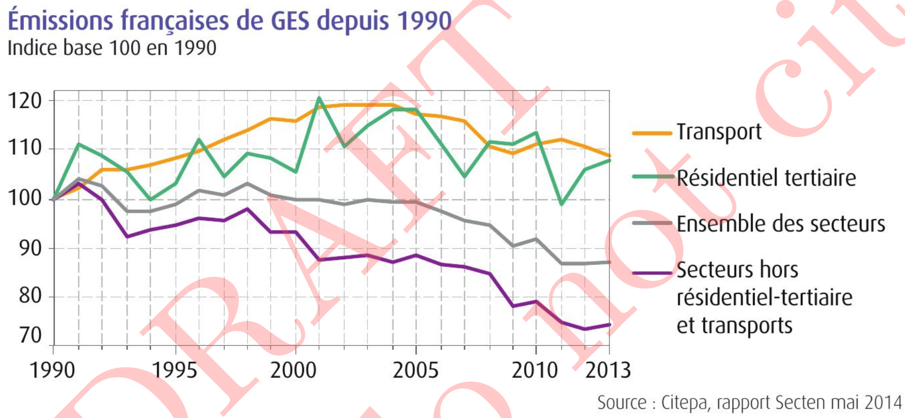


Figure 4: Evolution of GHG emission by sector in France

of the country). The use of networks also showed a strong growth (in Île-de-France, between 2003 ane 2013, 1.1 % in local trains, 1.6 % in metro and 1.5 % for buses)

It is the purpose of this paper to look at the pollution caused by local urban passenger transportation. How does the pattern outlined here aboved, *i.e.* a stabilized high share of polluting personal vehicule traffic accompanied by a growth in local public transportation, translate into pollution?

Firstly, at the aggregate level, transport is the largest contributor to Greenhouse Gas emissions (GHG, 27.0 % in 2013). Its share has increased since 1990 by 21.7 %, but they seem to have stabilized since 2010. Between 1990 and 2013 GHG emissions from transport have increased by 0.4% each year on average. However a break in the growth trend seems to appear since 2004 (see Fig. 4).

In the transportation sector, road is by large the main contributor to GHG emissions (94.8% of total transportation GHG emissions). However, since 2004, road traffic emissions decreased moderately. This is due to a relative slowdown in road traffic, an increased share of less polluting new

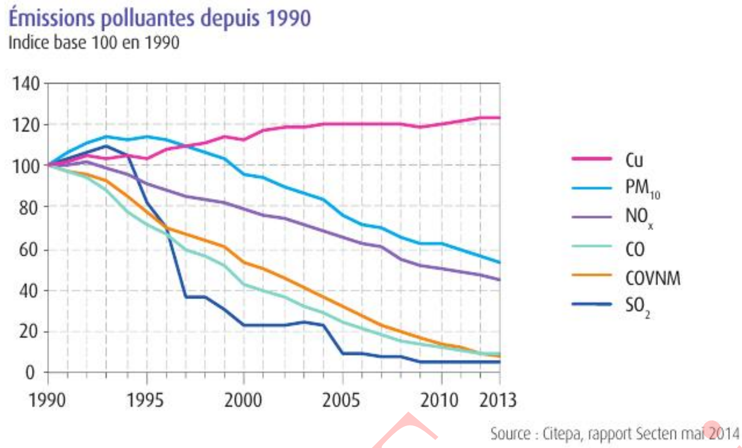


Figure 5: Evolution of local pollutants in France

vehicles and a larger share of diesel use which generates relatively less GHG (but higher local pollutants). Among road emissions, personnal cars count for 56.1% of CO_2 emissions from transport (1% decrease every year from 2004 and 2012).

Turning to local pollutants emissions (those causing sanitary issues), since 1990, there has been a decrease in emissions in all sectors, due to the effectiveness of standards and to technical progress (see Fig. 5).

Even if we observe a stabilization of personal vehicle trafic, a growth in passengers public transportation in urban area, a expansion of public transportation network and a stabilization of GHG emission frome transport and a decrease in local pollution from transport, it remains that, given the objectives setteld by french an europan authorities, the question of reducing pollution from transport is still at the center of public concern[2]. The question we ask in this paper is the following *Thus can modal shift contribute to abating pollution from transport?*

In a report for the *Conseil d'Analyse Stratégique*, Didier and Prud'homme (2007) express skeptical arguments about the role that modal shift can play to cope with pollution abatement. They advocate that, given that the price elasticity of demande for road trips is -0.3 (DAEI-SES, 1998), a 10 % increase in gasoline price (equivalent to a 14 % rise in the French tex on oil products *TIPP*), would entail a 3 % decrease in traffic, i.e. a *-26 billions decrease in passenger-km.* At the same time, given that the cross price elasticity of rail trips demand w.r.t. the price of road trips is 0.2, the same 10 % increase in gasoline price would produce only a 2 % increase in railway traffic, i.e.*+ 2 billions increase in passenger-km.* They conclude that 92 %

[2]See the EU 2020 Climat and energy package aiming at cutting by 20 % the GHG emissions, increasing by 20 % the share of renewable energy and improving by 20 % the energy efficiency

of the traffic would disappear because of the weakness of the modal shift toward public transportation.

Indeed it is well-known that road and railway are poor price substitutes. However there are limits to an aggregate approach to modal shift economy. Aggregating markets irons out marked differences in transportation markets. Such an aggregate cross elasticity between transportations modes is difficult to interpret. A more accurate approach would have to get to the microeconomics of transportation services, assess distinct elasticities of distinct mobility markets (daily trips, weekly trips,...), distinct travel motivation (home-to-work, leisure,...)[3]

But even if only a weak green modal shift is to be expected if we only change relative prices, we should not disregard other characteristices of transport services. A much larger share of modal shift towards public transportation is explained by *progresses in service quality*. The elasticities are much higher when looking at these dimensions of transport.

This leads us to focus on a particular mobility market, *home-to-work mobility*, and to study the role played by service quality. Home-to-work mobility is characterized by the fact that travelers have limited options and constrained schedules. These trips are most of the time unavoidable and regular. Finally public transit home-to-work does depend on characteristics of service quality. And above all, travelers are highly heterogenous on their attitude towards service quality.

The literature on urban mobility and modal shift with heterogenous agents features either simulation models (integrated simulation models without any microeconomic foundations or agent-based models) or microeconomic models with principal-agents relationship.

Okushima (2015) proposes an integrated simulation model and studies agents whose choices are directly influenced by their neighbors's behavior and their socio-economic peers. Pollution abatement can be achieved through technological progress or modal shift, the latter can be fostered either by the interaction with the neighborhood or by price and supply transport policies A tax on emission seems efficient to reduce pollution. However there is no microeconomic foundations underlying the analysis.

Mc Breen (2009) proposes an agent-based location and mobility model. Focusing more on congestion he takes into account different sources of heterogeneity: heterogeneity in the schedule delay cost (arriving too early or too late), heterogeneity in the preferred arrival time and heterogeneity in preferences on housing and location. However there is no heterogeneity in access to public transport.

Batarce and Ivaldi (2014) study nonlinear pricing of public transport services. They model congestion as the outcome of a game. Their social planner has incomplete information on travalers' type and looks for the

[3]See for instance Oum and Waters, 2000

optimal nonlinear pricing scheme. Again all agents have access to public transport network (no heterogeneity on that dimension). Their focus is on congestion, not on pollution. Nonlinear pricing evicts some agents from public transport but increases the use of this mode by those who pay the tariff)[4]

In our paper, we focus on local pollution caused by passenger home-to-work transportation modes[5] and we take into account two key sources of heterogeneity: the attitude towards discomfort of alternative modes, and the travelers' location and access to public network.

First we emphasize the role of heterogeneity in the attitudes (i.e. preferences) towards discomfort of alternative transportation modes. If they use the private polluting mode (car), travelers produce their own transportation service but suffer from congestion, road works, risks, etc ... If they use a public clean mode (metro, tramway, local train network), which we will call *public transit*, travelers get transported but can experience discomfort such as low frequency of the service, necessity to transfer, etc ...

Usually in the literature and among policy makers, only public transit has discomfort characteristics. This bears heavily on economic evaluation of benefits and costs of public transportation projects. We suggest that each mode has its own discomfort characteristics and that each traveler has its own preferences towards discomfort in each mode.

Second, we take into account heterogeneity in the access to the public transit network (though locations are considered as given). According to their location, travelers have or do not have direct access to the public transportation network. As a consequence, some of them may combine the otherwise alternative modes of transportation to reach the center of the cuty where working activities take place.

The objectives of the paper are the following: (1) building a stylized framework for the analysis of commuters' mobility in urban (and suburban) areas, (2) analyzing the responses of heterogeneous commuters' modal choices to changes in economic and policy variables, (3) deriving the resulting changes in urban pollution and (4) searching for the optimal modal split (still to be completed)

2 The model

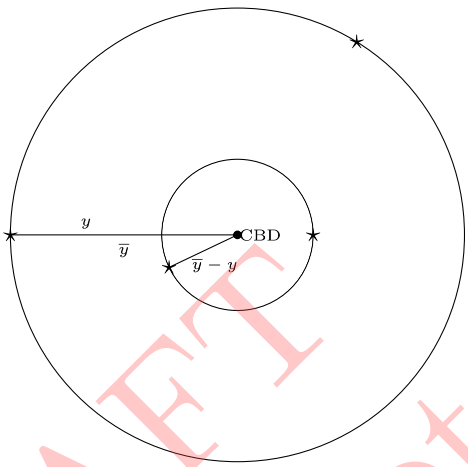
2.1 Agents' decisions

We consider a monocentric circular isotropic city with the central business district (CBD) as the destination of regular and unavoidable commutes to work. In addition to agents living in the CBD, therefore not needing to

[4]See also Anwar (2016) for another principal-agent model with heterogeneity in preferences.

[5]We ignore other sources of urban pollution: urban freight and the residential sector

commute to work, we consider: (i) commuters living in the urban area, covered by the public transit network, at a distance $(\overline{y}-y)$ to the CBD, and (ii) agents living in the urban area at a distance $\overline{y}$ to the CBD and distance y to the urban area.



The problem of the urban area residents

Residents living in the area covered by the public network are denoted by N, they represent a proportion α of the total population. They have an income z_N and derive utility from consuming a numeraire good x and suffer disutility from traveling from their residence to the CBD either by car (mode C) or by public transit (mode T), they also suffer from aggregate pollution P.

Their utility is

$$U_N^t(x, \underbrace{(\overline{y}-y)v^t(\theta)}_{d}, P), \tag{1}$$

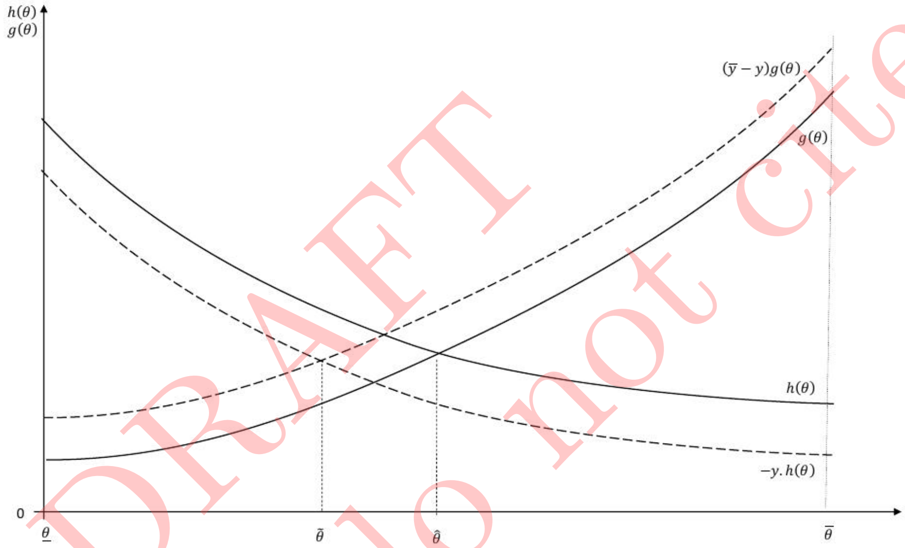
where $t \in \{C, T\}$ denotes the transportation mode and $v^t(\theta)$ a weight attached to the distance according to the discomfort of the transportation mode t, such that

$$v^t(\theta) = \begin{cases} h(\theta), & \text{if } t = C \\ g(\theta), & \text{if } t = T \end{cases} \tag{2}$$

We assume the following about the utility function:

- $\partial U_N/\partial x > 0$, $\partial^2 U_N/\partial x^2 < 0$
- $\partial U_N/\partial d < 0$, $\partial^2 U_N/\partial d^2 < 0$
- $\partial U_N/\partial P < 0$, $\partial^2 U_N/\partial P^2 < 0$

The type of the agent is denoted by $\theta \in [\underline{\theta}, \overline{\theta}]$ with distribution $f(\theta)$ and cumulative distribution $F(\theta)$. The weight functions $h(\theta)$ and $g(\theta)$ are depicted in the figure below, it is to be noted however that as long as they are monotonic their curvatures are not of particular importance in our analysis. In the figure below agents whose type is $\theta < \hat{\theta}$ are more inconvenienced by driving than by using public transit, and the opposite is true for those with type $\theta > \hat{\theta}$, while those with type $\theta = \hat{\theta}$ are equally inconvenienced by either modes of transportation.



The budget constraint of agents in the urban area is,

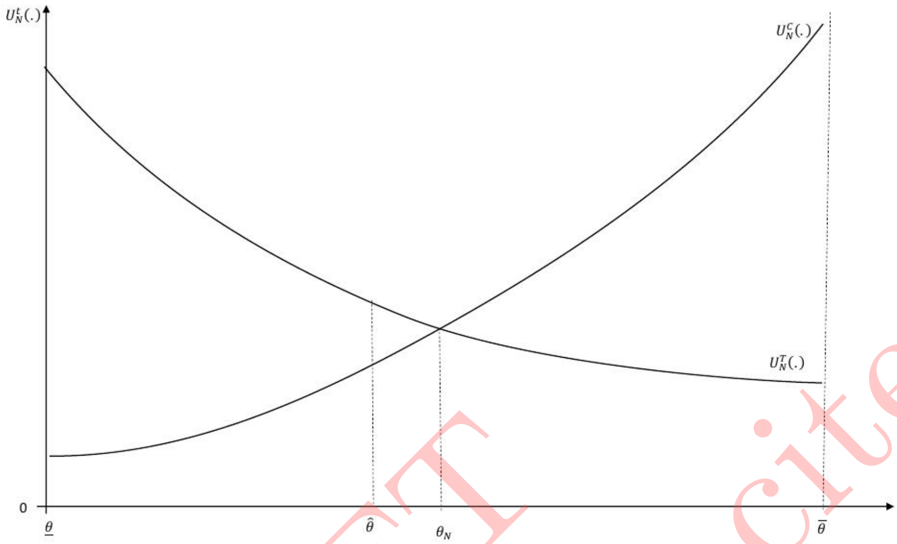
$$z_N = x + p_t(\overline{y} - y) \tag{3}$$

and their utility maximization problem is,

$$\max_{t \in \{C,T\}} U_N^t(z_N - p_t(\overline{y} - y), (\overline{y} - y)v^t(\theta), P) \tag{4}$$

they choose a transportation mode by comparing utilities derived in each case. If $U_N^C < U_N^T$, then the agent chooses public transit, $t = T$, otherwise she chooses to drive, $t = C$.

We show that $U_N^C(.)$ is increasing w.r.t. θ and U_N^T is decreasing w.r.t. θ.



Agents with type θ_N are indifferent between C and T. The agent with $\theta = \theta_N$ is the *marginal driver*, i.e. the driver with the lowest θ. We show that for $\theta = \hat{\theta}$ we have $U_N^T > U_N^C$, therefore it must be that $\hat{\theta} < \theta_N$.

For agents with type $\theta \in [\hat{\theta}, \theta_N]$, although driving is more convenient, they prefer transit because it is cheaper and the utility includes consumption of the numeraire good.

The problem of suburban residents

Residents living in the suburban area are denoted by S, they represent a proportion β of the total population. They have income z_S, they also derive utility from consuming x and incur disutility from traveling from their residence to the CBD either: all the way by car (mode C) or by driving to reach the network and from there ride public transit to the CBD (mode mix CT). They also suffer from aggregate pollution P.

Their utility is

$$U_S^t(x, \underbrace{yh(\theta) + (\overline{y} - y)v^t(\theta)}_{d}, P), \tag{5}$$

and their budget constraint is

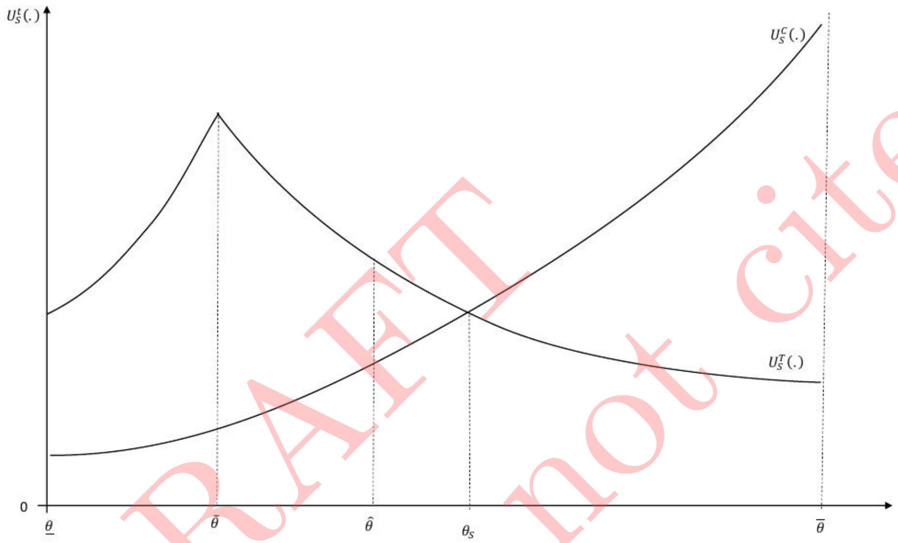
$$z_S = x + \overline{p}_C y + p_t(\overline{y} - y). \tag{6}$$

Their maximization problem is

$$\max_{t \in \{C,T\}} U_S^t(z_S - \overline{p}_C y - p_t(\overline{y} - y), yh(\theta) + (\overline{y} - y)v^t(\theta), P). \tag{7}$$

Agents in S area choose transportation mode by comparing utility derived in each case. If $U_S^C < U_S^T$, then the agent chooses public transit, $t = T$, otherwise she chooses to drive, $t = C$.

We show that $U_S^C(.)$ is increasing w.r.t. θ but U_S^T is not monotonic w.r.t. θ. It first increases and then decreases. We also show that $\tilde{\theta} < \hat{\theta} < \theta_S$.



For $\theta \in [\underline{\theta}, \tilde{\theta}]$, $\partial U_S^T / \partial \theta > 0$ because the slope of $h(.)$ is greater than the slope of $g(.)$ in absolute value, in other words the gain in comfort from driving the car to the urban area over-compensates the loss of comfort from public transit. For $\theta > \tilde{\theta}$, $\partial U_S^T / \partial \theta < 0$.

The problem of non-commuters

The set of residents living in the CBD is denoted by O, they represent a proportion $1 - \alpha - \beta$ of total population. These agents have income z_O and derive utility from consuming a composite good x, they do not incur any transportation cost but suffer from aggregate pollution P.

Their utility is:

$$U_O(x, P), \tag{8}$$

and their budget constraint is,

$$z_O = x. \tag{9}$$

To summarize, the trade offs to consider are depicted in the table below and they consist in two separate problems. The first problem is the decision of urban commuters to either drive or use public transit. The second problem is the decision of suburban residents, the decide if they should drive all the way to work or to drive until they reach the network and then switch to public transit.

Location \Mode	–	*C*		*T*
Residents within network area or CBD	Non commuters	**Downtown drivers**	← *trade-off* →	**Transit riders**
Suburbia residents	–	**All the way drivers**	← *trade-off* →	**Mode mixers**

2.2 Aggregate pollution and aggregate welfare

As stated elsewhere urban (private and public) transportation is a source of pollution. We denote by E_C the level of aggregate emissions from driving and by E_T the level of aggregate emissions from public transit, they are defined as

$$E_C = e_C \left(\alpha \int_{\theta_N}^{\overline{\theta}} (\overline{y} - y) dF_N(\theta) + \beta \int_{\underline{\theta}}^{\overline{\theta}} y dF_S(\theta) + \beta \int_{\theta_S}^{\overline{\theta}} (\overline{y} - y) dF_S(\theta) \right), \tag{10}$$

and

$$E_T = e_T \left(\alpha \int_{\underline{\theta}}^{\theta_N} (\overline{y} - y) dF_N(\theta) + \beta \int_{\underline{\theta}}^{\theta_S} (\overline{y} - y) dF_S(\theta) \right). \tag{11}$$

Aggregate pollution is therefore $P = E_c + E_T$.

Aggregate welfare is defined as

$$W = (1-\alpha-\beta) \int_{\underline{\theta}}^{\overline{\theta}} U_O(.) dF_O(\theta) + \alpha \int_{\underline{\theta}}^{\theta_N} U_N^T(.) dF_N(\theta) + \alpha \int_{\theta_N}^{\overline{\theta}} U_N^C(.) dF_N(\theta) + \beta \int_{\underline{\theta}}^{\theta_S} U_S^T(.) dF_S(\theta) + \beta \int_{\theta_S}^{\overline{\theta}} U_S^C(.) dF_S(\theta). \tag{12}$$

3 Comparative statics

Changes in incomes, prices or distances modify the split between driving and riding public transit for urban and suburban residents, they change the values of θ_N and θ_S in the above expressions of aggregate pollution and aggregate welfare, hence they change the modal split. The critical values θ_N and θ_S are in fact functions of all the parameters in the model and well as the functions g and h.

$$\theta_N \equiv \theta_N \Big(z_N, p_T, p_C, \overline{y}, y, g(.), h(.) \Big) \tag{13}$$

$$\theta_S \equiv \theta_S \Big(z_S, p_T, p_C, \overline{p}_C, \overline{y}, y, g(.), h(.) \Big) \tag{14}$$

In turn θ_N and θ_S as well as other parameters determine the aggregate pollution

$$P \equiv P\Big(\alpha, \beta, e_C, e_T, \overline{y}, y, \theta_N(.), \theta_S(.)\Big) \tag{15}$$

In what follows we examine the sign the derivatives of these functions. However for tractability we assume that utility functions are additive $U = u_1(x) + u_2(d) + u_3(P)$.

3.1 Comparative statics on θ_N and θ_S

We show that in the network area:

$$\frac{d\theta_N}{dz_N} \leq 0 \tag{16}$$

$$\frac{d\theta_N}{dp_T} \leq 0 \tag{17}$$

$$\frac{d\theta_N}{dp_C} \geq 0 \tag{18}$$

$$\frac{d\theta_N}{dg(.)} \leq 0 \tag{19}$$

$$\frac{d\theta_N}{dh(.)} \geq 0 \tag{20}$$

$$\frac{d\theta_N}{d\overline{y}} \geq 0 \tag{21}$$

$$\frac{d\theta_N}{dy} \leq 0 \tag{22}$$

Our preliminary analysis shows that while the effects of the various parameters on θ_N are clear, those on θ_S can be determined only for y sufficiently low.

$$\frac{d\theta_S}{dz_S} \leq 0 \text{ (if } y \text{ suffic. low)} \tag{23}$$
$$\frac{d\theta_S}{dp_T} \leq 0 \text{ (if } y \text{ suffic. low)} \tag{24}$$
$$\frac{d\theta_S}{dp_C} \geq 0 \text{ (if } y \text{ suffic. low)} \tag{25}$$
$$\frac{d\theta_S}{d\overline{p}_C} \geq 0 \text{ (if } y \text{ suffic. low)} \tag{26}$$
$$\frac{d\theta_S}{dg(.)} \leq 0 \text{ (if } y \text{ suffic. low)} \tag{27}$$
$$\frac{d\theta_S}{dh(.)} \geq 0 \text{ (if } y \text{ suffic. low)} \tag{28}$$
$$\frac{d\theta_S}{d\overline{y}} \geq 0 \text{ (if } y \text{ suffic. low)} \tag{29}$$
$$\frac{d\theta_S}{dy} \leq 0 \text{ (if } y \text{ suffic. low)} \tag{30}$$

3.2 Comparative statics on P and W

The comparative statics on P with respect to θ_N and θ_S are straightforward

$$\frac{dP}{d\theta_N} = (e_T - e_C)\alpha(\overline{y} - y) f_N(\theta_N) \leq 0 \tag{31}$$
$$\frac{dP}{d\theta_S} = (e_T - e_C)\alpha(\overline{y} - y) f_S(\theta_S) \leq 0 \tag{32}$$

Which means that if the marginal driver is characterized by a higher θ type, pollution decreases because $e_T - e_C < 0$

For many of the parameters comparative statics of W are not easily derived.

$$\frac{dW}{d\theta_N} \geq 0 \tag{33}$$
$$\frac{dW}{d\theta_S} \geq 0 \tag{34}$$
$$\frac{dW}{dp_T} \leq 0 \tag{35}$$

However, the signs of dW/dP_C, $dW/d\overline{P}_C$, $dW/dz_.$, $dW/d\overline{y}$, $dW/dg(.)$, and $dW/dh(.)$ depend on the balance of gains in utility of consumption and losses of utility due to pollution, and the weights, α and β, of groups of agents: downtowners (CBD), urbans and suburbans.

3.3 Optimal modal split

Recal that social welfare is defined as follows:

$$W = (1-\alpha-\beta)\int_{\underline{\theta}}^{\overline{\theta}} U_O(.)dF_O(\theta)+\alpha\int_{\underline{\theta}}^{\theta_N} U_N^T(.)dF_N(\theta)+\alpha\int_{\theta_N}^{\overline{\theta}} U_N^C(.)dF_N(\theta) + \beta\int_{\underline{\theta}}^{\theta_S} U_S^T(.)dF_S(\theta)+\beta\int_{\theta_S}^{\overline{\theta}} U_S^C(.)dF_S(\theta) \quad (36)$$

Given the continuum of types we have assumed, the search for the socially optimal level of welfare is a little tricky. How can we characterize the planner's problem? Starting from the equilibrium and the indirect utilities, we could proceed by *tâtonnement*, i.e. by marginally changing θ_N and θ_S and look at variations in gains and losses. For example, a marginal increase in θ_N would have the following effects for agents in the neighbourhood. The agents who drive their car at equilibrium would be asked to switch to public transit, that would reduce their spending on transport and increases their consumption but also increases their discomfort so that they would be worse off, and hence social welfare would decrease. But their contribution to aggregate emissions would decrease, therefore social welfare would increase. This move would be desirable for the planner if the gain from decreased pollution were larger than the net loss in individual utility.

Assessing the gains and losses associated to a marginal change in θ_N and θ_S is complicated because these changes on *discontinuous*[6]. Calculating the derivatives of the social welfare function W w.r.t. θ_N and θ_S is not the adequate strategy.

Sticking to a *tâtonnement solution strategy* and to a deterministic approach, but simplifying the model by assuming only two types of agents $\underline{\theta}$ and $\overline{\theta}$, the social planner determines the socially optimal modes mix by comparing several outcomes according to their associated welfare value (W).

$N \setminus S$	$\underline{\theta}\to T, \overline{\theta}\to T$	$\underline{\theta}\to T, \overline{\theta}\to C$	$\underline{\theta}\to C, \overline{\theta}\to T$	$\underline{\theta}\to C, \overline{\theta}\to C$
$\underline{\theta}\to T, \overline{\theta}\to T$	.	.	.	.
$\underline{\theta}\to T, \overline{\theta}\to C$	.	↑ ← **(Decentralized) Equ.** → ↓	.	.
$\underline{\theta}\to C, \overline{\theta}\to T$	.	.	.	.
$\underline{\theta}\to C, \overline{\theta}\to C$	.	.	.	.

[6]We thank the participants to the Environmental Economics seminar of EconomiX, (University Paris-Ouest La Défense) for stressing that this is due to the absence of a probabilistic function defined on the mode choices.

Rows indicate four cases in which the social planner ask urbans (N for "living in the area covered by the network") to change their mode of transportation: in the first row, high and low θ would be asked to use public transit, in row 2, only low θ would be asked to use public transit, etc. Columns represents the four cases for travelres living in the suburbian area. The decentralized equilibrium is represented by the case "$\underline{\theta} \to T$, $\overline{\theta} \to C$" for urbans and by the case "$\underline{\theta} \to T$, $\overline{\theta} \to C$" for suburbans. Starting from this case, an algorithm would have to be constructed to moven around in the table and spot the social optimum.

The model could also be used to analyze second-best optima. Fixing a target for pollution (and not social welfare), we could look at the mix of mode choices leading to this target.

Identifying second-best optima is to be completed by the conference date

4 Conclusion

Preliminary results can be summarized as folloxs. One result that stands out is that the distance, y, to reach the network area for those in the suburbs matters. *Modal switch is easier when y is small, i.e. when the network has a wide reach.* Indeed this infuences their decision to mix modes ($d\theta_S/dy \leq 0$), and the effectiveness of policies and economic instruments to promote more mode switching.

As we showed, these policies can influence the modal split (1) either through prices: toll or parking fee (changing p_C), price of gasoline or price of car use (changing $\overline{p}_C$ and p_C), public transit tariff (changing p_T), or (2) through discomfort: discomfort of car use (suppressing or adding car lanes, changing the flow of traffic: changing $h(\theta)$), discomfort of public transit (higher frequency, punctuality, overall comfort, wifi, services: changing $g(\theta)$).

5 References

1. Anwar, 2016, "Presenting traveler preferences heterogeneity in the context of Agency Theory: Understanding and minimizing the agency problem", Urban, planning and transport research: An open access journal Volume 4, Issue 1,(pp 26-45) 2016: principal-agent model on quality of service

2. Batarce and Ivaldi, 2014, "Urban travel demand model with endogenous congestion", Transportation research A: Policy and Practice, vol. 59, pp 331-345

3. DAEI-SES (Direction des affaires économiques et internationales du ministère de l'Equipement et des Transports), 1998, "La demande de transport : perspective d'évolution à l'horizon 2020, DARI-SES, 72p.

4. Didier and Prud'homme, 2007, "Economie du report modal", ch. VI in *Infrastructures de transport, mobilité et croissance*, report for the Conseil d'Analyse Stratégique, La documentation française

5. Mc Breen (2009), "Agent-based simulations in urban economics: Applications to traffic congestion and housing market", Ph. D. thesis

6. Okushima (2015), "Simulating social influences on sustainable mobility shifts for heterogeneous agents", Transportation, sept. 2015, vol. 42, issue 5, pp 827-855

7. Oum and Waters, 2000, "Transport Demand elasticities", ch. 12 in *Handbook of Transport Modelling*, Eds. Hensher and button, pp 197-210