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POLICY PACKAGES FOR MODAL SHIFT AND CO_2 REDUCTION IN LILLE, FRANCE

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This paper proposes a second-best approach to cutting CO_2 emissions caused by the urban mobility of passengers. We develop policy scenarios that compare the first-best tool of carbon tax, to a combination of second-best tools, not originally aimed at reducing CO_2 (i.e. congestion charging, parking charges, and public transport services). We study their efficiency in attaining a CO_2 target, through a change in the modal split. In our model, modal choices depend on individual characteristics, journey features (including the effects of policy tools), and land use at origin and destination zones. Personal "CO_2 emissions budgets" resulting from the journeys observed in the metropolitan area of Lille (France) in 2006 are calculated and compared to the situation related to the different policy scenarios. We find that an increase of 50% in parking charges combined with a cordon toll of €1.20 and a 10% travel time decrease in public transport services (made after recycling toll-revenues) is the winning scenario. The combined effects of all the policy scenarios are superior to their separate effects.

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HIGHLIGHTS

- This paper proposes a second-best approach to cutting CO_2 emissions caused by urban mobility.

- Beyond CO_2 savings, we explore the induced modal shifts and the user costs of a series of policy scenarios.

- Using a nested logit model for Lille (France), we find that an increase of 50% in parking charges combined with a cordon toll of €1.20 and a 10% improvement in journey times (based on the revenue from tolls) is the winning scenario.

- Combining the tools is more efficient than implementing them separately.

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INTRODUCTION

Uncertainty about the damage caused by climate change is related to three dimensions. From a spatial perspective, the generation of CO_2 emissions and the impacts of climate change do not necessarily occur in the same place or within the same time horizon; the next generation may be more affected than the present one. Also, the magnitude of events (temperature variations, hurricanes, flooding, etc.) remains largely unknown. This makes the CO_2 externality difficult to evaluate. However, in the EU-27, transport activities represented more than a third of overall CO_2 emissions in 2009 (European Commission, 2012), with an increasing trend since 1990 (EEA, 2012).

Europe has established far-reaching goals in relation to reducing the risk of climate change, and has identified a potential CO_2 reduction of 60% related to transport. In France, transport accounted for almost 40% of national CO_2 emissions in 2009, and road transport accounted for 80% of this total (European Commission, 2012). The French Grenelle I Act (MEDDTL, 2011) has set the binding target of a 20% reduction in CO_2 emissions from transport activities by 2020, i.e. to return to the level in 1990.

In this paper, we propose a second-best approach to cutting CO_2 emissions from the urban mobility of passengers. The originality of this work is that it considers the link between urban transport policies and climate policies. We analyze travel demand applying a mode choice model to the metropolitan territory of Lille in the North of France. The modal choices are based on the characteristics of individuals and journeys, and land usage in the origin and destination zones, based on household travel survey data for 2006. We reconstruct CO_2 emissions for each trip following the European methodology COPert 3. We test several transport policy instruments often used at urban level such as congestion charging, parking charges, and reduced public transport travel times. We complement these instruments with a national carbon tax. We then develop policy scenarios to increase the share of low carbon modes in the modal structure. We look for the combination of instruments that leads to the highest CO_2 emissions reductions. Beyond CO_2 reductions, we also consider the induced modal shifts and the user costs involved in each scenario.

Section 1 reviews the literature on the role of second-best tools for reducing CO_2 emissions from passenger transport in urban areas, through a change in modal split. Section 2 presents the methodology. Section 3 presents the study context and describes the data. Section 4 presents the estimations and simulation results. Section 5 concludes by highlighting the practical relevance of this work and providing some recommendations for policy-makers.

1. Literature review

1.1. The urban mobility context for climate action and the second-best environment

Most of the distances travelled (60%) are within an 80km perimeter of the individual's residence (CGDD, 2010), which is in line with global demographic and urbanization trends and climate change effects (Crozet and Lopez-Ruiz, 2012). Thus, urban road mobility offers the greatest opportunities for cutting CO_2 emissions from transport. More precisely, and comparing French cities with other world cities, urban transport represents between 10% and 30% of urban CO_2 emissions depending on the level of demand for travel, transport supply, technologies, urban form, economic activity, industrial structure, and other characteristics (World Bank, 2009). Developing country cities are characterized by a high demand for transport and overreliance on inefficient transport systems. The share can be as high as 50%, for example in Mexico City, while in Beijing and Shanghai, carbon emissions from transport represent less than 10%, and other pollutants are more significant. In developed country cities, urban CO_2 emissions from transport activities are decreasing, in line with travel demands that have reached almost saturation point, and better performing transport systems. In cities such as London or New York, the share of transport in urban emissions is around 20%.

Since most of the challenges associated with transition to low carbon mobility are concentrated in cities, we develop an urban level analysis.

From the perspective of the local decision-maker, it is important to comment on the second-best environment. According to the theory proposed by Lipsey and Lancaster (1956), the rules underpinning a first-best equilibrium, e.g. reaching global agreement on actions to mitigate climate change, lose their optimality in practice, because of the transaction costs involved in such coordinated actions. If we apply this to the management of urban mobility, the introduction of climate related actions on this scale results in a ‘second-best’ setting due to pre-existing factor taxes (Goulder et al., 1998), the difficulty to capture individual passenger’s journey preferences for climate protection, the shortcomings of public economics to account for and monetize reductions in CO_2 emissions following the implementation of a policy, the presence of interacting externalities (local air pollution, congestion, safety, noise, etc.). Since such constraints on transport policy choice prevent the optimal allocation of a ‘CO_2 charge’ according to the Pigovian *polluter-pays-principle*, one instrument does not suffice (the ‘first-best instrument’ here being a fuel tax) and a mix of several complementary tools is needed (Santos et al., 2010a; 2010b). In particular, a combination of ‘push’ measures (disincentives) and ‘pull’ tools (incentives that increase travelers’ freedom of choice) is known to reinforce the success of policy implementation (Ison and Rye 2003; Schuitema et al. 2011).

1.2. The influence of economic instruments on travel demand

To analyze travel demand we consider a mode choice model. Modal shift is recognized as one of the most efficient levers for reducing CO_2, and mode choice is one of the most important steps in transport-related choices.

According to Schipper et al.’s (2000) Activity–Structure–Intensity–Fuel (ASIF) equation, mode choice seems to be preferred means of reducing CO_2, with the most room for policy action. Modal shift and car sharing policies to try to limit the number of journeys, are generally among the top priorities in the urban mobility plans of French agglomerations (Didier and Prud’homme, 2007; see Madre et al. (2010) for an analysis of the influence of the loading factor on CO_2 emissions).

Also, mode transfer can be implemented in the short term unlike reductions in the carbon content of fuel, or energy efficiency improvements to vehicles, for instance, which require specific market conditions and policies (e.g. regulations for on biofuels, CO_2 emissions performance standards for new vehicles, etc.) and interactions among the industry actors.

According to the sequences in Ortuzar and Willumsen's (2011) *Four stage model*, which includes choice of journey origin, journey destination, travel mode, and route,[1] all the steps are in continuous dynamic interaction. Mode choice is considered a structuring component of these steps, and has been studied in depth in the literature.

The policy levels have different impacts on those stages; however, some integrated models allow all these effects to be evaluated simultaneously (see e.g. Hensher's (2008) TRESIS model and the effects of policy instruments on location choice, fleet size and commuting mode choice).

Three main determinants of mode choice can be identified: the built environment, the socio-demographic characteristics of individuals, and the influence of policy tools.

Land use factors affect mode choice and can reinforce or weaken the welfare gains from the adoption of (a combination of) policy-tools. Thus, information on the attraction of destination zones is relevant since mode choices and destination choices are often interrelated (see Timmermans (1996) for shopping trips). Similarly, activity scheduling and tour formation patterns also have an impact on mode choice. Note that the mode choice model we develop later, excludes the influence of trip chaining on mode choice.

Correspondingly, including household characteristics structurally modifies the travel mode choice. For example, the empirical results in Commins et al. (2012) show that age is a significant predictor of commuter mode choice (in Dublin, the 15–24 year age group are the most likely to use public transport and soft transport modes to get to work), as also are gender (being female decreases the probability of walking), marital status, number of children, and education level (those with higher education tend to use cars more despite their generally better awareness of the environmental effect of their transport choices, their greater likelihood of an accessible transport network and thus are more likely to use soft modes and public transit). Finally, Jara-Diaz (1998) incorporates the income variable in the mode utility functions by dividing travel and parking costs by the rate of transport expenditure in household income.

Increasing the costs of car travel by imposing parking charging seems to be effective (e.g. Kaufmann and Guidez, 1996; Su and Zhou, 2012), since availability and cost of parking seem to be the main reason for switching from private car to public transport, followed by personal car availability, public transport fares and frequency improvement policies (Hensher, 2007). Charging drivers to enter a specified geographical zone (congestion charging) is also a useful

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[1] Note that the two stages of choice of journey origin and choice of journey destination affect the vehicle ownership choice, and land usage in the long term. In the short term, the route choice also potentially changes, e.g. choice of departure time.

instrument to deter car use and encourage less carbon emitting transport modes. Estimates from a charging trial in Stockholm (Eliasson, 2009) show that journeys to work by car which involved driving in the congestion charge area, reduced by nearly a quarter, most of whom moved to public transit, with the remainder reducing the frequency of their journeys or combining trip purposes and increasing trip chaining. In some cases, the imposition of a congestion charge combined with high parking charges, have resulted in public transport improvements.

Public acceptance of congestion charging is usually lower than acceptance of parking charges (Zatti, 2004).[i] Reducing travel times including waiting for transport, is a 'policy pull' measure that has been shown to have a significant impact on travelers' mode choices (Outwater et al., 2010; Chen and George, 2011).

The literature on the determinants of mode choice and the different responses of travelers allows us to calibrate the utility functions of travel modes and to structure the model.

2. Methodology

To represent modal choice we refer to discrete choice modeling theory (Ben-Akiva and Lerman, 1985). Discrete choice decisions in the context of random utility theory are modeled and estimated using a multinomial logit model (MNL). The MNL has been widely used for both urban and intercity mode choice models due primarily to its simple mathematical form, ease of estimation and interpretation, and the ability to add or remove choice alternatives. However, the MNL model has also been criticized, notably for its Independence of Irrelevant Alternatives (IIA) property. Hence, we use the nested MNL or NL, (McFadden, 1974; 1981), which has also been applied to the study of transportation mode choice (see Thobani (1984) and Train (1980) for mode choice modeling in Karachi and San Francisco).

To analyze what drives travelers' mode choices, and to test the mix of policy-tools presented below to achieve CO_2 targets, we employ a disaggregated mode choice model that incorporates four alternatives: car driver (CD), car passenger (CP) car accompaniment (e.g. CD and CP) and car-pooling, public transport (PT) including metro, tram, bus, and walking (W).

Following e.g. Bekhor and Shiftan (2009) and Su and Zhou (2011), we test several structures of the NL. The first diagram on the left side of Figure 1, highlights the carbon footprint of the various transport modes. The second diagram (right side of Figure 1) emphasizes the motorized (except for walking) alternatives. The equations in box 1 emphasize the indirect utility functions of the four alternatives – car driver (*CD*), Car passenger (*CP*), public transport (*PT*) and walk (*W*) – include an observable part, *V*, with mode-specific attributes (e.g. generalized times and costs), traveler specific characteristics (e.g. age, gender, residence, earnings, etc.) and zones descriptions (land occupation), and an error term, ε. The probability of choosing one of the nested alternatives in both cases can be obtained by multiplying the conditional choice probability of the relevant nested alternative by the marginal probability of the nest.

Assuming the tree of probabilistic choices selected above, and having estimated the modal choices at the individual level, we use the complete aggregation method (Ortuzar and Willumsen, 2011) to obtain predictions at the sample level. We calculate the aggregate CO_2 emissions resulting from the modal structure of reference. In the simulation phase, the alternative-specific attributes are modified in the utility functions, as an effect of the policy scenarios. This leads to a new modal structure and to a change in the overall level of CO_2 emissions. Simulation outputs are then compared to the baseline situation.

3. Data

3.1. Presentation of the study area

We illustrate our theoretical framework using a concrete case study in Lille agglomeration[ii] which includes 85 districts distributed across an area of 611.45 km^2, two urban poles (Lille and Roubaix-Tourcoing), and a total population of 1,107,861 in 2006. The area is interest is characterized by a share of diesel vehicles lower than the national average (due to the slower pace of vehicle fleet renewal, and therefore delayed introduction of diesel cars), but which has increased significantly over the last two decades (see e.g. Hivert, 2013).

In relation to transport supply, the public transport system in Lille is operated jointly by the local public authority and a private operator. This intermediate situation (competitive tendering model) between public monopoly and full deregulation can be found in London, and in certain Swedish and Danish cities, and contrasts with most other European cities, where public transport is mostly under the control of the local transport public authority (Fiorio et al., 2013). Note that the first urban mobility plan of Lille Métropole published in 2000 emphasized the need for a mode shift (promotion of alternative modes to car, and strengthening of public transport supply), among other environmental and social policy targets (LMCU, 2000).

3.2. Data collection

The Household Travel Survey (HTS) carried out in 2006 provides information on the 36,244 week day (Monday to Friday) trips in this urban area, related to a representative sample of 8,990 inhabitants. It provides detailed information on the journey purpose, the mode used, the places of origin and destination, and the departure and arrival times of the journeys made by the respondents on the day preceding the survey. After removing irrelevant data (such as external, intra-zone, bicycle travel which was too marginal, and return trips for the sake of simplicity), our dataset is composed of 15,071 journeys to and from the 1,041 zones in the territory (administrative boundaries applied in the survey).

Addresses and numbers of parking places, parking charges, and maximum parting times in 2006, were provided by the Lille Parking Observatory and were geocoded into the different HTS zones. To represent land use occupation, metadata from the SIGALE® base were projected from IRIS level[iii] to our level of investigation (HTS zones), assuming a homogeneous intra-zone distribution of the items (schools and universities, sports equipment, dense urban areas, collective housing, rural housing, shops, and industry). We obtained the

CO_2 diagnostic of the journeys using the 'Environment-Energy Budget of the Trips' (EEBT; Gallez et al., 1997). This tool calculates energy consumption, CO_2 emissions, and local pollutants from the daily trips of the residents in the focal urban community. The EEBT provides the best estimate of the CO_2 emissions from the journeys covered by the HTS, according to time of day, weather conditions, length, average speed, transport mode used, and energy consumption. Emissions factors are provided by the MEET European methodology and the COPert3 model (INRETS et al., 1999; EEA, 2000).

3.3. Descriptive statistics

We provide summary statistics for the variables related to the trips, the individuals' socio-demographics, and the zonal description, used in the utility functions of travel alternatives.

Table 1 shows that car use dominates (accounting for almost two-thirds of journeys) in 2006, followed by walking (close to one-third) and public transit (10%). The journeys are distributed equally among recreational purposes, work, and shopping, with the 7% for school attendance relevant to accompaniment. The greenhouse gas (GHG) emissions profile for the trips in 2006 is depicted in Figure 2 and reveals the effect of urban sprawl and the fact that emissions are concentrated mostly on the fringes of the urban community (i.e. outside of the two main poles of Lille-Villeneuve d'Ascq and Roubaix-Tourcoing).

With the exception of income distribution, the socio-demographic structure in our sample more or less replicates the national orders of magnitude reported in table 2. Indeed, 22% of the population earned less than €10,000 per year in 2006, a percentage that is above the national average of 8%. Note that this may affect the acceptability of the transport pricing measures presented later. Since 2000, diesel vehicles have accounted for two-thirds of the car fleet. This is an interesting result since the carbon tax we simulate weighs mostly on diesel fuel consumption. Environmental awareness is quite high, with 94% of the population considering the environmental situation an important lifestyle criterion (6% do not) and only a third claiming that a car is necessary in town (66% disagree).

Figure 3 shows that the studied territory is 33% residential and 18.5% dense urban zones.

4 RESULTS

This section presents the results of the estimations and simulations. Biogeme software (Bierlaire, 2003) was used for the model estimation. Biosim was used for the scenario simulations.

4.1. Estimation results

Table 3a shows that the significance of the inclusive values justifies the estimation of a NL rather than a MNL. Inclusive values in both nested structures - NL1 'high carbon/low-carbon' and NL2 'motorized/non-motorized' - are between zero and one and are statistically significant, with high predictive power (about 83%). However, although the significance tests and goodness of fit are relatively close for both nested model structures, we retain the NL1 structure. This representation better describes our focal policy target – i.e. orienting urban mobility choices towards low-carbon transport alternatives, and in particular, public transport, rather than only non-motorized modes (NL2).

Estimation results using the NL1 structure are presented in table 3b, and confirm the findings in the literature. Travel cost and time negatively and significantly affect all transport mode demands. Parking constraints, by increasing the time to find a parking place at destination, significantly increase the probability to opt to walk or to use public transport. Recreational trips tend to involve walking rather than car use which applies also to journeys to school (probably because the individual involved is too young to have a driving license).

In relation to socioeconomic characteristics, age influences pedestrian journeys (probably due to different physical conditions) but is not significant for other journey modes. Being a male is highly correlated with car driving. Being a student (low rates of driving license ownership and available revenue) increases the probability of public transport and walking. Blue collar workers tend to be more car dependent and to live at a distance from the city center where housing is less expensive, than socio-professional categories (SPC). The low significance and the negative sign of the ‘income’ coefficients for private car use (as a driver) for the class “annual income of €40,000 to 60,000” may point to better public transport system performance in urban areas (and/or higher congestion) and more subtle environmental preferences among those categories, leading to reduced car use in line with higher purchasing power. Couples without children are less in favor of using a car while the parents of one or two children consider it a priority.

Dense urban areas seem to have a positive and significant effect on choice of transit mode, and decrease the probability of using the car.

4.2. Simulation results

Based on the model in the previous section, we define the scenarios, and gradually introduce the combinations of instruments in order to determine which enables the highest CO_2 reductions.

4.2.1. Scenarios

A *local* and *sectoral* CO_2 emissions reduction target of 2% is assumed for the year 2006. The following scenarios are evaluated in relation to their impacts on residents’ mode shift and the user costs involved.

According to the ongoing French policy project (de Perthuis, 2013) and assuming average energy consumption of vehicles in urban areas of 8liters/100km, the per-kilometer carbon tax assumed for Lille equals 1.6 €cents/liter of diesel fuel, i.e. increases by 0.13€cents/km in 2006. We proceed in the same way to estimate gasoline taxation, based on a value of 0.04€cents/km. The row ‘Carbon tax’ in table 4 presents these amounts.

The simultaneous simulation of second-best tools is based on the following hypotheses.

Parking fees are gradually increased by 10% ('Parking charge10'; see table 4) and 50% ('Parking charge50'; see table 4) within the urban center. Parking charges differ depending on the zone, and more expensive in the city center; a quarter of all journeys are within the Lille agglomeration. Non-resident on- and off-street parking places are taxed uniformly in order to avoid extending the length of a journey in the search for cheaper parking. Residential parking (and park-and-ride facilities) benefits from attractive pricing to encourage car drop-off and use of low-carbon modes.

Following the recommendations in Tignon et al. (2008), the cordon toll (referred to as 'Cordon1' in table 4) is set at €1.20 per passages at the edge of the city. For the sake of simplicity, the lump sum cordon toll is expressed here as a daily average fee. However, in practice, the scheme could differ from day to day and hour to hour to reflect the marginal cost of the congestion.

We assume that the revenue from the previous two schemes (parking charges and congestion charges) are redirected to transit system improvements. In practice, the reduction in public transport travel time (assumed to be 10% on average) might come from higher on-time reliability, greater frequency, and increased number of bus lanes or reserved lanes. The designation 'Transit time90' in table 4 shows in-vehicle travel times improvements of 10%.

Several intensities of the scenarios presented above were tested in order to introduce scaling effects in the analysis. However, those where a high probability of public rejection was expected, such as doubling of the parking charges or implementation of a €2.40 congestion charge, are not shown.

The column 'Change in travel costs' in table 4 represents the rate of growth of the cost of traveling by private car and by public transport according to the simulations of the measures. It is expressed as percentage changes between the baseline situation (before) and the cases with different measure(s) simulated (after), resulting both from the number of travelers paying more for car use because of the policy, and higher use of public transport (higher share of travelers who will buy PT tickets), to different extents depending of the scenario considered.

4.2.2. Stand-alone instruments

'Carbon tax only' is the most effective scenario for reducing CO_2 emissions, with 1.94% of CO_2 savings. 'Cordon1' is ranked next and reduces CO_2 emissions by 1.06%. However, the effectiveness of the instruments must be related to the scope of their effect: the carbon tax, by definition, covers the entirety of the sampled trips, while the congestion charge affects only 16% of them. 'Transit time90' and 'Parking charge50' are the least effective, with 0.10% of CO_2 emissions reduction. Again, their effectiveness differs, with only 24% of trips covered in by latter scenario.

4.2.3. Pairing second-best instruments

The pairing ‘Parking charge50 & Cordon1’ leads to the best result in terms of $CO_{2,}$ with 1.92% CO_2 emissions reduction, which is close to the result obtained by the carbon tax only. However, the pairing of these tools is the most efficient scenario, with a user cost increase that is nearly half (8.24%) that for the ‘Carbon tax only’ scenario (15.84%).

The simulation results in table 4 also show the synergy effects of combining instruments. If implemented separately (i.e. at different periods of time) ‘Parking charge10’ and ‘Cordon1’ would lead to 1.16% of CO_2 emissions reduction (obtained by adding the italicized number in table 4 (-1.06) and (-0.10)), leading to -1.21% of CO_2 emissions reduction, which creates a synergy effect of 0.05 points when they are put in place simultaneously.

The same applies to the subsequent stand-alone/combination cases, with synergy effects of respectively 0.04 points for ‘Transit time90 & Cordon1’, 0.03 points for ‘Parking charge50& Cordon1’, 0.04 points for ‘Transit time90 & Parking charge10’, and 0.02 points for ‘Transit time90 & Parking charge50’. Note that the non-linear effects of the stage simulations are visible not only at the CO_2 emissions outcomes stage but also at the modal transfer stage. Figure 4 depicts these respective effects, in each case combining urban toll and PT travel time savings.

4.2.4. All second-best instruments

We add PT travel time savings to the wining pair of instruments ‘Parking charge50 & Cordon1’ because this combination of second best tools is the most acceptable. In the previous pairing, the pricing levers are set to their maximum. Thus, additional CO_2 emissions reduction can be obtained only through the implementation of ‘policy pull’ measures such as increasing the attractiveness of public transport.

The combination ‘Parking charge50&Cordon1&Transit time90’ (in bold in table 4) seems to be the most efficient situation. It leads to the highest CO_2 emissions savings (2.37%), and is also the most acceptable solution (user cost increase of 7.39%) as long as the transit improvement costs are not passed on through ticket prices but are financed by the congestion charge revenues. In addition, the wining package ‘Parking charge50&Cordon1&Transit time90’ provides the greatest transformation to the modal structure compared to the ‘Carbon tax only’ scenario. This applies particularly to walking (+2.62% in the former scenario versus +1.26% in the latter) and public transport modes (+19.52% versus +14.21%). The difference is less marked for modal shift of car drivers (with respectively -8.66% versus -6.43% for car-passengers; and -1.91% versus -1.06% for car drivers).

5. Conclusions

This paper highlights the use of second-best policy tools, i.e. instruments not originally designed to reduce CO_2 emissions caused by urban mobility but which may contribute to this goal as a side-effect, sometimes at least cost to society. This gives a practical relevance to our results, since a second-best environment often prevails over the ‘academic ideal case’ in the case of urban areas (large presence of interacting and cross-sectoral externalities), and since bottom-up policy levers are easier to implement from the perspectives of the local policymaker, compared to imposition of a national carbon tax for instance. This research should help local practitioners to follow up on the outcomes of urban mobility plans.

We use a nested logit model to simulate the impact of a set of policy tools on CO_2 emissions in the Lille agglomeration, through a change in modal structure. The simulated instruments were selected according to the local authority's political agenda. We find that an increase of 50% in parking charges combined with congestion charge of €1.20 and a 10% improvement in public transport travel times (made after collecting and redistributing toll-revenues) provides better results in terms of CO_2 emissions reduction and modal shift than a stand-alone carbon tax on fuels (i.e. a tax increase of 0.13€cents/km for diesel and of 0.04€cents/km for gasoline). We showed the presence of synergy effects among policy tools and build on the literature on which policy instrument to implement and how to combine them.

Discussing the results in more detail, and particularly the observed changes in modal structure (more modified in the wining scenario), we would suggest that improved air quality could be obtained from a combination of second-best instruments compared to the implementation only of a carbon tax. The inclusion of these local externalities in the model is work in progress.

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List of tables

Table 1 Summary statistics of trip specific variables (purposes and modal split)

Variables	Frequency	%
Purposes		
School	1,035.37	6.87
Work	2,042.12	13.55
Shopping	1,754.26	11.64
Recreational	2,114.46	14.03
Home	5,921.39	39.29
Other	2,203.38	14.62
Modal split		
Car (driver)	7,209.97	47.84
Car (passenger)	2,195.84	14.57
Public Transport	1,540.26	10.22
Walk	4,124.93	27.37
Total	15,071	100.00

Table 2 Summary statistics of socioeconomic variables

Variables	Frequency	%
Gender balance		
Male	7,098.44	47.10
Female	7,972.56	52.90
Occupation		
Craftsmen	2,63.742	1.75
Inactive	565.16	3.75
Scholars	2,910.21	19.31
White collars	3,758.71	24.94
Students	1,425.72	9.46
Blue collars	2,235.03	14.83
Intermediate prof.	2,219.96	14.73
Liberal prof.	1,657.81	11.00
Income class		
I < to 10,000 p.a.	3,354.81	22.26
10,000 < I < 20,000 p.a.	4777.06	31.70
20,000 < I < 30,000 p.a.	3215.91	21.34
30,000 < I < 40,000 p.a.	1926.53	12.78
40,000 < I < 60,000 p.a.	1225.97	8.13
I > 60,000 p.a.	570.71	3.79
Household composition		
Single person	3,571.82	23.70
Couple without children	2,868.01	19.03
Couple with 1 or 2 children	4,828.75	32.04
Large family	2,143.10	14.22
Lone parents with 1 or 2 children	1,264.46	8.39
Lone parents > 2 children	394.86	2.62
Age (mean)	37	
Total	15,071	100.00

Table 3 Estimation results

a) Measurements of fit of the MNL and NL models

Choice model structures	MNL	NL1 ‘high/low-carbon’	NL2 ‘motorized/non-motorized’
Number of parameters	84	85	85
Final log-likelihood	-6,995.75	-6,922.43	-6,914.76
Likelihood ratio test	13,981.78	14,127.41	14,142.76
Logsum parameter value		0.52 (14.57)***	0.49 (14.01) ***
Smallest singular value of the hessian	2.53	1.91	2.83
Adjusted Rho-square of McFadden	0.49	0.50	0.50
Rate of correct predictions		83.30%	83.40%
Number of observations	15,071	15,071	15,071

*indicates a significance at 10%, **, at 5% and ***, at 1%.

Table 3 Estimation results

b) Summary of the estimation results for NL1 'high-carbon/low-carbon'

	Walk	Public transit	Car driver	Car-passenger
Variables	Coefficient	Coefficient	Coefficient	Coefficient
Alternative attributes *Reference: other purpose*				
Travel cost		-0.52 (-7.30)***	-0.52 (-7.30)***	-0.52 (-7.30)***
Travel time	-0.02 (-38.03)***	-0.04 (-8.99)***	-0.04 (-8.93)***	-0.04 (-8.93)***
Parking time	0.62 (7.44)***	0.59 (6.02)***		
School purpose	0.63 (4.67) ***	0.99 (6.21)***	-0.76 (-5.30)***	
Work purpose	0.19 (1.49)	00.83 (5.66)***	0.00 (0.05)	
Commercial purpose	0.10 (0.90)	-0.08 (-0.45)	-0.33 (-4.32)***	
Recreational purpose	0.69 (6.64)***	-0.20 (-1.39)	-0.56 (-7.93)***	
Socio-demographic characteristics *References: craftsmen, scholars, annual income inferior to 10,000 and couples without children)*				
Age	0.01 (3.38)***	0.00 (0.05)	-0.00 (-0.77)	
Male	0.11 (1.39)	0.05 (0.50)	0.54 (9.64) ***	
Employers	0.18 (1.47)	-0.30 (-1.93)*	0.34 (4.26)***	
Students	0.55 (3.43) ***	0.65 (4.27) ***	0.05 (0.46)	
Inter. Prof.	0.17 (1.15)	-0.37 (-1.98)**	0.48 (5.19)***	
Managers	0.37 (2.34)**	-0.41 (-2.04)**	0.35 (3.77)***	
Blue collars	-0.07 (-0.50)	-0.20 (-1.07)	0.42 (4.35)***	
Income class 10-20 000 p.a.	0.23 (2.54)**	0.17 (1.52)	-0.09 (-1.51)	
Income class 20-30 000 p.a.	-0.09 (-0.84)	0.017 (0.13)	0.11 (1.65)*	
Income class 30-40 000 p.a.	-0.19 (-1.54)	0.06 (0.44)	-0.15 (-2.12)**	
Income class 40-60 000 p.a.	-0.47 (-3.07)***	-0.65 (-3.27)***	-0.13 (-1.57)	
Income class sup. to 60 000 p.a.	-0.44 (-2.21)**	-0.34 (-1.30)	0.11 (0.90)	
Couple without children	-0.07 (-0.57)	0.01 (0.09)	-0.43 (-5.98)***	
Couple with 1 or 2 children	-0.11 (-0.98)	-0.18 (-1.32)	-0.19 (-2.66)***	
Large family	0.16 (1.17)	0.19 (1.23)	-0.25 (-2.89)***	
Lone parents with 1 or 2 children	-0.04 (-0.23)	0.07 (0.42)	0.09 (0.89)	
Lone parents with more than 2 children	-0.29 (-1.31)	-0.14 (-0.53)	-0.17 (-0.96)	
Zones features *References: residential areas and population density*				
Commercial area	-0.80 (-4.60)***	0.02 (0.12)	-0.29 (-3.54)***	
Industrial zone	-0.018 (-0.06)	0.16 (0.45)	-0.07 (-0.39)	
Schol./university	0.66 (1.68)*	1.22 (3.56)***	0.37 (1.45)	
Dense urban area	0.17 (1.17)	0.49 (3.14)***	-0.32 (-4.11)***	
Constant	1.26 (6.35) ***	-0.96 (-6.03) ***	1.10 (8.57) ***	

*indicates a significance at 10%, ** at 5% and *** at 1%.

Table 4 Simulation results

Scenarios simulation	Change in travel costs (%)	Change in CO_2 em. (%)	Effect on modal shares (%)			
			Walk	PT	Car driver	Car pass.
Stand-alone tools						
Carbon tax	**15.84**	**-1.94**	**1.26**	14.21	-1.06	-6.43
Parking charge10	0.52	*-0.10*	0.42	0.50	-0.19	-0.37
Parking charge50	2.30	-0.58	1.70	4.50	-0.77	-3.03
Cordon1	6.81	*-1.06*	1.01	9.21	-0.70	-4.57
Transit time90	-0.19	-0.10	-0.02	1.40	-0.04	-0.62
Paired tools						
Parking charge10& Cordon1	7.21	*-1.21*	1.43	10.01	-0.93	-4.95
Parking charge50& Cordon1	**8.24**	**-1.92**	2.64	16.02	-1.69	-7.73
Transit time90& Cordon1	6.33	-1.36	0.99	11.71	-0.83	-5.38
Transit time90& Parking charge10	0.25	-0.24	0.40	2.10	-0.20	-1.24
Transit time90& Parking charge50	2.03	-0.71	1.70	5.51	-0.80	-3.53
All second-best tools						
Transit time90 & Cordon1 & Parking charge10	6.58	-1.54	1.41	13.11	-1.08	-6.00
Transit time90 & Cordon1 & Parking charge50	**7.39**	**-2.37**	**2.62**	**19.52**	**-1.91**	**-8.66**

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Figure 1 Test of two structural form of the nested model: the high-carbon/low-carbon structure (NL1 on the left) and motorized/non-motorized design (NL2 on the right)

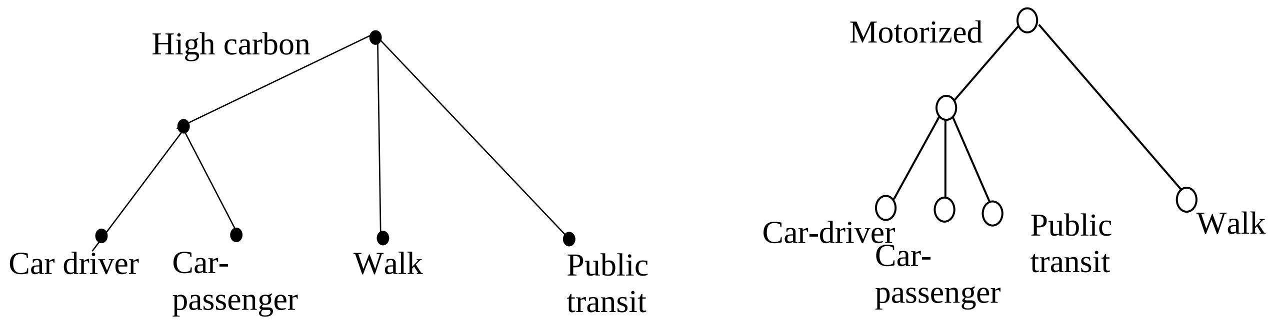
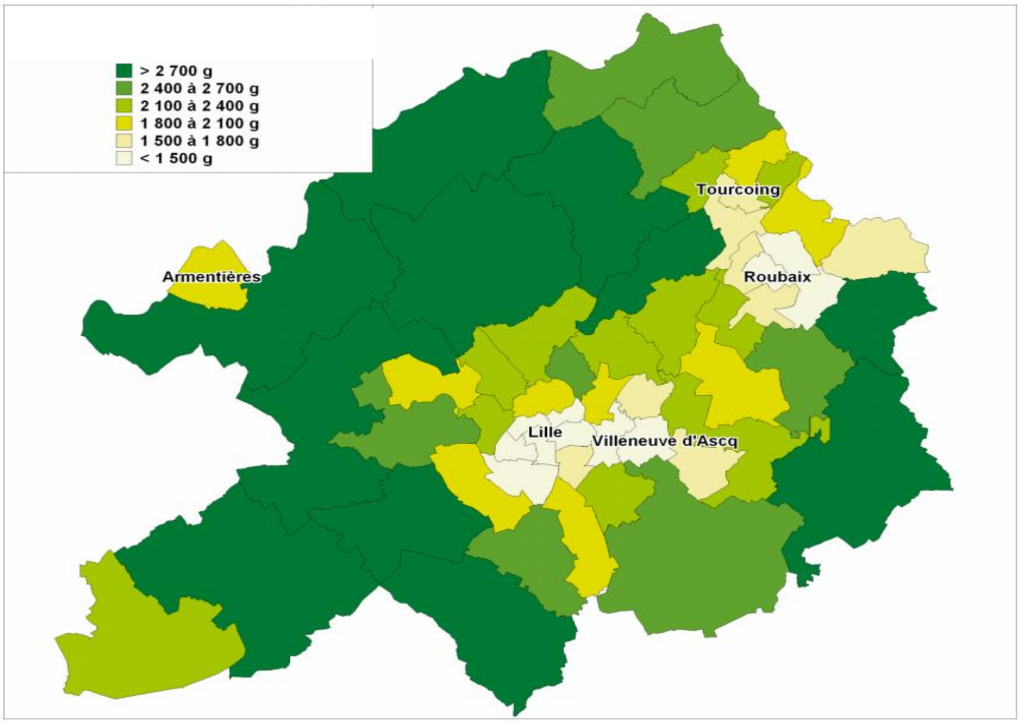
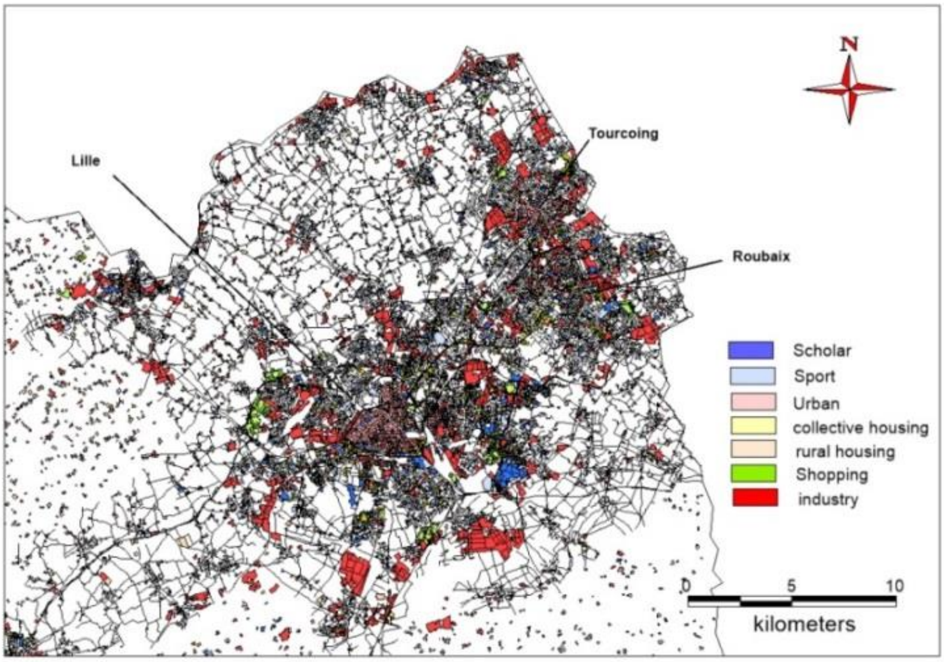


Figure 2 Individual GHG emissions (g) per HTS zones in 2006



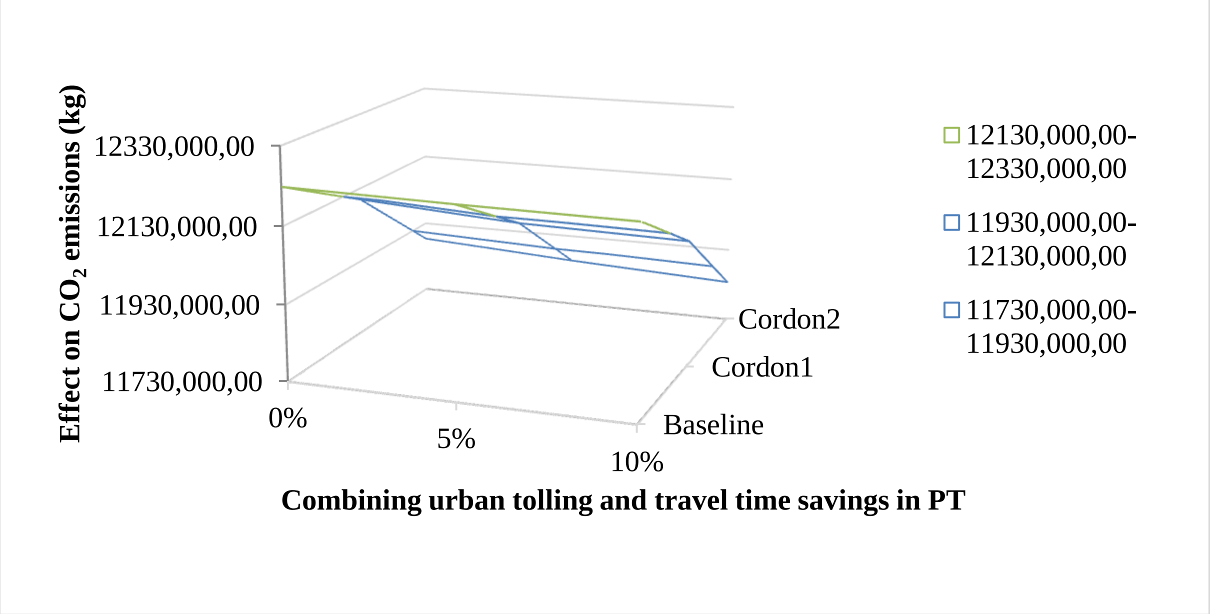
Source: CETE-INRETS estimations from EEBT software (2006)

Figure 3 Land use occupation in the Household Travel Survey zones in 2006



Source: Output from MapInfo Professional®

Figure 4 The non-linear effect on CO_2 emissions (kg) in the LMCU in 2006 when combining urban toll and PT travel times savings measures



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Box 1 Expressions of indirect utility functions and choice probabilities

(a) Equation of indirect utility functions for 'Car driver' (CD), 'Car passenger' (CP), 'Public transport' (PT) and 'Walk' (W):

With:
N_CARBON = nest with the 'High carbon modal alternatives'

U CD = VN_CARBON + VCD + εN_CARBON +εCD;

U CP = VN_CARBON + VCP + εN_CARBON +εCP;

U PT = VPT + εPT;

U W = VW + εW.

(b) Equation of the marginal choice probability:

With:

θ = the logsum parameter, i.e. the degree of substitutability between different alternatives in the same nest (should be comprised between 0 and 1 for the nested structure to be kept);

Γ = the logsum *variable*, i.e. the expected value of the maximum of the car driver and car passenger utilities.

$$P(CD|N\_CARBON) = \frac{exp\left(\frac{VCD}{\theta_{N\_CARBON}}\right)}{exp\left(\frac{VCD}{\theta_{N\_CARBON}}\right)+exp\left(\frac{VCP}{\theta_{N\_CARBON}}\right)} \text{ and } P(CP|N\_CARBON) = \frac{exp\left(\frac{VCP}{\theta_{N\_CARBON}}\right)}{exp\left(\frac{VCD}{\theta_{N\_CARBON}}\right)+exp\left(\frac{VCP}{\theta_{N\_CARBON}}\right)};$$

(c) Equation of the conditional choice probability:

$$P(N\_CARBON) = \frac{exp(V_{N\_CARBON}+\theta_{N\_CARBON}\Gamma_{N\_CARBON})}{exp(V_W)+ exp(V_{PT})+exp(V_{N\_CARBON}+\theta_{N\_CARBON}\Gamma_{N\_CARBON})} ;$$

(d) Equation of the total probability of choosing a nested alternative:

P(CD)=P(CD|N_CARBON)× P(N_CARBON) and P(CP)=P(CP|N_CARBON)× P(N_CARBON).

Footnotes

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[i] In Santos et al. (2010a).

[ii] The city of Lille, in the northern part of France near the Belgian border is the fourth largest city according to the population census of 2006, after Paris, Lyon and Marseille and before Toulouse. Our study area is called ‘Lille Metropole Communauté Urbaine’ (MCU) in French.

[iii] In French, IRIS is the acronym for ‘aggregated units for statistical information’. It has been developed by Insee (the national statistical institute) in order to divide the country into basic units of equal size, known as IRIS2000, 2000 being the target size of residents per unit.

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