IS THERE AN URBAN ENVIRONMENTAL KUZNETS CURVE DUE TO URBAN MOBILITY?


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Abstract

The Environmental Kuznets Curve (EKC) has given rise to a flourishing literature since the beginning of the 90’s. The EKC postulates an inverted U-shaped relationship between income and polluting emissions. Surprisingly, this issue has rarely been applied to the cities. This article aims at testing the Urban EKC (UEKC) hypothesis.

Previous studies on the UEKC hypothesis are very scarce. They suffer from methodological problems that we try to deal with. First, we use polluting emissions per capita instead of pollutants concentrations so as to control for the influence of urban size. Second, we only take in account pollutants due to a unique source, which is daily mobility. This makes the explanation of the income-polluting emissions relation more consistent, as our comments are based on a specific, well constituted literature about factors of daily mobility.

We expose the theoretical mechanisms by which the UEKC due to daily mobility could be validated. The impact of income on polluting emissions is threefold: behavioural, with a direct effect and an indirect one; technical (the environmental efficiency of the vehicles increases); political (planning authorities wish to evolve towards a “sustainable mobility”).

The empirical part of the paper is a test of the UEKC thanks to the Millenium Cities Database edited by the International Association of Public Transport (IAPT). We proceed in two stages. First, we show that the UEKC hypothesis is not robust: the link between individual wealth and polluting emissions is very weak. In the second stage, we test separate thematic models to get a more general explanation of the environmental performance of urban transport systems. We show that urban form, the level of infrastructure supply, and relative cost for different transport modes, play a crucial role in determining environmental performance of cities.

JEL Classification: Q53, Q56, R12, R14, R41

Keywords: Environmental Kuznets Curve, daily mobility, city, sustainability, urban transport
Introduction

In a recent book of M. Polese and R. Shearmur (2005), one can read the following sentence: “[The relationship between] the level of urban pollution [and the real income per capita] is, broadly speaking, bell-shaped” (p. 94). It means that, beyond a given threshold, the increasing relation between economic development and the level of pollution becomes decreasing. This is due to the demand for environmental quality and the regulators’ ability to implement a panel of instruments devoted to the preservation of the ecosystems’ integrity. Ultimately, economic development is “both a foe and a friend of the urban environment”. (Kahn, 2006, p. 30).

These sentences may be the first steps towards an application of the 15 years–old controversy of the Environmental Kuznets Curve (EKC) to urban concerns.

Since the 1992 World Bank Development Report (Banque Mondiale, 1992), environmental economists discuss the idea that the dynamic between the level of GDP per capita and ecological degradations due to pollutants emissions could follow an inverted-U shaped curve (Grossman and Krueger, 1994; Selden and Song, 1994; Holtz-Ekin and Selden, 1995; Common and Stern, 2001; for a survey, see Dinda, 2004). The stake of this dispute is crucial: it gives an estimation of the intensity of the environmental pressure that is imposed to economic systems. If EKC hypothesis appears to be robust, then the perspective of an infinite accumulation of wealth is possible. Such an interpretation of the interrelations between human activities and ecosystems gives optimistic conclusions about the necessary mutations to achieve sustainable development.

EKC dynamics are obtained through the simultaneous and indirect action of three structural effects:

- The **scale effect** relates that, all things being equal, ecological degradations increase with the scale of economic activities. More production means more inputs and more polluting emissions.

- The **composition effect** isolates the consequences of sectoral transformations along the development path. In a first step, when economic structures evolve from an agrarian to an industrial society, polluting emissions increase; in a second step, the decline of heavy, polluting industries and the development of both light industries and services induce a decline of the polluting intensity of GDP.

- The **technological effect** is the most relevant parameter of the EKC dynamic. The scientific and organisational improvements, such as the supply of “green” products, or the implementation of polluting norms, are able to relax the ecological constraint. They drive the curve downward. Indeed, once society is wealthy enough, public regulators can promote green innovations and firms can allocate capital to environmental R&D so that production processes are more efficient.
Then, the existence of an EKC supposes that, beyond a specific GDP per capita threshold, the scale effect is overwhelmed by the other two effects.

In such a dynamic process, the demand side plays a crucial role. Under the assumption that consumer preferences comprises an environmental component, individuals will buy more “green” goods when income increases, and “voice” considerations to preserve ecosystems. As a consequence, firms and regulators will pay more attention to ecological problems. Those types of comportments prompt the green R&D processes and ratify innovations.

Furthermore, public regulation constitutes the key adjustment of these mechanisms. Because of the importance of externalities, the market mechanisms cannot spontaneously lead to a sustainable growth path (Arrow et al., 1995). The role of environmental policies is to encourage the development of “green” innovations and practices, or to implement rules devoted to the respect of ecological concerns.

EKC hypothesis must be considered with precaution, as many authors have criticized it on several points (Meunié, 2004).

First, there is a risk of abusive generalization. The empirical findings show different shapes according to the pollutant considered. Even if such a curve is found for a local pollutant, it doesn’t mean that the general environmental degradation follow the same tendency. For instance, in the case of CO$_2$ emissions, most of the studies don’t find any arguments in favour of the EKC hypothesis (Grimes and Roberts, 1997).

Second, the declining part of the curve may be just a transitory phase. When the econometric specification is flexible enough, the curve often takes an “N” shape (Meunié, 2005). It means that, after a phase of industrial modernization where the relation is downward oriented, the opportunities to further improve ecological efficiency of the production system may weaken. Thus, beyond a second threshold, the scale effect becomes dominant again and the sustainability of wealth accumulation is uncertain.

Third, the dispute about the “pollution havens hypothesis” (PHH) must be carefully analysed. Like the NIMBY concept, it could be possible that the EKC actually result from the ability of richest consumers to spatially remove the environmental consequences of their choices. In wealthy countries, governments implement stricter ecological regulations and, as a consequence, some of the dirtiest industries may locate their production in less environment-friendly countries. If the PHH appears to be significant, then the EKC is relevant at a local level, but it is wrong at a global one (Dinda, 2004).

These considerations impose to be very careful about the relevance of the EKC. Like Baghwati (2004) says, “the only value of these examples [of EKC] is in their refutation of the simplistic notion that pollution will rise with income. They should not be used to argue that growth will automatically take care of pollution regardless of environmental policy”.

Another limit that we try to deal with is the lack of investigation for the EKC into the urban dimension. Authors introduce city concerns simply as a measure of economic
development. Urbanization appears to be a factor (among others) of environmental degradation: “Urbanized, open, high-income and high-energy use economies are clearly associated with a high degree of environmental degradation” (Jha et al. 2004). Now that more than half of the world population lives in cities, such a lack of empirical research appears to be mistaken.

In this paper, we directly test the hypothesis of an inverted-U curve between a specific source of urban pollution (urban mobility) and the level of GRP (Gross Regional Product) per capita. We call such a relation the **Environmental Urban Kuznets Curve (UEKC)**. We consider that an application of the EKC hypothesis to the urban milieu is relevant for two reasons:

- From an empirical point of view, a quick look at some pollutant concentrations in 77 cities around the world (World Bank, 2006) and their level of GRP per capita seems to give some relevance to the UEKC hypothesis. Indeed, Figure 1 suggests that such a two-step relation may exist: from the left to the right, as income per capita decreases, we first have an increasing trend of pollutant concentrations, then a reversal trend.

- From a theoretical point of view, it is easy to extrapolate the EKC mechanisms to the urban functioning (see below).

![Figure 1. Pollutant concentrations and GRP per capita in 77 cities around the world](image)


1. Past studies on the UEKC

Studies on the UEKC hypothesis are extremely scarce for two main reasons. First, the topic is an emerging one in the environmental-urban literature. Second, data on polluting emissions in cities is limited. Some results have nevertheless been obtained by Kahn (1998, 2006), Peters and Murray (2004), and Hank Hilton and Levinson (1998).
In a short article, M. E. Kahn (1998) shows the existence of an UEKC for hydrocarbon emissions in California State. His proof is indirect: the mileage ratio (that is, the distance that each income group has to travel to create same annual hydrocarbon as households of the lower income group) declines, then increases with respect to household income. An extension of this work to the whole United States can be found in M. E. Kahn (2006). The analysis of the hydrocarbon emissions with respect to income class gives “the familiar shape of the EKC” (p. 56, Figure 2).

However, such an indicator only allows to take in account the technological effect, not the travel behaviour. Indeed, this UEKC results from two opposite effects: on one’s hand, high income group households own more recent vehicles, which integrate up-to-date environmental innovation. On the other hand, richer households may own high power vehicle, which supposes higher energy consumption. As a consequence, travel behaviour in itself is banned of his analysis.

Furthermore, there are some doubts on data reliability. The emissions are “predicted”, that is appraised from both an estimated indicator of hydrocarbon emissions per mile per vehicle, and an estimated number of miles driven per household.

![Figure 2. Nationwide EKC Curve for hydrocarbon emissions (2001)](image)

**Source:** Kahn, 2006, p. 56

For L. Peters and F. Murray (2004), the UEKC hypothesis is not valid for a sample of 17 great Asian cities. Instead of a bell-shaped curve, they obtain an “L-shaped” one for five pollutants. Astonishingly, such a result doesn’t lead them to refute the UEKC hypothesis but only to suppose a change in its shape. It would be due to different Air Quality Management measures in some of the cities of the sample: “This paper does not challenge the existence of EKCs for urban air pollution – instead it proposes a radical change in EKC shape in the modern era of environmental regulation in developed and developing countries” (p. 13).

The role of environmental regulation is also underlined by F. G. Hank Hilton and A. Levinson (1998). The empirical analysis of lead emissions due to car use in 48 countries shows the existence of an EKC. They state that polluting emissions originates from both polluting intensity (that is, the quantity of pollution emitted by gasoline litre) and pollution
activity (that is, gasoline consumption *per se*). According to them, the decreasing part of the curve has mainly been due to a reduction of pollution intensity, whereas pollution activity has increased. Such a reduction is imputed to political action, which challenges the hypothesis of a direct influence of income on polluting emissions: “*Some government action such as taxes or bans on leaded gasoline appears to be behind much of the decline in automotive lead pollution. This undermines the claim that income growth is itself a panacea for environmental problems.*” (p. 140).

These studies, whereas they bring some preliminary and interesting results on the UEKC hypothesis, make us unsatisfied for two reasons:

- On a methodological ground, they use *concentrations* of pollutants. Yet, in a comparison of different cities, urban size exerts a mechanical influence on such variables, which doesn’t allow to isolate the impact of income.
- On a heuristic ground, the way results are explained may be weak, because the data they use doesn’t allow these authors to identify the *source* of the pollution: industry, transport, housing…

This paper aims at avoiding these both problems. First, we use polluting emissions *per capita*, to control for urban size, as A. Rupasingha *et al.* (2004) have done for their study of 3029 American counties; second, we focus on an unique source of pollution: daily mobility\(^1\).

The article is organized as follow: first, we give the detailed mechanisms of an UEKC due to daily mobility (for the first time in the literature, as we know). Second, we present data and method. Third, we give our main results, in two stages. The estimation of quadratic regressions gives mixed results about the validity of the UEKC hypothesis. We put forward some explanations, like the crucial role played by public regulation as a mediator between growth dynamics and polluting emissions patterns. Thus we are led, in a second stage, to suggest a more global explanation of the sustainability performance of urban transport systems. By testing several different models, we provide a detailed study of the factors of energy consumption due to daily mobility.

2. **Theoretical mechanisms of an UEKC due to daily mobility**

Polluting emissions arising from daily mobility is mainly due to travel behaviour, that is more precisely:

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\(^1\) Furthermore, this methodological choice allows us to avoid the *displacement problem*, that is the location of polluting industries into poor countries, which explain the declining part of the EKC (Dinda, 2004). In the case of urban daily mobility, it seems difficult to “export” polluting activity to another city.
• Modal choice: differences in pollution are mainly due to differences in car use. The use of non-motorized modes doesn’t pollute, and pollution due to transit is not linked to its use.

• Travel distance and number of travels: gasoline consumption and polluting emissions increases with distances travelled. This is the pollution activity.

• State of the fleet. Old vehicles emit usually more pollution, because they do not incorporate environmental innovations; the difference in power and/or type of motorization also plays a role. This is the pollution intensity.

The UEKC hypothesis supposes an increase in polluting emissions with income, then a decrease from a certain income threshold. As a consequence, we have to consider in a detailed way the influence of income on polluting emissions due to urban mobility, which is threefold:

• **Behavioural**, with a direct effect and an indirect effect.
  
  o The direct effect of income on urban mobility: “people buy more mobility as income rises” (Newman, Kenworthy, Vintila, 1995)

  Income has a positive influence on car ownership as well as on car use (Pouyanne, 2004; Paulo, 2006), as richer individuals are able to pay higher costs of mobility (Froud et al., 2000; Jullien, 2002). According to many authors, rising incomes is the “root cause” of automobile dependence (Gomez-Ibanez, 1991, p. 377). This supposes that mobility is a normal good (its consumption raises with income), whereas some authors consider mobility as an investment to achieve a well-defined goal (Wiel, 2001, pp. 34-35): in this latter case, mobility wouldn’t raise automatically with income.

  o The indirect effect of income on urban mobility: “people buy more space as income rises” (Newman, Kenworthy, Vintila, 1995)

  Higher income allows to afford a detached house, which are more numerous in the peripheral parts of the cities. It helps to build a low-density “car-dependent land use pattern”, as in these areas, car use is “a necessity, not a choice” (Newman and Kenworthy, 1998, p. 31). Nevertheless, some authors have argued that higher income increases location choice, and allows to bring closer home and workplace (Levinson and Kumar, 1994, 1997; Gordon and Richardson, 1997; Gordon et al., 1991): it is the co-location hypothesis (Krizek, 2003).2

• **Technical**.

  The technical influence of income on polluting emissions is ambiguous, as underlined by M. E. Kahn (1998, 2006). On one’s hand, rising income allows to own a more efficient vehicle, which incorporates the last environmental innovations (e.g. hybrid motorization). On the other hand, automobile is an indicator of social position (e.g. Kaufmann, 2003), and high

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2 Such an hypothesis is criticized, in both an empiric way (Cervero and Wu, 1998; Aguilera, 2004) and a theoretical point of view (Newman et al., 1995; Bourne, 1992; Ross and Dunning, 1997).
income may in fact lead to own high-power vehicles, which means a higher energy consumption.

The influence of energy price has also to be taken in account. A raise in energy price may go along with a price effect (a decrease in mobility consumption); it may also be a strong incitation for the automobile industry to develop “green” (energy-saving) products (the so-called “induced technology” hypothesis).

- Political.

The influence of governments on the diffusion of “green” technology can’t be ignored. Environmental regulation can be incentive (see the pastille verte in France, or the Californian Clean Air Act, for example), as well as coercive (see the obligation to provide catalytic converters on new vehicles in Europe). Such measures are easier to implement when national income is high and growing: “a nation is more likely to enact environmental regulation when its economy is growing and income inequality is falling. Under these conditions voters are more likely to agree on policy priorities, and the government has the resources necessary to pursue environmental goals” (Kahn, 2006, p. 39).

An indirect way for governments to influence urban mobility is to implement sustainable cities measures. They can act on transport system through traffic calming initiatives (so as to encourage a shift towards “soft” transport modes), as well as on urban system through the quest of a low transportation energy form, like the Compact City (Jenks et al., 1996) or, more recently, the Coherent City (Korsu and Massot, 2004; Pouyanne, 2005b).

The increase in the quality of the information has an accelerating role in the definition of environmental strategies by the governments. The Great Smog in London (1954), the wreck of the Exxon-Valdez in 1989, etc. have made evolve the legislation. More generally, the profusion of journal articles on environmental subjects, or the growing production of environmental indicators, may develop a kind of “environmental consciousness” in the population, which may influence the government’s decisions.

3. Data and Method

As we have seen in the previous section, the impact of income on polluting emissions due to urban mobility is extremely ambiguous: many effects play contradictory roles, without being able to disentangle them. As a consequence, it is of particular interest to test the hypothesis of UEKC.

Two types of UEKC coexist in the literature, depending on the available data. The first is the “diachronic” one, used with times series: the evolution of polluting emissions is compared with the evolution of income for a given city. The second is the “synchronic” one, used with cross-section data: it links income and polluting emissions for a sample of city (cf. Figure 3)
In this article, we test the hypothesis of a synchronic UEKC for two reasons: first, the availability of data, which is only for the year 1995; second, because a synchronic UEKC allows to control for the influence of time, that is the continuous trend of increase in income. Besides, an examination of the methods used in the literature shows that the synchronic EKC is often tested (e.g. Lucinda and Peters, 2004; Rupasingha et al., 2004).

We use the Millenium Cities Database (MCD), which stems from a collaboration of the IATP (International Association of Public Transport) and the Murdoch University, through two eminent specialists of daily mobility, J. Kenworthy and F. Laube. For 100 of the world’s cities, 66 raw indicators on mobility behaviour, transport supply and cost, etc. are compiled (Vivier and Mezghani, 2006). The data concerns energy consumption and polluting emissions per capita, as well as GDP (Gross Domestic Product of the city, in PPP). The MCD has been criticized on several points (Godard, 2001). First, the urban perimeters which were taken in account cannot be directly compared. The authors of the database have tried to use the national definitions, such as the american MSAs or the french aires urbaines, even if they are not built exactly in the same way. Such a critic is common to most of the international comparisons of cities. Second, it doesn’t exist an “user’s guide”: the way variables were computed is not precisely defined. Third, some indicators are estimated or interpolated, because of the lack of data, but one cannot know which ones are estimated or not. Despite these critics, the MCD is today considered as the most complete and the most reliable database for comparing daily mobility in cities from different parts of the world (e.g. Joly, 2004). Table 1 provides descriptive statistics for the variables we use as dependant ones and for the gdp par capita.

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3 Because of the unavailability of data for some cities, we use here a sample of 88 cities.
Table 1 – Descriptive statistics for polluting emissions and energy consumption

<table>
<thead>
<tr>
<th></th>
<th>World Mean</th>
<th>World Minimum</th>
<th>World Maximum</th>
<th>Asie Mean</th>
<th>Asie Mean</th>
<th>Asie Mean</th>
<th>PED Mean</th>
<th>PED Mean</th>
<th>Europe Mean</th>
<th>Europe Mean</th>
<th>USA Mean</th>
<th>USA Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy per capita</td>
<td>20345</td>
<td>981</td>
<td>103332</td>
<td>7512</td>
<td>10194</td>
<td>16031</td>
<td>46415</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO (kg/person)</td>
<td>93787</td>
<td>8570</td>
<td>399690</td>
<td>45033</td>
<td>97053</td>
<td>70997</td>
<td>173801</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO2 (kg/person)</td>
<td>1366</td>
<td>100</td>
<td>6000</td>
<td>1131</td>
<td>1609</td>
<td>1282</td>
<td>1537</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VHC (kg/person)</td>
<td>14168</td>
<td>1090</td>
<td>43710</td>
<td>9665</td>
<td>15277</td>
<td>12198</td>
<td>20711</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOX (kg/person)</td>
<td>15614</td>
<td>900</td>
<td>85710</td>
<td>8774</td>
<td>13828</td>
<td>12584</td>
<td>28222</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DENSPOLL (kg/ha)</td>
<td>6495</td>
<td>1245</td>
<td>25468</td>
<td>10479</td>
<td>8842</td>
<td>5235</td>
<td>3616</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDPC (USD/person)</td>
<td>21425</td>
<td>396</td>
<td>54692</td>
<td>13185</td>
<td>4912</td>
<td>29741</td>
<td>25843</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Millennium Cities Database; IATP – Murdoch University; treatment from the authors.

4. Results of the test of an UEKC

First we test the UEKC hypothesis for pollution caused by transports. Then we use energy consumption per capita to further discuss the pertinence of UEKC and its links with other explanatory variables.

a) Patterns of polluting emissions issued from urban transport systems

We have tested the hypothesis of an UEKC for the main pollutants due to daily mobility: CO, Nox, VHC and SO₂ (cf. Table 2). The pertinence of the hypothesis of an UEKC for these pollutants seems to be ambiguous.

Table 2. The UEKC and polluting emissions due to urban daily mobility (quadratic form)

<table>
<thead>
<tr>
<th></th>
<th>CO</th>
<th>NOx</th>
<th>VHC</th>
<th>SO2</th>
<th>DENSPOLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>62,234</td>
<td>8,369</td>
<td>12,203</td>
<td>1,240</td>
<td>11,858</td>
</tr>
<tr>
<td>gdpc</td>
<td>-4.22***</td>
<td>-2.60**</td>
<td>-4.86**</td>
<td>-4.80***</td>
<td>-6.92***</td>
</tr>
<tr>
<td>gdpc2</td>
<td>-9.26e-05</td>
<td>-1.45e-50</td>
<td>-8.13e-06</td>
<td>-6.86e-06</td>
<td>5.08e-06</td>
</tr>
<tr>
<td>R² adjusted</td>
<td>0.05</td>
<td>0.05</td>
<td>0.01</td>
<td>0.02</td>
<td>0.25</td>
</tr>
<tr>
<td>Turning point</td>
<td>23,739</td>
<td>27,433</td>
<td>--</td>
<td>--</td>
<td>40,436</td>
</tr>
</tbody>
</table>

*Slanting numbers in brackets are the t-ratio.

***: significant at 1%; **: significant at 5%; *: significant at 10%.

NB: Polluting emissions are expressed in kg per capita; DENSPOLL is the total emissions per urban hectare (kg/ha).

For the CO and NOx emissions, the “inverted-U” form of the curve is significant but the explanatory power of the models is very low (5%). For the VHC and SO₂ emissions, the UEKC is not a pertinent specification. It clearly shows that the UEKC model fails to closely explain the environmental output of transport behaviours. Especially for the two last pollutants, public policies may be the most relevant cause of the amounts of emissions. Indeed, the SO₂ emissions are mainly due to diesel motorization. Their levels are then shaped by political incentives to adopt such technology. For particles emissions (VHC), public regulations may also lower wealth effects because of the more or less stringent norms on catalytic converters.
For the density of pollution, the UEKC is valid. It could indicate that the effect of income on concentrations of pollutants is more relevant. Higher concentrations lead population to express stronger preferences for ecological regulation, and a higher wealth allows to lay on environmental policies. As such, the virtuous implications of individual wealth are channelled by the ability of city dwellers to influence political choices. The EKC literature suggests such a sequence in which the richer citizens are, the more powerful means they have to influence regulations (Scruggs, 1998).

The test for an UEKC for polluting emissions is quite inconclusive. As a consequence, we have to go “beyond wealth” and try to explain more precisely the environmental performances of cities.

b) Beyond the UEKC: an attempt to explain the environmental performance of urban transport systems

This section is an attempt to explain the main environmental output of an urban transport system: energy consumption per capita. Such a task is complex, because energy consumption per capita is caused by many intertwined factors, such as urban form, individual wealth, availability of public transport or road infrastructures, etc. As a consequence, we had to face important problems of multicollinearity, which introduces a bias in the estimation of OLS coefficients (Greene, 2000, p. 256). The solution, adopted by Pouyanne (2005a) among others, is to test separate models, built on a technical criterion (non-collinearity within the variables of the model) as well as on a theoretical one: models are thematic and try to understand the impact of a certain type of effect on energy consumption. We use four complementary models: a regional model, a behavioural model, a transport supply model and a costs model. Results of the regressions are given in table 3.

As shown in the table 3, in the pure EKC model, the quadratic specification is largely significant. UEKC then appears to be more robust when applied to energy purposes. 27 cities are above the value of the turning point, whereas 61 are below. The large number of cities in the declining part of the curve is a quite astonishing phenomenon: it shows that the decrease in energy consumption can be attained with a relatively low level of wealth.

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4 In fact, multicollinearity tends to inflate the estimated variance of the OLS regression coefficients. A diagnostic for multicollinearity is the Tolerance: it is a measure of the « non-collinearity » of a variable with the other ones of the model. A unitary Tolerance indicates the absence of collinearity; the empirical rule is to reject the non-collinearity of the variable for values of Tolerance inferior to 0.3.
<table>
<thead>
<tr>
<th>overall energy consumption per capita</th>
<th>&quot;pure&quot; UEKC</th>
<th>Regional model</th>
<th>Transport supply model</th>
<th>Behavioural model</th>
<th>Costs model</th>
<th>Collinearity Tolerance</th>
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<td>7,139</td>
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<tr>
<td></td>
<td>(0.24)</td>
<td>(-4.96)***</td>
<td>(2.45)</td>
<td>(-0.16)</td>
<td>(0.30)</td>
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<tr>
<td>GDPC</td>
<td>1.946</td>
<td>0.669</td>
<td>0.657</td>
<td>-0.466</td>
<td>0.815</td>
<td>(6.12)***</td>
</tr>
<tr>
<td>(USD per capita)</td>
<td>(6.61)***</td>
<td>(5.61)***</td>
<td>(3.04)***</td>
<td>(1.77)*</td>
<td>(3.45)***</td>
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</tr>
<tr>
<td>GDPC2</td>
<td>-3.20e-05</td>
<td>-6.45e-06</td>
<td>-9.62e-06</td>
<td>8.16e-06</td>
<td>-1.33e-05</td>
<td>(-5.31)***</td>
</tr>
<tr>
<td></td>
<td>(-5.31)***</td>
<td>(-3.39)***</td>
<td>(-2.43)**</td>
<td>(1.87)*</td>
<td>(-2.89)***</td>
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<tr>
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<tr>
<td></td>
<td>(-3.47)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>26,551</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>(6.49)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>-4,199</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>(-1.99)**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human Density</td>
<td></td>
<td>-25.99</td>
<td></td>
<td></td>
<td></td>
<td>0.65</td>
</tr>
<tr>
<td>(persons/ha)</td>
<td></td>
<td>(-3.10)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of jobs in CDB</td>
<td>-216</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.86</td>
</tr>
<tr>
<td>(jobs/ha)</td>
<td>(-2.93)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public transport capacity</td>
<td>-1.521</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.79</td>
</tr>
<tr>
<td>(seat km/person)</td>
<td>(-2.22)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative average time in public transport</td>
<td>32.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.79</td>
</tr>
<tr>
<td>(public vs private; minutes)</td>
<td>(1.81)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of freeway per 1000 people</td>
<td>130</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.64</td>
</tr>
<tr>
<td>(m/1000 persons)</td>
<td>(3.40)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of non motorised modes</td>
<td>-431</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.61</td>
</tr>
<tr>
<td>(% over all trips)</td>
<td>(-6.54)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of motorised public modes</td>
<td>-336</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.64</td>
</tr>
<tr>
<td>(% over all trips)</td>
<td>(-3.82)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall average trip distance</td>
<td>2,208</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.74</td>
</tr>
<tr>
<td>(km)</td>
<td>(4.94)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total daily trips per capita</td>
<td>9,214</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.48</td>
</tr>
<tr>
<td>(trips/person)</td>
<td>(3.42)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative public transport operating cost</td>
<td>217</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.66</td>
</tr>
<tr>
<td>(public vs private; USD/passenger km)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(6.83)***</td>
</tr>
<tr>
<td>Public transport investment per capita</td>
<td>-45.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.68</td>
</tr>
<tr>
<td>(USD/person)</td>
<td>(-4.44)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R² adjusted</td>
<td>0.30</td>
<td>0.71</td>
<td>0.58</td>
<td>0.79</td>
<td>0.70</td>
<td></td>
</tr>
<tr>
<td>Turning point</td>
<td>30,415</td>
<td>51,880</td>
<td>34,174</td>
<td>28,538</td>
<td>30,569</td>
<td></td>
</tr>
</tbody>
</table>
The **behavioural model** brings a confirmation of what has been said in section 2: energy consumption for transport can be mainly explained by travel behaviours. Hence, distance travelled and number of trips have a positive impact on energy consumption, whereas the proportion of travels made by public transport and non-motorized modes (the so-called “soft” modes of travels) have a negative impact. The explicative power of the model is very strong ($R^2_{adj.} = 0.8$). It is possible to suppose that the 20% that are not explained come from technological aspects, that is the state of the fleet, for which we don’t have any information: as a consequence, it can only be treated as residual.

In contrast with other models, the quadratic form exhibits an inverse-UEKC, first declining then rising beyond a threshold at 28,500 USD. This result confirms the key impact of consumers’ behaviour. In the EKC literature, it is often supposed that rising incomes imply a growing importance of environmental quality in the utility function. Here, it is not the case. In line with Lancaster’s demand theory (1966), ecological performance is only one characteristics of the consumed good among others, and it seems to be inconsistent with them. There is no reason to suppose *a priori* that, as incomes grow, the distortion of preferences overwhelmingly plays in favour of ecological characteristics. Our results even argue in the opposite direction.

The issue is then to explain such travel behaviours, consumers’ choices being dependent on exogenous features\(^5\) and subjective preferences\(^6\). One conclusion we can already put forward criticizes the deterministic model often provided by the pro-EKC authors (Beckerman, 1992). On the contrary, public policies are conclusive to shape the form of the curve (Arrow *et al*., 1995).

The **regional model** shows strong continental influences on energy consumption. The explanatory power of the model is more than twice the “pure EKC” model, which indicates that regional contingences, such as cultural and geographical characteristics, or continental specificities in terms of urban form, are of an equal importance compared to the wealth effect. Asian cities and European cities use less energy than developing countries ones (the reference category), whereas American cities use much more energy, as shown by the sign and the level of the coefficients.

Moreover, the computed turning point increases, leaving only 2 cities above it (München and Frankfurt). It means that, when regional contingences are controlled for, the UEKC looses much of its pertinence. Indeed, the declining part of the curve is no longer significant: pollutant emissions can then be considered as continuously rising. The effect of continental appartenance on energy consumption has to become clearer, by understanding the “hidden effects” of regional belonging.

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\(^5\) Cultural, historical and social ones are partly contained in regional appartenance. The impacts of infrastructures and the influences of prices of alternative modes are discussed in the two last models.

\(^6\) This dimension is not treated here because our data are not calibrated for.
The **transport supply model** shows two distinct influences on energy consumption for transport: first, urban form; second, supply of public transport.

Human density is a measure of urban concentration, that is the number of people and jobs per urban hectare (which is, according to V. Fouchier (1997), the best measure of the intensity of land use by human activities). We show that human density is inversely linked to energy consumption, which is in accordance with most of the studies on that topic (e.g. Newman and Kenworthy, 1989, 1998; Levinson and Kumar, 1997; Breheny, 1995; Ross and Dunning, 1997; Cameron et al., 2003). Indeed, high densities have a double impact on energy consumption. First, accessibility is enhanced, because the origin of the trip is closer from its destination (Fouchier, 1997): hence, distances travelled are shorter, which not only directly reduces energy consumption, but also facilitates a split towards non-automobile modes. Second, high densities favour induced travel, raise automobile congestion, and increase time travelled in car; that is, the time-competitiveness of the automobile is dramatically reduced when compared to on-site transit or non motorized modes of transport. Yet, time is a crucial variable in the choice of the transport mode. As a consequence, modal split may be facilitated by high densities, and energy consumption may decrease. Such a result, which is today very well documented, has been underlying many European urban planning policies, so as to control urban sprawl and build more “compact cities”, in the name of sustainable cities principles (e.g. Jenks et al., 1996; Breheny, 1995; van der Walk, 2002; Pouyanne, 2005b).

The proportion of jobs in the CBD is a measure of urban centralisation. The more the jobs are centralized in the CBD, the lower energy consumption is. The research has always considered that “relationships between sub-centring and commuting are complex” (Cervero and Wu, 1998, p. 1073): on one’s hand, polycentricism may decrease distance travelled, by allowing people to (re)locate near their jobs. People are rational locators, they seek to move closer to their home so as to reduce their commuting cost: it is the co-location hypothesis. For Levinson and Kumar (1997), sub-centring make such relocations easier, because “there are more opportunities to find a residence around the workplace” (p. 320): it may explain the famous “commuting paradox” of Gordon et al. (1991), who found a significant decrease in commuting times for 9 out of 20 American cities; it may also explain why distances travelled become independent from distance to CBD for the most remote locations (Pouyanne, 2007). Furthermore, a polycentric urban structure may facilitate transit service of peripheral zones, by serving subcentres according to the principles of the Transit-Oriented Development (Laliberté, 2002).

On the other hand, urban polycentrism may increase circumlinear travels (Kaufman, 2003) and multi-purpose travelling or “tours” (Krizek, 2003; Wiel, 2001), for which the automobile is almost inevitable (Aguilera and Mignot, 2003). The literature on “wasteful commuting” tries to quantify the “excess travels” due to a polycentric structure (the

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7 In French in the text.
monocentric configuration, with 100 % of the jobs located in the CBD, is the reference case). The first studies have found very large excess commuting (Hamilton, 1982, 1989; Massot and Orfeuil, 1995), whereas some more recent works have put into perspective such results, finding smaller amounts of excess commuting (Small and Song, 1992; Giuliano and Song, 1993). The idea underlying the “wasteful commuting” literature is that, on the criterion of daily mobility, a monocentric structure is more efficient than the polycentric one. Our own result corroborates this assessment; it shows that a monocentric city may have advantages on a polycentric one, as the proportion of jobs in the CBD has a negative influence on energy consumption for transport.

The strong influence of both human density and the proportion of metropolitan jobs located in the CBD show that urban form has a strong influence on travel behaviours, as was shown by an extensive literature since the middle of the 90’s (see, for example, Handy, 1996; Cervero and Kockelman, 1997; Pouyanne, 2005, 2006). But if sustainable mobility has to be attained, some alternatives to the car must be offered, in particular public transport. Thus the question of the impact of the level of transport supply on energy consumption must be raised.

The supply of transport infrastructure has a significant influence on energy consumption. The sign of the coefficients confirms our hypothesis: the number of seats-kilometres offered has a negative influence on energy consumption, whereas the influence of the length of freeway per 1,000 people is positive. Such results underline the importance of the supply of infrastructure on energy efficiency. Thus automobile use depends on the development of an automobile system (Dupuy, 1999): owning a car is only a necessary condition to its use, when a set of infrastructure linked to the automobile, such as parkings, freeways, etc. is a sufficient condition to its use. The same reasoning can be applied to transit use: it is only beyond a certain threshold of service that modal split towards public transport is possible.

The model underlines the importance of the efficiency of public transport compared to the automobile: the ratio of public versus private transport journeys duration has a positive influence on energy consumption, that is the faster public transport is compared to the automobile, the lower energy consumption is. Indeed, the duration of journeys is a crucial element to determine modal choice – given that there is a choice, as some parts of the urban area are characterized by an automobile dependence (Newman and Kenworthy, 1998, p. 31). Such a result is a justification of on-site transit supply politics, as we have seen above.

Just as journey duration has an influence on travel behaviour, the relative user cost of public versus private transport has a positive impact on energy consumption (in the sense that

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8 The model, with the number of parking places in the CBD instead of the length of freeway, gives the same result: we couldn’t test both variables in the same model because of collinearity problems.

9 Which is contrary to the results of Vivier and Mezghani (2006), for whom « there is no apparent link between the volume of [public transport] service offered and the percentage of journeys made in public transport » (p. 5). But their analysis is in terms of intercontinental comparison, whereas ours is multivariate regression.
journey duration is considered as an opportunity cost by transport specialists: e.g. Quinet, 1998). In a perspective of attaining sustainable mobility, this would plead in favour of an increase in the cost of automobile use (such as taxes on fuel), or a decrease in the cost of public transport (such as subsidies); but some further investigation must be made, as the final effect depends on the relative price elasticities of each transport mode. Some studies have evoked a possible perverse effect of political measures attempting to decrease the relative user cost of public versus private transport: in European cities, many poor households live far from the city center, because housing prices are lower. Such peripheral zones are often characterized by automobile dependence, as density is low and transit lines don’t go so far: it means that their price elasticity of car use is equal to zero. Thus, a raise in automobile user cost may have a significant impact on their income level, which would be in contradiction with the social dimension of sustainable mobility (Camagni and Gibelli, 1997). At last, the cost model shows that, as was expected, a strong investment in transit tends to decrease energy consumption for transport. As if automobile dependence exists in some of the more peripheral zones, such a result is encouraging, because it shows that a strong commitment in transit supply has a significant effect on travel behaviours.

Conclusion

This article is an analysis of the hypothesis of the EKC applied to urban daily mobility. We present the detailed mechanisms by which the hypothesis of the Urban Environmental Kuznets Curve (UEKC) could exist in the case of daily mobility, and we discuss such mechanisms in the view of recent development of research on daily urban mobility.

According to our empirical investigation, based on the Millenium Cities Database, the relevance of an UEKC model has to be considered with caution. Institutional dimension seems to deeply interfere in the relation between individual wealth and polluting emissions. State capacity or willingness to regulate environmental consequences of urban transport systems may be the key feature to implement a sustainable path for daily urban mobility. Here, further studies could focus on which dynamics are the most influential on policymakers’ choices. For instance, the growth of GDP per capita could be seen as a decisive factor of change in voter preferences (richer people integrate the environmental quality in their utility functions). Another example highlights the role of pollutant concentrations: when they reach a threshold, health impacts may lead to stronger environmental regulation.

However, as far as energy consumption is concerned, the UEKC seems to be robust, even when controlling for urban forms and for cost profiles. It gives some credibility to the assumption of a virtuous dynamic between quantitative economic growth and sustainability of urban transportation. But, the inverted-UEKC obtained with the behavioural model hardly complicates the overall interpretation. It could mean that objective influences (contingences and systemic characteristics) achieve to get along with the supposed relation between GDP per capita and polluting emissions. But subjective variables, those depending on consumer’s
choices, contradict the UEKC. Richer people may prefer private modes of mobility and (for example) bigger cars. The impact of individual wealth is then reversed. A consequence is that State’s intervention is needed to get urban transportation sustainable. Market forces alone fail to attain this goal. Another limit is revealed by the regional model. It seems that contingences associated with remove almost all the significance of the declining part of the UEKC. Here again some further research could highlight what are the main factors leading to this result.

Finally, our study confirms the idea that “Kuznets Curve is not a law of physics” (Kahn, 2006, p.37). Nevertheless, the relative scarcity of studies on the UEKC hypothesis calls for further empirical research, especially for a single city (which would allow not only to work with more accurate data, but also to use time series, giving dynamic results).

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