SELF-DRIVING CARS AND THE EFFICIENCY OF CITIES[1]

Rémy Prud'homme[2]

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This paper assumes that all cars, or most of them, have become self-driving cars. Such cars are better informed and more reactive than to-day's motor vehicles and drivers. This makes them safer, and above all faster because it reduces the safety margins presently required. In other words, they are associated with higher car speeds and reduced car travel times. The paper tries to explore what it can mean for the structure and the efficiency of cities.

The problem is not as new as it might appear. In the second half of the 19th century, a new mode of transport, the railroad, was invented, that played a key role in the pace and the patterns of urbanization, as well as in the economy at large. Then, in the past 120 years, the automobile appeared, and subsequently changed many times (in particular by becoming faster). Each time, it had significant impacts upon the structure of cities, basically because it expanded the location choices of enterprises and of households. As is well known, it facilitated sprawl and the development of suburbs. However, the relationships between changes in transport technology and changes in urban form are not simple, for at least two reasons. One is that they are not one-way relationships: the development of the automobile did influence sprawl, but it was also influenced by sprawl. The other is that urban patterns were also caused by a number of other factors, such as growing urban population, higher incomes, changes in the structure of industry, planning ideologies and constraints, changes in non-transport technologies, etc. In short, the processes at work were, and continue to be, reciprocal and multicausal.

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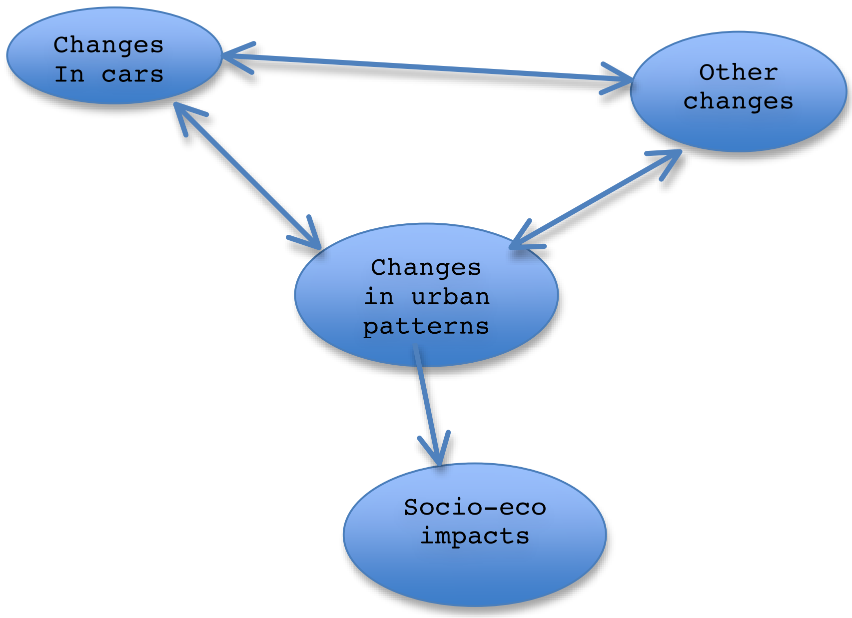
[2] Professor (emeritus), University of Paris-Est

Figure 1 represents the forces at work in a highly simplified and stylized manner.

This is why we must first ask ourselves, in the first part of this paper: are the "other forces" presently at work producing non-car cities? Non car-cities are cities in which the demand for services offered by cars (standard as well as self driving cars) is disappearing. Or, to put it otherwise, is Venice, the no-car city, the model likely to prevail in the future? If the answer is "yes", then self-driving cars will never play much of a role. If the answer is "no" (as we believe it is), it is worth trying, in the second part of this paper, to assess some of the impacts self-driving cars are likely to have upon cities. The key driver of such changes will be the increased speed, comfort and safety made possible by self-driving cars.

Figure 1 – Changes in cars and urban patterns



I – The Venetian utopia

A number of people wish and/or predict the end of the automobile in cities. Implicitly or explicitly, their ideal is Venice.

Venice, or more precisely the historic center, is indeed a city without cars. It was created in the middle ages, on a set of islands in the middle of a laguna, with canals playing the role of streets and avenues. This well-protected and maritime city became very powerful and prosperous at the time of the Renaissance, remained so for several centuries, and started to decline economically and politically at the end of the 18th century. Its geography, which had been an asset, became a liability. It made it impossible for Venice to adapt and expand, and in particular to accommodate horse carriages in the 19th century, and cars in the 20th century. Transportation still consists only of boats (vaporetti and gondole) and walking. Venice, which looks very much the way it was three centuries ago, is indeed a most beautiful and pleasant city[3].

But Venice is a dying city. It completely missed the industrial revolution. It is also missing the services revolution. Efforts made to develop heavy industry on the nearby land failed. Veneto, the region of which Venice is the capital city, has enjoyed Korean growth rates in the post war period, and is now one of the most prosperous areas of the world. This success story owes nothing to Venice, and did not benefit the city: this contrast only underlines the incredible inefficiency of Venice. Population has constantly declined. Tourism has evicted out most other productive activities, and Venice is becoming a sort of de luxe Disneyland.

Yet, it is the dream that many, indeed most, planners project for us and want to impose upon us. This fantasy of a city without cars is based on two myths: the myth of city densification, and the myth of alternative transport modes.

The myth of city densification

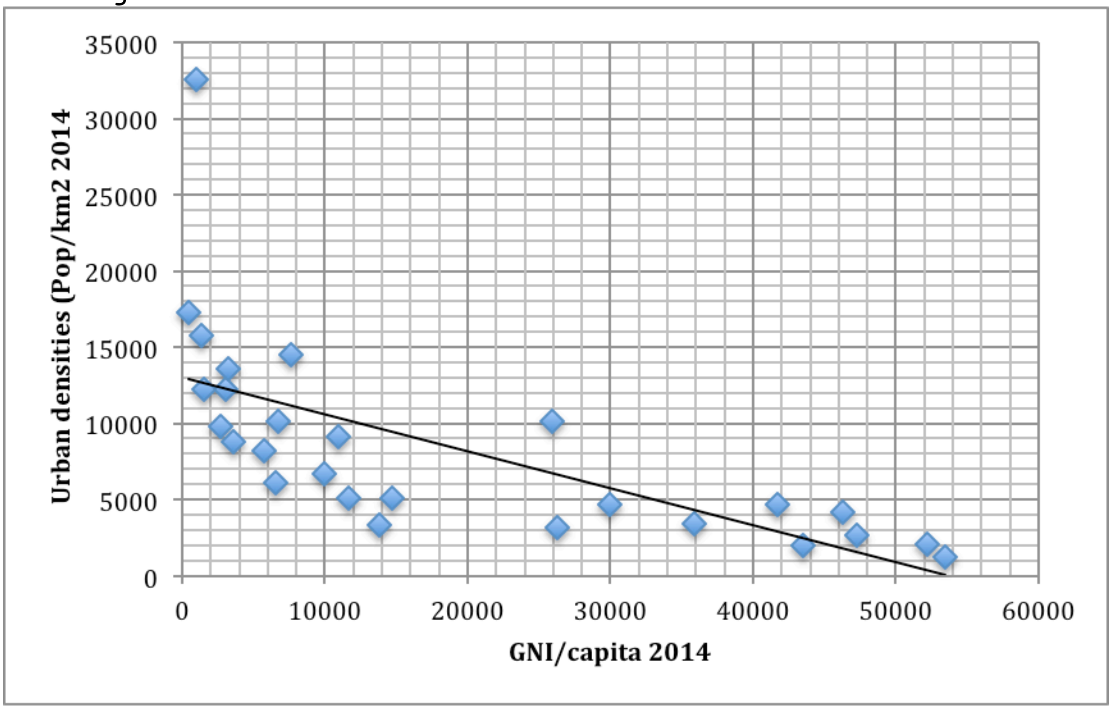
It is often claimed that densification is the future of cities. With incomes rising - are we told - people are and will be increasingly willing to come back to city centers, in order to enjoy the amenities of urban life. The cases of yuppies or millionaires flocking back to downtowns in a handful of world cities are routinely quoted to illustrate this predicted (and desired) trend. This is the tree that hides the forest.

[3] this author who had the privilege to spend a sabbatical year there would be the last to deny it.

Everywhere in the world, higher incomes are associated with lower densities.

Demographia, a US consultancy (www.demographia.com), establishes and publishes the list of the 1,000 agglomerations of more than 500,000 people in the world. Agglomerations are defined as continuous built up areas (as opposed to administrative areas). For each agglomeration, it figures out the area (km2) and the density (inhabitants/km2). We considered all the countries with at least 8 such agglomerations), and compared the average density of these large urban areas in each country with the Gross Income Product of the country (as estimated by the World Bank), for 2014. The outcome, presented in Figure 1, is impressive. Practically all low income countries have large cities with high densities. Inversely, all high income countries have large cities with low densities.

Figure 1 – Urban densities as function of income



For readers who prefer actual cases and numbers, Table 1 presents the numbers for three representative countries (representative means they are on or near the regression line of figure 1). In a low income country like Morocco, urban densities are very high (more than 10,000 people/km2). In a high income county like the USA, urban densities are 10 times lower. In a middle income country such as Spain (closer to the USA than to Morocco), densities are in the middle.

Table 1 – Urban densities and income, three countries, 2014

	GNI/capita (US $)	Urban densities (People/km2)
Morrocco	3,000	11,200
Spain	30,000	3,400
USA	53,000	1,200

Sources and notes : www.demographia.com for densities. World Bank for GNI. GNI (Gross National Income) is the GNI of the country, Urban densities are the average density of the cities larger than 500,000 people of the country considered.

Another way to express the same reality is to note that in the Demographia ranking by densities of all large world cities, the 500 cities with highest densities are all located in low income countries[4]. The spatial relationship between income and densities is therefore very robust, and it is negative.

A similar temporal relationship is also valid for nearly all cities. Over time, for a given city, densities decline as population, activity, and income per capita increase. It is not so much that densities decline in city centers (in many cases, they do; in a minority of cases, they don't). It is because practically all the growth of large cities takes place outside city centers, in suburbs, where densities are much lower. Table 2 illustrates this dynamics on the case of France over the 1962-1999 period.

Table 2 – Densities in Largest French Cities, 1962-99

	1962	1999	Change(%)
Population (in M)			
Central cities	8,3	8,0	-4%
Suburbs	7,1	15,1	+113%
Urbanized areas	15,4	23,1	+50
Densities (Pop/km2)			
Central cities	5,460	5,280	-4%
Suburbs	1,751	1,110	-36%
Urbanized areas	2,764	1,530	-45%

Sources and notes : Demographia.com, quoting INSEE. The data relates to the 30 largest French cities in 1999.

As can be seen, the overall population of French agglomerations increased significantly, by about 50%, in the period considered. Practically all of this increase took place outside central areas, in suburbs the population of which more than doubled. As a consequence, densities did not change much (on average) in central cities, but the share of people living in lower density suburbs increased from less than half to about two-thirds, and as a consequence average

[4] With the exceptions of Las Palmas, Bucarest and Vladivostock

agglomeration densities declined by nearly 50%. This pattern is not at all typical of France; it on the contrary fairy representative of what is happening everywhere in the world, including in the USA and in developing countries.

This robust relationship is easy to explain. It is not driven by demographic forces. Suppose the boundaries of an urban area are fixed. A constant population would mean a constant density; and an increased population would lead to an increased density. But urban boundaries are not fixed. They are modified by changes in income and in transport technology. Increased income plays a key role. Households with higher incomes want more housing space. So do business and civic activities. This increased demand for built up areas cannot be met within existing boundaries. It can, in part, be met by taller buildings. This, however, increases both costs and land rents, and pushes prices up. Some (in fact many) households and enterprises are priced out of the initial urban boundaries, and settle in the nearby suburbs. As they want to continue to benefit from the agglomeration amenities (particularly the large and efficient labor market they offer), urbanites substitute transportation for centrality. Their choices are of course influenced by transportation time and money costs.

Efforts to keep urban densities high, or to increase them, have been numerous, in many (not to say most) countries. As the numbers show, they have largely failed.

There is no reason to expect things to change in the coming decades. Incomes are likely to continue to increase, particularly in developing countries; the demand for more build up area is likely to continue to be strong; densities are likely to continue to decrease; efforts to contain them are likely to fail.

The myth of alternative transport modes

The Venetian utopia is supported by another myth: the idea that urban car transport can be largely substituted by alternative means, such as walking, bicycling, and transit. This view, which is held by many planners and politicians worldwide, is mostly generated by a psychological aversion (not to say hate) of the car. There are indeed many problems associated with car usage, such as accidents, pollution, natural resource depletion, noise, congestion, etc. What the enemies of the car detest are not these negative car consequences (which can be, and are actually, controlled to a growing extent), but the essence of the car. They are not interested in reducing these externalities, but in evicting cars out of our cities. They predict – they have been predicting for the past half a century - that this will inevitably happen soon. Their favorite replacement solutions are slow modes (walking, bicycling) and public transport (metros and buses). In reality, the development of both is limited by geographic and/or cost considerations.

Table 3 presents the speeds, the average distance, and the share of the various modes for local daily trips in France in 2008. Speed data is most probably largely similar in all countries. Trips lengths and modal shares vary more from country to country, but the numbers for France are likely to be indicative of what happens in most developed countries.

A key characteristic of each mode is speed, here calculated as the average distance (measured as the crows flies) divided by the average time from origin to destination (including access times). Modes are ranked according to speed. Unsurprisingly, walking trips are undertaken at a speed of 3.6 km/h, and bicycling trips at 10.4 km/h. Less known (at least by non transport specialists), the speed of public transport trips (17.7 km/h) is less than half the speed of car trips (36.6 km/h). This car speed, which is measured, not postulated, includes the much talked about car congestion. The slow public transport speed is explained by the obvious, although often neglected, fact that public transport trips include longer access times (to the bus or metro nearby stop), waiting times, and that buses and metro have the habit of stopping every 2 or 3 minutes in order to let people in and out. The speed of motorized two-wheelers (motorcycle and scooter) is close to that of cars.

Table 3 – Daily Trips Speeds, Lengths and Shares, France, 2008

	Walking	Bicycling	Public transport	2-wheelers	Cars
Speed (km/h)	3.6	10.4	17.7	30.0	36.6
Trip length (km)	0.8	2.8	11.2	8.1	10.3
Share (%)	2	1	12	2	84

Sources & notes : ENTD 2008 (Enquête Nationale Transports et Déplacements), Table 5.1. Distance are measured as the crow flies. The share of each mode is calculated in passengers*km, not in numbers of trips.

This pattern of speeds goes a long way to explain trip lengths and modal shares. Walking is restricted to short trips (less than 1 km on average); practically none of these trips are made by car; walking is not an “alternative mode” (alternative to car transportation) for such trips.

Similarly, and for the same obvious reasons, bicycling is used for relatively short trips (on average 2.8 km as the crow flies, about 3.6 km in reality). For these trips, there is some possible competition with car transportation, at least for people who are not disabled, and do not have heavy things to carry with them. However, this short-trip market is relatively small. In France, the 2-5 km trips account for less than 10% of total local mobility, measured in passengers*km, the most significant indicator of transportation. This segment of local transport is shared between cars, public transport, two-wheelers, walking, and bicycle. Bicycling can indeed increase its present market share on this segment. But this will only have a minor impact on automobile transportation. As shown on Table 3, bicycling account for 1% of total local transportation, compared with 84% for cars. A doubling of bicycling usage, assuming it were done at the expense of the automobile (an extreme assumption), would decrease car usage by 1.2%.

On the dominant longer trip segment, the competition is between public transport and car. Slow modes are obviously excluded. In all developed countries, cars overwhelmingly dominate the picture: 84% of total local transportation is by car versus 12% by public transportation in France, as shown in Table 3. This dominance is not at all the outcome of pro-car policies. In France, and more generally in Europe, policies are clearly pro mass transit: car transportation is heavily taxed[5], whereas mass transit is heavily subsidized[6].

The main explanation has already been mentioned: car transportation is twice as fast as public transportation. This does not mean that public transportation has no role to play. Rail and subway are

[5] In France, gasoline (taxed at about 150%) and diesel oil (taxed at about 90% are, after tobacco (taxed at 400%), the goods most heavily taxed. The numbers for other European countries are not very different.

[6] In France, user fees cover about 1/3 of the cost of local public transport, and the balance consists of subsidies.

much more efficient than cars to transport large amounts of people on a given link, and metros and buses to transport large amounts of people in densely populated areas. Megacities like New York, Tokyo, London, Paris, Munbai, Seoul, etc. with dense CBDs could not function properly without public transport systems. But even in these megacities, many, in many cases most, people live in areas where densities are too low to support frequent mass transit services. For public transport, low densities therefore mean either empty carriages - requiring very high subsidies - or unfrequent services - meaning low speeds - or both. This sets severe limits to the much talked about substitution of cars by public transport. Even in an agglomeration like Paris, which is large (12 M[7]. people), has a relatively high average density (3,800 people/km2), and is equipped with a very good and heavily subsidized public transport system, car transportation accounts for about 2/3 of total transportation (in terms of trips and in terms of passengers*km).

There is no reason why this dominance of car transportation would not continue to prevail in the coming decades. As a matter of fact, there are two reasons why it might be expected to increase: declining densities and growing public finance constraints. These two worldwide trends favor cars rather than public transport. Lower densities and reduced subsidies are enemies of mass transit.

The idea that "alternative" transport mode, mostly walking, bicycling and public transport, are going to eliminate car transportation from our cities is but a dream. Ironically, the two alternative transport modes which are developing most rapidly are modes that have been largely ignored by transport planners: motorized two-wheelers, and teleworking. Anti-car policies, where they have been implemented, did not benefit much public transport, but rather motorized two-wheelers, in both developed and developing countries. Table 3 shows why. Two wheelers, which are nearly as fast as cars, and are much cheaper, offer a valuable alternative to cars (they are also 15 times more lethal). The other interesting development, at least for home-work trips, is teleworking. In the USA, it is by now quantitatively as important as transit.

[7] In what follows M stands for million, and G (giga) for billion.

To sum up, it seems safe to conclude that the Venetian model is likely to remain a dream, a utopia. Far from being dense and car-less, the cities of the future will mostly be low density, with people and goods moving around in cars. The issue is not: will there be cars in the streets? but rather : what sort cars will there be?, and : what will this imply for cities and the economy?

II – Some impacts of self-driving cars

We assume that the cars of the (near) future will be largely driverless. We also assume that this will be achieved at a relatively low additional monetary cost. Such cars will cost slightly more than conventional cars, perhaps 5-10% more, because the additional devices they will require are complicated to develop but cheap to manufacture. Operating costs, mostly fuel costs, which are a significant share of total monetary costs, will not be increased and will even probably be lower than conventional cars operating costs. Overall, driverless devices will probably not impact car usage monetary costs. Obviously, monetary costs might decrease because of additional progresses, for instance in fuel efficiency, but this is independent of the self-driving features of the cars.

The impacts of self-driving cars will mostly be non-monetary, which does not mean valueless, only more difficult to value. They include (i) safety gains, (ii) comfort gains, (iii) time gains, (iv) increased transport gains, and (v) urban efficiency gains. We will discuss these gains in turn, trying to guestimate their magnitude on the case of the Paris agglomeration[8]. Paris, with about 12 million people, and an output of about 700 billion dollars, is one of the largest world cities (and one for which we have a substantial amount of data).

Safety gains

Driverless cars are safer because computers are better drivers than humans. Unlike drivers they do not exceed speed limits, do not drink, do not telephone, do not fall asleep, do not have eye problems, do not react slowly, etc. They are able to do things humans cannot

[8] In what follows, « Paris » means Paris agglomeration, not Paris municipality (about 2 M. people).

do, such as “viewing” (with their many sensors) obstacles on several sides simultaneously. They will not prevent a bridge to collapse, or a tree to fall and crush the car. But they will avoid most or all driver-related accidents. Indeed, they will do so, or disappear from the scene. Users are likely to prefer a 1% probability of accident in a car they themselves drive to a 0.1% probability of accident in car driven by a machine. They will only buy and use driverless cars if it is proven that these are extremely safe.

The potential safety gains of driverless cars are enormous. They are basically equal to the accident costs avoided, which fall into three main categories: the cost of fatalities, the cost of injuries, and the cost of material damages. There is an abundant literature on such costs. There are also interesting debates on the issue of whether (or to what extent) they should be considered an externality; and on the issue of whether they are properly covered by the insurance system. These debates are of no interest here: accident costs are costs to society at large, irrespective of who causes them and of who bears them.

Table 4 presents an estimate of road accidents costs in the Paris agglomeration. Unit costs are from an official French government report[9]. The total cost amounts to about 4.5 billion dollars.

Table 4 – Paris Accident Costs, 2013

	Numbers	Unit costs (M$)	Costs (M$)
Fatalities	288	3.40	979
Injuries			
Severe	4,704	0.51	2,378
Minor	16,900	0,067	1,139
Total	21,604	-	3,517
Total			4,496

Sources : Direction Régionale de l’Equipement et de l’Aménagezment de l’Ile-de-France. 2014. *Sécurité routière - Bilan Ile de France 2013*. 16p. for the numbers ; Commissariat Général à la Stratégie et la Prospective. 2013. *L’Evaluation socio-écoomique des investissements publics*. 354p. for unit costs.

Comfort gains

[9] I find them vastly exagerated, and more guided by a desire to prove that the automobile is an evil to be fought than by cold reason.

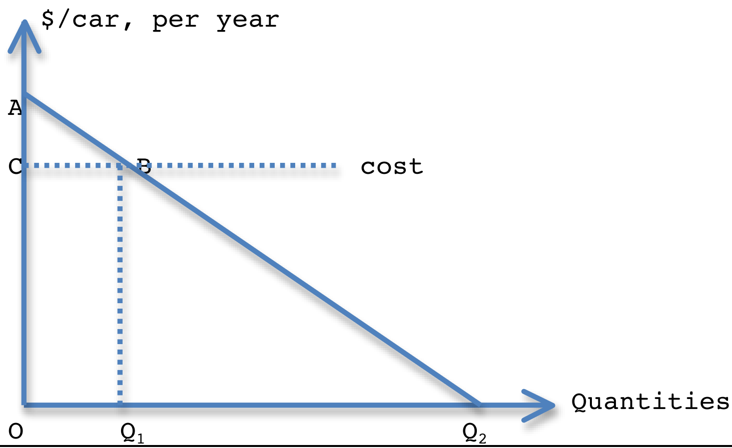
Riding a car without having to drive it will be experienced as more comfortable by most travellers. First, it is less tiring; driving requires a great deal of attention, and generates some stress; the range of body movements compatible with driving is limited, and only a few muscles are mobilized. Second, being driven makes it possible to perform a number of tasks useful or pleasant or both, such as engaging in conversation with fellow travellers, taking a nap, reading, moving freely, telephoning, and even writing.

We have at least three pieces of evidence of the existence of such comfort gains. First, in car versus train comparisons surveys, respondents rarely fail to mention the possibility to "do things" in trains as a comparative advantage of train travel relative to car travel. Second, most of the people who can afford it, choose to have a chauffeur to go around. This may be in part a status symbol, but it is also because a chauffeur buys you (relatively) free time, a precious commodity. A self-driven car is basically a chauffeured car. Third, in cost-benefit analyses, the value of time of passengers is lower than that of drivers. This reflects the fact that the cost of one hour spend on the road is greater for a driver than for his/her passenger(s). Both suffer, but the driver suffers more, for the reasons mentioned above.

It is notoriously difficult to value comfort gains (or losses). Difficult-to-conduct contingent analyses would be required to that effect. However, the last two pieces of evidence of comfort gains generated by driverless cars can be used to produce some very crude numbers, again on the case of Paris.

We know how much people pay to enjoy the services of a chauffeur: in Paris, about 40,000 $ per year (labor and other taxes included). Figure 1 represents the comfort gain of chauffeured cars as a function of the number of such cars. AQ_2 is the demand curve for chauffeured cars, with Q_2 the total number of cars in Paris (4.9 M cars). CB is the present cost curve of a chauffeured car (40,000 $/year). Q_1 is the number of car users who presently buy the services of a chauffeur (the value Q_1 is mall and does not matter much for the calculation). Presently, chauffeur users pay OQ_1*OC, and enjoy a consumer surplus of CAB. Driverless cars will offer the same services for free, moving the cost curve from CB to OQ, and the equilibrium point from B to Q_2. Car users will therefore enjoy a consumer surplus equal to Q_1BQ_2. If AQ_2 the demand curve, were a straight line, this surplus would be equal to 4.9 M*40,000$*0,5, or 98 billion $ per year. Actually, AQ_2 is likely to be a concave curve, asymptotic to OQ for many car users, and therefore Q_1BQ_2 much smaller than 98 billion. In the absence of additional information on the exact shape of the demand curve, we will assume that this surplus is about half what has been calculated above, around 49 G$. This is about 7% of the GDP of Paris.

Figure 1 – Market for chauffeured cars, Paris



The other approach is based on the difference in the value of time for drivers and for passengers, which is widely recognized to be around 30%[10]. Assuming a 30 $ per hour for drivers[11], this means a differential of about 10 $/h. There are in Paris every working day 12.2 M car trips of an average duration of 23 minutes. Drivers therefore spend daily about 5.3 M hours driving a car, or (multiplying by 300 days) 1.6 billion hours per year. If the benefit of being driven instead of driving is valued at 10 $/hour, the generalization of self-driving cars will create a total benefit of about 16 billion dollars – per year.

Our two estimates of the comfort gain (49 G$ v. 16 G$) are quite high, although very different.

Increased speed gains

[10] This is the order of magnitude given by the UK Departyment of Transport in its *New Approaches to Appraisal*, or by the Victoria Transport Policy Institute (vtpi.org) in its *Transport costs and Benefits Analysis II – Travel Time costs*.

[11] This is more than what is often assumed in the US, but less than official UK government numbers.

A key feature of driverless cars is that they will go faster than man-driven cars. There are at least four reasons for that.

First, because it is safer and more reactive than an ordinary car, a driverless car can travel at a shorter distance from the preceding vehicle.

Second, because a self-driving car will adjust faster (than a man driven car) to traffic difficulties and problems, the time presently "lost" in adjustments to traffic speed variations will be reduced. Traffic will be smoother, and average speeds will be higher.

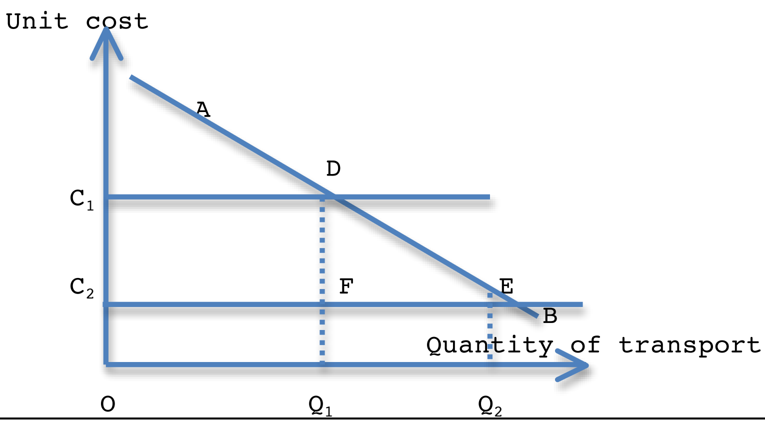
Third, accidents are a major cause of congestion and of slowed traffic. Less or no accidents will therefore result in a substantial reduction or elimination of this cause of speed reductions, and therefore in speed increases.

Fourth, self-driving cars will be able to park by themselves. Users will exit the car when arrived at destination, and let the car go to the nearest parking space or garage. This will also save a significant amount of time for the user, therefore decreasing the origin-destination travel time, and increasing travel time defined as origin-destination distance divided by total trip time.

All this will reduce the time cost of car travel, (which is by far the most important cost of car travel). Cost reduction has always been the essence of progress in transportation, and the basic justification of transport investments. Figure 2 plots costs as a function of the quantity of transportation. There is a demand curve for transportation AB, and a unit cost of transportation (mostly a time cost) C_1D. They intersect in D, an equilibrium point that corresponds to a quantity of transportation Q_1. A transport improvement (in our case the advent of self driving cars) is introduced, that lowers unit costs, from C_1 to C_2. A new equilibrium is established, in E, corresponding to a quantity of transportation Q_2, with $Q_2>Q_1$. The welfare gains generated by the transport investment are the difference between the consumer surplus before and after the investment, the C_2C_1DE area of Figure 2. It consists of two parts: the time gain of initial travellers (the C_2C_1DF rectangle), and the welfare gain of new, investment induced, transport (the FDE triangle).

The introduction of self-driving cars plays exactly the same function as additional transport investment: it lowers transportation costs, thereby increasing the quantity of transportation. In that sense, self-driving cars are a substitute to transport investment. In urban areas, where transport investments are usually very costly and quite often technically and politically infeasible, it is a much better substitute: it does the same thing at a much lower cost, and can do it when transport investments cannot.

Figure 2 – Benefits generated by the self-driving cars

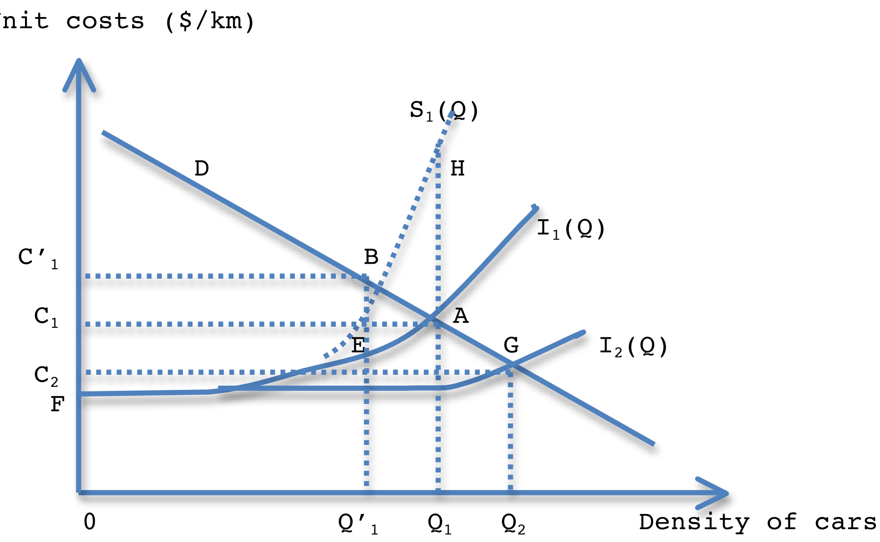


In short, self-driving cars increase the productivity of the transport system. With a given stock of capital infrastructure, of cars, and with less labor, self-driving cars will produce more transportation services. More output with the same amount of inputs or less inputs is the very definition of increased productivity. As is usually the case, this is what technological innovation achieves.

This benefits holds in the important case of urban congestion. It is often argued that a transport investment is useless in a congested area or on a congested road, because it will attract additional road users, and quickly reinstate the initial level of congestion. This argument is rather weak.

Consider Figure 3 that presents unit costs ($ per km driven) as a function of car densities Q (number of cars per meter or square meters). $I_1(Q)$ is a cost curve, representing the time cost of driving as a function of density Q. For a zero density, or empty road, $I_1(Q)$ is equal to F (free-flow cost). As density increases, speed declines, time spent and cost per km driven increase. There is a demand curve D for road usage. $I_1(Q)$ intersects D in $A(Q_1,C_1)$ which describes the equilibrium situation.

Figure 3 – Benefits of self-driving cars in the case of congestion



A is a congestion equilibrium. The prevailing speed is lower that the free flow speed, and cost C_1 higher than F. More significantly, this equilibrium is not optimal. It ignores the externality imposed by each road user upon fellow road users. This marginal congestion cost is equal to $I'_1(Q)$, the derivative of $I_1(Q)$, multiplied by Q. When added to $I_1(Q)$, it defines a social cost curve $S_1(Q)$. $S_1(Q)$ intersects the demand curve in $B(Q_1',C_1')$, which represents the optimal situation. A congestion tax BE will reduce car usage to the optimal level Q_1', and produce a welfare gain equal to ABH.

What will a road investment - or a driver-less car system - achieve ? Il will shift rightwards the cost curve from $I_1(Q)$ to $I_2(Q)$. $I_2(Q)$ will intersect the demand curve D in $G(Q_2,C_2)$, the post investment or post self driving car equilibrium situation. For sure, G does not "eliminate" congestion: the new unit cost C_2 remains above the free-flow cost F; and a new social cost curve $S_2(Q)$ can be drawn (not presented here for the sake of simplicity) that would determine a new optimal situation, together with a new optimal congestion tax. Nevertheless the road investment/driverless car system achieves two desirable things. First, it enables cars and people to drive faster than before, since $C_2<C_1$. Second, more people benefit from the road, since $Q_2>Q_1$. The consumer surplus has been increased by C_1AGC_2. The difference between the road investment and the driverless car system is not that the gross benefits are greater with the driverless cars (they are identical), it is that the road investment is costly whereas the driverless car system is costless; net benefits are indeed greater.

To produce orders of magnitude of the benefits for the Paris agglomeration, we need an estimate of the speed increase produced by self-driving cars. Self-parking alone would save 2 or 3 minutes per trip, that is about 10% of total trip time, producing a 10% speed increase (actually about 11%). It is reported that self-driving could amount to a 40% road capacity increase. The relationship between capacity increases and speed increases is poorly known (to us). Cheng and Small (2011) provide numbers that suggest an elasticity of speed to capacity of 0.13. A 40% capacity increase would therefore produce a 5% speed increase. Let us assume a 15% speed increase. In Paris, the number of car trips is about 4,620 M per year. The (time) cost of a trip is about 7.6 $ (0.38 hours x 20 $/hour). A 15% decrease in this cost amounts to 1.14 $ per trip. The time gain on existing traffic would therefore be 4,620 M trips x 1.14 $ per trip, or 5.3 billion dollars. Assuming a price-elasticity of demand of -0.4, the generated traffic would be 6% of 4,620 M trips, or 277 M trips. This generates a 0,16 billion dollars welfare gain for generated traffic. The total benefit appears to be around 5.5 billion dollars.

Increased labor market gains

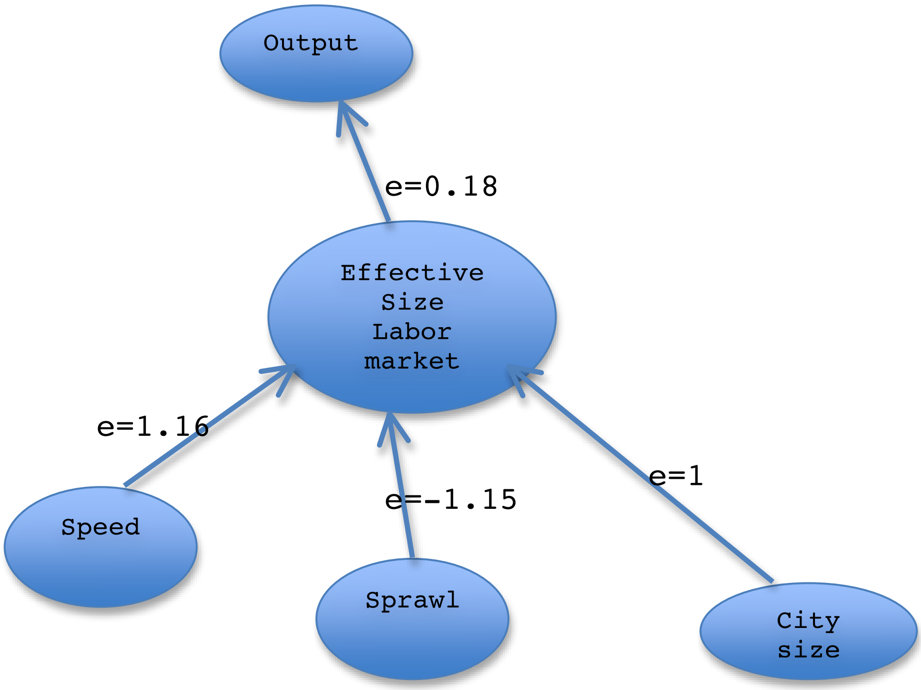
This is not the end of the driverless car gains story. The benefits of increased speed discussed so far relate to tangible and actual changes such as time saved or additional trips undertaken. But increased speed brings another type of benefits: it *enlarges the range of choices* of people and firms, and in so doing improves competition and increases the efficiency of markets. This is true for the culture, purchases, housing or marriage markets, and in particular for the labor market. A large labor market, where people find the job that suits them best, and firms the workers they need most, is the key (or at least a key) to the efficiency of cities. It is often referred to under the name of “agglomeration economies”, and is the very *raison d’être* of cities. In a small town, with a small labor market, the matching of labor demand and labor supply will be imperfect. Firms will not find exactly the workers they need because their choice of workers will be limited; and workers will not find exactly the jobs they want (and for which they are qualified), because their choice of job will be restricted. The productivity of this small town will therefore be rather low. The opposite will happen in a large town.

This is empirically verified. In every country, output, income, wages (when corrected for available capital and for labor force qualifications) in a city are a function of the size of the city. In the cases of France or the United Kingdom, for instance, income per capita or per worker is about 50% higher in the capital city (Paris and London) than in the rest of the country.

In very large cities, however, the effective size of the labor market is not equal to the number of workers (or of jobs). Not all the 5 M workers living in Los Angeles county have in practice access to the 5 M Los Angeles jobs. In a reasonable amount of time (let us say 60 minutes) a worker living in a certain part of Los Angeles will have access to only 4 M jobs; a worker living in another part of LA to 2 M jobs. The average effective size of the labor market at 60 minutes is probably closer to 3 M then to 5 M. What accounts for the efficiency of a city is not the total or potential size of the labor market, but its effective size.

This is where transportation, and in particular transportation speed, enters the picture. The effective size of the labor market is a function of the speed at which people move from home to work (and also of the spatial layout of the city). For a given spatial layout, increased speed translates into a larger effective size of the labor market, which in turn means a higher labor productivity, i.e. a larger output.

Figure 4 – Increased speed and increased output



We were able to verify empirically this theory on the case of 22 French cities (Prud'homme & Lee 1999). For each of them, we calculated the labor productivity, the effective size of the labor market (at 30, 45 and 60 minutes), an index of sprawl, and the average transport speed. Labor productivity was well explained by effective size of labor market; and effective size of labor market was well explained by: total size of the labor market, sprawl, and – this is what is of interest here – by transport speed. Regression analyses produced elasticities of productivity to effective size of the labor market and of effective size of the labor market to transport speed. Figure 4 shows the relationships and the elasticities[12].

This suggests that (for a given city, with a given size and a given and a given level of sprawl), a 1% increase of transport speed leads to a 1.16% increase of the effective size of the labor market; and that a 1% increase in this effective size of the labor market produces a 0,18% of the city output. It follows that a

[12] For a more complete and formal presentation see Prud'homme & Lee, 1999.

1% increase in transport speed generates a 0.3% increase in the city output.

These numbers, which have been estimated on a limited number of French cities, must be taken with caution, and cannot easily be extrapolated to other contexts. They nevertheless provide a useful starting point, and offer a rough estimate of the economic benefit to be expected from driverless cars-induced increased speed. In a city like Paris, with an output of about 680 billion $, a 15% increase in speeds would translate into a 30.6 billion additional output.

Table 5 – Estimated benefits of driverless cars in Paris

	Billion $/year
Safety gains	4.5
Confort gains	
based on chauffeured car market	49.0
based on driver/passenger values of time	16.0
Increased speed gains	5.5
Increased labor market efficiency	30.6
Total	56.6 – 89.6

Sources : see text. The lower total figure is obtain by adding the lowest numbers for each item ; the higher total figure by adding the highest numbers for each item. The last two items are based on a 15% increase in speed.

Table 5 summarizes the orders of magnitudes of driverless cars benefits estimated on the case of Paris. These numbers are largely guesstimates. But they suggest two important findings. One is that these benefits appear very substantial: 8% to 10% of the GDP of a large city such as Paris. The other is that the picture is dominated by the comfort gains and by the increased labor market efficiency, rather than by the safety gains and the increased speed gains.

Conclusion

The first part of this paper dismisses the utopia of cities without cars. Our world is rapidly urbanizing, and will soon be predominantly urbanized. The traditional dichotomy of dense cities versus rural areas will slowly disappear. Our world will more and more consist of suburban areas, where cars will be the dominant transportation mode. To reap the potential benefits of agglomeration economies, efficient urban transportation, which means largely car transportation, is required. This will be – it is already – a great challenge. For years, increased transportation speed did the job. Larger cities *cum* faster transportation meant more efficient cities. Faster transportation was achieved mostly by a shift from low transport modes (walking, public transport) to faster ones (cars). This is still experienced in developing countries. But it is no longer happening in developed countries: the share of car transportation is so large that it cannot increase significantly. More generally, transport costs (in time, safety, comfort) have ceased to decrease. We have lost one engine of productivity improvement.

Driverless cars, as we have shown, offer the potential to lower all these transportation costs. Driverless cars will therefore make it possible to re-ignite an engine of urban progress, and to help our cities improve productivity and welfare, as they have always done.

Driverless cars are an outcome the marriage of technology and private initiative. They do not require government action in the form of subsidies, public investment, or changes in existing laws and regulations. This will facilitate the development of driverless cars. It does not mean that great achievements cannot be expected of the marriage of technology and government initiative (in the area of urban transport). They include car-to-car and car-to-infrastructure digital links. Such innovations, that might take longer than driverless cars to materialize, are also extremely promising.

References

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