Buses, Houses or Cash? Socio-Economic, Spatial and Environmental Consequences of Reforming Public Transport Subsidies in Buenos Aires

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Abstract

Transit subsidies in the urban area of Buenos Aires are high, amounting to a total of US$5 billion for 2012. They have been challenged on several counts: suspected of driving urban sprawl and associated infrastructure costs, diverting resources from system maintenance, and failing to reach the poor among others. In this context, this paper examines the impacts of cost recovery fares under a range of different policy scenarios that could cushion the impact of fare increases. The alternative scenarios that are scrutinized are the uncompensated removal of the transit subsidy, its replacement by a lump sum transfer, and its replacement by two different construction subsidy schemes. Using a dynamic urban model (NEDUM-2D) calibrated for the urban area of Buenos Aires, all scenarios are assessed along four dimensions: (i) the efficiency/welfare impact on residents, (ii) the impacts on the internal structure of the urban area and sprawl, (iii) the impact on commuting-related carbon dioxide emissions, and (iv) the redistributive impacts, with a focus on the poorest households. A series of results emerge. First, there are consumption-related welfare gains for residents associated with replacing the transit subsidy by a lump sum transfer. Second, there are only moderate reductions in urbanization over time and thus infrastructure costs associated with the subsidy removal. Third, the replacement of the transit subsidy leads to only moderate increases in carbon dioxide emissions despite lower public transport mode shares, because households will chose to settle closer to jobs, thereby reducing commuting distances. Finally, the replacement of the transit subsidy by a lump sum transfer will lead to short-term harsh redistributive impacts for captive transit users in some areas of the urban area. Medium-term adjustments of land and housing prices will partially mitigate the negative impacts of higher transport costs for tenants, but will further hurt homeowners.

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Buses, houses or cash? Socio-economic, Spatial and Environmental Consequences of Reforming Public Transport Subsidies in Buenos Aires

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1 Introduction

Public transport is highly subsidized in the urban area of Buenos Aires. The fares paid by the users only cover around a third of the cost of the trips with total transit subsidies amounting to more than US$ 5 billion for the urban area of Buenos Aires alone in 2012. This level of subsidization is in line with what is found in developed country cities but is high for a developing country. In light of these figures, the transit subsidies have been challenged first on a financial and fiscal basis[2]. Is this the best use of scarce public resources? Or could alternative policy and interventions lead to better welfare outcomes? Commentators have focused on many potential weaknesses of the subsidy – including the impact of diverting resources originally earmarked for system maintenance and investment both of which have been inadequate in the last decade; issues of financial management; as well as the lack of transparency or incentives to foster efficiency in the allocation mechanism.

There is also a debate on the impact of the low fare on the aggregate modal share of public transport in the metropolitan area. On one hand, all else equal, low fares make for more competitive public transport. But the evidence also suggests that for most riders of choice, quality trumps fare, so that when transit subsidies come at the expense of quality of service (comfort, reliability, passenger information systems), as is the case in the Buenos Aires urban area, the public transport ridership balance is unclear. In particular, Gwilliam (2017) reports evidence from London that reductions in public transport fares are less likely to bring about mode share changes in favor of transit than service quality improvements.

There are also a number of other dimensions along which the subsidies need to be assessed. First there are concerns that these artificially low public transport prices have fueled urban sprawl and related negative externalities such as excessive loss of farmland, or the need for costly infrastructure (sewage systems, roads, etc.). Second, the transit subsidy has an impact on commuting-related energy expenditures and CO_2 emissions. This is closely linked to the impact of lower fares on both transit ridership – which is less carbon-intensive than travel by private cars – and in parallel on location decisions of households in the Buenos Aires urban area. Whereas higher public transport mode shares would tend to decrease emissions, lower transport costs would also enable households to settle further from job centers, thereby lengthening commuting distances and increasing CO_2 emissions. The net effect is a priori ambiguous.

Finally, transit subsidies are generally believed to be pro-poor, enabling the poor to maintain a reasonable level of accessibility to jobs. Evidence however suggests that in Buenos Aires Metropolitan area, transit subsidies disproportionately benefit the middle income class rather than the poor (Bondorevsky 2007). If the aim of the transit subsidy is to provide the poor with urban transport options then the targeting is inefficient, resulting in both bad resource use and low accessibility for the poor.

In this context this paper examines the spatial development, welfare, redistributive and environmental impact of cost recovery fares under a range of different policy scenarios that could potentially cushion the impact of fare increases. The scenarios that we scrutinize are the uncompensated removal of the public transport subsidy, its replacement by a lump sum transfer, and its replacement by two different construction subsidy schemes. The first construction subsidy device assumes that a fixed share of the construction costs is subsidized wherever construction occurs, while the second device targets specific zones that benefit from high transit accessibility within the urban area. Special attention is paid to the lump sum transfer counterfactual as it is theoretically optimal and because there is a rich history of cash transfers in Argentina, in particular following the 2001 crisis. The outcomes of counterfactual scenarios

[2] In April 2016, fare increases were introduced with the minimum bus fare doubling from AR$ 3 in 2014 to AR$ 6. This study assumes subsidies and fares before their revision in 2016.

are compared to the baseline and the results are assessed along four dimensions: 1/ the aggregate welfare or efficiency impact on residents, 2/ the impact on the internal structure of the urban area and on sprawl, 3/ the impact on commuting related CO_2 emissions and 4/ the redistributive impact of each policy scenario with a focus on the poorest households in the urban area of Buenos Aires.

To investigate the respective impacts of cost recovery fares associated with compensatory policy options along the efficiency, spatial, environmental and redistributive dimensions, we use a simple land-use transport interaction model calibrated for the urban area of Buenos Aires, NEDUM-2D (Viguié and Hallegatte 2012), which can account for all these dimensions. Many land use – transport integrated models (LUTI) exist and the applied research community has made great progress on these in the past decades. No single LUTI model however is perfect and the choice of the most appropriate model is very dependent on the research question and the degree of detail/simplicity which is expected. A number of criteria explain the choice of NEDUM-2D: 1/ it is a simple and understandable model – not a black box; 2/ it is one of the only ones that describes the housing and land market with micro-economically founded behaviors; 3/ it is not a data greedy model which makes it usable in data scarce situations and 4/ it is a dynamic model which can capture the impacts of shocks and transitions, including adjustment costs. As we will see below, however, the model is not able to capture all the mechanisms that would be required to answer all questions, and we explore options for further developments.

A series of results emerge from our exercises which paint a complex picture of transit subsidies and alternative cost-recovery options in the urban area of Buenos Aires. First, there are efficiency/welfare gains associated with replacing the transit subsidy by a lump sum transfer. These are non-negligible when subsidization rates are high. In the case of Buenos Aires, the average gains would correspond to an extra US$ 325 per household when expressed in equivalent income or 1.75% of the average household's annual budget in 2014. Our definition of welfare includes only consumption of housing space and other goods. For example, we do not explicitly account for distributional impacts or various externalities such as the access of the poorest to economic opportunities and the associated benefits of social inclusion. Nor do we feature specific preferences such as preferences for low density housing. For these reasons we will refer to consumption-related welfare in the rest of the paper.

Second, the removal of the transit subsidies leads to moderate reductions in urbanization over time. This indicates that the argument that low transit fares could fuel large amounts of sprawl in the future and associated infrastructure costs are likely to be overplayed. The changes in the internal structure of the urban area of Buenos Aires are much larger however with higher densities close to jobs and a decrease in the average distance to jobs triggered by the removal of the subsidy, which in turn reduces commuting distances. So, although public transport ridership decreases in the medium to long term as a result of the fare increase, the increase in commuting related CO_2 emissions is expected to remain limited. In fact, if the transit subsidy is replaced by a targeted construction subsidy, the model predicts a net reduction in emissions by 0.7%. The most CO_2 intensive policy alternative is the lump transfer with emissions increasing by more than 5% in 2050.

Thirdly, whereas some efficiency gains are to be expected from replacing the transit subsidy by a lump sum transfer, these will come at the expense of short term harsh redistributive impacts for the heaviest users of public transport. These negative redistributive impacts are stronger as the distance to the city center increases. For tenants, they will be partially mitigated over the medium term by land and housing markets mechanisms whereby the hardest hit areas of the urban area will see a decrease in housing rents reflecting lower accessibility. This adjustment in housing prices will benefit tenants and newcomers to the urban area but will penalize homeowners residing in these areas as they will face both higher commuting costs and lower resale values of their dwellings. The high rate of home ownership, across all income groups in Buenos Aires, including the poor, increases the negative impact of higher transit prices.

The remainder of this paper is structured as follows. Section 2 provides a literature review of the welfare, spatial, environmental and distributional impacts of transport and construction subsidies. Section 3 describes the history and functioning of transit subsidies in Argentina and Buenos Aires in particular. Section 4 investigates the welfare impacts of a public transport subsidy in a very simplified urban economics framework and describes the mechanisms at play. Section 5 describes the principles and mechanisms of the land use – transport modeling framework, NEDUM-2D, used in the remainder of the paper to assess the impacts of the transit subsidy in Buenos Aires and of alternative policy options. It also shows how simulations compare to data which serves to validate the use of the model. Section 6 describes the various cost-recovery options studied and how they affect the extent of the urban area and the CO_2 emissions from commuting as well as households' welfare. Section 7 investigates the distributional impacts of removing the public transit subsidy and replacing it by a lump sum transfer for all income groups in the urban area of Buenos Aires. Finally, section 8 concludes.

2 Literature review

There is a relatively well established literature focusing on the link between welfare and transport subsidies starting with Mohring (1972). This seminal paper argued that in the presence of scale economies in public transport provision (for example because a train or a bus is indivisible), marginal cost pricing schemes would lead to low public transport ridership which in turn would result in low frequencies and long (and sub-optimal) waiting times for users. This Mohring effect would warrant public transport subsidies so as to reduce waiting times and increase welfare. The magnitude and even the existence of the Mohring effect is however debated (Estupiñán et al. 2007). Gwilliam (2017) in his recent review on transport pricing emphasizes that if urban transport can be considered as a "merit good", i.e. a good which is undervalued by its consumer and the consumption of which generates positive externalities, this would provide a theoretical basis for subsidization. There are reasons to argue that urban transport indeed is a "merit good" as the accessibility for example to an increased number of jobs generates positive externalities through larger and more integrated labor markets (Rosenthal and Strange 2004). Other scholars (I. W. Parry and Small 2009; I. W. H. Parry and Timilsina 2010; Basso and Silva 2014) have built models and frameworks which aim at identifying optimal transportation policies in urban settings in the presence of externalities such as congestion, CO_2 emissions contributing to climate change, air pollution and road fatalities. All these papers find positive welfare effects associated with transit subsidies. But they argue that transit subsidies are only a second best and are dominated by policies which affect congestion (the main negative externality) more directly such as congestion tolls, gasoline taxes or dedicated bus lanes. However, these models are non-spatial in essence and although they are evaluated in urban settings they do not represent households' locational decisions explicitly. This means that they miss the tradeoff between housing and transport costs and may underestimate the benefits that policies which decrease transport costs may bring (because they can also decrease housing costs for residents) and conversely overestimate the benefits of policies that increase transport costs such as congestion tolls.

The reliance on non-spatial models also means that it is not possible to shed light on the urban expansion consequences of transit subsidies and their associated costs. To fill this gap, scholars have resorted to the classic urban economics framework based on the pioneering works of Alonso (1964), Mills (1967) and Muth (1969). In urban economic theory, a decrease in transport costs tends to flatten the land and housing rent curves thereby encouraging residents to settle further away from the city center and displacing the urban area's boundary outwards (see for example Fujita (1989)). Whether transport subsidies lead to urban sprawl when the decrease in transport costs is financed through income taxation is however not as trivial. Brueckner (2005) tackles this issue and shows that despite the higher tax burden needed to finance a transport subsidy, the transport cost reduction dominates the tax burden effect and leads to urban sprawl. He also concludes that if the transport system displays constant returns to scale, the subsidy is welfare reducing. Building on Brueckner's work, Su and DeSalvo (2008) develop a monocentric model with two modes, cars and transit, which are characterized by different fixed and marginal costs as in LeRoy and Sonstelie (1983). The authors also employ empirical methods. They find that car subsidies tend to increase the size of urban areas while transit subsidies would reduce sprawl. In both cases the effects are limited in magnitude. Conversely, while they do not directly assess the spatial impact of any transport subsidization scheme, Gonzalez-Navarro and Turner (2014) study the impact of subway system construction in 138 cities around the world and conclude that they have caused population decentralization. It is not obvious how to make sense of these contradictory results. There are a number of subtle mechanisms at play, which would push the overall net result in one direction or another: 1/ a higher tax burden to finance the transit subsidy would tend to curb sprawl by reducing available income for housing space consumption; 2/ the lower transport cost would push the urban area's boundaries outwards; and 3/ because public transit is by nature more localized than road (think of bus or urban rail stops for example) we could have a combination of more concentrated population with transit subsidies around transit stops and a larger urban footprint.

Scholars have also investigated the distributional impact of transit subsidies by distinguishing between income groups (Estupiñán et al. 2007; Basso and Silva 2014) but also between renters and landowners (Borck and Wrede 2005, 2008). Basso and Silva (2014) find that congestion pricing, dedicated bus lanes and, more importantly for this paper, transit subsidies unambiguously increase the welfare of the poorest. Borck and Wrede (2005, 2008) use a monocentric model with two income classes to study the reasons for popular support to transport subsidy schemes despite clear inefficiencies. Their conclusions are less straightforward. When only one transport mode is available, they show that transport subsidies can benefit all residents in the case of absentee landowners at the expense of the landowners. When conversely all land is owned by residents of the urban area, commuting subsidies lead to a distributional antagonism between central residents and suburbanites. While the rich would benefit at the expense of the poor if they reside in the periphery, benefitting proportionately more from the subsidy, the poor do not necessarily benefit if they live on the outskirts (Borck and Wrede 2005). Borck and Wrede (2008) then complete their model by introducing two distinct transport modes, cars and public transport. In this case the conclusions are much more subtle as the winners and losers depend not only on their location within the urban area and whether they are landowners or not but also on the commuting mode they use.

Finally, Estupiñan et al. (2007) conduct an in-depth review of real world transit subsidy schemes and focus on whether they are pro-poor. They find that whereas in developed countries transit subsidies mainly benefit the poor, this is mostly not the case in developing countries where transit remains a luxury good. The authors argue that, as the more wealthy urban residents benefit more than the poorest, a lump sum transfer would actually be a better device to reach the poor than a transit subsidy. In particular, they document that the transit subsidy program in the Buenos Aires region disproportionately benefits the middle income class rather than the poor, although subsidized fares are available to all. There are indeed significant errors of exclusion, defined as the share of the poor (the bottom quartile) not benefitting from transit subsidies because they do not use transit. For bus users the error of exclusion was as high as 70% in 2002 and 60% in 2006 (Bondorevsky 2007). Conversely the errors of inclusion, defined as the share of beneficiaries which are non-poor was 59% in 2002 and 75% for bus users in 2006 (Bondorevsky 2007). These figures indicate that if the aim of the transit subsidy is to provide the poor with urban transport options then the targeting is inefficient, resulting in both bad resource use and low accessibility for the poor.

To the best of our knowledge, the most comprehensive effort at addressing welfare, spatial, environmental and distributional impacts of transport subsidies is a paper by Tscharaktschiew and Hirte (2012). The authors develop a Computable General Equilibrium model, inspired by Anas and Xu (1999) and Anas and Rhee (2006), which includes many real world features such as congestion, polycentric urban structures, multiple household types, different trip purposes and endogenous labor supply among others. They calibrate their model so as to reproduce the main features of an 'average' German city and test a wide range of urban transport subsidies schemes; one of them being a variant of a transit subsidy in the form of a reduced sales tax rate on public transport fares. The authors find that transit subsidies lead to only low levels of suburbanization, are welfare enhancing (including for landowners) and decrease CO_2 emissions.

The urban economics literature is surprisingly silent on the issue of construction subsidies, despite the acknowledgment that land and housing markets are central to urban development. Construction and buildings have rightfully been investigated because their durability imposes some path dependencies in cities (Duranton and Puga 2015). Other scholars have focused on the impact of building height regulations on welfare and spatial expansion (Bertaud and Brueckner 2005) and on environmental externalities such as CO_2 emissions (Borck 2016). It is however surprising that in a world which faces large housing deficits (estimated to be a billion homes according to UN-Habitat), especially in the rapidly urbanizing developing countries, little attention has been paid to the potential impact of construction subsidies. This is perhaps even more surprising as the compact city concept has gained a lot of attention as a sustainable urban growth trajectory (OECD 2012). Indeed, whereas compact cities carry the potential to reduce commuting related CO_2 emissions, their critics often argue that they would lead to higher housing costs (Krupp and Acharya 2014) and the actual densification of an urban area would prove difficult because taller buildings are typically too costly (Castel 2007). In this respect, construction subsidies – justified by the positive externality of higher densities – seem like an a-priori promising avenue to reduce the housing deficit while enabling the construction of taller building and therefore achieving more compact and sustainable cities without leading to strong housing price increases. As Glaeser (2009) puts it "The best thing that we can do for the planet is build more skyscrapers." A notable exception to this silence is Helsley and Strange (2007) who develop an urban economics model where positive externalities are generated by social interactions. They find that a construction subsidy can increase the housing supply near the city center and lead to a densification of the urban area which would promote social interactions and therefore increase social welfare.

3 Public transport subsidies in the metropolitan area of Buenos Aires

Following the 2001 crisis and the peso depreciation which led to spiraling inflation in Argentina, public transport fares were frozen (or increases were restrained) in an attempt to dampen the impact of rising prices and protect the incomes of the poor. In parallel, the costs of operating public transit systems increased strongly in part as oil imports were purchased using a devaluated currency. The government provided direct (supply-side) subsidies to operators in order to maintain public transport service in a post-crisis period. While buses (colectivos), which today account for 87% of the public transport ridership, were not subsidized prior to the 2001 crisis, subsidies now account for over two-thirds (71%) of their operating costs. The average commercial fare of AR$ 3.5 can be compared to the AR$ 12 average fare necessary to achieve cost recovery. On the regional railway and metro (SUBTE) systems subsidization rates today represent respectively 94% and 68% of operating costs. Their passenger market shares are however much lower than for buses at 7% and 6%. In total, the public transport subsidies in the Area Metropolitana de

Buenos Aires (AMBA) amount to AR$ 25 billion or around US$ 5.4 billion[3] in 2012 which represents close to 0.7% of Argentina's GDP.

While public transport is subsidized in other metropolitan areas in Argentina, the subsidization rates are lower and the minimum bus fares are higher: AR$ 6 and AR$ 9.15 in Mendoza and Córdoba respectively for example compared to AR$ 3 in AMBA.

The public transit subsidies in Argentina are currently financed by the Treasury (85%) and SISTAU (Sistema Integrado de Transporte Automotor) for the remaining 15%. The SISTAU funds are based on a 18.5% tax on gasoline while the Treasury funds are channeled through the RCC (Régimen de Compensatión Complementaria). Together the Treasury funds and SISTAU finance 72% of the operating costs of public transport systems in AMBA while earnings from travel fares account for the remaining 28%.

How does this compare to other cities worldwide? These public transport subsidization levels are commonplace in developed countries; for example they reach around 70% of operational costs for the largest 20 cities in the United States (I. W. Parry and Small 2009), 55% in London, 70% in Paris (Institut Montaigne 2012) and the Millennium database reports similar figures for many developed country cities around the world (Kenworthy, Laube, and Vivier 2001). In developing country cities however, public transport subsidies are very low or non-existent. In this respect, Argentina and above all the Metropolitan area of Buenos Aires are exceptions (Basso and Silva 2014).

Beyond the general discussions about public transport subsidy merits and potential inefficiencies that are mentioned in the introduction and literature review, there are a couple of specific points that deserve to be reported here. First, public funds have an opportunity cost, meaning that when they are mobilized for financing public transit systems, they are not available for other priorities such as education, health and sanitation for example. While public funds have opportunity costs in all countries and at all times, the necessity to allocate them wisely is arguably more critical in a developing country which is recovering from a major economic crisis as occurred just above a decade ago and where fiscal resources are likely to be scarcer than elsewhere. The need to evaluate whether these resources should be sunk into public transit subsidies or not is even more pressing as Argentina is an exception in the developing world in its choice to instore a transit subsidy scheme.

Second, the design of the scheme is conducive to some inefficiencies and perverse effects. Indeed, the supply side subsidies from the government are calculated so as to cover the deficits of the private transit operators. The latter therefore do not have any incentive to rationalize their operations and seek inefficiencies in their system as this would only result in a reduction of the subsidy level received from the government.

Thirdly, the massive level of subsidies poured into the public transit systems cover only the operational costs and leave very little available fiscal resources for investments and crucial maintenance of the public transport infrastructure. The lack of investment and maintenance has led to a slow degradation of the infrastructure and to the impossibility of keeping pace with urban growth through the addition of new routes or extension of existing ones.

The Argentine government is well aware of these issues and is exploring ways in which to reduce the fiscal burden of public transport subsidies without adversely impacting the poorest 40% of households which crucially rely on transit to reach jobs and other services. In early April 2016, fare increases were

[3] All monetary values were converted into US$ for data consistency. The exchange rate that is used throughout this exercise is AR$1 = US$0.2198. The conversion factor was retrieved from the web for the month of July 2012.

implemented with a doubling of the minimum fares for buses and trains (fares for colectivos now stand at min AR$ 6; trains AR$ 4); and recently fares for SUBTE (metro) also increased. Operating subsidies for buses have been reduced to 66%. Alongside this process, the government has also been offering demand-side subsidies to protect the poor from these fare increases. In this study we do no account for the changes in transit fares that took place in 2016 and rely on the subsidization levels and fares prior to these increases.

4 What is the efficiency of public transit subsidies and other policies?

To explore the efficiency of transit subsidies in a general case we will compare these to a policy option whereby transit subsidies are removed but a lump sum redistribution of the total initial transit subsidy savings is introduced. Comparing transit subsidies to a lump sum transfer is justified because lump sum transfers are usually deemed to be a more efficient public intervention as they do not distort household choices toward the consumption of a specific good, in this case transport. The comparison of the outcomes of a transit subsidy with that of a lump sum transfer through the measurement of households welfare and landowners' profit in an urban economy aims to provide a benchmark for measuring the (in)efficiency of a transit subsidy (through orders of magnitude). We will focus distinctly on households' and landowners in order to untangle the impacts of removing a public transit subsidy and compensating through lump sum transfers for each group of actors in the urban economy.

4.1 A simple model to compare lump sum transfers to transit subsidies

To investigate the efficiency of public transport subsidies, we will first focus on a very simple and schematic case. We use a monocentric model based on the works of Alonso (1964), Mills (1967), Muth (1969) and comprehensively described in Fujita (1989). This model displays one city center which is the commuting destination of all households of the urban area (the CBD). There is only one transport mode and we run the model in a static framework, i.e. at equilibrium with only one time period. In this simple model, residents derive utility from housing space q and a composite good z:

$$Max_{r,z,q}\ U(z,q) \qquad s.t. \quad z(r) + R(r)q(r) + T(r) \leq Y + \bar{L} \tag{1}$$

Each worker has to commute once a day to the CBD, and this commuting entails transportation costs $T(r)$. All households are supposed to earn the same income Y and – at the equilibrium – they have the same level of satisfaction described by a utility function U. The level of rents per square meter (or, equivalently, the annualized real estate price per square meter) is $R(r)$, at each location in the city. Each household maximizes his utility function under the budget constraint described in (1) by choosing where to settle in the urban area r, how much housing space q to consume and what to spend on other goods z. The term $\bar{L}$ represents the annual amount accruing from land rents per household which is recycled in the urban economy in the form of increased incomes.

In parallel, developers decide how much floor space to build and where in the city. They do so by choosing the amount of capital to invest at a specific distance to the city center $K(r)$ in order to maximize their profit function which also represents land values.

$$\pi(r) = [(R(r) - R_0)F\big(K(r), L(r)\big) - (i+\rho)K(r)] \tag{2}$$

The amount of floor space built and the annual land rents depend on an exogenous specific construction technology which displays decreasing returns to capital: $H(r) = F(K(r), L(r))$. These decreasing returns to capital will cap the building heights and as consequence the total amount of residential floor space. Developers will only invest large amounts of capital to build tall buildings when the anticipated rents they expect will offset the extra building costs. The edge of the city is given by a transaction cost R_0 below which it is no longer profitable to build. At the edge of the city (r_f) we therefore have $R(r_f) = R_0$.

The term $\bar{L}$ found in (1) can schematically take on one of two values depending on the type of model used: Closed City model with Absentee landowners (CCA) or Closed City model with Public ownership of land (CCP). In the closed city model with absentee landowners (CCA), landowners are supposed to live outside the urban area which means that land rents are not recycled in the local economy in the form of increased incomes. In this case $\bar{L} = 0$. At the opposite end of the spectra, if all land plots are supposed to be owned by a local government (or by all households in equal shares) then $\bar{L} = \int_0^{r_f} \frac{\pi(r)}{N} dr$, where N is the number of households in the urban area.

The functional forms used in this paper as well as more details on the construction function can be found in appendix 10.1

4.2 Numeric simulations: Aggregate welfare description of results

4.2.1 Impacts on tenants and landowners of replacing a transport subsidy with a lump sum transfer

Solving the static model described in 4.1 with specific functional forms described in Appendix 10.1 in the closed city model with Absentee landowners (CCA), it can be shown that the impacts of replacing a transport subsidy by a lump sum transfer are complex. We run a numerical model with a number of realistic values for key parameters and data values for the model in 2012 described in Appendix 10.2, but with the assumption of a unique transport mode, linear transport costs, no land regulations and with a transaction cost of zero. We also assume, as in Parry and Timilsina (2010), that public transport displays constant returns of scale, meaning that only the variable costs of transport are accounted for and not the fixed costs linked to infrastructure provision. This is a reasonable proxy for buses which constitute the main public transport means. We run simulations for a large range of subsidization/taxation levels: from a 100 percent taxation level to a subsidization level equivalent to two-thirds of the transport costs. Impacts of these transportation policies on tenants' welfare and landowners' aggregate profits are depicted in Figure 1 and Figure 2.

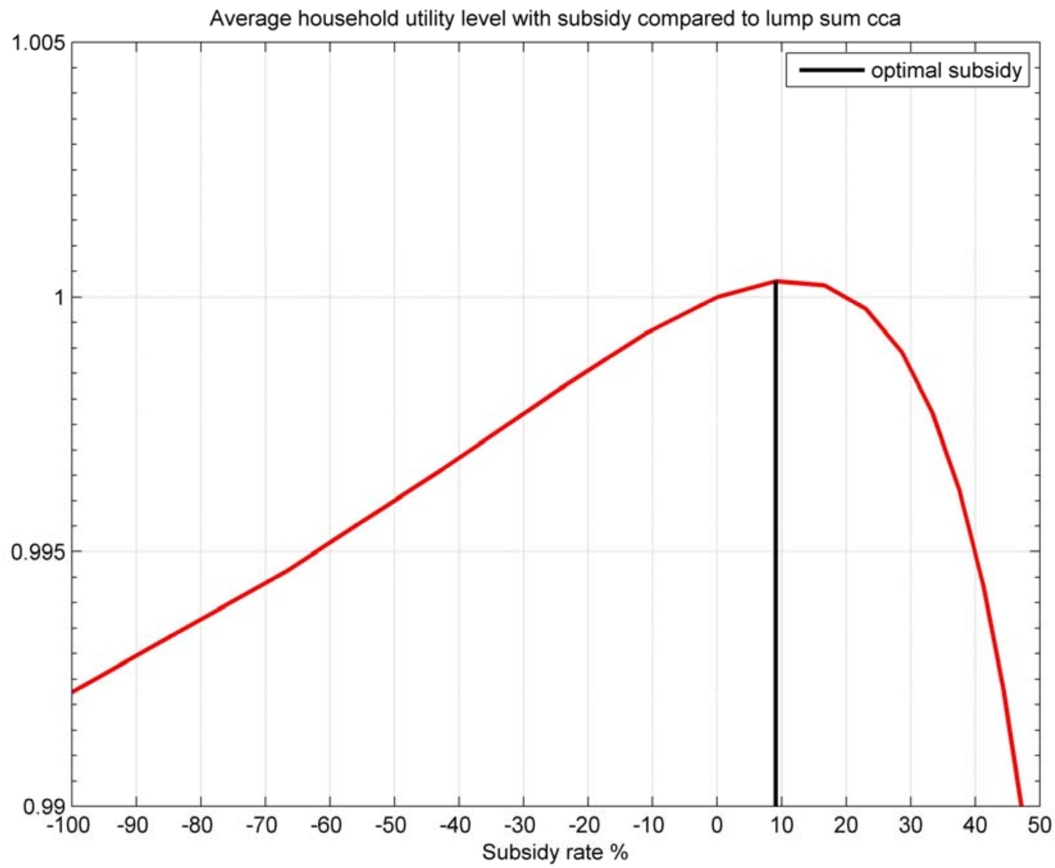

Figure 1: Comparison of tenants' consumption-related welfare with transport subsidies and lump sum transfers in a Closed City model with Absentee landowners (CCA).

Figure 1 shows that transport taxes/subsidies (transport taxes are the negative values on the x-axis while subsidies are the positive ones) are generally detrimental to tenants' welfare when compared to lump sum transfers. This is visible from the curve representing the ratio between tenants' utility with subsidies and with lump sum transfers mostly being lower than one. However, there are some values of the transport subsidies for which tenant's consumption-related welfare is higher with subsidies. These welfare improving subsidization rates are 9% and 17% with the optimal subsidization rate being 9% and with welfare improving very slightly by 0.03% by comparison to lump sum transfers which makes it visually difficult to discern on Figure 1.

The transport subsidy relaxes tenants' budget constraint and allows them to settle further from the city center, thereby consuming more floor space and land at a cheaper unitary rate. As such a transport subsidy transfers rents from landowners to tenants as can be seen in Figure 2.

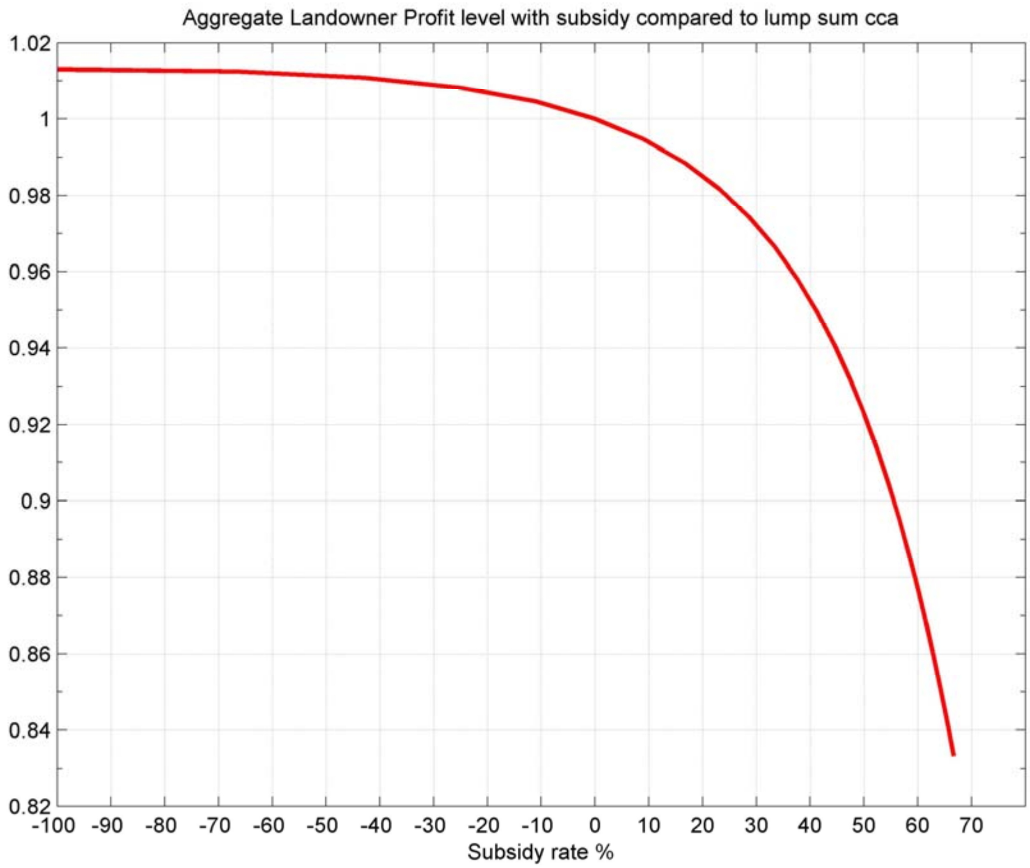

Figure 2: Comparison of Aggregate Landowners' profit with transport subsidies and lump sum transfers in a Closed City model with Absentee landowners (CCA).

When the subsidization rate is positive, it can be seen that landowners' aggregate profit decreases with the subsidy relative to lump sum transfers in a closed city model with absentee landowners. The opposite is true for transport taxation which increases landowners' profits. The implicit transfer of wealth from landowners' to tenants triggered by the transport subsidy is sufficient to increase tenants' welfare relative to lump sum transfers for specific subsidization rates as documented above (Figure 1).

In Buenos Aires urban area, as documented in section 3, public transport is subsidized by around two-thirds. We are therefore mainly interested in depicting the impacts of a drastic subsidy of 67%. It can be shown that replacing this level of transit subsidy with a lump sum transfer:

- increases household utility by 5.20%
- increases Aggregate Landowners' Profits by 20%

We can draw two conclusions from this section. First, transport subsidies are not unambiguously negative for tenants in a closed city model with absentee landowners (CCA). In fact, low levels of transport subsidies (between 9% and 16%) can marginally increase tenants' consumption-related welfare relative to lump sum transfers. This impact can be interpreted as a wealth transfer from landowners to tenants and is consistent with findings in Gusdorf and Hallegatte (2007). Second, a transport subsidization rate as high as 2/3 of the transport cost constitutes a less efficient means of improving both welfare and land rents than a lump sum transfer. In particular transport subsidies hurt landowners quite harshly compared to a lump sum transfer.

Household utility and landowners' profits are however difficult to compare because landowners' total profit is measured directly in monetary terms, whereas households' utility level is a convenient yet abstract construction which cannot be directly translated into a monetary value. We would, however, like to understand how a transit subsidy performs against a lump-sum transfer policy through one unique indicator.

4.2.2 Moving toward a city model with land rents recycling in the local economy

One way of achieving a unique indicator of the welfare impact of transport subsidy for landowners and households is to incorporate landowners' proceeds into the households' utility function by switching to a Closed City model with Public ownership of land. As detailed above, in such a model, landowners' rents are recycled in the local urban economy through increased household incomes. This corresponds to a case whereby, $\bar{L} = \int_0^{r_f} \frac{\pi(r)}{N} dr$. This is equivalent to assuming that one dollar has the same value for tenants and for landowners, or that both groups have the same marginal utility of consumption. While this representation is still a simplification, it does make sense for Argentina where the rate of dwelling ownership is very high, close to 80% over all income quintiles (Fay 2005, pp 93) reported for the early 2000s. It also allows us to take into account the impacts of transit subsidies and lump sum-transfers on land rents in the form of a welfare impact.

With a fully closed city model with public ownership of land, it can be shown that the optimal subsidization/taxation level is zero (Figure 3), which is consistent with findings from Brueckner (2005) and Gusdorf and Hallegatte (2007) among others.

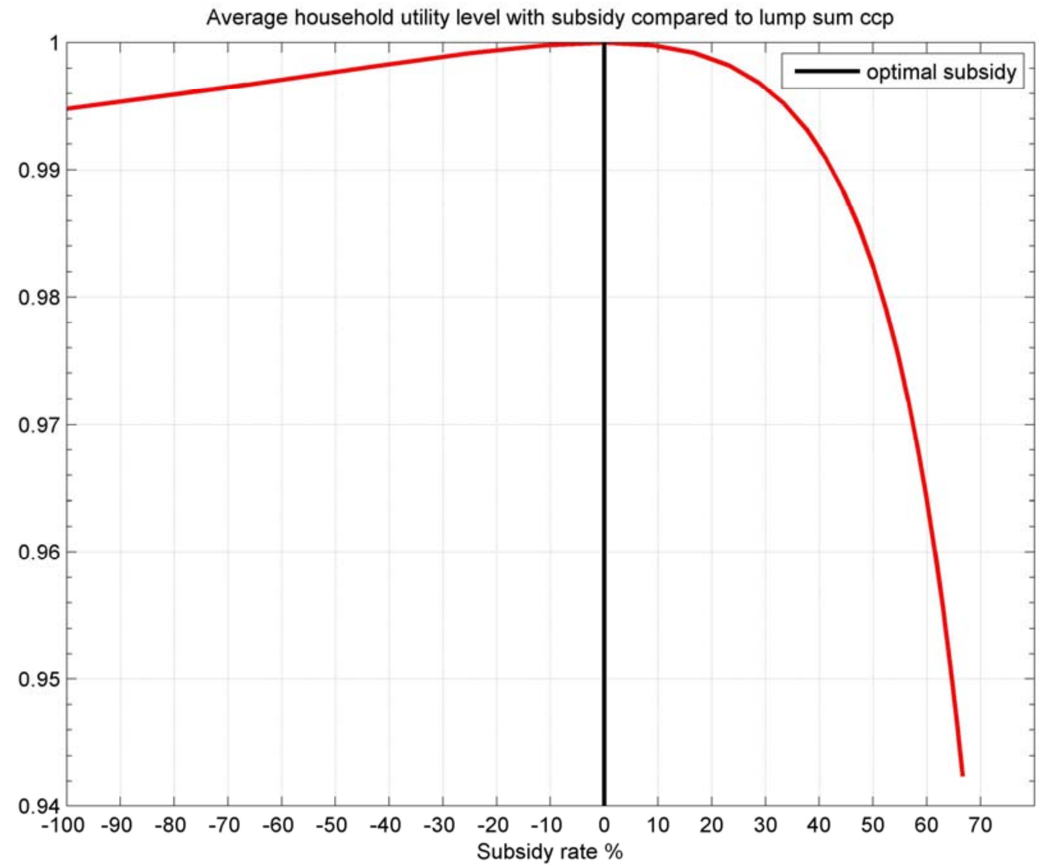

Figure 3: Comparison of household consumption-related welfare with transport subsidies and lump sum transfers in a Closed City model with Public ownership of land (CCP).

While the uncompensated removal of the transit subsidy (equivalent to two-thirds of the transport costs) leads to 22.6% decrease in household utility, the compensation in the form of a lump sum transfer yields a 5.7% increase compared to the baseline scenario with transport subsidies. This result confirms the economic intuition that cash transfers are preferable to subsidies because they allow households to choose how to use them, thereby providing them with a supplementary degree of liberty.

But these results should be interpreted with caution for a number of reasons. First, the increase in consumption-related welfare triggered by switching from a transport subsidy to a lump sum transfer depends on the level of recycling of land rents into the local economy. Second, this increase in welfare depends equally on the rate of subsidization of the transport system. In both cases, welfare improvements from replacing the subsidy by cash transfers are higher when 1/ the ratio of land rents recycling into the local urban economy is high and 2/ the transport subsidization rate is high. Both these effects are depicted in Table 1:

		Transport subsidization rate		
		1/3	1/2	2/3
Share of land rents recycled in the local urban economy	0: Absentee landowners (cca)	0.2%	1.3%	5.2%
	0.2	0.3%	1.4%	5.4%
	0.5	0.4%	1.6%	5.7%
	0.8	0.4%	1.7%	5.9%
	1: Public ownership of land (ccp)	0.5%	1.8%	6.1%

Table 1: Consumption-related welfare impacts of replacing a transport subsidy by a lump sum transfer as a function of subsidization rates and ratio of land rents which are recycled into the local urban economy.

Table 1 shows that potential welfare gains are large with a lump sum transfer rather than a transport subsidy, especially if subsidization rates are high and land rents are recycled in the local urban economy, which is the case in Buenos Aires. This warrants a more in depth exploration of the welfare impact of transit subsidies in a more realistic model tailored for the urban area of Buenos Aires.

This picture omits two important dimensions of the discussion. The first is the dynamics of urbanization and in particular how each policy influences urban sprawl and its associated infrastructure costs and transport emissions. The second is the re-distributional impacts of each policy. To look into these dimensions we need a model which is spatially explicit so as to capture realistically the urbanization trajectory of the urban area of Buenos Aires and how the poor will be affected by an increase in public transport fares. The next section will present the model that we use in the rest of this paper while sections 6 and 7 will address the urban sprawl, environmental, welfare and political economy issues involved with public transit subsidies and other alternative policy options.

5 Dynamic model NEDUM-2D

5.1 General principles of NEDUM-2D

A theoretical framework that reflects the interplay between households' localization decisions, project developers' construction decisions and transport costs is required to evaluate the impacts of removing public transport subsidies in an urban area. The NEDUM-2D model (Non Equilibrium Dynamic Urban Model) developed in CIRED (Viguié and Hallegatte 2012) is well suited to conduct such a study.

This tool is an extension of the standard urban economic model such as defined by Fujita (1989) building on the pioneering works of Alonso, Mills and Muth at the end of the 1960s (Alonso 1964; Mills 1967; Muth 1969). It aims at explaining the variation in land costs in cities and thus the level of real estate prices together with the distribution of the households and buildings in an urban area. Classically, it is based on two very simplified, yet realistic, fundamental mechanisms. First, households, when choosing where to live, trade off between the proximity to the city center and the level of real estate prices (or equivalently between the proximity to the city center and the size of the dwelling they will occupy). Second, the project developers (or landowners[4]) maximize their profits and choose to build more or less housing surface in a given place depending on the level of real estate prices. The higher the real estate prices, the denser the developers choose to build. We assume that the land is publicly owned (or equivalently owned in equal value shares by all households of the urban area) and that the annual rents generated are entirely recycled

[4] A standard calculation (Fujita, 1989) proves that this hypothesis does not change the results of the model : in the model, the reasoning and the calculations that are conducted are identical whether project developers have to rent or buy the land from landowners.

into the local economy in the form of increased income. A description of the analytical framework used to express these mechanisms can be found in Appendix 10.1 which goes into the details of the main analytic relationships but section 4.1 has already introduced these in their most basic form.

NEDUM-2D differs from the standard model developed in Fujita (1989) for three main reasons. First, it can be used dynamically, which enables to take into account the effect of a global change in income or population. As explained in Gusdorf et al. (2008), urban economics has mostly been used to explore the characteristics of long run equilibria. However, the existence of urban stationary equilibria is questionable: when population, transport prices, or income vary (sometimes in unpredictable ways), housing infrastructure cannot adapt instantaneously to changing conditions. NEDUM-2D explicitly takes these dynamics into account and describes cities as non-equilibrium systems. The model can also be run at the equilibrium for a specific year if data for a larger time period are not available.

Second, the theoretical model described by Fujita (1989) represents spatial differences solely as a function of the distance to the city center. As the name suggests NEDUM-2D is two dimensional meaning that it is an urban model that represents urbanization on a map rather than on a single axis. NEDUM-2D uses a grid with cells of variable size (classically 1km²). It can therefore account for spatial differences in land use and accessibility at a much finer scale. The model can represent differences between two cells situated at the same distance from the city center such as the amount of land that can be built upon or the proximity to public transport.

Third, the classic urban economy model only represents one means of transport. In NEDUM-2D there are three main transport options: private cars, public transport and walking. For each location in the urban area, citizens choose between walking, public transport and private vehicles, or a combination of these as a means for commuting. The competition between these modes is organized on the basis of their *generalized costs* (i.e. the total cost including both the cost of time and the monetary costs incurred during the trip to the city center). It is assumed in this study that modal switch does not affect congestion levels and therefore leaves commuting times unchanged. In order to reflect the heterogeneity of citizens' preferences in terms of transport modes we employ a discrete choice model (De Palma and Thisse 1987). We follow a common approach in transportation economics by using a multinomial logit model which assigns usage probabilities to each transport mode (see Salon 2009; Washbrook, Haider, and Jaccard 2006). This method ensures that even when one mode is much cheaper than the others, it will not be used by all residents in a location for all trips.

In the present study, we use this model with a certain number of simplifying hypotheses. First, we assume that all households commute every day to the center of the *Ciudad Autónoma de Buenos Aires* (CABA), where jobs are assumed to be located. This mono-centric hypothesis is a clear simplification but one that is widely used in the literature and that finds some support in the data for the specific case of Buenos Aires. Indeed, the Buenos Aires region displays a strong mono-centric structure. For instance, in 2012 more than 40% of all jobs in the Buenos Aires region are localized in CABA even though CABA only represents 5.3% of *Region Metropolitana*'s area (see Appendix 10.1.5 for a more in-depth discussion about the validity of the mono-centric assumption for the Buenos Aires urban area) [5].

Second, NEDUM-2D also relies on the hypothesis that all households within the urban area earn the same average income. It does not currently account for multiple household types and thus ignores income

[5] Projections for 2012 based on Censo Nacional Economic 04/05 (CNE 04/05) and Encuesta Permanente de Hogares, 2011 (EPH, 2011).

inequalities[6]. This simplification is acceptable for some indicators such as the extent of urbanization. However it can have some impacts for NEDUM-2D's ability to capture the dispersion in rents and real estate prices around an average. Indeed, real estate prices are strongly affected by neighborhood characteristics among which social segregation can play a role. We will overcome this limitation to a certain degree below by interacting our results with a map of current income dispersion.

5.2 Geographic scope of the study

The study area is slightly larger than what the INDEC (Instituto Nacional de Estadística y Censos de la República Argentina) defines as the Gran Buenos Aires (GBA). GBA encompasses 24 fully or partially urbanized partidos and the City of Buenos Aires (CABA). Supplementary to the 24 partidos of GBA, our study area also includes 3 other partidos. Altogether the study area that we will name GBA+ in the rest of this report can be broken down as follows:

- The city of Buenos Aires (CABA)
- 14 fully urbanized partidos that belong to GBA:

Avellaneda	Lanús	San Isidro
General San Martín	Lomas de Zamora	San Miguel
Hurlingham	Malvinas Argentinas	Tres de Febrero
Ituzaingó	Morón	Vicente López
José C. Paz	Quilmes	

- 10 partially urbanized partidos that belong to GBA:

Almirante Brown	Florencio Varela	San Fernando
Berazategui	La Matanza	Tigre
Esteban Echeverría	Merlo	
Ezeiza	Moreno	

- 3 partidos that do not belong to GBA

Escobar	Pilar	Presidente Perón

The Gran Buenos Aires covers more than 3,800 km² of land and the GBA+ area is close to 4,000 km².

5.3 Validation of NEDUM-2D on the urban area of Buenos Aires (GBA+)

With a limited amount of data describing the size of the population, households' income, the transport system, land use, construction costs, households and developers' behavior, the mechanisms described above can reproduce the structure of an urban area in a fairly accurate way. This section aims at demonstrating this for the Buenos Aires region[7]. Appendix 10.2 provides an in-depth description of the data and parameters used in the simulations both for 2012 and for the projections.

The last phase in applying the NEDUM model to a city is to run a calibration procedure. This is done by comparing results (map of urbanized area, real estate/rents, population and housing density) to observed

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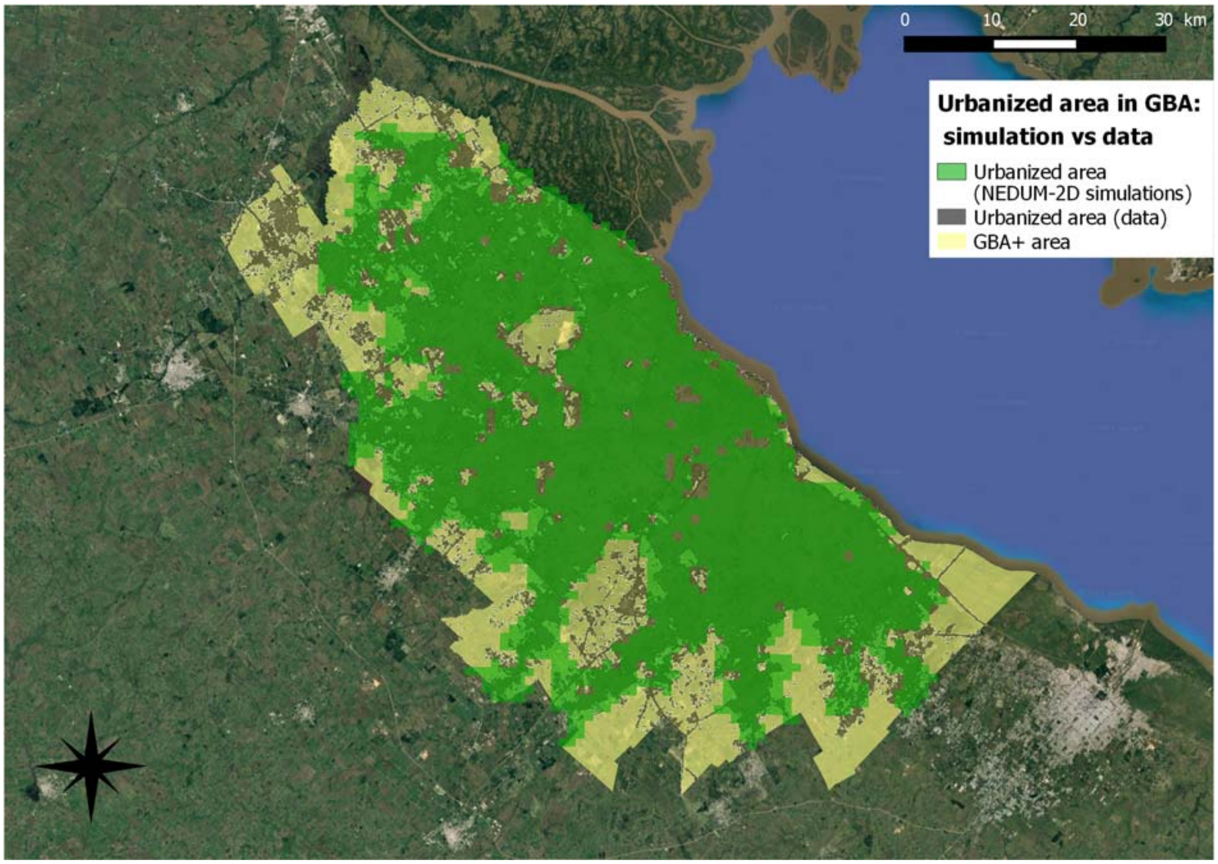
[6] A version of NEDUM-2D that is able to represent multiple household types differing by annual average income is currently being developed in CIRED.

[7] The model has been successfully applied to the urban area of Paris (Avner, Rentschler, and Hallegatte 2014; Viguié and Hallegatte 2012), London (Viguié 2012) and Toulouse (Masson et al. 2014).

data. Overall, the NEDUM-2D model is very robust as it relies on very simple basic economic behaviors that are likely to remain true both through space and time. As a consequence the calibration process is mostly done through refining the data that are used to inform the model. However, a very limited number of parameters can then be marginally modified so as to minimize the discrepancies between observations and model results.



Map 1 : The simulated and real urban area of the GBA+ region in 2012. The green shade corresponds to the simulation whilst the black is geographic data. The dark green shade shows areas where the model accurately predicts urbanization. Light green shows areas where the model inaccurately predicts urbanization. Black stands for areas where the model fails to reproduce urbanization. Finally where the map is yellow, there is no urbanization and the model agrees with the data.

It can be seen from Map 1 that the simulated and the actual urban area in 2012 coincide quite well within the GBA+ region (which appears in light yellow). The model captures the general size of urbanized area but also its shape and specific urbanization directions along the transportation network. There are however some discrepancies even within the GBA+ boundaries. In particular it can be seen that the map misses some areas towards the North and the North West of the GBA+ region. This can mainly be explained either by the existence of local secondary employment centers that attract settlements or the presence of local amenities.

The shape and size is one among other features of an urban area. Below we compare data with simulations for the distribution of land values and population densities.

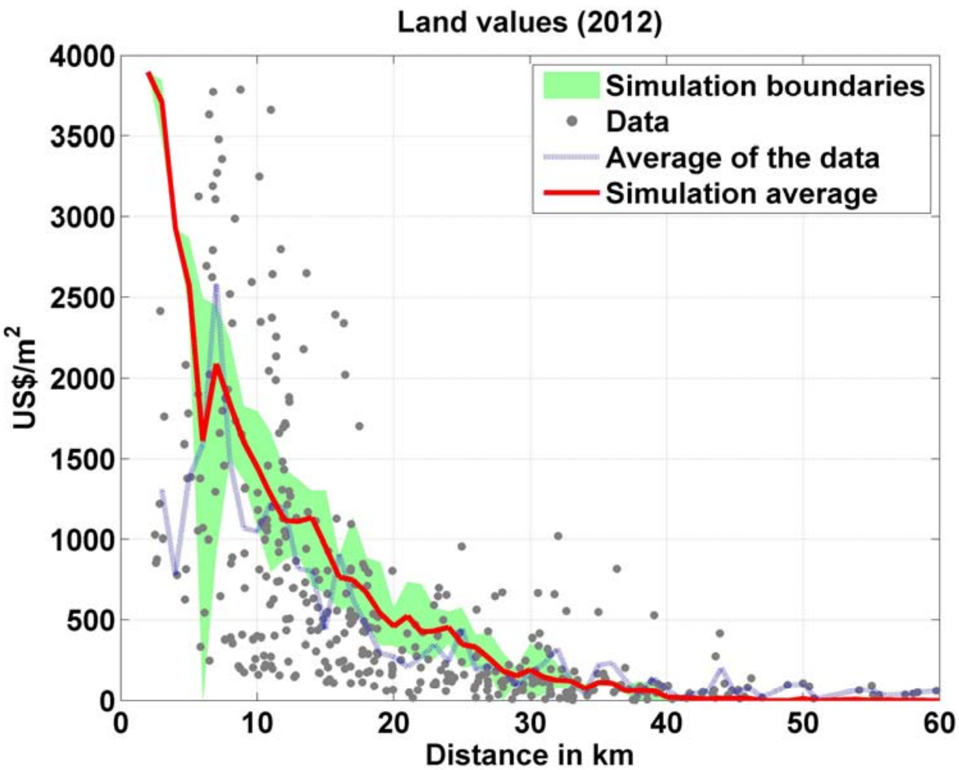


Figure 4 : Simulated and actual land values as a function of the distance to the city center.

Figure 4 shows the classic result that land values decline as the distance to the city center increases both in the data and the simulations. It shows land value data represented by grey circles as well as the average of the data (dashed blue line). The green area captures the spread of the simulations for a given distance to the CBD, while the red plotted line represents the average of the simulation. The one dimensional R^2 coefficient – comparing the averages of the simulation and the data – is 0.68 meaning that the model can explain 68% of the one dimensional variance in the data. The two-dimensional R^2 coefficient – comparing the each pair of simulation and data points locally – is lower at 34%. As we move closer to the city center, the model tends to either underestimate or overestimate land values. In particular, the model fails to reproduce the spike in land values visible around km 10. There is also quite a lot of dispersion in the data (grey dots) which is only partially captured by the model (simulation boundaries are represented by the light green area). This dispersion in the data is highest in the vicinity to the city center.

This phenomenon is likely to be explained by social segregation processes and the existence of amenities (such as good schools). As the NEDUM-2D version we use in this study only accounts for one average social group it fails to reproduce the segregation mechanisms. More generally land values are in reality not only determined by land developers' behavior. Land is subject to speculation and performs a 'reserve value' function that the model does not account for. Indeed, within the urban economics framework, the value of land is determined only by its value as an input in housing production. It is likely that this partial representation of the value of land leads to some discrepancies as the ones discussed above. For this reason, where they are available (not the case in Buenos Aires), it is better to calibrate land use transport models based on rents rather than land values. They indeed display much more regularity across time and space and are less subject to speculative behaviors.

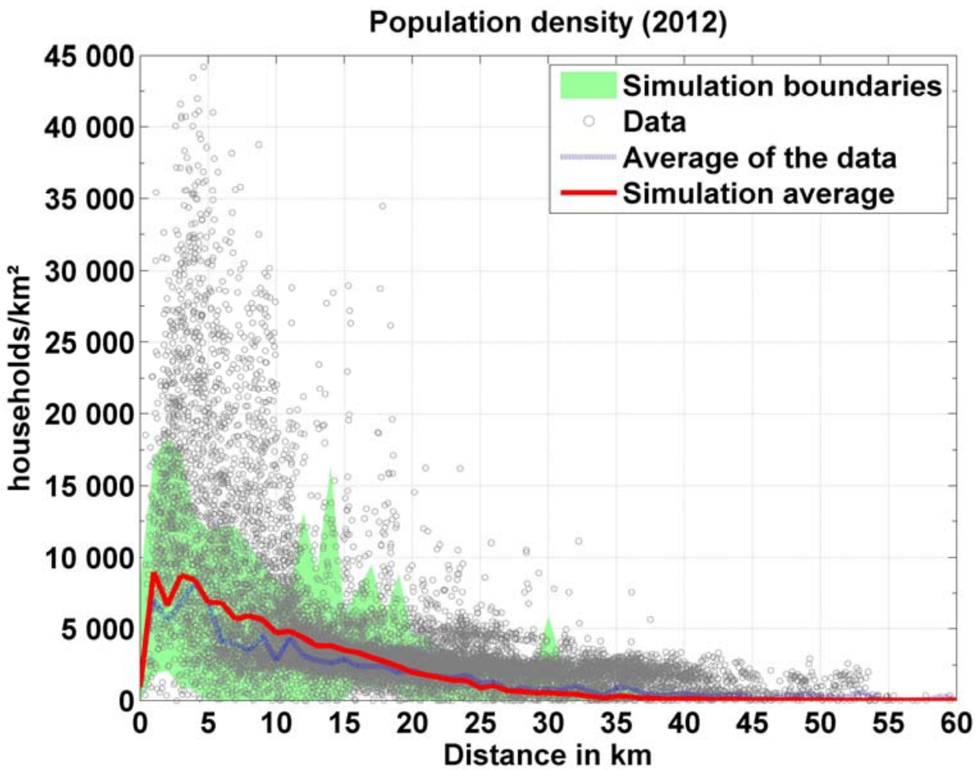


Figure 5 : Simulated and actual population densities for all radios in GBA+ as a function of the distance to the city center.

Figure 5 has the same color codes and purpose as Figure 4 but looks into whether and to what extent the simulations and the data agree for population densities at the census tract level (households/km^2). A similar conclusion can be drawn from the figure, that there is a general agreement on the shape of the two curves representing the averages of the data and the simulations. In particular, toward the city center, both curves display similar spikes and slumps. The model's spread also captures a large share of the data points (grey circles), although there is a greater dispersion in population densities of radios (census tracts) within 10km of the CBD that the model only partially accounts for. The one-dimensional R^2 coefficient is high at 0.95 meaning that the model can explain 95% of the variance between the simulation and data average. The two-dimensional R^2 coefficient comparing data and simulation at the census tract level, and accounting for the population of each census tract, is lower at 0.32.

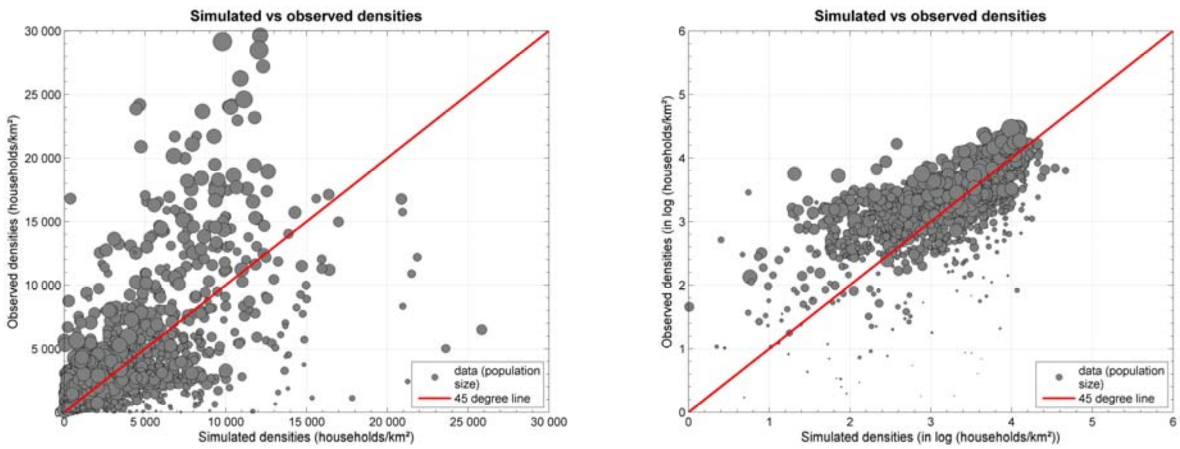


Figure 6: Comparison of simulated (on the x-axis) and observed (on the y-axis) population densities (densities on the left and log10 numbers on the right) at the *zonificaciòn* administrative level. The size of the bubbles is proportional to the population in each administrative unit.

Figure 6 usefully complements Figure 5. It shows on a scatter plot the differences and agreement between simulated and observed population densities at the *zonificaciòn* administrative level, which is slightly larger than a census tract. The closer the grey bubbles are to the 45 degree line, the better the correspondence between simulated and observed densities. Bubbles above the red line indicate that the model underestimates densities while bubbles below indicate overestimation. The left panel of Figure 6 shows a clustering of points toward the bottom left quadrant around the 45 degree line, indicating small discrepancies in absolute terms. The model however struggles to reproduce higher densities. It can indeed be seen that as the observed population densities increase beyond 15,000 households per square.km, corresponding simulated densities tend to remain around the 10,000 household per square.km threshold. The right panel of Figure 6 shows the same comparison in log format and is a useful complement to the right panel. It shows the clustering of points along the 45 degree line but indicates that, although small in absolute terms, the discrepancies are highest in relative terms for lower densities which the model tends to underestimate. Overall, when excluding areas where population density is low, below 10 households per hectare, in 46% of the census tracts (*radio censales*) and 51% of the slightly larger administrative units (*zonificaciòn)*, the absolute variation between simulated and observed density is below 50%[8].

The model is reasonably accurate (i.e. less than 50% variation) at medium distances (around 10 km from the city center). However it tends to overestimate population densities going towards the south of the city center and the North. It also clearly underestimates population densities as we move towards the urban fringe of the GBA+ region. As argued above, spatial discrepancies, in particular towards the urban area edge can be explained by the existence of secondary employment centers, social segregation or local amenities that NEDUM-2D does not model, and which attract households. Some major employment centers, indeed exist toward the North, Northwest and West of the urban area, precisely where it appears that NEDUM-2D underestimates population densities.

Finally, the model is also validated against several figures that describe mobility behaviors for households in the Buenos Aires metropolitan area. The mode share for public transportation, which is determined

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[8] If the population density threshold is lower, for example one and five households per hectare, then the agreement between the model goes down to 44% and 45% at the census tract level but remains stable at 50% and 51% at the *zonificaciòn* level. If the population density threshold is increased to 20 households per hectare, the agreement goes up to 49% at the radio level and stays at 51% at the *zonificaciòn* level.

endogenously in NEDUM-2D, is 56%, very close to the 57% average figure reported by the ENMODO mobility survey for the AMBA region (Ministerio del Interior y Transporte 2010). The average commuting times computed by the model is 54 minutes so slightly higher than, yet in the same magnitude order as the 44 to 49 minutes reported by ENMODO.

While we have shown some local discrepancies between model results and data, the calibration of NEDUM-2D is satisfactory overall for the main features of the internal structure of Buenos Aires urban area: size and shape of the urban footprint, population distribution, land values, average commuting times and mode shares. Improving the NEDUM-2D modelling framework so that it can account for multiple employment centers would improve the fit of the model to data. This endeavor is left for the future, with the belief that although it will add some realism, it will not modify the main conclusions of the current analysis.

6 Policy analysis: Urban sprawl, emissions and welfare

6.1 Evolution of the urban area in the baseline

In order to investigate the impact over time of the removal of public transport subsidies and alternative scenarios, our study relies on projections of various inputs to the NEDUM-2D model from 2012 to 2050; in particular the future evolution of transport prices, income and population. In the baseline scenario population and income are supposed to pursue their recent trends over the next four decades. In particular, incomes are assumed to grow at the same average annual rate as Argentina's per capita net income over the 1970 – 2015 period (in constant 2010$), i.e. 1.24%, starting at US$ 18,140 in 2012 and reaching close to US$ 29,000 in 2050. The number of households in the urban area will evolve at the same annual pace as it did over the 2001 – 2012 period, reaching a little over 6.96 million in 2050. In the baseline scenario the prices of fuel and public transport fares increase at an identical pace to reach 120% of their 2012 levels in 2050. The evolution of these demographic and economic variables are summarized in Figure 7. It is also supposed that the current subsidization rate of public transport remains unchanged over time – around 2/3 of public transport fares. These inputs are a priori identical in the alternative counterfactual scenarios, unless the policies investigated explicitly impact some variables such as transit fares. Robustness to these assumptions on the evolution of main socio-economic variables is explored below with a high growth scenario.

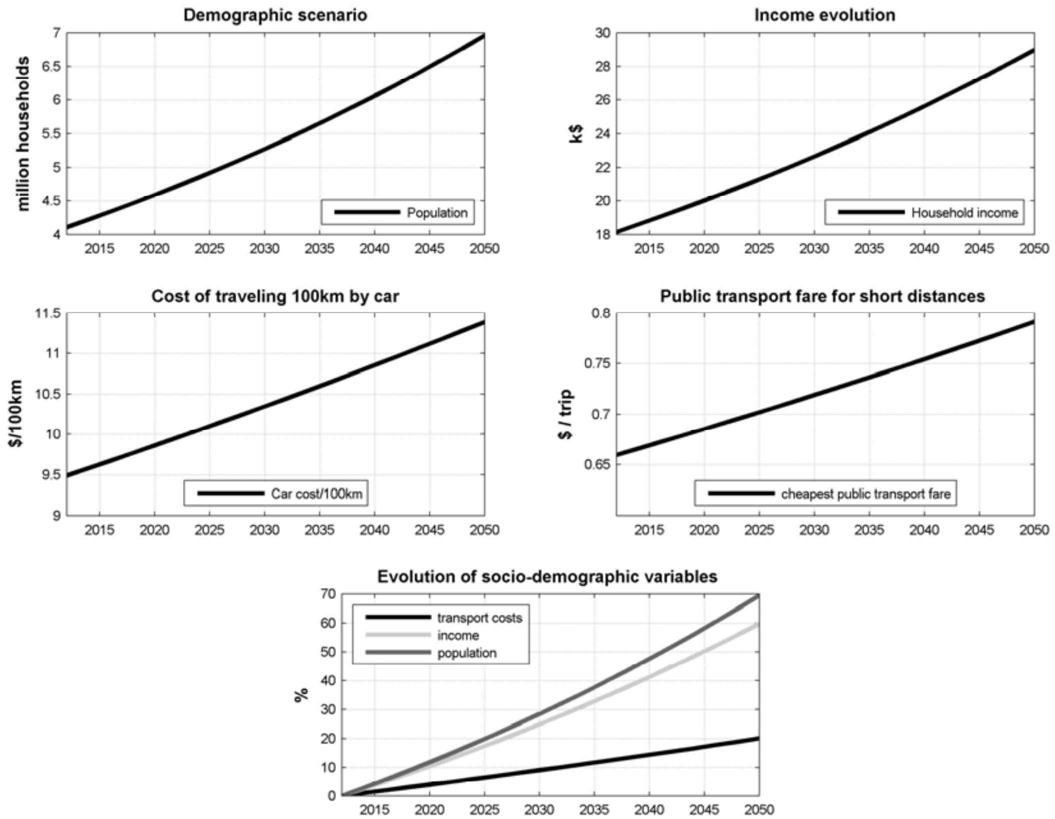
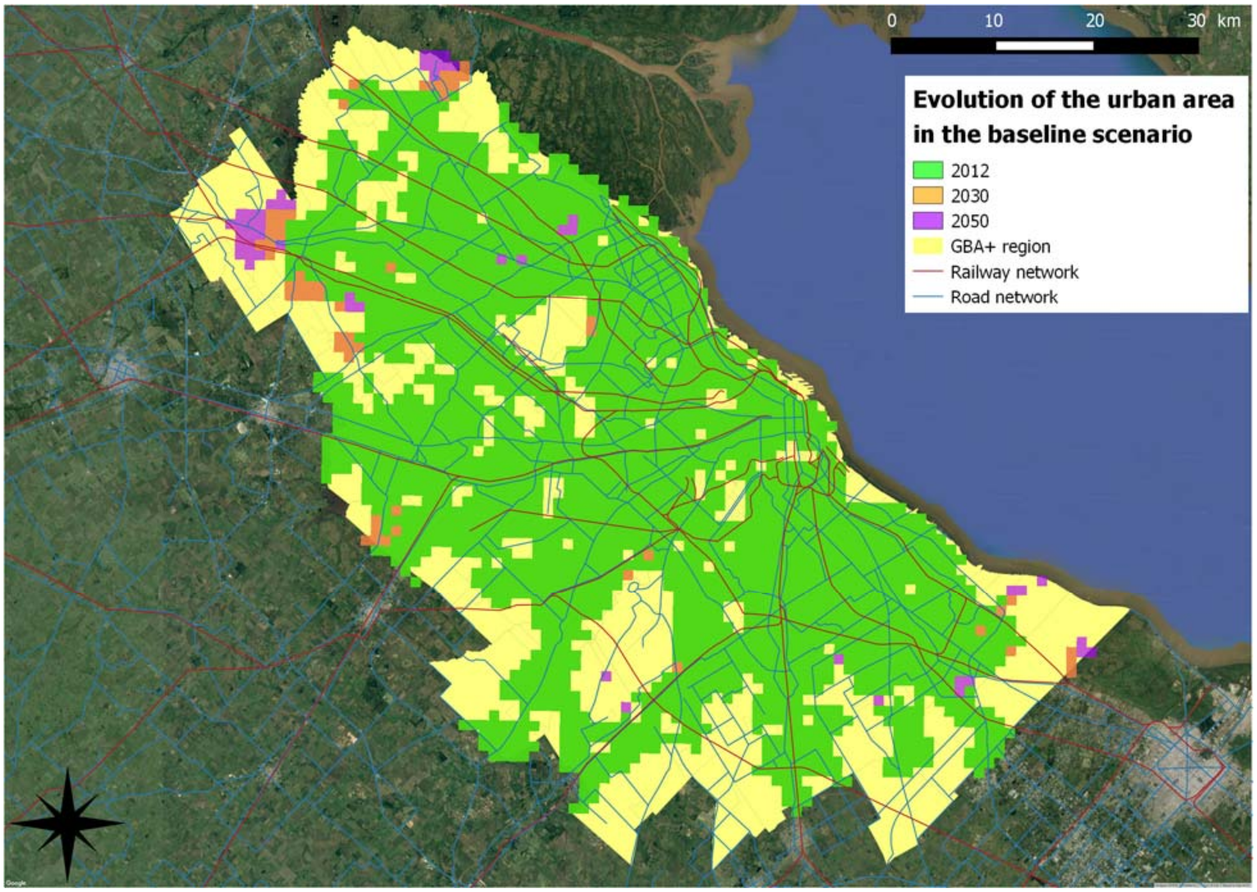


Figure 7: Evolution of the population, income and transport costs in the urban area of Buenos Aires over the 2012 – 2050 period in the baseline scenario.

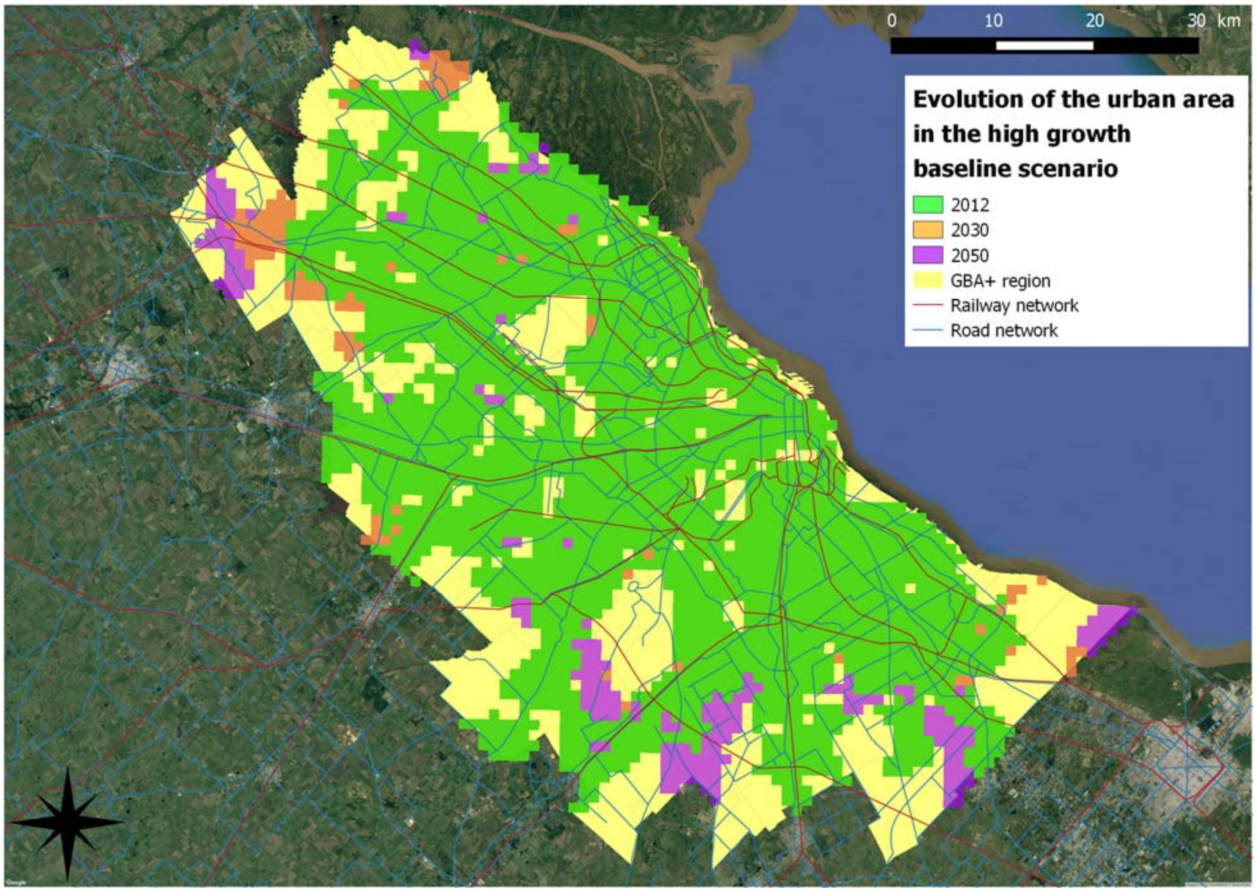
With these main input variables feeding the NEDUM-2D modeling framework we can show the evolution of the urban area over time. It can be seen from Map 2 that, as the population and incomes increase so does the consumption of land in the urban area. The extra urbanization in the simulations occurs mainly in the North along the major transport corridors. The urbanized area increases from 2568 km^2 in 2012 to 2750 in 2050. This 7.1% increase can seem low. It can be explained by two main reasons. First, whereas population increases always lead to more land consumption in an urban area, income increases have an ambiguous effect. On one hand higher incomes increase the demand for housing space which will translate into more construction and floor space throughout the urban area but also into housing consumption at the fringe which pushes the boundaries of the urban area. On the other hand, higher incomes also mean higher opportunity costs of time thereby increasing the generalized transport costs and promoting density. This effect is far from being negligible as on average in the urban area of Buenos Aires time costs represent 72% of the generalized transport costs in 2012 and increase over time, as time opportunity costs increase more than monetary transport costs, to reach 76% in 2050. So time costs are a strong limit to sprawl.

Second, the model underestimates future urban expansion because it misses urbanization that occurs outside of the GBA+ area, represented as the light yellow background layer in Map 2, due to lack of data on public transport costs and times beyond these boundaries.



Map 2: Evolution of the Buenos Aires urbanized area over time in the baseline scenario.

We also built a second baseline scenario, to test how sensitive the urban expansion is to our assumptions about the evolution of the main datasets in the model. In this scenario, population in the urban area and the average household income double between 2012 and 2050 reaching respectively 8.2 million households and US$ 36,290. The monetary transport costs for cars and public transport evolve in parallel and decline by 10% over the simulation period. This scenario, by combining a decrease in transport costs and high growth rates of both population and incomes – all factors conducive to sprawl (Brueckner 2001), naturally leads to an increase in the urbanized area. This increase however, here again remains moderate with 396 extra urbanized km^2 between 2012 and 2050 (compared to 182 km^2 in the previous scenario), a still modest 15% growth over the period. These results are indicative that the amount of new urbanization that is likely to take place over the next four decades in the Buenos Aires urban area is not very sensitive to socio-economic and demographic evolutions to come, that is if the spatial structure of the urban area remains reasonably similar to what it is today.



Map 3: Evolution of the Buenos Aires urbanized area over time in the baseline scenario with higher population and income growth as well as a decrease in transport monetary costs.

6.2 Description of alternative policy scenarios

6.2.1 Public transport subsidy removal

In this scenario, after 2012, public transport subsidies are removed which translates into a tripling of the public transport fares paid in the baseline scenario. This scenario is an extreme as any policy is likely both to increase fares less drastically and, in any case, more gradually. It is however useful to understand clearly the impacts of removing public transport subsidies and the resulting new urban trajectory. The results from this scenario can thus be interpreted as the maximum impact any public transport subsidy phasing out policy could likely entail. The transit subsidies, which are removed in this scenario, amount to US$ 4.22 billion. This figure is of the same order of magnitude as the reported transit subsidy volume for the urban area of Buenos Aires of US$ 5.4 billion (see section 3). As this figure emerges endogenously from NEDUM-2D, it is one supplementary indication of the realism of the model.

6.2.2 Lump sum transfers of the public transport subsidy to households

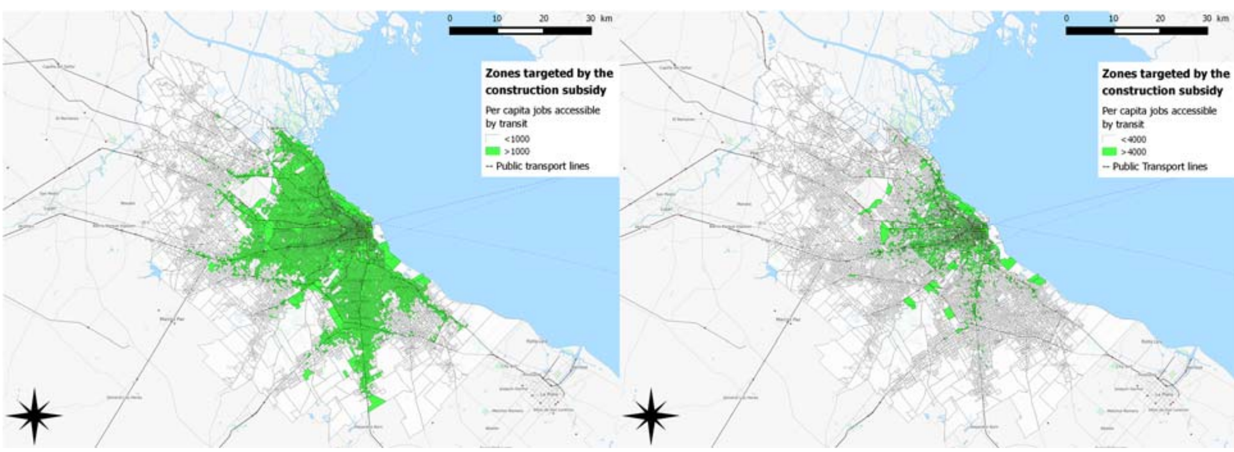
In this scenario where public transport subsidies are removed, the total savings are channeled to households on a lump sum basis. Note that we assume the money does not go to the rest of the country. As a result each household receives US$ 1,030 – 1,230 extra annually or, presented differently, around 4-5% of the average household income depending on the year in the urban area per year. This operation is neutral for local government budget but will reduce the incentive for public transport ridership. We will document the impact of this lump sum transfer on households' location decisions and well-being.

6.2.3 The introduction of a construction subsidy

In this scenario, public transit subsidies are entirely re-invested in construction subsidies so that this policy is again neutral for the local government's budget. The aim is to understand if encouraging construction (through lowering its cost) could limit urban sprawl and modify locational decisions of households within the urban area so as to reduce the need to travel long distances which justified in part public transport subsidies in the first place. The subsidized share of construction costs of the new structures reaches 4.7% immediately after the removal of the transit subsidy and decrease to 4.4% in 2050 because the transit subsidies increase less quickly than the construction costs[9].

6.2.4 The introduction of a construction subsidy which targets high accessibility zones

In this scenario, public transport subsidies are re-invested in construction subsidies targeted for high transit accessibility zones. Can these construction subsidies re-orient urban trajectories towards less land intensive pathways while intensifying land use around public transport corridors and stations? Building on work from Peralta Quirós & Mehndiratta (2015), we identify zones within the urban area of Buenos Aires which benefit from high transit accessibility. The construction subsidies are still equal in volume to the transit subsidies in the baseline scenario; however they can only benefit construction within the high accessibility zones. The choice of the zones and of the criteria to include some and exclude others is therefore crucial. In this exercise, we chose a threshold of 1,000 jobs accessible through transit per capita within one hour. The zones which are eligible to receive the targeted construction subsidy are presented in Map 4 in the left panel. This criterion limits the provision of construction subsidies to zones with high transit accessibility and relatively low population. Other choices are possible (as can be seen in the right panel of Map 4) and will be explored in the future. The construction subsidies when available in this scenario are higher than in the previous and range from 5.5% to 5.4% of the costs of new construction. Indeed, as some zones are excluded from potential subsidization, the structures in the eligible zones benefit from higher construction subsidy rates.



Map 4: Zones targeted by the construction subsidy in this scenario correspond to radios with high per capita transit accessibility (measured in number of jobs accessible per capita in the origin radio for one hour of travel). <u>Left panel</u> presents these zones when a criterion of 1000 jobs accessible by transit and per capita is selected. <u>Right panel</u> presents these zones with a criterion of 4000 jobs.

[9] Analytically and computationally, the construction subsidies intervene through a modification of the term A in the housing production function described in the appendix in section 10.1.3. An increase in the value of A means that less capital is needed to build a given amount of floor space.

6.3 Policy impacts: Sprawl, distances travelled, emissions and welfare

In this section we want to investigate the impact that each policy package described above will have on 1/ the size of the urbanized area: can alternative policies limit the growth of the urbanized area over time? and how substantial can the decrease be compared to a scenario with public transit subsidies?, 2/ what are the consequences of these counterfactuals in terms of distances travelled for commuting purposes and CO_2 emissions stemming from these? and 3/ what are the impacts on households' welfare of these policy packages?

6.3.1 Consumption-related welfare impacts of alternative policies

The consumption-related welfare and income-equivalent impacts of alternative policies with respect to the baseline are the described in Table 2. Income equivalents are the monetary translation of household utility changes and are reported here because they are more easily understandable.

	Without the public transport subsidy	**With a lump sum transfer**	**With a generalized construction subsidy**	**With a targeted construction subsidy**
Consumption-related utility in 2050 (%)	-3.73%	+1.30%	-2.67%	-2.69%
Equivalent income in 2014 (US$)	- $712	+$325	- $531	- $527
Equivalent income in 2014 (%)	-3.83%	+1.75%	-2.85%	- 2.83%
Equivalent income in 2050 (US$)	- $910	+$323	- $644	- $651
Equivalent income in 2050 (%)	-3.14%	+1.11%	-2.22%	- 2.25%

Table 2: Impacts relative to the baseline on consumption-related welfare and translation into income equivalent (in US$) in each scenario for 2014 and 2050

We draw two conclusions from these figures. First, while the lump sum dominates the transit subsidy as documented in the simple model presented in section 4, the welfare gains (utility) are lower than the schematic model previously presented pointed to (1.3% vs 6.1%). The reason for this difference resides in several realistic features of NEDUM-2D. The use of generalized costs instead of pure monetary costs means that an increase in transport fares does not translate into an equivalent increase of generalized costs because time costs remain the same. As time costs represent more than 70% of the generalized costs in the baseline, the increase in the monetary component only applies to the remaining 30%. So that the subsidy only represents around 20% (0.7*0.3) of total generalized transportation costs. This would place the transit subsidy in a regions which is much closer to its optimal level (see Figure 1). In addition, while in the schematic model only one transport mode is available, in the NEDUM-2D model, households have the choice of commuting by foot, using cars, transit or a combination of these modes. As a result when transit fares increase, a share of people will switch to an alternative and cheaper transport mode, say cars or walking, so that the actual cost of commuting will increase less than the transit fare increase. The existence of other transport modes can therefore mitigate the increase in public transport fares. So lump sum transfers can increase households' welfare but less than the schematic model would have led us to believe.

The second take-away from the comparison of alternative policies is that the construction subsidy schemes perform better than the uncompensated removal of public transport subsidy (-2.7% for both schemes vs -3.7%) but less well than the public transport subsidy. In terms of welfare, construction subsidies, targeted or generalized, are a poor substitute to transit subsidies.

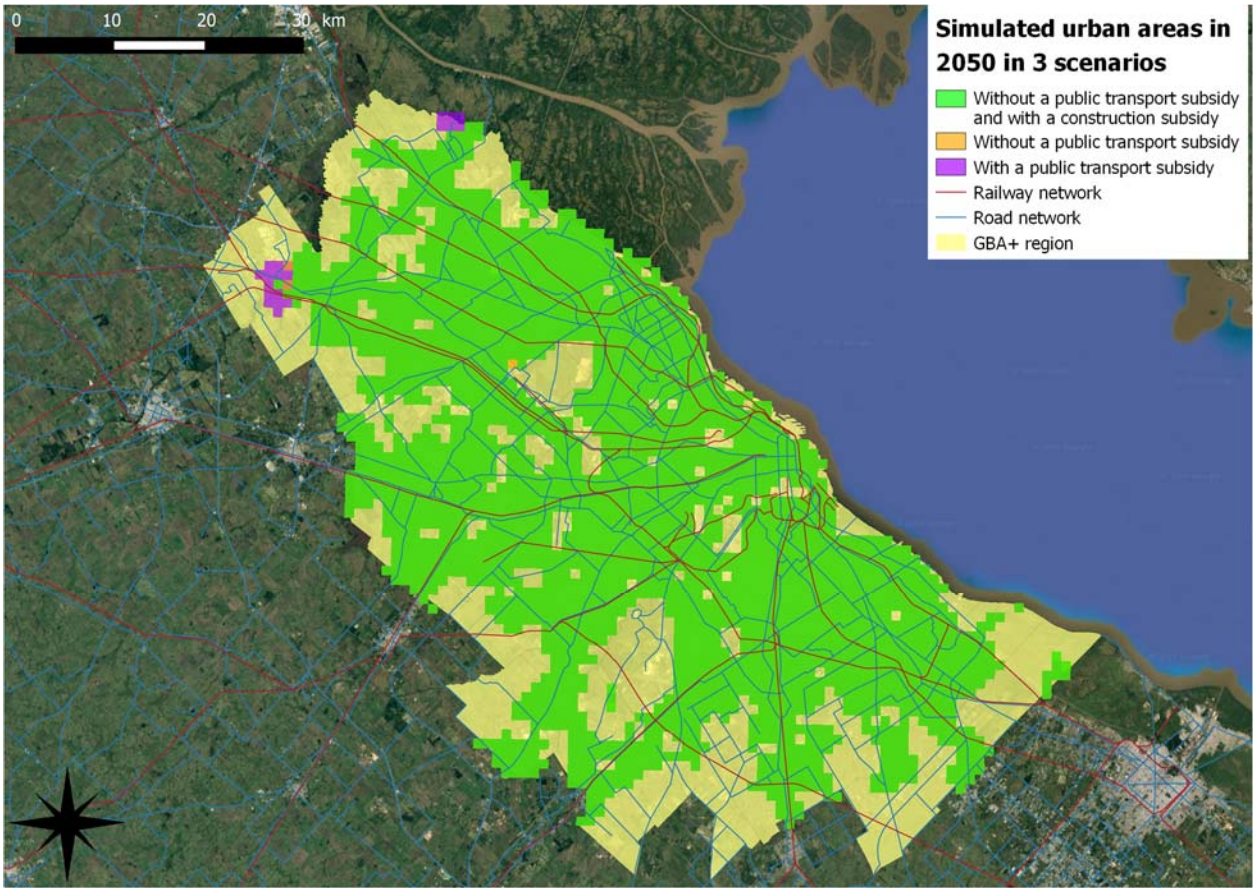
6.3.2 Beyond consumption-related welfare: Sprawl, distance travelled and emissions

In this sub-section we look into features that are not captured by our welfare function such as the impact of alternative policies on the extent of the urban area, the average distances travelled and the emissions that stem from commuting.

Map 5 provides a visual representation of how different policy packages would modify the size of the urbanized are in 2050 in our simulations. We selected three different scenarios: the baseline in which transit subsidies exist and amount to two-thirds of the full cost of a trip, the counterfactual in which the transit subsidy is removed, resulting in a tripling of the monetary costs of riding public transport and finally a scenario whereby subsidy removal is coupled with the redistribution of the savings in the form of construction subsidies.

It can be visually seen from Map 5 that the removal (compensated or not) of public transit subsidies has an overall limited impact on the size of the urbanized area. In 2050 the urbanized area decreases by only 11 km^2 (2739 km^2 vs 2750 km^2) for the uncompensated removal of the public transport subsidy (orange in the map) and by 14 km^2 (2736 km^2) for the scenario in which public transport subsidy removal is accompanied by a generalized construction subsidy (green in the map). The orange shade is virtually indistinguishable because it is overlayed with the green layer.

The lump sum transfer scenario yields an urbanized area in 2050 which is slightly larger compared to the baseline: 2797 km, i.e. a 1.7% increase. And finally the targeted construction subsidy scenario results in a slight decrease of the urbanized area of -0.8% (2729 km^2 vs 2750 km^2). The conclusion which we draw from these simulations is that the potential to curb urban sprawl through removing the public transport subsidies exists but is limited and therefore so would the savings in terms of infrastructure costs associated to increased urbanization.



Map 5: Simulated urban areas in the three scenarios which differ by the existence of public transport subsidies and construction subsidies.

The next question is: would the public transport subsidy removal trigger an increase in transport related CO_2 emissions? This question is even more relevant as we have just seen that the benefits to be expected in terms of lower land consumption for residential purposes are limited.

	Without the public transport subsidy	With a lump sum transfer	With a generalized construction subsidy	With a targeted construction subsidy
Urban sprawl				
Average distance to the city center	-6.97%	-3.65%	-7.10%	-8.73%
Urbanized area	-0.40%	1.71%	-0.51%	-0.76%
Average density in the urban area	0.40%	-1.68%	0.51%	0.77%
Climate change / CO_2 emissions				
Public transport mode share	-19.15%	-18.95%	-19.14%	-19.18%
CO_2 emissions from commuting	1.28%	5.11%	1.12%	-0.69%
Welfare				
Household utility	-3.73%	1.30%	-2.67%	-2.69%

Table 3: Evolution of indicators pertaining to urban sprawl, CO_2 emissions from commuting and household welfare in alternative scenarios when compared to the baseline scenario with public transport subsidies.

The most notable fact in the first half of Table 3 is that whereas the reductions in urbanized area are small (or even increase with the lump sum transfer), the average distance of a household to their job center decreases much more substantially and across all counterfactual scenarios. This is the long term (2050) result of an internal restructuring of the urban area caused by the rise in public transport fares, where, in order to save on transportation costs, households choose to locate closer to the city center. Higher buildings will progressively replace smaller ones in the vicinity to the city center and residents will occupy smaller dwellings, both these mechanisms leading to higher central population densities.

This finding is important because it also means that the traveled distances to jobs will be shortened substantially – not exactly by the same amount as the distance to the city center, as roads are not straight, but not far off. This should lead to lower CO_2 emissions from transport, all else equal. On the other hand public transport ridership will also decrease as the result of the increase in fares triggered by the subsidy removal. And because cars are less energy efficient[10] than public transport, mainly buses or *colectivos* in the urban area of Buenos Aires, this will lead to the opposite effect on CO_2 emissions with an increase, all else equal. The net effect in terms of commuting related CO_2 emissions is a priori ambiguous and this is precisely where numerical simulations can be useful. The last line in Table 3 summarizes the impacts on CO_2 emissions in the various counterfactual scenarios. It can be seen that the reduction in the distances travelled for commuting nearly cancel out the increase in emissions/pkm resulting from mode share switch away from public transport. The increase in emissions is indeed limited (around 1%). It can also be seen that the lump sum transfer scenario would result in a much less anecdotal increase in emissions. Part of the lump sum will be used to consume moor floor space per household, thus limiting the internal movement of households closer to the city center[11]. Finally the targeted construction subsidy, is able to achieve an overall reduction in commuting related CO_2 emissions, although such a reduction remains limited.

It appears overall that removing the public transit subsidy would have only limited impacts in reducing sprawl over time and thus the associated costs in terms of infrastructure for example. This is disappointing because it appeared to be a reasonable motivation for removing the public transport subsidies and maybe replacing them by another policy less likely to induce sprawl. On the other hand, it is equally surprising that although the removal of the transit subsidy leads to a decrease in public transport ridership, this mode switch leads to only moderate increases in commuting related CO_2 emissions (except in the scenario where transit subsidy savings are channeled to households through a lump sum transfer). Our simulations even show that alternative policies such as targeted construction subsides could decrease the level of transport related CO_2 emission with respect to the baseline, although the decrease would remain limited.

It should be noted however that the switch away from public transport, triggered by the subsidy removal, could complicate future CO_2 emission reductions as cities display path dependencies which make subsequent mitigation actions more expensive (Avner, Rentschler, and Hallegatte 2014).

7 Political economy/hotspot analysis of transit subsidy removal

An important concern for policy makers when considering the modification of public transport prices is the redistributive impacts of these changes and in particular for the poor. NEDUM-2D, in this present

[10] See section 10.2.4.5 for details about respective gasoline consumption of buses and cars over time in the Buenos Aires region. In our simulations buses emit 3.5 less than cars per passenger.kilometer. If this number increased, so would emissions in alternative scenarios compared to the baseline. If buses were less than 3.5 more efficient than cars then the opposite situation would arise and a decrease in public transport ridership would be associated with a lower increase in emissions.

[11] We do not account for larger AC/heating costs of larger dwellings.

version, cannot be used to perform a full study of the impact of public transport subsidy removal on the poorest. To be able to do so, the model would need to endogenously represent the location decisions of various income groups, which is beyond its current capacity. We however can document how the budget committed to transport and housing costs would be affected by location by the subsidy removal, coupled or not with lump sum transfers and other devices, if this modification did not impact the location of the households. In the short term, this assumption is valid as relocation is characterized by high inertia. Over a longer time frame however, decisions about where to live and how much living space to consume will adjust to changed transport costs.

The urban area of Buenos Aires is characterized by sizeable inequalities in terms of socio-economic levels. We capture these inequalities in Table 4 through the disaggregation of annual household income by quintile. It can be seen that the average annual income of the richest 20% of households in Buenos Aires is about eight times that of the poorest.

Annual household income by socio-economic quintile (US$)				
1	**2**	**3**	**4**	**5**
5,196	10,268	15,471	22,747	41,756

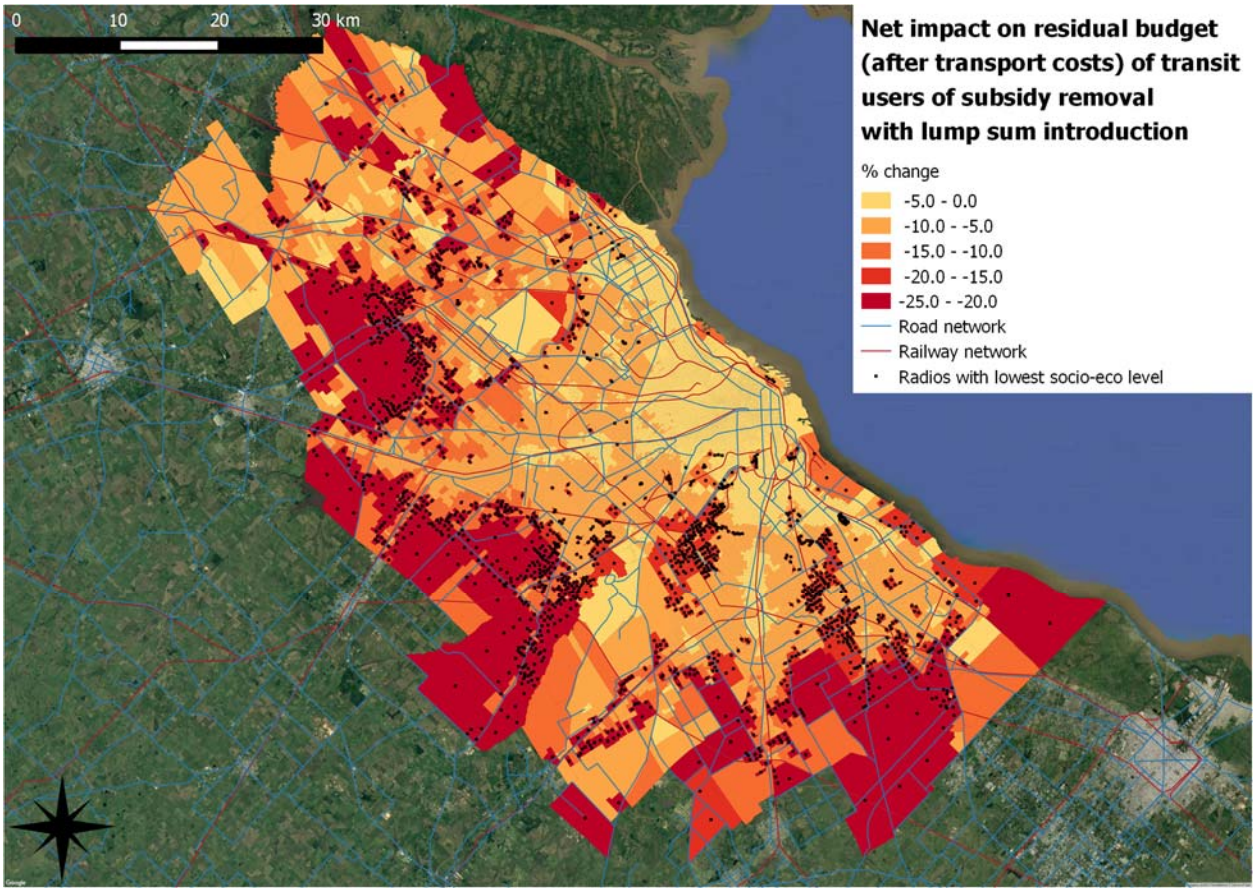
Table 4: Annual average income for a household in Greater Buenos Aires disaggregated by socio-economic quintile in 2012 (data source: INDEC 2013)

7.1 In the short run: Detrimental to transit users

With the NEDUM-2D model we assess the distributional impact of removing the public transport subsidy and replacing it with a lump sum transfer. The lump sum transfer is distributed to each household and amounts to a little over US$ 1,000 in 2012. While this amount represents around 4% of households' average income it is nearly 20% of the poorest budget. We place ourselves in the very short term, immediately after the policy change, when it can be safely assumed that households have not had time to adjust and move to areas within the Buenos Aires area which benefit from lower transport costs.

Map 6 shows the spatial impact of the replacement of the transit subsidy by a lump sum transfer for transit users. It displays for households that commute by transit the net impact on the evolution of residual budgets after transport expenditures of increasing public transport fares (by a factor of 3 as before) but receiving a compensatory lump sum transfer.

Map 6 shows that all transit users lose from the replacement of the transit subsidy by a lump sum transfer as their budgets after transport expenditures decrease everywhere. Even in the most central locations of the Buenos Aires urban area, the annual cost of commuting daily to jobs outweighs the lump sum. The increase in transport budget for transit users is not spatially uniform: it increases with the distance to the city center (in parallel to transit budgets) and is higher for lower income quintiles. The black dots in Map 6 represent the centroid of the census tracts where the 20% poorest households reside. It can be seen that these census tracts are often hit the hardest, simply because a given monetary increases in fares has a larger impact on their budget. Some exceptions are however found when the census tract of the poorest is close to the city center.



Map 6: Hotspot analysis of the subsidy removal coupled with a lump sum transfer on the residual budget after transport expenditures of transit users by census tract accounting for the socio-economic level of each census tract.

So, whereas a generalized the lump sum transfer is the most efficient use of public funds, as discussed in section 4, it also potentially carries negative redistributive impacts in the very short term which will hurt the heaviest users of public transport or those that do not have the option to switch modes (for cars for example).

A solution to benefit from the efficiency virtues of lump sum transfers and yet protect the poorest against the adverse impacts of removing the transit subsidy would be to channel the transfers exclusively to the poorest households. Whereas such a policy is technically feasible it requires up to date registries which can capture the earnings of all households in the urban area of Buenos Aires. The allocation of lump sum transfers would then be decided on the basis of these registries following an agreed upon criteria. When registries of household earnings do not already exist, implementing cash transfers is not a trivial task[12] as urban targeting is notoriously difficult (Gentilini 2015).

The picture painted here hinges on the limits of the model as NEDUM-2D in its current version is unable to link mode shares to income brackets. Whereas we show budgetary impacts of transit fare increases on transport budgets for public transport users we are unable to show explicitly how price increases would affect the poorest vs the others because Map 6 considers only users of public transport. The literature

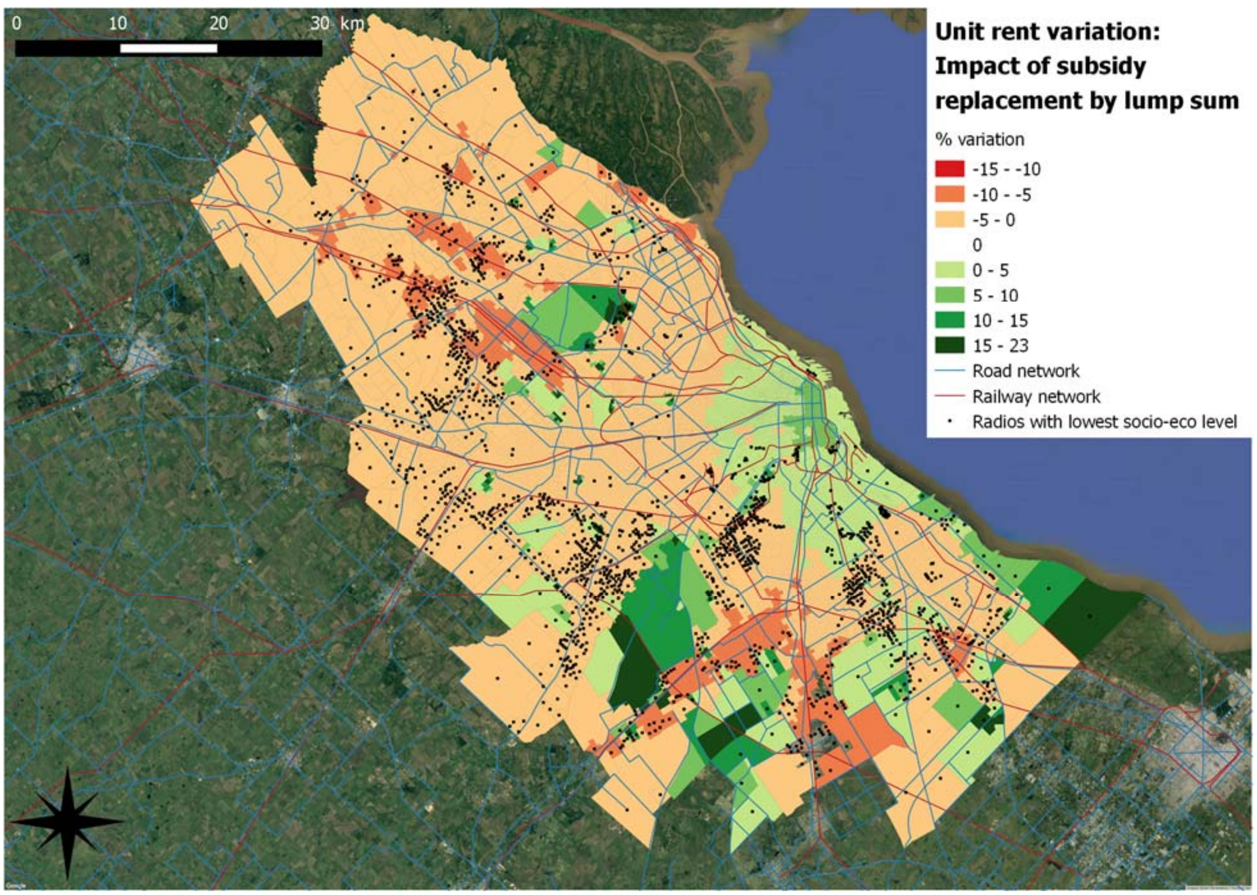
[12] Although, there are successful precedents such as in Chile between 2004 and 2006 (Estupiñán et al. 2007).

suggests that the middle income class is the heaviest user of transit so that they are likely to be hit harder than both the poorest and the richest.

7.2 In the longer run: Housing market adjusts

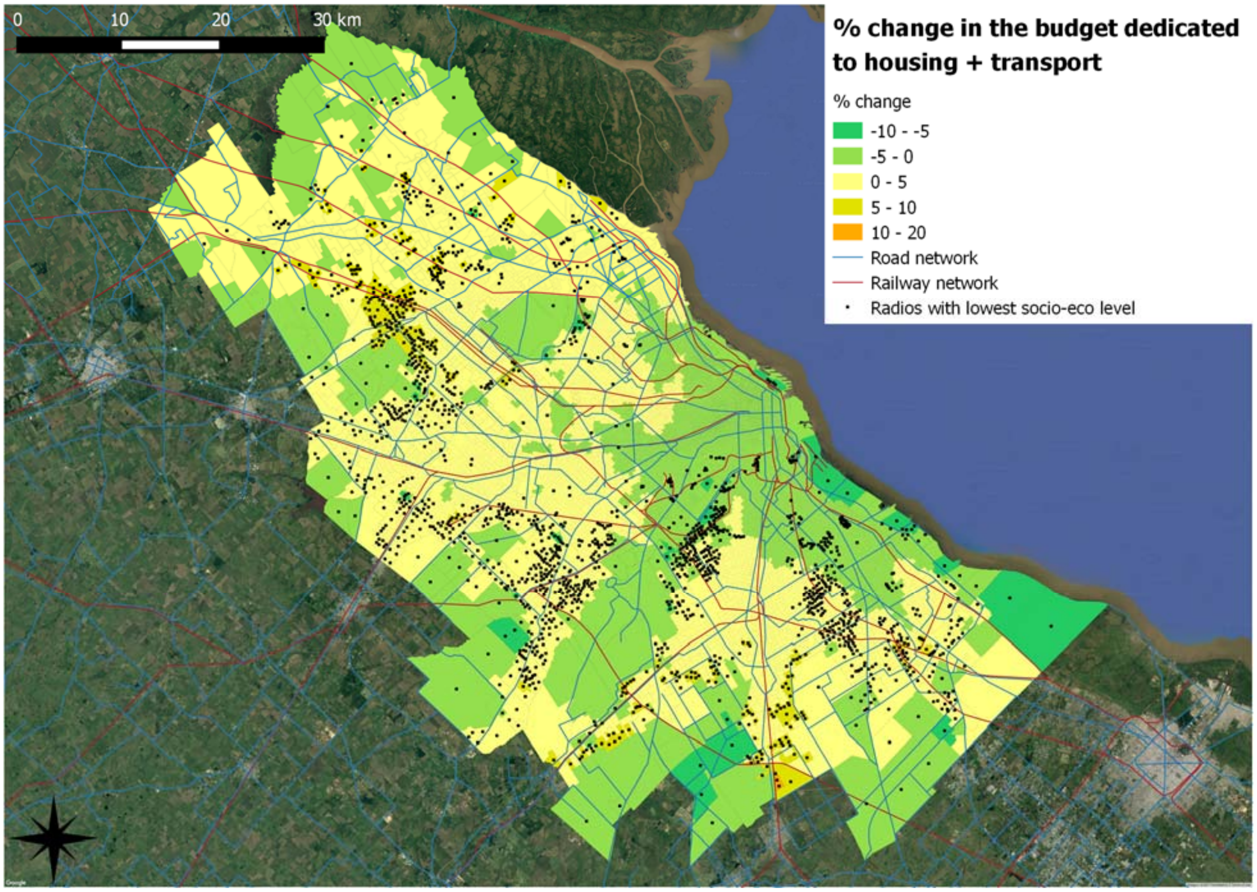
The discussion above focuses on the very short run, immediately after the replacement of transit subsidy by a lump sum transfer. As discussed, the consequences for the users of public transport are harsh, in particular if they are poor. Over a longer time frame, however, the housing market will adjust to the shock on public transport fares. In particular, areas that face strong increases in generalized transport costs will become less desirable for households and so will lead to a decrease in housing rents.

Map 7 visually depicts the change in rents per square meter of housing with a lump sum transfer compared to the situation with a transit subsidy. For tenants, the impacts on rents will mitigate in part the negative redistributive impacts of removing the transit subsidy and implementing a lump sum. Indeed, the areas that benefit most from a decrease in rents are also the ones which are hardest hit by the increase in transit fares (see Map 6) and in most instances coincide with where the poorest currently reside. Conversely, the areas with green shades will see an increase in rents because generalized transport costs will increase less than in other parts of the urban area and thus become more attractive in relative terms.



Map 7: Variation in rents per square meter with replacement of the public transport subsidy with a lump sum transfer.

Map 8 shows the impact of replacing transit subsidies by lump sum transfers on the combined housing and transport households' budgets. A first important results is that in some areas of the cities the change in rents induced in the medium term by the increase in transit fares will more than compensate the price increase resulting in a net decrease in the budget allocated to transport and housing (accounting for changes in housing space consumption). These areas appear green in Map 8. Conversely in areas which appear in yellow, the decrease in rents or housing space consumption does not compensate for higher transport costs. In many instances the NEDUM-2D model predicts that the census tracts where the poor reside will face a higher combined budget dedicated to housing and transport. However, the increase in transit prices appears to be less harsh when accounting for the housing adjustment than when looking solely at budgets affected to transport.



Map 8: Change in household budget shares dedicated to housing and transport with replacement of the public transport subsidy with a lump sum transfer.

The decrease in rents and housing expenditures shown in Map 7 has been interpreted as welfare improving in the previous section. This assumption is true for newcomers to the urban area and for renters but does not hold for households which own their dwelling. If households own their dwellings they are actually hit even harder by the increase in transit fares as they will both have to face higher transport costs and accept a loss in the resale price of their dwelling.

Finally an important caveat needs to be mentioned here. As acknowledged, the NEDUM-2D modeling framework does not represent the locational decisions of multiple income classes. We have circled around this difficulty by looking at very short and short term impacts of replacing transit subsidies by lump sum transfers, assuming that in these time frames households would not have time to move. But our research is silent on the longer term redistributive impacts when households will adjust their consumption of housing, transport and other goods to the increase in public transport fares. Our short term result should therefore be interpreted with caution and not as a long term exercise.

8 Conclusions and perspectives

The research presented above could benefit from modeling improvements to become more realistic and shed light on a richer set of issues. The most pressing need is to develop the NEDUM-2D model so that it can represent multiple income classes and their locational decisions within urban areas. This would allow to look at the long term redistributive impacts of various policies. A second possible direction for improvement is to enhance NEDUM-2D so that it can account for multiple job centers, going beyond the monocentric assumption, and include amenities and social segregation mechanisms. This addition to the model would help get rid of some discrepancies between simulation results and data and would therefore increase its capacity to convince. While we strongly believe that our main conclusions would be unaffected by the addition of polycentrism, it remains an empirical question. Lastly, the NEDUM-2D model does not account for congestion as it implicitly assumes that investments can be made so that additional road or public transport frequentation does not lead to higher transport times. Explicitly accounting for congestion would be an important improvement to the modeling framework.

The set of results presented in this paper paints a complex picture of public transport subsidies in the urban area of Buenos Aires. It appears that an ideal solution would be to channel lump sum transfers only to the poorest households. This solution requires detailed registries recording households' incomes and their evolution over time. A second best alternative would be to have only the poorest households in Buenos Aires benefit from transit subsidies. This solution would protect the poor users of transit without entailing dramatic efficiency or environmental negative impacts. It would also allow for some public finance savings which could be channeled toward other issues such as investments in the public transport infrastructure or could be put towards targeted construction subsidies as discussed in this paper.

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10 Appendices

10.1 Description of the NEDUM-2D modelling framework

We use a model inspired by Von Thunen (1826), adapted by Alonso (1964), Mills (1967), and Muth (1969) and comprehensively described by Fujita (1989) and Brueckner (1987). Assuming that a city is defined by a number of jobs located in a single location, this model is based on two trades-offs, made by two categories of economic actors:

- Households choose their housing location in the agglomeration by arbitrating between larger and cheaper apartments further from the city center, and increased commuting costs to the city center where all jobs are supposed to be located.

- Landowners choose where and how much to invest (i.e., what buildings to construct), as a function of expected rents at each location.

These two trades-offs characterize a static equilibrium in the urban system.

Symbol	Signification
R	Housing rents (or, equivalently, annualized real estate price per square meter)
R_0	Metropolitan area border rent or transaction costs
L	Available land for construction
K	Invested capital
ρ	Depreciation rate of capital
i	Interest rate : cost of capital
p	Unitary transport cost/km
n	Household density
q	Flat size
N	Population in the agglomeration
r	Distance to the city center
r_f	Limit of the city, maximum radius to the center

Table 5 : Nomenclature

10.1.1 Household behavior

Each household is composed of one representative worker living at a distance r from the city business district (CBD) where all jobs are located. Each worker has to commute once a day to the CBD, and this commuting entails transportation costs $T(r)$. All households are supposed to earn the same income Y and – at the equilibrium – they have the same level of satisfaction described by a utility function U that depends on both the level of consumption of a composite good z and of the size of their apartment q. The level of rents per square meter (or, equivalently, the annualized real estate price per square meter) is $R(r)$, at each location in the city. Each household maximizes his utility function under a budget constraint:

$$Max_{r,z,q}\ U(z,q) \qquad s.t. \quad z(r) + R(r)q(r) + T(r) \leq Y + \bar{L} \tag{3}$$

The term $\bar{L}$ found in (3) represents the annual amount accruing from land rents per household which is recycled in the urban economy in the form of increased incomes. It can schematically take on one of two values depending on the type of model used: Closed City model with Absentee landowners (CCA) or Closed City model with Public ownership of land (CCP). In the closed city model with absentee landowners (CCA), landowners are supposed to live outside the urban area which means that land rents are not recycled in the local economy in the form of increased incomes. In this case $\bar{L} = 0$. At the opposite end of the spectra, if all land plots are supposed to be owned by a local government (or by all households in equal shares) then $\bar{L} = \int_0^{r_f} \frac{\pi(r)}{N} dr$, where N is the number of households in the urban area.

10.1.2 Landowner behavior

Landowners choose what amount of capital $K(r)$ to invest at each distance from to produce a housing surface $H(r) = F(L(r), K(r))$; in this framework, they are thus also the owners of the buildings. The construction function F is assumed to have constant returns to scale. The profit function of a landowner or equivalently the land value assuming $R(r)$ as exogenous and known is then given by:

$$\pi = [(R - R_0)F(K, L) - (i + \rho)K] \quad (4)$$

ρ represents the joined effect of real-estate depreciation and annual taxes payed by land owners on real-estate capital. i is the interest rate so that iK represents the annual cost of borrowing capital or its opportunity cost. Finally the border of the metropolitan area is defined by a rent R_0, below which it is no longer profitable to build housing. This value corresponds to transaction costs in the building and renting process, such as the costs of finding tenants, ensuring that the communal areas of collective housing remain clean…, and can be considered to be proportional to the quantity of housing built. NEDUM-2D differs from traditional urban economics models in this respect, as they usually assume that the edge of the metropolitan area is given when land value for housing falls below the revenue that could be generated from using this land for agricultural purposes. Although this method is appealing, it is not supported by data which shows a clear disconnection between land values for agricultural and housing purposes even at the edge of urban areas. The much lower values for agricultural land are indicative that another mechanism is at play. We chose to capture this through transaction costs R_0.

Landowners maximize their profit function to determine how much housing to build and how much capital to invest:

$$K^*(r) = Argmax[(R(r) - R_0)F\big(L(r), K(r)\big) - (\rho + i)K(r)] \quad (5)$$

The absentee landowner in fact chooses the capital/land ratio $k = K/L$ that maximizes his land's value. If we assume that the housing production function has constant returns to scale[13], then this ratio does not change as a function of the amount of land that is used but varies only as a function of the distance to the CBD. We can then use $f(k) = \frac{F(K,L)}{L} = h$ as a proxy for housing density or building's height and define:

$$k^* = \arg\max_k [(R - R_0)f(k) - (\rho + i)k] \quad (6)$$

[13] This is logical as a doubling of both capital and land factors should lead to two similar housing structures being built (Brueckner 2011).

At the city limits we have:

$$R(r_f) = R_0$$

10.1.3 Functional forms and assumptions

We use Cobb-Douglas functional forms with constant returns to define households' utility and the housing service construction function. This choice is widely shared in urban economics (Brueckner 1980; Fujita 1989; Mills 1972). It is possible to show analytically that there is both existence and uniqueness of an urban equilibrium (Gusdorf and Hallegatte 2007).

$U(z,q) = z^{\alpha} q^{\beta} \;\; where\ \alpha, \beta > 0\ and\ \alpha + \beta = 1$

$F(L,K) = AL^{a}K^{b}\ where\ a, b > 0\ and\ a + b = 1$

10.1.4 Dynamics of NEDUM-2D

NEDUM-2D is a dynamic model which explicitly represents inertia and path dependence. This feature allows the model to account for the fact that housing infrastructure cannot adapt instantaneously to changing conditions (income, transport prices etc…). NEDUM-2D can therefore account for temporary imbalances between housing supply and demand.

There are two steps in defining the dynamic behavior of the NEDUM-2D model. First, developers' decisions on how much to build and where in the urban area are determined (or equivalently how much capital to invest for residential purposes in each location). This allows the model to determine the new housing stock which accounts for inertia in building decisions. Second rents, dwelling sizes and population densities (and all other model outputs) adjust in such a manner that an equilibrium utility can emerge consistently with the static version of the model. This two-tier approach to the dynamics of NEDUM-2D differs from the one used in Viguié et al. (2014), Viguié and Hallegatte (2012) and Avner et al. (2013). We will discuss these differences and their consequences a bit further in this section.

Step 1: In practice for each time step a "pseudo-equilibrium" value is computed for the housing stock. This "pseudo-equilibrium" value is the value toward which the housing stock state variable will evolve. It depends on the model input, but also on the value of the other state variables (rents, population densities, dwelling sizes…). Between this time-step and the following, the housing stock state variable will evolve towards its "pseudo-equilibrium" value with some inertia. At the following time step, a new "pseudo-equilibrium" value for the housing stock is computed. It can be identical to the last one, or can be different because the values of the other state variables have changed, or because model inputs are different (e.g. construction costs have changed). The housing stock state variable will now again evolve towards this new "pseudo-equilibrium" value etc. The pseudo-equilibrium value for the housing stock is computed in such a manner that, if exogenous model inputs (population, transport costs, construction costs, income…) do not evolve any more, the housing stock state variable converges towards the actual equilibrium value.

For each time step, developers when choosing whether or not and how much to build assess their expected profits using equation 4. In this version of the model the developers are considered to be myopic, meaning that they do not anticipate that housing rents from the previous time step will change as a function of different socio-economic conditions. They choose the new amount of capital that they would wish to instantaneously invest in each location ("pseudo-equilibrium"), or equivalently the capital to land ratio k' leading to the housing to land ratio h' through:

$$k'(r) = \arg\max_{k'(r)}[(R(r) - R_0)h'(r) - (\rho + i)k'(r)] \qquad (7)$$

Construction and building depreciation however, take time so that the capital invested does not translate immediately into new buildings or the destruction of old ones. We here follow Viguié et al. (2014) in supposing that financial investments are transformed into buildings with a time lag τ_H, which corresponds to the time required to achieve the construction. We also suppose that a decrease in current built floor space ratio to land ($h(r)$) can happen through depreciation only, with the timescale τ_{dH}. It follows that in a dynamic perspective housing evolution at each time step is given by:

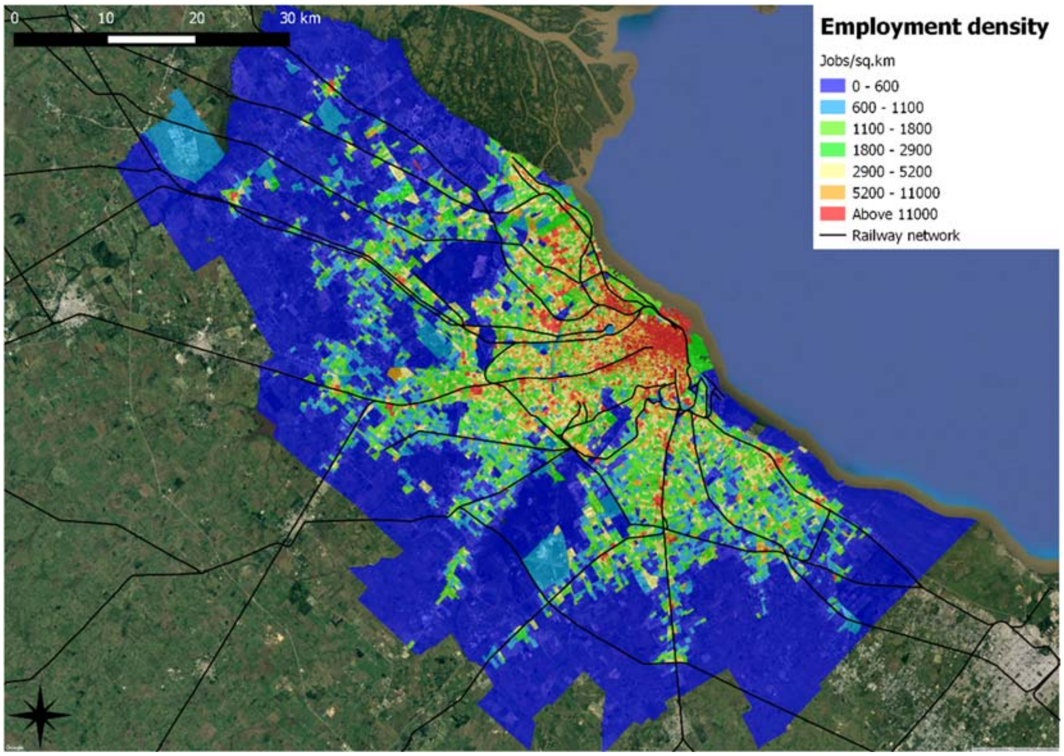
$$\frac{dh(r)}{dt} = \begin{cases} \dfrac{h'(r) - h(r)}{\tau_H} \; if \; h'(r) \geq h(r) \\ -\dfrac{h(r)}{\tau_{dh}} \; if \; h'(r) < h(r) \end{cases} \tag{8}$$

Step 2: At each time step the other model variables (rents, population densities, dwelling sizes…) adjust perfectly to the new socio-economic conditions and to the new housing stock. Indeed households adjust their locational and consumption choices in a way that ensures that utility levels are equal for all households throughout the urban area, consistently with the static version of the model. This second step of the dynamics of NEDUM-2D is equivalent to the maximization of households' utility in a static framework with an exogenous housing stock.

10.1.5 Discussion of the mono-centric assumption

In the present study, we use this model with the assumption that all households commute every day to the center of the *Ciudad Autónoma de Buenos Aires* (CABA), where jobs are assumed to be located. This mono-centric hypothesis is important, and can seem a strong assumption as secondary employment centers exist within the urban area of Buenos Aires. However, the Buenos Aires region displays a very strong mono-centric structure. For instance, in 2012 more than 40%[14] of all jobs in the Buenos Aires region are localized in CABA even though CABA only represents 5.3% of *Region Metropolitana*'s area. Map 9 represents the employment densities for each census tract or "radio" in the Buenos Aires region. The use of employment densities instead of absolute employment numbers can correct a statistical "radio size" bias. Indeed, as radios have different sizes, larger radios would appear as very "employment-rich" while smaller radios will display only small employment numbers.

[14] Projections based on Censo Nacional Economic 04/05 (CNE 04/05) and Encuesta Permanente de Hogares, 2011 (EPH, 2011).



Map 9 : Employment densities for each census tract (Radio censal) unit within the Buenos Aires region in 2012 (data source: projections based on Censo Nacional Economic 04/05 (CNE 04/05) and Encuesta Permanente de Hogares, 2011 (EPH, 2011))

Map 9 shows that job dispersal exists along the major public transport lines, the railway network (represented as black lines), but is nearly non-existent elsewhere. This suggests that the radial public transportation network plays a strong role in the location of employment centers which is characteristic of dominantly mono-centric urban forms.

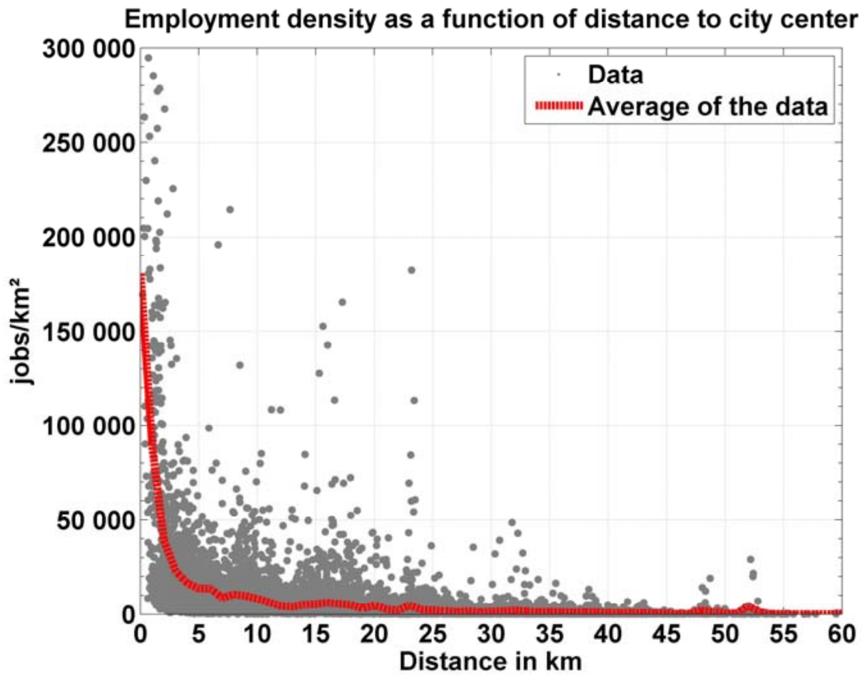


Figure 8 : Employment density as a function of the distance to the city center in 2012 within the Buenos Aires region.

Figure 8 shows in another manner the very clear concentration of employment around the city center. The most important features of the curve (red dashed line) is 1/ that it is virtually flat and close to zero beyond km 12 and 2/ that the slope of the curve is very steep within eight kilometers of the city center. There is a real Central Business District which has slightly extended beyond CABA. This tendency should not mask that there is also clearly some dispersion around the average of the data, indicating the existence of employment centers beyond the CABA region. Some of the decentralized employment centers can even be very "job intensive".

There are also indications that the radial public and, to some extent, private transportation networks plays a strong role in the mono-centric structure of the Buenos Aires region. Indeed, even when people work outside CABA, they mostly still have to commute through the city center. Therefore, in deciding where to live, the location of housing relatively to the city center is still fundamental.

Considering that cities are perfectly monocentric is a widespread assumption in urban economics and land use – transport models. In the case of Buenos Aires, it is clearly an approximation, but, as we have demonstrated above, an approximation which finds strong support in the data. Hence, the mono-centric version of NEDUM-2D is a priori a useful and well suited framework to represent the internal structure of the Greater Buenos Aires.

A more fundamental line of argument against the mono-centric approach is that the importance of distances travelled for commuting trips is declining relatively to trips for other motives such as leisure. Adversaries of the mono-centric approach therefore argue that there is little reason to consider commuting costs as decisive when choosing where to live. Although it is true that commuting travel shares are declining, we argue that trips made and costs incurred on a daily basis play a much larger role in determining housing patterns than lengthy trips which are undertaken only a few times a year.

In its current version, NEDUM-2D also relies on the hypothesis that all households within the urban area earn the same average income. It does not currently possess the sophistication to account for multiple household types and thus ignores income inequalities[15]. This simplification is acceptable for some indicators such as the extent of urbanization. However it can have some impacts for NEDUM-2D's ability to capture the dispersion in rents and real estate prices around an average. Indeed, real estate prices are strongly affected by neighborhood characteristics among which social segregation can play a role. We will overcome this limitation to a certain degree by interacting our results with a map of current income dispersion.

10.2 Data and choice of parameters

We will detail in this section the data used and the choice of parameters for 1/ socio-economic and demographic inputs, 2/ household utility function 3/ developers' behavior, the housing production function and construction costs, 4/ transport data and modelling choices and 5/ land use and building regulation data.

10.2.1 Socio-economic and demographic inputs

- Population in the Greater Buenos Aires urban area: Population for the GBA+ region in 2012 is estimated to be 13,744,044 in 2012 according to projections of the Censo Nacional de Poblacion, Hogares y Vivienda 2001 (CNPHyV 01) for 2012. With an average household size of 3.3, this corresponds to 4,106,479 households. The demographic scenario used in this exercise considers that the population will increase smoothly at the same pace that it evolved over the 2001 – 2012 period, reaching a little over 6.96 million in 2050. This corresponds to nearly a 70% increase compared to 2012 with an annual demographic growth rate of 1.40%. We equally use a second demographic scenario whereby the number of households doubles in 2050 compared to 2012. This second demographic scenario corresponds to an annual growth rate of 1.84%.
- Income evolution of the average household: With the current version of the model in which we only consider one income class, we need an average income per household. Data from INDEC gives us this information separately for Buenos Aires and the other 'partidos' of the Gran Buenos Aires at trimestral intervals. We thus calculate a weighted average based on their respective household populations for all semesters of year 2012. This yields an average yearly income of AR$ 85,540 or around US$ 18,140. In the baseline scenario, average incomes will grow at the same average annual rate as Argentina's per capita net income over the 1970 – 2015 period (in constant 2010$), i.e. 1.24%, starting at US$ 18,140 in 2012 and reaching close to US$ 29,000 in 2050. In the sprawl scenario, average income doubles over the 2012 – 2050 period, increasing at an annual rate of 1.84% and reaching close to US$ 36,300.

10.2.2 Household utility

The household utility function reads as follows:

$$U(z(r), q(r)) = z(r)^{\alpha} q(r)^{\beta} \ \ where\ \alpha, \beta > 0\ and\ \alpha + \beta = 1 \qquad (9)$$

The widespread choice of this Cobb-Douglas functional form in urban economics is consistent with findings that households devote a near constant budget to rental housing expenditures through time and space (Davis and Ortalo-Magné 2011). In this case, households spend a share β of their income net of transportation costs on housing. Indeed, maximizing (9) with respect to q and replacing z with the budget constraint by $Y + \bar{L} - q(r)R(r) - T(r)$, we find: $q^*(r)R(r) = \beta(Y + \bar{L} - T(r))$. For the purpose of the

[15] A version of NEDUM-2D that is able to represent multiple household types differing by annual average income is currently being developed in CIRED.

simulations in this study we must characterize β. We chose a value of 0.4 for β and thus 0.6 for α. This means that in the city center, where transportation costs are assumed to be zero in the monocentric theory, households will spend 40% of their income on housing expenditures. This figure is consistent with official statistics from INDEC which place average expenditure shares at 15.2% and 17.7% respectively for transport and housing and expenditures at 164% of income (INDEC 2013).

10.2.3 Housing production function

The housing production function is defined by:

$$F(L(r), K(r)) = H(r) = AL(r)^a K(r)^b \textit{ where } a, b > 0 \textit{ and } a + b = 1 \tag{10}$$

The choice of a Cobb-Douglas function to represent the housing production function is widespread in the literature (Fujita 1989; Muth 1969) and finds some empirical support (Ahlfeldt and McMillen 2014; Thorsnes 1997). It can be rewritten as the absentee landowner in fact chooses the capital/land ratio $k = K/L$ that maximizes his land's value. Since F has constant returns to scale equation (10) can be simplified as the ratio of capital to land will only change as a function of rents and not the amount of land each landowner possesses.

$$f(k(r)) = \frac{F(K(r), L(r))}{L(r)} = A\left(\frac{K(r)}{L(r)}\right)^b = Ak(r)^b \tag{11}$$

In the absence of detailed datasets about construction costs, we relied on partial data gathered from the INDEC that provided some information about average construction costs for various building heights for July 2012. We interpolated the various data points and achieved a curve which seems to increase quasi linearly with building height. Model parameters A and b were calibrated so as to minimize discrepancy between the CSTB interpolated data and the simulated construction costs in the model. The calibration procedure led to values of $A = 0.25$ and $b = 0.70$ (with $a = 1 - b = 0.30$). As a result the construction cost curve of NEDUM-2D seems in general agreement with the partial data we have although it presents a more convex shape leading to an underestimation of costs for low building heights and an overestimation for larger number of floors (Figure 9). Parameter A of the construction function evolves over time with income as follows $A_t = A_0 * (Y_t/Y_0)^{-b}$ to account for the upward trend observed in building construction costs over the 2001 – 2012 period (INDEC, CLARIN).

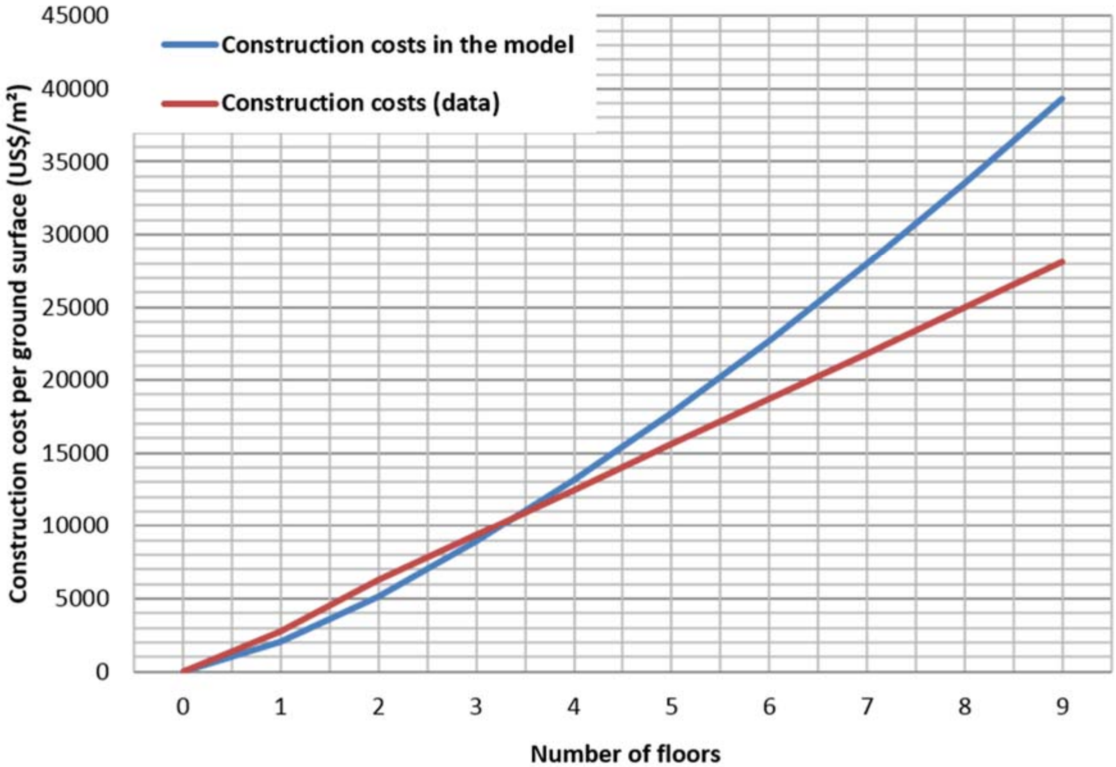


Figure 9: Comparison of data and simulated construction costs per square meter of ground floor as a function of number of floors of the building.

10.2.4 Transport data and competition between modes

Transport costs are essential to all land use – transport models. NEDUM-2D uses complete or generalized transport costs which encompass both the monetary and time components of travels.

10.2.4.1 Transport times

- Walking times: they are calculated on the basis of the Euclidian distance to the CBD. We assign an average speed of 5km/hour to pedestrians.
- Public transport times: Public transport times were retrieved from the Open Trip Planner Analyst (OPTA) accessibility tool, developed by the World Bank in conjunction with Conveyal. This tool is fed by GTFS data that represents the public transport network and provides Origin-destination travel times at peak and off-peak times. Public transport vehicles in the GBA+ region can be either Colectivo, Ferrocarril, Subte / Premetro, Charter / combi and Bus empresa. These transport times are considered to remain constant throughout the 2012 – 2050 period. This assumption is tantamount to assuming that there will be investments made in currently existing public transport lines in such a manner that the system can absorb population growth without additional congestion. The number of lines and their routes are assumed to remain unchanged throughout the time period.
- Private transport times: Travel times for cars were gathered by collecting Googlemap estimated times systematically throughout the urban area of Buenos Aires. We were able to collect transport times for trips originating in 9674 different locations (always apart by at least 1km) going far beyond the GBA+ region. As for the public transport infrastructure, it is assumed that there will be investment in

roads so that they can absorb a demographic increase without leading to additional congestion. We here again assume that the number of roads will remain constant.

10.2.4.2 Monetary transport costs

- Private car costs: These were estimated to be 0.44 AR$/km or 0.095 US$/km in 2012. They concern both cars and SUVs. It is assumed that the cost of traveling one kilometer by car increases by 20% over the 2012 – 2050 period to reach 0.114 US$/km in 2050 in the baseline scenario. In the sprawl scenario, fuel costs are assumed to decrease by 10% over the simulation period reaching US$ 0.085 in 2050.
- Public transport fares: The public transport fares were retrieved from the internet for the buses or *Colectivos*. They depend on the distance travelled and we proxied this distance by a bee line distance from origin to destination. The fares do not present a large spatial variation. The ticket costs between US$ 0.65 and US$ 1. As a simplification, and because buses are the overwhelmingly used public transport means in the Buenos Aires urban area (87%), it is assumed that the fares for the metro system (*subte*) and trains (*ferrocarril*) are identical to those of the buses. As for the costs of traveling by car it is assumed that they evolve to reach 120% of their 2012 level by 2050 in the baseline scenario. In the sprawl scenario, public transport fares are equally assumed to follow the evolution of the price of fuel and decrease by 10% in 2050.

10.2.4.3 Cost of time

NEDUM-2D uses generalized transport costs which encompass both monetary and time costs. How to value transport times is however a difficult issue which has triggered a vast number of scientific papers and reports (Boiteux and Baumstarck 2001; Mackie et al. 2003; Oort 1969; Small, Winston, and Yan 2005; Litman 2008) focusing mainly on the topic of how to quantify the benefits of transport investments which accrue in the form of travel time savings. No definite consensus has emerged from the literature; in fact estimates range from 25% (Litman 2008) to close to 180% of an hourly wage with large heterogeneities depending on the traveler (Small, Winston, and Yan 2005). Most estimates however seem to fall within the 50%-100% range of an hourly wage with Small and Verhoef (2007) arguing for the former and Glaeser, Kahn and Rappaport inclined to the latter (2008). Given the uncertainty surrounding the value that should be chosen, we retained one that fell within the 50%-100% range of hourly wage and that led to a good agreement between simulations and data for population densities and land values. We use the value of 65% of the average hourly wage in our simulations.

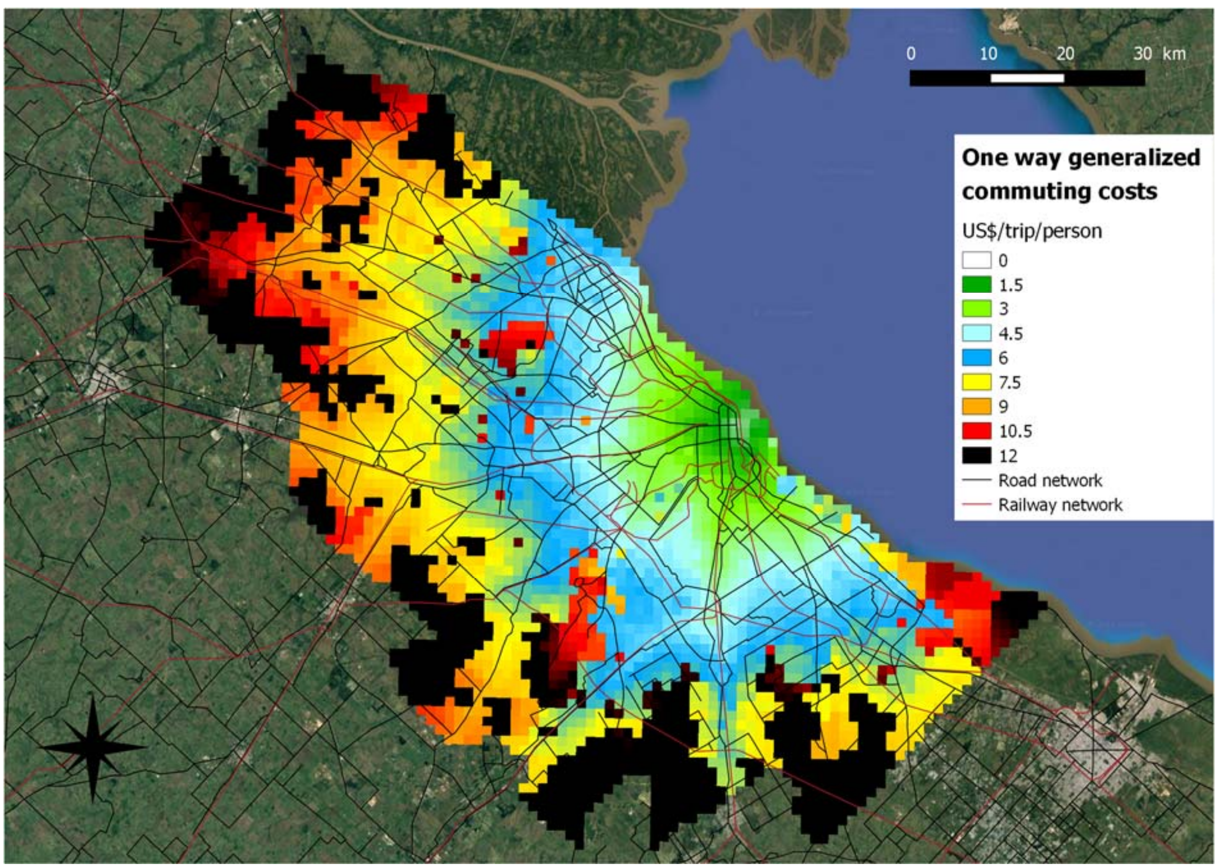
10.2.4.4 Mode competition and generalized transport costs

Mode competition: The transportation module of the NEDUM-2D model represents modal choice. For each location in the urban area, citizens choose between walking, public transport and private vehicles, or a combination thereof as a means for commuting. The competition between these modes is organized on the basis of their *generalized costs* (i.e. the total cost including both the cost of time and the monetary costs incurred during the trip to the city center). It is assumed in this study that modal switch does not affect congestion levels and therefore leaves commuting times unchanged.

In order to reflect the heterogeneity of citizens' preferences in terms of transport modes we employ a discrete choice model (De Palma and Thisse 1987). We follow a common approach in transportation economics by using a multinomial logit model which assigns usage probabilities to each transport mode (see Salon 2009; Washbrook, Haider, and Jaccard 2006). This method ensures that even when one mode is much cheaper than the others, it will not be used by all residents in a location for all trips. This approach assumes that, for each transport mode i, the inhabitants do not take into consideration the generalized cost p_i, but this cost plus an idiosyncratic random term following a Gumbel distribution. The result is that the probability of choosing mode i in a given location depends on the generalized cost of this mode relative to other modes. The cheaper it is, the higher the probability that it is chosen: the probability to choose the mode i is:

$$P_{m_i} = \frac{e^{-\lambda \frac{p_i}{p_{min}}}}{\sum_k e^{-\lambda \frac{p_k}{p_{min}}}} \tag{12}$$

where $P_{min} = \min_k(P_k)$ and λ is a coefficient. At a given location, the average transport cost, taking into account all transport modes, is given by the log-sum of generalized transport costs of all modes.
The value of λ is calibrated so as to minimize average mode share discrepancies with the data and is estimated to be equal to 1 in this study. The mode share of public transport in the model in 2012 for the Buenos Aires urban area (measured as the share of people using public transport) is around 56%, so very close to the 57% reported in 2009 by the ENMODO travel survey (Ministerio del Interior y Transporte 2010). Map 10 shows the resulting map of one-way generalized commuting costs used in this study.



Map 10: One-way generalized costs of commuting for the GBA+ urban area based on the simplifying hypothesis that all jobs are situated in the center of Buenos Aires. The transport costs thus tend to increase as we move away from downtown Buenos Aires. For a given distance to the center they are lower when one is close to a public transport line.

10.2.4.5 Vehicle consumption, load factors and emissions

In order to compute the CO_2 emissions from commuting in our simulations we need some information about vehicle gasoline consumption and load factors both for cars and for buses. We use the data and projections of the IEA and WBCSD Sustainable Mobility Project (SMP) focusing on inputs for the Latin America region (IEA and WBCSD 2004).

Fuel consumption of cars: For the Latin America region, the SMP spreadsheet indicates that cars will consume 8.3 liters/100km in 2010. We interpolate their data so that cars consume 8.2 liters/100km in 2012 and reach 6.5 liters/100km in 2050. This corresponds to a 20% decrease over the 2012 – 2050 period.

Fuel consumption of buses: We here again draw our data from the SMP model, so that buses in the model consume 26 liters/100km in 2012. We make the supplementary assumption that technological progress will allow the consumption of buses to decrease at the same pace as for cars so that consumption of buses reaches 21 liters/100km in 2050.

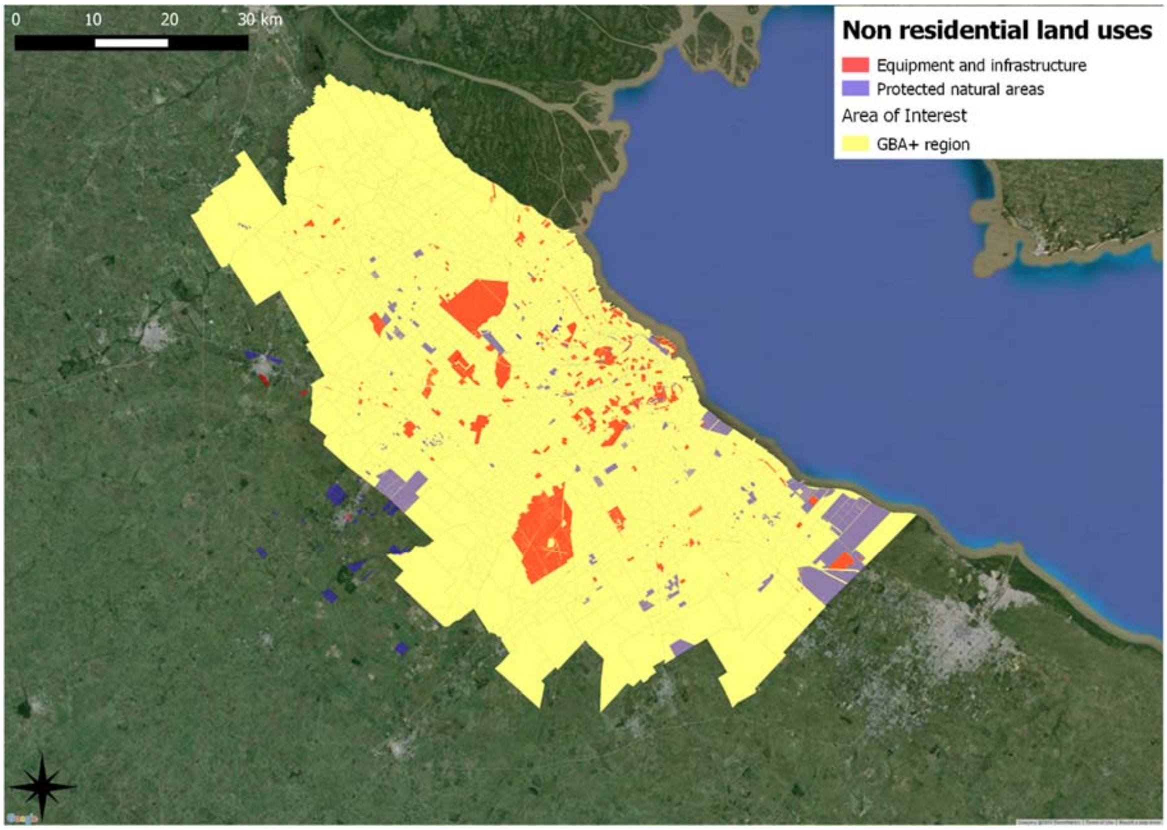
Load factors: cars are supposed to carry 1.72 passengers/trip on average in 2012 and buses approximately 19. These average load factors decrease at the same pace reaching 1.51 for cars and 16.68 for buses in 2050. This corresponds to a little more than a 12% decrease over the 2012 – 2050 period.

Vehicle unitary emissions: With a CO_2 content of 2416 gCO_2/liter of gasoline, vehicles emit on average 114 and 33 grams of CO_2/passenger.km for cars and buses respectively in 2012, i.e. a ratio of 3.5. These figures go down to 104 gCO_2/pkm for cars and 30 gCO2/pkm for buses in 2050. The ratio between unitary emissions remains constant throughout time as gasoline consumptions and load factors evolve in parallel for cars and buses. These figures are in line with those reported by Carbontrust[16].

10.2.5 Land use and building restrictions

Land uses incompatible with urbanization: In order to be able to reproduce the location and extent of urban areas in the Buenos Aires region correctly, NEDUM-2D accounts for regulations or land uses that are incompatible with the development of residential areas. NEDUM-2D therefore requires a map of land use constraints which is used as a filter to exclude some zones from potential urbanization. For example, it excludes zones occupied by water or protected natural areas such as forests. Water bodies (sea, rivers and lakes) are excluded from potential urbanization as a first step. In a second step a detailed land use map (see Map 11) is used to identify supplementary zones that need to be excluded from potential urbanization. The exclusion map encompasses any area occupied by protected natural areas, equipment such as the military zones in Campo de Mayo and infrastructure (port, railway station, Ezeiza international airport for example). While the total area of exclusion is non-negligible, it remains, by far, lower than the area that could be potentially urbanized. This is indicative that although the exclusion map can avoid major discrepancies between the simulation and the data, it is not a main driver behind the overall accuracy of our results regarding the match between simulated and observed urbanized areas.

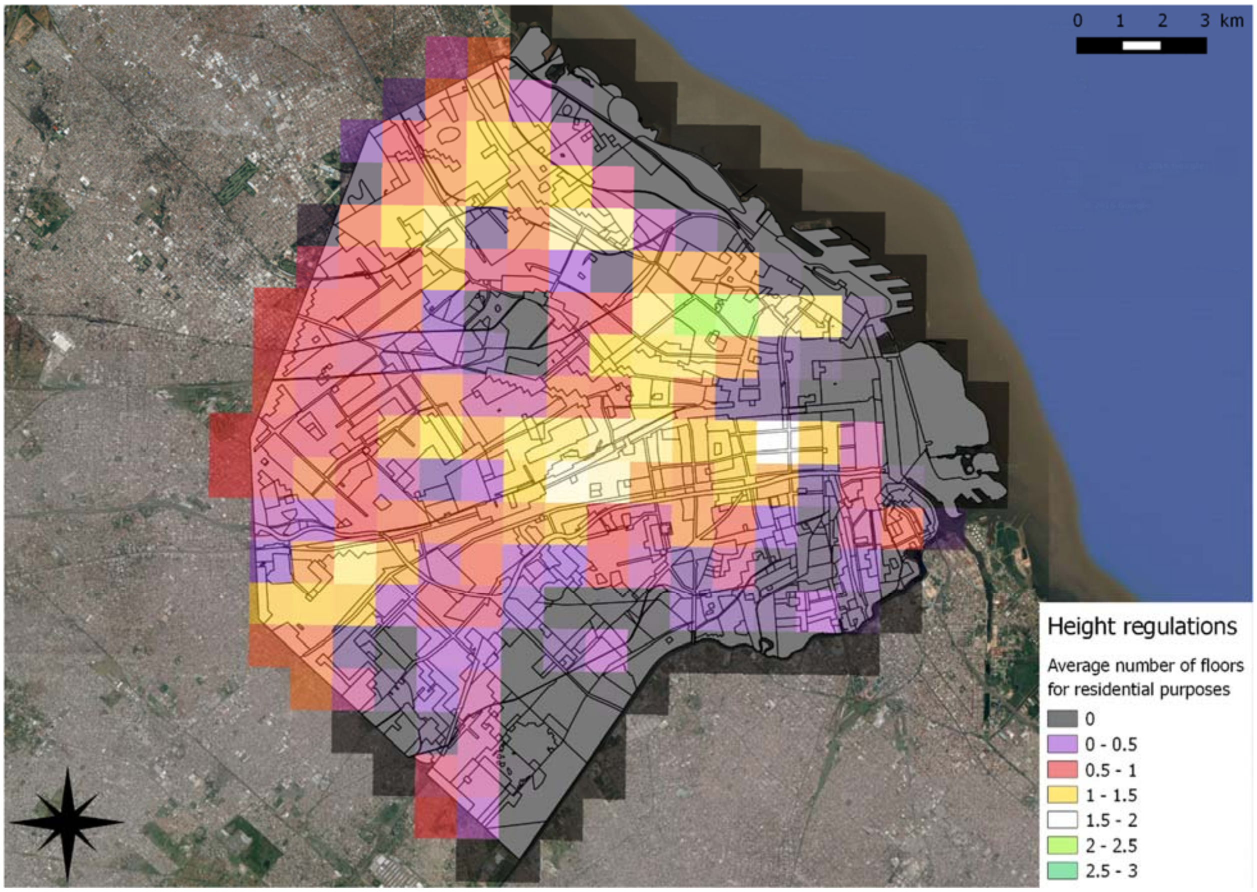
[16] https://www.carbontrust.com/conversionfactors



Map 11: Land use exclusion map showing areas that are excluded from potential urbanization in the model for 2012 (Goytia and Pasquini 2013). Land used for "equipment and infrastructure" or which is labelled as "protected natural areas" cannot be used for residential purposes and is therefore excluded from potential NEDUM-2D simulated urbanization.

<u>Land area available for buildings:</u> We assume that in each pixel of our grid, after excluding for restricted land uses as shown in Map 11, a maximum of 55% of the land area can be used for buildings. The remaining 45% is expected to be used for roads and infrastructure which are essential for any urban area to function correctly.

<u>Building height regulations:</u> We also add a map that provides information about the maximum Floor Area Ratios in *CABA* together with the type of use allowed in each zone. We thus limit the maximum height of buildings within *CABA*. We also exclude zones that are uniquely destined to commercial or industrial uses from being urbanized for residential purposes. To do so we intersected our grid with data from the 2011 Código de Planeamiento Urbano (CPU accessible at: http://data.buenosaires.gob.ar/). The CPU map provides for each zone the classification of buildings that can be built. From this information we can retrieve the type of buildings (residential commercial etc…) and the maximum allowed height. For each grid cell we averaged the data to obtain the average building height for residential purposes in *CABA*. Beyond *CABA* however we do not introduce maximum building heights for residential purposes.



Map 12: Maximum number of floors for residential purposes in CABA (data source: Código de Planeamiento Urbano - 2011, SSPLAN). Outside CABA, we assume that there are no building regulations.

10.2.6 Other parameters

A few other parameters are required by NEDUM-2D:

- Building's depreciation rate ρ: The depreciation rate of buildings ρ intervenes in landowner's profit function and plays a role in the determination of the amount of capital invested in structures throughout the urban area (equation 5). It represents the natural depreciation of structures and is therefore used to express the average yearly annual costs of refurbishing them. Given that structures in urban areas tend to have widely varying lifetimes ranging from 30 to 150 years (Hallegatte 2009) we chose a simple figure of 0.01 to express that on average annual maintenance costs are 1% of buildings' construction costs.
- Interest rate i: The interest rate also intervenes in the model by affecting construction costs as it represents the opportunity cost of capital or the financial cost of borrowing money to finance the construction of buildings. It is difficult to ascertain an interest rate that would adequately represent the annual financial burden of construction in an urban area like Buenos Aires which has developed over centuries. We therefore chose the value of 2% which appears to be reasonable.
- Border rent/transaction costs R_0: As discussed in section 10.1.2, NEDUM-2D differs from classic urban economic models because it chooses to model the edge of a city through a transaction cost below which it is no longer profitable to build structures instead of using an agricultural land value. The transaction cost that was retained in NEDUM-2D for the Buenos Aires urban area is 1US$/m^2 in 2012.

The border rent/transaction cost is assumed to evolve over time at the same rate as household income.

- Time lags for the dynamics of the housing stock: The inertia that characterizes investments in building structures, τ_H, is set to a value of 10 years. This time lag encompasses necessary time for the actual construction to take place and other transaction costs such as possibly negotiating a bank loan, finding the appropriate location and land plot, finding a suitable construction firm and negotiating building permits. This value of 10 years means that each year only a tenth of the optimal construction can take place. In terms of the inertia that characterizes the destruction of buildings, τ_{dH}, it is set at the same value as the depreciation rate, ρ, meaning that without any investments, buildings would be destroyed over the course of 100 years.