Climate Policy and Inequality in Urban Areas

Beyond Incomes

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Paolo Avner
Vincent Viguié
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Abstract

Opposition to climate policies seems to arise, at least partly, from their effects on inequality. However, so far, the impact of climate policies on inequality has mainly been studied through the lens of income inequality, and their spatial dimension is poorly understood. This paper, using Cape Town, South Africa, as a case study, investigates the impact of a fuel tax on both spatial and income inequalities. It uses a model derived from the standard urban economics land use model, accounting for four income classes and four housing types. This modeling framework allows decomposing the impacts of the tax by income class, housing type, and housing location. The analysis also decomposes the impacts of the tax over different timeframes, assuming that households and developers progressively adapt to the tax. The findings reveal strong evidence that in the short term, there are both income and spatial inequalities, with households being more negatively impacted by the fuel tax if they earn low incomes or live far from employment centers. In the medium and long term, these inequalities persist: the poorest households, living in informal settlements or subsidized housing, have few or no ways to adapt to changes in fuel prices by changing housing type, adjusting their dwelling sizes or locations, or shifting transportation modes. Low-income households living in formal housing also remain impacted by the tax over the long term due to complex effects driven by the competition with richer households on the housing market. Complementary policies promoting a functioning labor market that allows people to change jobs easily, affordable public transportation, or subsidies helping low-income households to rent houses closer to employment centers will be key to enable the social acceptability of climate policies.

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Climate Policy and Inequality in Urban Areas: Beyond Incomes

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1. Introduction

The transportation sector was responsible for 23% of global energy-related CO2 emissions in 2010 (Sims et al., 2014), and decarbonizing transportation is a major challenge for climate change mitigation (Creutzig et al., 2015). However, implementing transportation mitigation policies that are efficient and that encounter strong public support at the same time is a challenge. To mitigate transportation GHG emissions, standard economics recommends internalizing the externalities related to polluting transportation by taxing polluting transportation modes and/or by subsidizing the clean ones (Baranzini et al., 2017). In its most simple form, taxing polluting transportation modes could take the form of carbon pricing: 61 national or subnational jurisdictions have implemented or scheduled a carbon pricing initiative (World Bank, 2020). Many environmental economists advocate for this policy, arguing that, theoretically, it will incentivize people to shift transportation mode or to move closer to their jobs and other frequent destinations, allowing at the same time to mitigate emissions and to maintain households’ welfare (Borck and Brueckner, 2018; Creutzig, 2014). However, in practice, lack of public support prevents or slows down its implementation (Carattini et al., 2019). For example, in 2016 and again in 2018, more than half of voters in Washington state opposed a carbon tax. In France, the carbon pricing policy has been frozen following the Yellow Vests protest movement of 2018.

Opposition to climate policies seems to arise, at least partly, from their effects on spatial inequalities: a recent example is the Yellow Vest movement in France, which has mainly been led by suburban and rural households, more impacted by the fuel price increase as they commute longer distances and have less access to public transportation. The fact that spatial dynamics can generate or worsen inequalities is well-known. For instance, Dodson and Sipe (2007) show that low socioeconomic status cumulates with higher car dependency in Australian cities, and Roberto (2008) finds that higher commuting costs cumulate with higher housing costs for low-income households in US cities. The spatial mismatch literature also shows that low access to employment in segregated areas has an impact on the risk of long-term unemployment (Andersson et al., 2018; Bastiaanssen et al., 2021; Gobillon et al., 2007). However, so far, there is no study of spatial dynamics and inequalities in the specific case of climate policies. Instead, climate policies are mainly studied through the lens of income inequalities (see for instance Bureau, 2011; Dorband et al., 2019; Fullerton et al., 1980; Ohlendorf et al., 2021; Wang et al., 2016), with existing studies showing that the impact of climate policies varies with income groups and can be progressive in low-income countries and in the case of transportation sector policies. However, the spatial inequalities arising from climate policies are not accounted for in these studies.

In this paper, we aim at understanding how transportation climate policies impact inequalities, with a focus on spatial inequalities. As a simple example of climate policy, we simulate a fuel tax, affecting either private vehicles only or private vehicles and polluting public transportation modes. We use the model derived from urban economics from Pfeiffer et al. (2019) to decompose its welfare impacts between i) direct impacts on transportation costs, ii) impacts on employment subcenter and modal choice, iii) rents, iv) dwelling sizes, and v) household locations, in order to provide a spatial analysis of the direct and indirect impacts of the policy on households and inequalities. We also analyze the mechanisms that might impact the ability of households to adapt to climate policies, trying to determine the role of land and housing markets in that process. We aim at understanding how climate policies could be designed to reduce negative impacts or “unfair” consequences and become more acceptable to everyone.
We take the City of Cape Town, South Africa, as a case study. Cape Town is a rapidly sprawling city, with an extremely high level of inequalities (income-based Gini index of 0.63 in 2011, UN-Habitat Global Indicators Database 2020\(^1\)). This translates into transportation and segregation issues; low-income households often living far from employment centers and being limited to use slow transportation modes as they cannot afford private cars. In addition, the housing market of the City of Cape Town is characterized by the coexistence of formal, subsidized, and informal housing, resulting in strong locational constraints for the people that cannot afford formal housing because informal and subsidized housing is only possible in some locations in the city.

We find that spatial inequalities can reinforce income inequalities. In the short run, households are more negatively impacted by the fuel tax if they earn low incomes or if they live far from employment centers. In the medium and long term, there is a persistence of spatial and income inequalities: the poorest households, living in informal settlements or subsidized housing, have few or no ways to adapt to changes in fuel prices by changing housing types, adjusting their dwelling sizes or locations (as informal or subsidized housing is only possible in some locations), or shifting transportation modes and employment locations. Low-income households living in formal housing are also impacted by the tax over the long run, due to complex effects driven by the competition with richer households on the housing market. These mechanisms are summarized in Table 1 and will be detailed throughout the paper.

<table>
<thead>
<tr>
<th>Timeframes</th>
<th>Short term</th>
<th>Medium-term</th>
<th>Long term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanisms</td>
<td>Direct impacts of the tax</td>
<td>Job location and transport mode adjustment</td>
<td>Rents adjustments</td>
</tr>
</tbody>
</table>
| Main drivers | • Low-income households more affected.  
• Households living in periphery more affected. | • Households more affected by direct impacts (low income, living in periphery) adapt more. | • Households living in subsidized housing cannot adapt.  
• Real estate prices increase near employment centers, with negative impacts for tenants and beneficial impacts for owners.  
• Low-income households living in formal housing are the losers of the competition with other income classes on the formal private housing sector. | • Households living in subsidized housing, informal settlements, or backyarding have fewer opportunities to adapt due to dwelling size and land-use constraints.  
• Low-income households living in formal housing are the losers of the competition with other income classes on the formal private housing sector. |

Table 1- Summary of the impacts of the tax on inequalities.

2. Context: The City of Cape Town
The city of Cape Town is a middle-income city of 4.2 million residents located in South Africa, facing multiple demographic, economic, social, and environmental stakes. First, the city is sprawling because of the legacy of the Apartheid-era urban planning with low-income households living in the urban periphery and a population growth rate of 2% annually mainly fueled by rural-urban migration in South Africa and by migrations from other African countries. The city has also an extremely high level of inequalities (its

Gini index of 0.63 is one of the highest in the world), inherited from the Apartheid: the city is composed of 46% Black Africans, 40% “Coloured” (Mixed Descent), 13% Whites and 1% Indians/Asians, and inequalities remain strongly correlated with race.

The City of Cape Town faces urban planning and transportation issues. The housing market of Cape Town is extremely segregated, with many low-income households living in informal settlements historically located in areas at the periphery of the city. The government’s answer to this issue has been large-scale housing building programs, aiming at providing new houses for free for low-income households. These houses, typically large (about 40sqm and a 70sqm garden), are mainly built in the periphery of the cities. However, these programs have been insufficient to meet the large demand, and many low-income households keep living in informal settlements. Some households also live in informal settlements in the backyards of these subsidized houses, gaining security against a rent paid to the subsidized houses’ inhabitants. These housing issues combine with transportation issues: low-income households living in subsidized houses, informal dwellings in backyards, or informal settlements are far from employment centers (IRR, 2020), in areas poorly served by public transport (Vanderschuren et al., 2021) and can spend as much as two-thirds of their income on transportation (Teffo et al., 2019).

To illustrate these income inequalities, Table 2 shows the four income classes that we use in this study. These four classes are defined such that only income class 1 (poorest households) is eligible for subsidized housing programs, and only classes 1 and 2 are observed to reside in informal housing, so that they do not correspond to income quartiles. Data on the number of households living in each housing type per income class are not available and can only be deduced from the model (see section 4.2).

<table>
<thead>
<tr>
<th>Income class</th>
<th>Annual income range in 2011 (ZAR)</th>
<th>Average 2011 income (ZAR, estimated using Census)</th>
<th>Percentage of the total population in 2011 (estimated using Census)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 - 38200</td>
<td>19580</td>
<td>38.6%</td>
</tr>
<tr>
<td>2</td>
<td>38200 - 76400</td>
<td>57300</td>
<td>16.7%</td>
</tr>
<tr>
<td>3</td>
<td>76400 - 307600</td>
<td>170140</td>
<td>28.9%</td>
</tr>
<tr>
<td>4</td>
<td>&gt; 307600</td>
<td>780723</td>
<td>15.8%</td>
</tr>
</tbody>
</table>

Table 2: Income classes used in the simulation

The City of Cape Town also faces strong environmental challenges, including a fast urban sprawl that has consequences in terms of biodiversity losses, carbon sequestration, water quality, and transportation emissions increase (City of Cape Town and TDA, 2018). Transportation is the second most emitting subsector in South Africa. In Cape Town, private cars are used in 53% of the commutes, and minibuses/taxis, the second most polluting transportation mode, in 12% of the commutes. However, attempts to mitigate transportation emissions in Cape Town could have large welfare and distributional impacts due to the current lack of affordable transportation options available for low-income households.

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2 This point is in discussion with the City of Cape Town at the time of the writing of this draft (28/04/2022), but the corresponding data are not available yet.

3 [https://tdacontenthubstore.blob.core.windows.net/resources/756c7e76-1ab5-45a9-9e97-ecee4e150e79.pdf](https://tdacontenthubstore.blob.core.windows.net/resources/756c7e76-1ab5-45a9-9e97-ecee4e150e79.pdf)
3. Methods

We aim at understanding how transportation climate policies impact inequalities, with a focus on spatial inequalities. We adopt the same approach as in Avner et al. (2017), computing the impact of a transport policy on transportation costs, rents, and housing and transportation budget of households, and showing that these effects vary spatially, with different impacts for households living in different parts of the city. However, the model of Avner et al. (2017) does not account for income inequalities, and therefore does not allow to study the interplay between income and spatial inequalities. In this paper, we use the model of Pfeiffer et al. (2019), which accounts for 4 income classes, 4 housing types, and polycentricity, allowing to further investigate the heterogeneity in the policy’s impacts and to accurately model the polycentric city of Cape Town. Many recent quantitative spatial models allow to consider income inequalities and polycentricity (Herzog, 2021; Tsivanidis, 2019), but the model of Pfeiffer et al. (2019) has the advantages of being tractable, not greedy in terms of data, while allowing to account for 4 income classes but also for 4 housing types.

3.1. Urban economics modeling

This section introduces our urban modeling framework, developed and fully described in Pfeiffer et al. (2019).

Urban modeling is based on the closed-city version of the Alonso-Muth-Mills (AMM) standard model of urban economics. The AMM standard model allows to spatially forecast housing construction, population density, rents, and transportation choices based on the distance to the city center (and CBD) in a monocentric city. This model relies on two main mechanisms: households are willing to pay higher rents to live closer to the city center and decrease their transportation costs; private developers decide on the housing they build and its capital intensity based on their expected profit, which depends on construction costs and the rents that households are willing to pay. As a result, with standard utility and construction functions, areas close to the city center are expected to be denser, with more expensive dwellings. Households derive utility from the consumption of housing, a composite good, and local amenities and disamenities (green spaces,...). We use the closed-city version of this model, assuming exogenous city population growth scenarios.

In this study, we use a modified version of the AMM standard model, enriched in four ways. First, we use a polycentric version of the model. Second, we account for five transportation modes: private cars, walking, minibuses/taxis, buses, and trains. Transportation modes differ in terms of monetary cost and opportunity cost of time. Third, we define 4 income classes to account for income inequalities, as detailed in the Context section. We assume that only income class 1 (poorest households) is eligible for subsidized housing and that only income classes 1 and 2 can accept to live in informal settlements or informal housing in backyards. Finally, we also account for inertia in formal private housing construction, assuming that it takes 3 years to build a new dwelling and buildings need 100 years to depreciate.

The main feature of the model of Pfeiffer et al. (2019) is to account for four housing types. (i) Formal housing is modeled as in the standard model of urban economics, with households trading off between housing sizes and transportation costs and private developers maximizing their profit, leading to higher densities, higher rents, and lower dwelling sizes near employment centers. Hence, rents, dwelling sizes, and population densities are endogenous. There are few land-use constraints on formal housing, as all locations are available except areas with natural constraints and areas where subsidized and informal
housing take place. (ii) Subsidized housing is exogenously provided for free by the state in exogenously predetermined areas, and is available for the poorest households only (income class 1). We assume that all subsidized houses have an exogenously given size of 40sqm and a garden of 70sqm. (iii) Households can build informal settlements in the backyards of subsidized houses. We assume that these dwellings have an exogenously given size of 14 sqm. Inhabitants of informal dwellings in backyards pay an (endogenous) rent to the owners of the subsidized houses, and subsidized houses owners decide on the share of their backyards they open to informal housing based on these rents, so that the density of informal dwellers in backyards is endogenous in the model. (iv) Finally, informal settlements also have a fixed exogenously given size of 14 sqm and are only possible in some specific locations. Informal rents paid to the informal owner of the land and the density of informal settlers are endogenous.

We assume that there is a disamenity parameter associated with informal settlements and informal housing in backyards, which captures the fact that informal dwellings are of a lower quality than formal dwellings and are associated with a certain probability of eviction. This disamenity parameter is spatially calibrated to fit the 2011 population distribution. At each location, each income class chooses the housing type that maximizes its utility, so that at each location, one income class can only live in one housing type.

3.2. Policy scenarios

We simulate a simple climate policy and look at its impacts, particularly in terms of income and spatial inequalities. We assume that a fuel tax increases the fuel price by 20%, starting in 2020. We consider two variants. In a first scenario, the fuel tax increases the variable component of the monetary cost of private cars by 20% but does not impact walking or public transport costs. In a second scenario, the fuel tax increases the variable component of the monetary cost of private cars, buses, and minibuses/taxis by 20%. Trains (already electrified) and walking costs are unchanged. These two scenarios are two extreme scenarios, while the actual implementation of a fuel tax is likely to stand in between: in the first scenario, we assume that public transports are fully subsidized so as not to be impacted by the tax, or that they become electrified, and in the second scenario, we assume that public transport prices are fully indexed on fuel price.

Concretely, as transportation costs are composed of a fixed monetary cost (e.g. depreciation of private car or subscription to public transportation), of a variable monetary cost (e.g. fuel price, or public transportation ticket), and of the opportunity cost of time, and as only the variable monetary cost is impacted by the policy, a 20% fuel tax translates into an increase in transportation costs of less than 20%. In practice, in scenario 1, the fuel tax translates into a 2.9% increase on average in transportation costs for car users of income class 1 (maximum of 4.8%), and into a 0.4% increase on average in transportation costs for car users in income class 4 (maximum of 0.6%). The increase in transportation costs is more important for low-income households as their opportunity costs of time are low so that their transportation costs are mainly driven by their monetary transportation costs.

We compute the equilibrium in the city with and without a fuel tax, and decompose the changes between these two equilibria into five steps, assuming that they happen sequentially:

i. Transportation costs increase for the workers commuting by private cars (scenario 1) or by private cars, buses, or minibuses/taxis (scenario 2).

ii. Households change their employment subcenter and modal choice to maximize their income net of transportation costs, accounting for the transportation costs increase. More precisely, workers
choose the transportation mode that minimizes their transportation costs, and the probability to choose each employment subcenter depends on income net of commuting cost.

iii. *Rents are adjusted*, as changes in transportation costs modify the relative attractiveness of locations in the urban area. All else equal, locations that are furthest from jobs and where households largely commute by transportation modes subject to the tax become less attractive because they are tied with higher transportation costs. As a result, housing rents in these locations will decrease proportionally more than rents in more central or more job-dense locations.

iv. *Households adjust their dwelling sizes* in reaction to rents changes, if they live in the formal private sector (as we assume that dwellings have fixed size in informal housing, backyarding, and formal subsidized housing).

v. *Households’ locations change*, i.e. they move within the urban area to maximize their utility.

4. Data, calibration, and validation

4.1. Data and calibration

We use the same data as Pfeiffer et al. (2019). The spatial distribution of the population is taken from National Censuses for the years 2001 and 2011. Incomes are also from the 2011 Census, and reclassified in four groups. For transportation, we use the transport model used by the City of Cape Town to retrieve transportation times between pairs of transport zones for each transport mode and jobs’ locations. We also use aggregated statistics on modal shares and residence-workplace distances in Cape Town derived from Cape Town’s 2013 Transport Survey. We use housing prices from the housing sales registry of the City of Cape Town. Concerning land use, areas of subsidized housing are identified from the cadastre of the City of Cape Town. The area available for backyard housing is estimated as the yard size of these units. Informal settlements areas are taken from the 2011 census. Finally, amenities are taken from various sources (see Pfeiffer et al., 2019). For the estimation of the model’s parameters, we also use property price data extracted from the City of Cape Town’s geocoded data set on property transactions for 2011, as well as data on dwelling sizes made available to us by the City of Cape Town.

As described in Pfeiffer et al. (2019), three sets of parameters need to be estimated. The first set consists of the minimum lot size, the size of the backyards of informal dwellings, and agricultural rents, and are directly derived from the available data without solving the model. The second set consists of the housing production function parameters, the utility function parameters, the wages, and the amenities, that had been calibrated in Pfeiffer et al. (2019) using partial relations from the model. Finally, we spatially calibrate the disamenity parameters for informal housing and informal settlements by running the entire model in order to replicate the population distribution by housing type from the 2011 Census.

4.2. Validation and baseline

We performed some validation checks to assess the validity of our modeling approach. All results can be found in Appendix A. First, at the aggregated level, we checked that the number of households per income class and per housing type simulated by the model in 2011 matches the data from the Census (Appendix A1). Then, we compared simulated population spatial distribution for each housing type in 2011 with the data from the Census (Appendix A2). Finally, we compared simulated rents and housing prices data (Appendix A3).

Regarding housing types, our simulations fit the data: we slightly overestimate the number of households living in formal private housing and informal housing in backyards, and underestimate the number of
households living in informal settlements (Figure 1 in the appendix). By construction, our calibration matches the number of households living in subsidized housing of the data. Regarding densities, the overall fit is good. Looking at the detail by housing types, we can see that the fit between data and simulations is very good for informal settlements and informal housing in backyards (this is due to our calibration of the disamenity parameter), and that the fit is also good for formal private housing even if we tend the overestimate densities in some parts of the city (Figure 9 in the appendix). Finally, our model allows reproducing housing prices, except for one peak in the city center (Figure 10 in the appendix).

The rest of this section shows some elements of context about housing types, population densities, employment, and transportation in Cape Town before the policies’ implementation. Table 3 shows the number of households per income class as well as the distribution among housing types in 2020, from the model's simulations. In terms of number of households, income class 1 (poorest households) is the biggest income class with 516,594 households, followed by income class 3, income class 2, and income class 4. Households from income class 1 live in subsidized housing, informal settlements, or informal housing in backyards; they cannot afford formal private housing. Households from income class 2 could technically live in informal housing, but most of them decide to live in formal housing instead. They, therefore, are the poorest households in the formal private housing market. Finally, income classes 3 and 4 live in formal private housing.

<table>
<thead>
<tr>
<th>Income class 1 (poorest households)</th>
<th>Income class 2</th>
<th>Income class 3</th>
<th>Income class 4 (richest households)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of households</td>
<td>516 594</td>
<td>223 515</td>
<td>388 234</td>
</tr>
<tr>
<td>... in formal private housing</td>
<td>0%</td>
<td>99.6%</td>
<td>100%</td>
</tr>
<tr>
<td>... in backyard housing</td>
<td>19.6%</td>
<td>0.18%</td>
<td>0%</td>
</tr>
<tr>
<td>... in informal settlements</td>
<td>29.4%</td>
<td>0.18%</td>
<td>0%</td>
</tr>
<tr>
<td>... in subsidized housing</td>
<td>51.0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 3 - Households per income class and distribution among housing types in 2020. Source: authors’ computations.

Then, we focus on the spatial distribution of the population before the implementation of the policy. Figure 1 shows the spatial distribution of the population of each income class and of employment centers in 2020, from the model’s simulations. It also shows the mean distance to jobs by income class. Households from income class 1 (poorest households) live far from employment centers, mainly because most of them live in informal settlements at the periphery of the city, in subsidized houses at the periphery of the city, or in informal dwellings in the backyards of subsidized houses. Households from income classes 2 and 3 live closer to employment centers, while income class 4 (richest households) can afford to live in larger dwellings very far from employment centers and to commute by private cars (IRR, 2020).
Our modeling of the spatial distribution of the population and of transportation choices allows retrieving the modal shares by income class Table 4. To our knowledge, no data on modal shares for the City of Cape Town are available for comparison. However, compared with the data from the National Household Travel Survey 2013 at the Western Cape region\(^4\) scale, we correctly estimate the modal shares of private cars (estimated as 27.7% of total trips, 37.1% in the data), walking (estimated as 20.2% of total trips, 17.1% in the data), and train (estimated as 7.6% of total trips, 10.6% in the data). We are less good at differentiating between buses and minibuses/taxis: we largely overestimate the modal share of buses (41.2% instead of 7.3%) and underestimate the share of minibuses/taxis (3.3% instead of 25.7%), with few incidences on our results as they are taxed the same way in our simulations. The overall picture remains valid: low-income households (income class 1 and 2) commute mainly by public transportation and walking and

\(^{4}\) About two-thirds of the Western Cape region live in Cape Town.
hardly use private cars, middle-income households hardly walk and commute mainly by private cars and public transport, and high-income households commute mainly by private cars.

<table>
<thead>
<tr>
<th></th>
<th>Income class 1</th>
<th>Income class 2</th>
<th>Income class 3</th>
<th>Income class 4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
<td>20.9%</td>
<td>13.0%</td>
<td>2.6%</td>
<td>0.0%</td>
<td>20.2%</td>
</tr>
<tr>
<td>Train</td>
<td>18.7%</td>
<td>18.7%</td>
<td>0.3%</td>
<td>0.0%</td>
<td>7.6%</td>
</tr>
<tr>
<td>Private car</td>
<td>1.6%</td>
<td>0.9%</td>
<td>18.5%</td>
<td>97.2%</td>
<td>27.7%</td>
</tr>
<tr>
<td>Minibus/taxi</td>
<td>10.8%</td>
<td>1.1%</td>
<td>1.1%</td>
<td>0.0%</td>
<td>3.3%</td>
</tr>
<tr>
<td>Bus</td>
<td>47.9%</td>
<td>60.3%</td>
<td>77.6%</td>
<td>2.7%</td>
<td>41.2%</td>
</tr>
</tbody>
</table>

*Table 4: Modal shares by income class in 2020. Source: authors’ computations.*

5. Spatial impacts of the fuel tax

In this section, we analyze what happens when a fuel tax is implemented, quantifying the various channels through which households are impacted and focusing on the spatial dimension of this impact. Our approach is similar to that of Avner et al. (2017) in their case study of Buenos Aires, but we deepen the analysis by using a richer model that allows accounting for multiple income classes, housing types, and employment centers. For the sake of simplicity, the results and figures of this section are displayed for scenario 2 only (the fuel tax impacts the cost of private cars, buses, and minibuses/taxis).

5.1. Direct impact on income net of transportation costs

Figure 2 – Direct impact of the fuel tax on incomes net of generalized transportation costs. Scenario 2 (taxing all polluting modes).

We start by analyzing the direct impact of the fuel price increase, assuming that, in the short run, workers do not adapt by changing employment centers, transportation modes, or locations. Figure 2 shows the direct impact of the fuel tax on incomes net of generalized transportation costs, in scenario 2, for income classes 1 and 4. These results are valid for the short run and show the immediate impacts of the
policy, but also inform on potential opposition to the policy from the populations. They also inform on the areas and people that are more likely to need support to adjust to the change in fuel prices.

Regarding income inequalities, direct impacts of the fuel tax on income class 1, corresponding to the poorest households, is larger than for the income class 4, corresponding to the richest households, with net income losses up to -11.6% for income class 1 against -0.34% for income class 4 in scenario 2 (taxing all polluting modes). Indeed, for high-income workers, transportation costs mainly consist of the opportunity cost of transportation time, and the monetary cost of transportation is low compared with their income. On the opposite, the monetary cost of transportation weighs heavily in low-income workers’ budgets, and they are thus more impacted by increases in this monetary cost. In scenario 1 (taxing cars only), the fuel tax impacts only private cars so that few low-income workers are affected, but the low-income workers that are impacted also suffer strong income net of transportation costs losses compared with higher-income workers.

Figure 2 shows evidence of spatial inequalities in scenario 2 (taxing all polluting modes), both for low-income and high-income workers: for a given income class, the workers living far from employment centers are more affected by the fuel price increase than workers living close to them. This effect depends on the employment centers of workers as well as on the modes of transportation chosen. Therefore, in the short term, there can be huge differences in the way the fuel tax affects two households in the same income class. Analyses of distributional impacts, looking at aggregated statistics per income class only, would have hidden these effects: a spatial lens is necessary to identify the most affected households, which would have the most to lose from the measure.

The next step is to understand how households can adapt to the fuel tax by changing their transportation modes and employment centers. Figure 3 shows the income net of transportation costs of households after changing their employment centers and mode choices, compared with the income net of transportation costs of households before adjustment. Since, in our framework, transportation mode and
Employment center choices are jointly optimized by households (see Pfeiffer et al., 2019), we do not distinguish them. However, in reality, while it is relatively easy to switch transportation modes, there may be rigidities in the labor market that make it more difficult to switch employment centers. We can see that the households that are the most affected by the fuel tax are also the households that adapt the most: households from income class 1 (the poorest) adapt more than households from income class 4 (the richest), and, within each income class, households living far from employment centers adapt more than households living close to employment centers. This ability to adapt is however mitigated by the availability of transportation modes allowing to switch to a non-taxed transportation mode or to change employment center. For instance, Lucas (2011) finds that low-income workers that cannot afford private cars or formal public transportation (trains, buses) or that do not have access to formal public transports (train, bus stations) near informal settlements are captive of informal transportation modes (minibuses/taxis) or over-relying on walking.

5.2. Rents

---

5 The poor quality of roads in informal settlements limits the opportunity for regular urban transportation implementation (Onyango, 2018).
Figure 4 – Impact of the fuel tax on rents (per sqm), for each housing type (except subsidized housing, as we assume they are supplied for free). Scenario 2 (taxing all polluting modes).

Figure 4 shows the impact of the fuel tax on rents per sqm for each housing type except for subsidized formal housing, as it is supplied for free by the government. The locations of employment centers as well as the number of jobs per employment center are also shown, as it is the changes in transportation costs to these employment centers that will lead to changes in rents.

For all housing types, we can see an overall trend of increasing rents near employment centers and of decreasing rents in the periphery. Indeed, the fuel tax makes central locations more desirable, while the increase in transportation costs makes households less willing to pay for housing far from employment centers. Due to the polycentric nature of the City of Cape Town, rents can increase in places that are far from the main CBD, but close to some other employment subcenters. Comparing the three housing types, the impact of the fuel tax on the rents paid for informal settlements or informal housing in backyards can be much more important than the impact on formal housing rents. Indeed, in this case, rents correspond to informal rents extracted by informal landowners or subsidized houses owners: in some locations, for informal settlements, they are almost equal to zero and the fuel tax might therefore bring important changes. In addition, informal settlements and informal housing in backyards depend on strong locational amenities such as the probability of eviction, the flood risk, or the availability of electricity or municipal water network: this might explain the variability in the impact of the fuel price between two close locations. By contrast, formal housing rents are more stable, with variations between -3.2% and +4.0% per sqm. A critical parameter is however the share of homeowners, compared with tenants: an increase in rents, negatively impacting tenants, is beneficial for homeowners. In South Africa, the share of homeowners is estimated at 35% (Statistics South Africa, 2018). Even if no statistics on the subject exist, this share is likely to vary with income class.
5.3. Housing + transportation budget

Figure 5 - Impact of the fuel tax on constrained expenses (housing and transportation), before and after dwelling sizes adjustment. Scenario 2 (taxing all polluting modes).

Figure 5 shows the impact of the fuel tax on constrained expenses (housing and transportation), after transportation mode, employment center, and rents adjustments. A decrease in these constrained expenses (green and yellow) therefore means a better situation after taxation, while an increase in these expenses (red and orange) means a worse situation after taxation. The top panel shows the impact before dwelling sizes adjustment, and the bottom panel shows the impact after dwelling sizes adjustment.

Three effects are at play. First, the fuel tax increases the transportation budget of households. Second, rents per sqm increase near employment centers and slightly decrease in the periphery of the city, with an ambiguous effect on constrained expenses, except for subsidized housing which remains free. Third,
dwelling sizes tend to compensate rent variations, and therefore to decrease in the city center and to slightly increase in the periphery; this applies however only for formal housing, as informal settlements, informal dwellings in backyards, and subsidized housing are of fixed sizes. In practice, it is very unlikely that households will move to smaller dwellings as an immediate consequence of the fuel tax, for instance because they cannot afford their rents anymore. Instead, dwelling size adjustment should be considered as medium to long-term adjustments: households will seize the opportunities to adapt their dwelling sizes in the medium or long-run, for example in the frame of a planned relocation. Reducing dwellings sizes allows households to reduce their constrained expenses and thus compensate for the increase in transportation costs, but living in smaller dwellings impacts their welfare. These effects are however complex, as rents are driven by the competition between households of the four income classes, having access to different housing types.

Comparing income class 1 (poorest households) and income class 4 (richest households) before dwelling sizes adjustment, we can see that we still have evidence of income and spatial inequalities. Households of income class 1 (poorest households) can be more impacted by the fuel tax than households from income class 4 (richest households), with constrained expenses increasing up to 14.5% against 1.5% for income class 4. Spatially, both for income class 1 (poorest households) and income class 4 (richest households), the households living close to employment centers seem to be the most impacted by the fuel tax, their transportation costs increasing moderately and their rents rising. However, after dwelling sizes adjustment, for income class 4, households that are the most impacted by the fuel tax are the households living in the periphery of the city: indeed, households living in the city center adapt by reducing their dwelling sizes, and households in the periphery by increasing their dwelling sizes. In addition, adjusting dwelling sizes allows households of income class 4 to mitigate their constrained expenses increase (it does not exceed +0.6% after dwelling sizes adjustment).

On the opposite, households of income class 1 (poorest households) cannot adapt by reducing their dwelling sizes in the city center or increasing their dwelling sizes in the periphery, as they mostly live in informal settlements, informal housing in backyards, and subsidized housing, which we assume to be of fixed sizes. For this reason, figure 5a) and 5c) are mostly identical. In practice, informal settlements are typically small (between 6 sqm and 20 sqm), and the largest ones host multiple families (Sustainable Energy Africa, 2014), so that a downscaling is very unlikely. Regarding subsidized houses, they are provided by the government at fixed rents, in fixed sizes and fixed locations. Even if these programs increase the welfare of low-income households by giving them access to housing, they do not allow households to trade-off between location and dwelling sizes, by moving closer to the city center and reducing their dwellings sizes to adapt to the fuel price increase for instance.

6. Aggregated impacts on welfare

6.1. Final welfare impact – comparison between scenarios 1 and 2

<table>
<thead>
<tr>
<th>Scenario 1 (taxing cars only)</th>
<th>Income class 1</th>
<th>Income class 2</th>
<th>Income class 3</th>
<th>Income class 4</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.03%</td>
<td>-0.19%</td>
<td>-0.21%</td>
<td>-0.06%</td>
<td>-0.06%</td>
<td></td>
</tr>
<tr>
<td>Scenario 2 (taxing all polluting modes)</td>
<td>-0.57%</td>
<td>-0.98%</td>
<td>-0.35%</td>
<td>-0.06%</td>
<td>-0.49%</td>
</tr>
</tbody>
</table>
Table 5 - Final welfare impacts by income class. In the model, welfare is derived from the consumption of housing and of a composite good and impacted by local amenities and by a disamenity parameter for households living in informal settlements or informal housing in backyards.

Table 5 shows the final welfare impact of the fuel tax after adjustment of modal choices, employment centers, rents, dwelling sizes, and households’ locations. In the long run, the overall impact on final welfare is low, and never exceeds -1%. In scenario 1, in which the fuel tax affects private cars only, the impact on the welfare of income class 1 (poorest households) is low, as low-income workers barely commute by private cars and live in different housing types than high-income workers so that they are almost unaffected by real estate market adjustments. In scenario 1, the impact on the welfare of income class 4 (richest households) is also low, as the fuel tax is low compared with the income of the richest households. The most impacted are income class 2 and income class 3. Therefore, qualifying this policy as progressive or regressive is insufficient in this analysis, as its impacts are U-shaped: poorest households are unaffected because they cannot afford private cars, middle-class households are impacted, and richest households are unaffected because the tax is low compared to their incomes.

In scenario 2 where the fuel tax affects private cars, buses, and minibuses/taxis, the final welfare impact remains low for income class 4 (richest households). However, in this scenario, the fuel tax affects more transportation modes, and therefore also has an impact on low-income households’ welfare. The most impacted are income classes 1 and 2. Qualifying the policy as progressive or regressive is also insufficient in this case as its effects depend on the interplay between income (income classes 1 and 2 tend to use less polluting transportation modes, as they are more expensive, but the tax weighs more heavily in their budgets as they are poorer) and spatial considerations (most households of income class 1 and 2 live in informal or subsidized housing, and thus are constrained to live far from employment centers).

### 6.2. Welfare impact decomposition – by income class

<table>
<thead>
<tr>
<th></th>
<th>Income class 1</th>
<th>Income class 2</th>
<th>Income class 3</th>
<th>Income class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct impact</strong></td>
<td>-0.86%</td>
<td>-0.69%</td>
<td>-0.32%</td>
<td>-0.15%</td>
</tr>
<tr>
<td>Employment centers and mode choice adjustment⁷</td>
<td>+0.19 pp</td>
<td>+0.03 pp</td>
<td>+0.00 pp</td>
<td>+0.00 pp</td>
</tr>
<tr>
<td>Rents adjustment</td>
<td>-0.02 pp</td>
<td>-0.18 pp</td>
<td>-0.04 pp</td>
<td>+0.07 pp</td>
</tr>
<tr>
<td>Dwelling sizes and households’ locations adjustment</td>
<td>+0.12 pp</td>
<td>-0.15 pp</td>
<td>+0.02 pp</td>
<td>+0.01 pp</td>
</tr>
<tr>
<td><strong>Final welfare impact</strong></td>
<td>-0.57%</td>
<td>-0.98%</td>
<td>-0.35%</td>
<td>-0.06%</td>
</tr>
</tbody>
</table>

Table 6 - Welfare impacts decomposition by income class. Scenario 2 (taxing all polluting modes).

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⁶ For the sake of comparison: a 5% reduction in income leads to a 4.2% loss of welfare for class 1, a 7.1% loss of welfare for class 2, a 4.3% loss of welfare for class 3, and a 4.1% loss of welfare for class 4.

⁷ Employment centers and mode choice adjustments cannot be distinguished, as they are optimized together in the model (see Appendix 1 for more details).
We decompose the welfare impacts of the fuel tax in scenario 2 by comparing the equilibria with and without the tax: we assume that the different steps (transportation costs increase, mode choice and employment, rents adjustments, and dwelling sizes and location adjustments) happen sequentially, and we estimate the impact of each step on welfare by computing the corresponding counterfactuals. Results are displayed in Table 5 and Figure 6.

First, the direct impact of the fuel tax on welfare before any adjustment is more important for income class 1 (poorest households) (-0.86%) and income class 2 (-0.69%) than for income class 3 (-0.32%) and income class 4 (-0.15%). Second, employment centers and mode choices adjustment unambiguously mitigate the impact of the fuel price increase on welfare, and this effect is particularly important for income class 1 (poorest households), which has been more impacted by the tax in the first place. Still, at this stage, income classes 1 and 2 remain the most impacted. After that, rents, dwelling sizes, and households’ locations adjustments also allow to mitigate the effect of the tax, but this effect strongly depends on the income group. For instance, rents increase in some locations (typically central) and decrease in others (typically periphery), which explains that the richest households (income class 4), generally living in the farthest suburbs, benefit from a decrease in their rents (table 3 shows that rents reduce the impact on the welfare of the fuel tax of 0.07 percentage points for income class 4). The impacts of dwelling sizes and households’ locations increase welfare for income classes 1, 3 and 4, and decrease welfare for income class 2. This surprising result comes from the fact that dwelling sizes and households’ locations adjustments result from the competition between the four income classes on the housing market. Households from income class 2 being the poorest households on the formal housing market, they are negatively impacted by adjustments on this market.

Graphically representing this welfare decomposition (Figure 6), we see clear evidence of income inequalities in the short run, with income class 1 (poorest households) and, to a lower extent, income class 2 being the most affected by the direct impacts of the fuel tax. These short-term impacts are important (up to 11.5% for income class 1). In the long run, income inequalities are mitigated (they remain...
below 1%), but persistent, especially for low-income households (income classes 1 and 2). For income class 1, what matters here seems to be the timing of the adjustment: if changing mode choices seems to be feasible in the short run, adjusting employment centers or housing locations can only be done in the medium or long run. Policies facilitating adjustment on the housing or employment markets could therefore prove efficient to reduce short-term inequalities related to the fuel tax. For income class 2, what matters is the fact that they are the poorest households on the formal housing market: income inequalities are crucial in this case. Financial assistance to help households compensate for the tax should target priority low-income households.

6.3. Welfare impact decomposition – by housing type

<table>
<thead>
<tr>
<th></th>
<th>Formal private</th>
<th>Informal in backyards</th>
<th>Informal settlements</th>
<th>Formal subsidized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct impact</td>
<td>-0.22%</td>
<td>-0.47%</td>
<td>-0.95%</td>
<td>-0.91%</td>
</tr>
<tr>
<td>Employment centers and mode choice adjustment</td>
<td>+0.00 pp</td>
<td>+0.08 pp</td>
<td>+0.20 pp</td>
<td>+0.21 pp</td>
</tr>
<tr>
<td>Rents adjustment</td>
<td>+0.03 pp</td>
<td>-0.26 pp</td>
<td>+0.07 pp</td>
<td>+0.00 pp</td>
</tr>
<tr>
<td>Dwelling sizes adjustment</td>
<td>+0.94 pp</td>
<td>+0.00 pp</td>
<td>+0.00 pp</td>
<td>+0.00 pp</td>
</tr>
</tbody>
</table>

Table 7 – Welfare impacts decomposition by housing type. Scenario 2 (taxing all polluting modes).

Understanding how welfare impacts depend on housing type helps to understand the persistence of inequalities between income classes, even in the long run. Table 7 decomposes the impact of the fuel tax by housing type. Impacts on households’ locations are not shown, as, after households’ locations adjustment, households living in each housing type are not necessarily the same: people can switch housing type because of their utility maximization behavior when they are impacted by a change in transportation costs.

The direct impact of the fuel tax is more important on informal housing in backyards, informal settlements, and subsidized housing than on formal private housing. This is mainly because households living in informal settlements, informal housing in backyards, and subsidized housing belong to the two poorest income classes, meaning that the increase in monetary transportation costs due to the fuel tax weighs heavily in their budgets. In addition, these housing types are under strong land-use constraints as they are only possible in some exogenous locations, often far from employment centers, which means that households have less flexibility to adjust and mitigate the increase in transport costs.

This direct impact is partially mitigated by adjustments in employment centers and mode choices, for all housing types. It is also mitigated by adjustments in rents, except for people living in subsidized housing, as subsidized houses are provided for free by the state. Finally, the direct impact is mitigated by dwelling sizes adjustment for formal private housing. Subsidized housing is provided by the state in the form of fixed-size houses, so that they do not adjust to the fuel tax. Informal housing is also of fixed size, typically very small.

After these adjustments, households can change housing types and locations. However, people living in informal settlements, informal housing in backyards, and subsidized housing often lack the financial resources necessary to afford formal private housing, and thus are forced to remain in informal housing, or subsidized housing if they benefit from this program. In addition, informal settlements, informal
housing in backyards, and subsidized housing are spatially constrained: informal settlements can only take place in some locations (with publicly owned vacant land), locations of subsidized housing are exogenously decided by the state, and backyarding mostly takes place in the backyards of subsidized houses.

We can draw two conclusions from this analysis. First, low-income living in informal settlements, informal housing in backyards, or subsidized housing are more affected by the direct impacts of the fuel tax, as their incomes are generally low. Second, they have fewer opportunities to adapt to the fuel tax as they are under stronger land-use constraints, can hardly switch to formal private housing and can hardly adjust rents or dwelling sizes. This shows the limitations of the subsidized housing program in the form of a fixed provision of housing units at exogenously determined locations and explains why the City of Cape Town is giving up on this policy.\(^8\)

6.4. Welfare impact decomposition – by spatial quartile

![Welfare variation as a function of distance to jobs](image)

*Figure 7 – Welfare decomposition by income class and spatial quartile. Scenario 2 (taxing all polluting modes).*

For each income class, we define spatial quartiles in relation to the weighted average distance to jobs: spatial quartile 1 corresponds to the 25% of households closest to jobs and spatial quartile 4 corresponds

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\(^8\) [https://www.businessinsider.co.za/government-is-calling-for-the-downscaling-of-housing-projects-heres-how-it-will-work-2020-12](https://www.businessinsider.co.za/government-is-calling-for-the-downscaling-of-housing-projects-heres-how-it-will-work-2020-12)
to the 25% of households farthest from jobs. We decompose the welfare impacts of the fuel price increase by income class and spatial quartile (Figure 7).

For income classes 3 and 4, as expected, we can see that the direct impact of the fuel tax strongly depends on the location, with spatial quartile 4 being more affected than spatial quartile 1. Employment center and mode choice adjustment slightly attenuate the welfare impact of the fuel price increase. Finally, rents increase for the households living near the city center and decrease for households living further away from the city center, leading to a nearly similar impact of the fuel tax on all households of the income class. By construction, in the long run, after adjustment, utilities of all households of each income class will be equal. However, figure 7 does not show the last step (dwellings’ sizes and housing locations adjustment), because, after housing locations’ adjustment, we do not have the same households in each spatial quartile anymore. Therefore, even if, by construction, all households of each income class will have the same utility in the end, we focus here on the convergence process: there are inequalities between spatial quartiles in the short run, that can be important if the convergence process takes time.

For income classes 1 and 2, the effects at play in the convergence process are less clear. First, for income class 2, there are few differences between spatial quartiles. Second, the direct impact of the fuel tax varies with spatial quartiles, but in a non-linear way. One explanation might be that contrary to the richest households which almost all commute by polluting transportation modes, the poorest households sometimes commute by non-polluting transportation modes. Finally, by construction, after dwelling sizes and housing locations adjustment, utilities within each income class are equal and spatial inequalities disappear. However, in the medium run, we find evidence of persisting spatial inequalities, especially within income class 2.

7. Aggregated impact on emissions

Table 8 shows the impact of the fuel price increase on passenger-km for each transportation mode, as well as the further decomposition between the variations due to modal shift and the variations due to workplace-residence distance changes. The last column estimates the impact on emissions, using emissions per km data from WWF (2016).

Scenario 1, in which only private cars are impacted by the fuel price increase, is more efficient in terms of emissions mitigation than scenario 2, in which private cars, buses, and minibuses/taxis are impacted. This result, which implies that taxing all polluting transportation modes does not necessarily lead to higher emissions reduction, can seem counterintuitive. There are two reasons for this. The first is that there are more modal shifts in scenario 1 than in scenario 2. Indeed, in scenario 1, taxing private cars leads to a strong reduction in their modal share, to the profit of buses and minibuses/taxis, which are less fuel consuming travel modes. In scenario 2, as private cars, minibuses/taxis and buses/taxis are taxed, the modal share of private cars is actually increasing: as buses and minibuses/taxis are slow, a tax makes them really unattractive, leading to a modal shift to the profit of private cars, more expensive due to the tax but also faster than other modes. This effect depends on the relative increase in private cars transportation costs compared to the relative increase in buses and minibuses due to the tax: it depends on the share of variable monetary cost among total transportation costs, which varies with income group and location. The second reason is that the decomposition of passenger-km variations between modal shares variations and average distances variations shows that passenger-km variations are mostly driven by modal shift and not by passenger-km variations. Indeed, informal settlements, backywarding, and subsidized housing are
strongly constrained in our model. Regarding formal housing, inertia in housing supply slows down potential formal housing relocations. As a result, urban reconfigurations have a low potential for emissions reduction in our model. We conducted two sensibility checks (Appendix B). First, we implemented a fuel tax of the same monetary amount (10cts) per kilometer for all transportation modes (Table 9). Second, we look at the result after 20 years, to let formal housing supply the time to adjust despite inertia (Table 10). In these cases, scenario 1 remains more efficient in terms of emissions mitigation, and urban reconfigurations play a small role compared with modal shares.

As a result, taxing polluting public transportation modes might be less efficient in terms of emissions mitigation than taxing private cars only, and policy makers should in priority account for potential modal shifts induced by the tax. This result is in line with Avner et al. (2014), which finds that, in Paris, reducing transportation emissions requires a lower level of gasoline tax if a dense network of public transportation is available: indeed, having public transportation options allow to play on modal shift, in addition of urban reconfiguration, to reduce emissions.

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Passenger-km variations</th>
<th>Emissions variations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walking</td>
<td>Train</td>
</tr>
<tr>
<td>- modal shares variations</td>
<td>+0.15%</td>
<td>+1.06%</td>
</tr>
<tr>
<td>- average distances variations</td>
<td>+0.30%</td>
<td>+0.18%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario 2</th>
<th>Passenger-km variations</th>
<th>Emissions variations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Walking</td>
<td>Train</td>
</tr>
<tr>
<td>- modal shares variations</td>
<td>+19.63%</td>
<td>+49.94%</td>
</tr>
<tr>
<td>- average distances variations</td>
<td>+2.20%</td>
<td>-2.10%</td>
</tr>
</tbody>
</table>

Table 8 - Impact of the fuel tax on transportation demand and estimations of its impact on transportation emissions.

The outputs of the model also allow us to provide a rough estimate of the monetary value of the improved health through reduced air pollution due to the tax (Appendix C). Overall, scenario 1 allows to gain 3.1 million USD from improved health, and scenario 2 allows to gain 2.1 million USD from improved health, partially offsetting the welfare impact of the tax.

8. Discussion

Beyond income inequalities, this work allows decomposing the spatial dynamics resulting from the implementation of a climate transportation policy. In the short run, the climate policy results in an increase in transportation costs, strongly impacting households living in the periphery of the city and commuting by polluting transportation modes. Low-income households are also strongly impacted by the tax, which weighs heavily in their budgets. Then, equilibrium effects tend to mitigate the impacts of the fuel price increase: workers adjust employment centers and transportation mode choices, rents increase in the city center and decrease in the periphery, and households adjust locations and housing types to, overall, live closer to the city center and job-dense locations.
However, to fully understand inequality issues resulting from this climate policy, the effects that prevent or delay the equilibrium need to be accounted for, and the analysis is best performed for various timescales:

- In the short run, households cannot adapt to the fuel tax, and households bear the direct impacts of the fuel price increase. We have very strong evidence of income inequalities, with low-income households being more affected by the fuel price increase, but also evidence of spatial inequalities, the direct impact of the fuel tax increase varying with distance to the city center.
- In the medium run, households can shift modal choice and employment centers to adapt to the tax. Low-income households and households living far from employment centers, that are the most affected by the tax, are also those who will adapt the most, but they remain more impacted by the tax than high-income households even after this step.
- In the long run, households do not have the same opportunity to adapt to the fuel tax. Low-income households living in subsidized or informal housing (income class 1) might not have the possibility to afford private housing and are forced to remain in informal housing or subsidized housing, and therefore are tied to certain locations. Plus, they cannot change dwelling sizes, preventing them to adapt to the fuel price increase. Regarding low-income households living in formal housing (income class 2), as they are the poorest households on the formal housing market, they struggle in adapting to the fuel tax and are hurt by adjustments made by richer households and competition on the housing market. Therefore, there is a persistence of the inequalities arising from the fuel tax, with low-income households remaining the more impacted. This finding might help in designing financial subsidies based on incomes to compensate households for the impact of the tax.

In terms of aggregate impacts, city-scale aggregated welfare losses due to the fuel tax are limited, and partially offset by the health co-benefits related to the reduced air pollution. In the Cape Town context, implementing a fuel tax on private cars only impacts mostly the richest households as low-income households cannot afford private cars, whereas a fuel tax on private cars, buses, and minibuses/taxis has a higher impact on low-income households. The city-scale aggregated welfare loss is higher when all polluting transportation modes are impacted than when cars only are impacted. A fuel tax affecting private cars only is also more efficient in terms of emissions reduction, as it generates a modal shift from private cars to other transportation modes. Therefore, we do not find an efficiency-equity trade-off: in the Cape Town context, our results suggest it makes sense to tax private cars only (or equivalently to tax fuel and to subsidies public transportation), as taxing all polluting transportation modes is at the same time less efficient in terms of emissions reduction and more regressive, possibly triggering political economy effects that could push households to oppose climate policies.

This work might be relevant for public policy. First, in terms of political economy, implementing a fuel tax can be perceived as strongly unfair, in the short run as some households are more impacted by the direct impact of the tax, as well as in the long run as all households do not have the same opportunity to adapt to the tax. The design of an integrated policy on transportation, land-use, and real estate, allowing households impacted by the tax to adapt by changing employment subcenters, transportation modes, and housing types and locations, could be considered. In practical terms, a functioning labor market allowing people to change jobs easily, the design of affordable and non-affected by the tax public transportation, or the implementation of subsidies helping low-income households to build or rent houses closer to the city center, could attenuate spatial inequalities resulting from a fuel tax increase alone. The subsidized
housing programs significantly improve the welfare of low-income households but do not provide flexibility and make them less resilient to shocks on transportation costs.

Despite a real estate market that is very city-specific, notably due to the coexistence of two informal housing types and subsidized housing, we believe these results can have implications for other cities. In terms of political economy, a climate transportation policy will be perceived as fair and acceptable only if all households have an equal chance to easily adapt to this policy, by having access to alternative transportation modes in the short run, and by having the chance to adjust the location of their residence in the long run. Segregated or gentrified cities are therefore major challenges for climate change mitigation in cities.
References


Herzog, I., 2021. The City-Wide Effects of Tolling Downtown Drivers: Evidence from London’s Congestion Charge. 120.


A. Validation

A1. Housing types and income classes

(a) Housing types

(b) Income classes

Figure 8 - Income classes and Housing types - Comparison between data and simulation

A2. Spatial distribution of the population

(a) All housing types
Figure 9 - Comparison between data and simulations - Densities

(b) Formal

(c) Backyard

(d) Informal settlements

A3. Housing prices

Figure 10 - Housing prices - Comparison between data and simulation
B. Sensitivity check

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Walking</th>
<th>Train</th>
<th>Private car</th>
<th>Minibuses/taxis</th>
<th>Buses</th>
<th>Emissions variations</th>
</tr>
</thead>
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<td>- modal shares variations</td>
<td>+0.33%</td>
<td>+0.82%</td>
<td>-10.65%</td>
<td>+1.15%</td>
<td>+7.08%</td>
<td></td>
</tr>
<tr>
<td>- average distances variations</td>
<td>+0.14%</td>
<td>+0.07%</td>
<td>+2.33%</td>
<td>+0.77%</td>
<td>+1.16%</td>
<td></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>+21.29%</td>
<td>+37.83%</td>
<td>+0.58%</td>
<td>-28.69%</td>
<td>-20.11%</td>
<td>-1.27%</td>
</tr>
<tr>
<td>- modal shares variations</td>
<td>+18.58%</td>
<td>+41.58%</td>
<td>+3.36%</td>
<td>-11.21%</td>
<td>-16.46%</td>
<td></td>
</tr>
<tr>
<td>- average distances variations</td>
<td>+2.29%</td>
<td>-2.65%</td>
<td>-2.68%</td>
<td>-19.69%</td>
<td>-4.37%</td>
<td></td>
</tr>
</tbody>
</table>

Table 9 - Impact of the fuel tax on transportation demand and estimations of its impact on transportation emissions – with a monetary tax of 10cts per km, for private cars in scenario 1, and for private cars, buses, and minibuses/taxis in scenario 2.

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Walking</th>
<th>Train</th>
<th>Private car</th>
<th>Minibuses/taxis</th>
<th>Buses</th>
<th>Emissions variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>- modal shares variations</td>
<td>+0.65%</td>
<td>+12.16%</td>
<td>-11.21%</td>
<td>+0.72%</td>
<td>+18.66%</td>
<td></td>
</tr>
<tr>
<td>- average distances variations</td>
<td>+0.39%</td>
<td>+0.17%</td>
<td>-1.43%</td>
<td>-0.09%</td>
<td>+4.57%</td>
<td></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>+16.72%</td>
<td>+28.23%</td>
<td>+1.86%</td>
<td>-19.85%</td>
<td>-39.55%</td>
<td>-0.27%</td>
</tr>
<tr>
<td>- modal shares variations</td>
<td>+13.30%</td>
<td>+30.77%</td>
<td>+4.21%</td>
<td>-17.09%</td>
<td>-32.67%</td>
<td></td>
</tr>
<tr>
<td>- average distances variations</td>
<td>+3.03%</td>
<td>-1.96%</td>
<td>-2.25%</td>
<td>-3.33%</td>
<td>-11.53%</td>
<td></td>
</tr>
</tbody>
</table>

Table 10 - Impact of the fuel tax on transportation demand and estimations of its impact on transportation emissions – after 20 years, to capture potential changes in urban forms that would occur in the long term.

C. Air pollution

Our estimates of the monetary gains from improved health, resulting from the reduced air pollution, are computed in the following way:

- Total passenger per km per year for private cars, buses, and minibuses/taxis are outputs of our model. We do not account for walking, as it does not generate air pollution, or for trains, assuming they are electrified.
- Using the WWF (2016) data, we compute the corresponding CO₂ emissions.
- From CO₂ emissions, we derive the liters of fuel that have been used, assuming that 1 liter of fuel emits 2.4kg of CO₂. From this estimate of the number of liters of fuel that are used per year, we derive the monetary cost of air pollution through reduced health using the values provided by the CPAT model of the World Bank (0.022 USD per liter of gasoline and
0.268 USD per liter of diesel). We assume that 35% of the vehicles are diesel vehicles, following the IEA (https://www.iea.org/articles/fuel-economy-in-south-africa, accessed 27/04/2022).

We find that the monetary cost of air pollution per year is 57.1 million USD in 2020 when no fuel tax is implemented, 54.0 million USD in scenario 1 and 55.0 million USD in scenario 2.