DISCUSSION PAPER SERIES

IZA DP No. 14642

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I Z A Institute of Labor Economics

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ABSTRACT

What If Working from Home Will Stick? Distributional and Climate Impacts for Germany*

The COVID-19 pandemic created the largest experiment in working from home. We study how persistent telework may change energy and transport consumption and costs in Germany to assess the distributional and environmental implications when working from home will stick. Based on data from the German Microcensus and available classifications of working-from-home feasibility for different occupations, we calculate the change in energy consumption and travel to work when 15% of employees work full time from home. Our findings suggest that telework translates into an annual increase in heating energy expenditure of 110 euros per worker and a decrease in transport expenditure of 840 euros per worker. All income groups would gain from telework but high-income workers gain twice as much as low-income workers. The value of time saving is between 1.3 and 6 times greater than the savings from reduced travel costs and almost 9 times higher for high-income workers than low-income workers. The direct effects on CO2 emissions due to reduced car commuting amount to 4.5 millions tons of CO2, representing around 3 percent of carbon emissions in the transport sector.

JEL Classification: D13, J22, J61, Q40, R11

Keywords: working from home, COVID-19, distributional effect, climate impact

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1 Introduction

In response to COVID-19 pandemic, governments urged people to stay at home and to reduce social contact to a minimum. In Germany, the federal governments and the Bundesländer took a series of measures from early March 2020, including limitations of public gatherings, border checks, border closures, school closures, partial lockdowns, and public services closures. As a consequence, many companies allowed their employees to work from home. This created a unprecedented social experiment in working from home and research suggests that it will stick due to good experiences, new investments in physical and human capital, technological innovations, and greatly diminished stigma associated with teleworking (Barrero et al., 2021). As workers spent more time at home, their energy consumption at home rose, driving the increase of their energy expenditure, while their mobility decreased, leading to a reduction of their transport expenditure.

In this paper, we study how the persistence of working from home may change energy and transport consumption and expenditures to assess the the distributional and environmental implications of teleworking in Germany. First we identify jobs that can be done from home. Recent studies estimate that between 37% and 56% of the workforce could work from home in Germany (Dingel and Neiman (2020), Alipour et al. (2020)). These results represent upper bounds estimates for the actual telework potential. A survey by the Economic and Social Research institute of the Hans Böckler Foundation showed that in April 2020, when restriction measures were the highest, 27% of employees were working from home. A new series of restrictions decided from October 2020 led to a new increase from 14% in November 2020 to 17% in December, and 25% in January 2021. Based on this survey, we assume that 15% of people could persistently work full time from home. Second we calculate the change in energy consumption and travel to work when 15% of people work full time from home. We assume a rise of 20% in residential energy needs for each day of telework for household where at least one member teleworks, and zero transport cost. We include the cost of the carbon price in 2021 (25 euros/ton of CO_2). We also take into account the reductions in the commuting allowance and the benefit of the home office allowance introduced in 2020.

Our findings show that the effects of telework on total expenditure is driven by savings in commuting expenses. We find that all income groups gain from telework, but savings of the richest workers are twice higher than those of the poorest (840 euros per worker and year, versus 420 euros). Workers living in rural areas and small cities (less than 20,000 inhabitants), who have longer commute to work, benefit more from teleworking. They save on average 1,380 euro per year on transport expenditure, versus 1,025 euros for workers living in large cities. The travel time saved by people who telework is on average 175 hours per year. If commuting time is valued at the hourly wage earned by the workers who telework, we estimate that savings are almost 9 times higher for higher-income workers than lowest-income workers (5,800 euros vs 650 euros for the lowest income decile). The value of time saving is between 1.3 and 6 times greater than the savings from reduced travel costs. We estimate that telework reduces CO_2 emission in transport by 4.5 million tons of CO_2. Emissions resulting from working from home (i.e. increased energy use at home) are estimated to be 2.9 million tons – but these emissions are expected to roughly replace heating-related emissions from working on site.

2 Existing works on teleworking and energy consumption

Existing works have focused on the suitability of specific jobs for teleworking as well as energy consumption effects from COVID-related lockdown measures. Both strands of literature have developed separately.

2.1 Jobs that can be done from home

A recent literature provides upper bound estimates of work from home potential. Dingel and Neiman (2020) classify the feasibility of working at home for all occupations using the responses to US O*NET surveys (Work Context survey and Generalized Work Activities survey). They conclude that 37% of jobs in the US can be performed entirely at home. To produce estimates for other countries, they merge their work-from-home classification of each 6-digit SOC based on the US O*NET surveys with the 2008 edition of the international standard classification of occupations (ISCO) at the 2-digit level. They obtain the share of work that can be done from home by occupation's group for 38 occupation's group. For Germany they find that 36.7% of jobs can be performed entirely at home.

Del Rio-Chanona et al. (2020) build a Remote Labour Index (RLI) to measure the ability of different occupations to work from home in the US. Rather than a binary assessments of whether an occupation can be performed at home, they provide an indication of the amount of work performed by a given occupation that can be done remotely. To do so, they calculate for each occupation the proportion of an occupation's work activities that can be performed at home. The RLI has values between 0 (=none of the activities associated with an occupation can be performed at home) and 1 (=all of the occupation's activities can be undertaken at home). They find that in the US, 43% of workers can work remotely.

Alipour et al. (2020) compute a measure for Work from home feasibility that relies on employees' own assessment concerning the feasibility to perform their jobs from home. Using the 2018 wave of the BIBB/BAuA Employment Survey covering 17,160 employees aged 18-65, they find that roughly 56% of all jobs in the current German economy can plausibly be performed at home.

2.2 Impacts of Covid-19 and telework on energy and mobility

Recent studies on the impact of Covid-19 on energy consumption and transport developed. Based on the monthly data from electric utilities nationwide in the US, Cicala (2020) shows that residential electricity consumption increased by 10% during the second quarter of 2020. Using hourly smart meter data from Texas, he finds that the consumption increased by 16% during work hours. Places with a larger share of the workforce potentially working from home have seen larger increases in residential electricity consumption, suggesting that telework is an important driver in the increase of residential consumption. In Spain, Bover et al. (2020) find that households' electricity demand was 9.6% above its normal level during the total lockdown of the first wave, and still 2.4% above during the second wave. Based on recent data on gas consumption from BDEW, we estimate that natural gas consumption for households increased by 3% in 2020 compared to 2019 (adjusted for the warm climate in 2020).

Analyzing movements recorded from mobile phones of 43.6 million individuals in Germany, Schlosser et al. (2020) find that mobility in Germany was substantially reduced during the COVID-19 pandemic. The largest reduction occurred in mid-March: over the course of 3 weeks, mobility dropped to 40% below baseline, with the total number of daily recorded trips decreasing from 3.8 to 2.3 daily trips per user. This decline was followed by an immediate rebound at the beginning of April, and in the following months mobility increased slowly, reaching its pre lockdown levels in early June. They also highlight that long-distance trips decreased more strongly than short-distance trips.

3 Data

Our simulation analysis is based on the German household survey, the Microcensus. The German Microcensus is an annual cross-sectional survey of private households in Germany covering 1% of the population. It contains data on core socio-demographic variables on the individual and household level, in particular marital status and household composition as well as detailed information on education, occupation, industry and living conditions. It provides information on income (at household and individual level) and on occupation, which is used to identify which jobs can be done from home. The 2014 wave includes variables on the characteristics of the dwelling, which are used to estimate energy consumption, and on the type of energy used for heating, which contributes to estimate energy cost. The 2016 wave includes variables on the distance to commute to work and the type of transport used to calculate transport costs.

Additional variables on the number of hours worked help to estimate the number of commutes. For both waves, we select people who are employed and for which information on occupation and income is available. This procedure excludes farmers and other self-employed, for whom information on income is not available, and the household to whom they belong.

For the 2014 wave, we remove households for which information on the dwellings and energy used is missing. The resulting 2014 sample contains 217,972 workers from 141,602 distinct households. For these individuals we have information on occupation, income category, working hours. For the households, we have information on the total income, and on the dwelling (size, year of construction of the building, number of dwellings in the building and type of energy used for heating).

For the 2016 wave, we remove workers and their corresponding household when information on commuting distance is not available. The resulting 2016 sample contains 200,539 workers from 132,427 distinct households. For these individuals we have information on occupation, income category, working hours, one-way commuting distance and time to work in categories, and mean of transportation to go to work.

The personal income of workers is provided in categories. However, to assess the heterogeneity of the effect of telework across income distribution, we need to calculate income deciles based on personal income. Therefore, we randomly attribute to each worker an income value between the two bounds of each category. For the last category, we cap income at 18,000 euros/month.

Similarly, information on commuting distance and time are provided in categories. To calculate transport cost we need to have continuous commuting distance. We thus use the same method to randomly attribute to each worker a specific distance and time to go to work between the lower and upper limits of each category. The maximum distance is capped at 50 km and the maximum time at 1 hour.

We also use information on the size of the municipalities to distinguish between small cities (less than 20,000 inhabitants), intermediate cities (20,000 to less than 100,000 inhabitants) and big cities (100,000 inhabitants and more).

In the following analysis, households' income deciles refer to household net income converted in 2020 euros using the consumer price index and household size adjustments based on the OECD-modified scale. Workers' income deciles refer to personal net income converted to 2020 euros.

4 Methodological approach

4.1 Estimation of energy expenditures

Energy consumption and cost

To estimate the expenditures related to residential energy use of a household, we use the Dena report (*Der dena-Gebäudereport 2016. Statistiken und Analysen zur Energieeffizienz im Gebäudebestand.*, 2016) that provides the annual energy consumption for space heating and hot water in kWh per square meter depending on two characteristics of the buildings:

- construction year of the building,
- number of dwellings in the building.

Based on this two variables available in the Microcensus, we attribute the yearly energy consumption per square meters for each type of dwelling in our 2014 sample. We assume that the same energy is used for heating and hot water. Using information on the size of the dwelling, we calculate the total annual energy consumption for each household's dwelling. To calculate the annual energy expenditure, we multiply the total energy consumption by the price of energy used [1]. The resulting distribution of energy expenditures over different income groups results from the following drivers (see additional Figures in the Appendix):

- Low-income households tend to live in multi-apartment houses while high-income households tend to live in individual houses or small buildings (Fig. 7a)
- Low-income households live more often in old dwellings where insulation is lower, and thus have a higher energy consumption per square meter. High-income households tend to live in newer (and thus more energy efficient) houses (Fig.7b) .
- High-income households tend to live in larger dwellings (absolute and relative to household size) (Fig.7c)
- Low-income households tend to use less heating oil and more district heating as energy source (Fig.7d)

As a consequence, households from low income deciles have a higher energy consumption per square meter implying also higher expenditure per square meter: they spend 10 euros/m2, while the average cost is 9 euros/m2 (Fig.8d).

[1] for gas, electricity and heating oil: see Daten zur Energiepreisentwicklung, Statistisches Bundesamt (Destatis), 2020; for district heating and wood pellets: see Dena report *Der dena-Gebäudereport 2016. Statistiken und Analysen zur Energieeffizienz im Gebäudebestand.* (2016), for solar energy: see Frauhofer ISE ; for geothermal energy: see Heizspeigel ; for briquettes, lignite, wood, wood pellets, biomass and biogas: based on assumption.

Because of increasing dwelling size, however, the annual energy expenditure for heating is increasing with the income of the household: it ranges between 730 and 1,120 euros per household, with an average of 920 euros per year (Fig.8c).

For calculating the cost of the national carbon price of 25 euros/ton of CO_2 established in 2021 for residential energy use, we use standard emission factors (in kg CO_2) for each source of energy based on UBA (*CO_2-Emissionsfaktoren für fossile Brennstoffe"*, 2016). The carbon price for residential heating with gas and heating oil results in an average cost of 80 euros per year (Fig.9). Again, high-income households tend to incur higher costs because of their higher energy consumption (Fig.8a).

Table 1: Cost of a carbon price of 25 euros/ton of CO_2 for residential heating with gas and heating oil

	Emission factors (kg CO_2/kWh)	Energy cost (euros/kWh)	Carbon price cost (euros/kWh)	(% of energy cost)
Natural gas	0.27	0.0597	0.0050	8%
Heating oil	0.20	0.0380	0.0068	18%

Source for emission factors: "CO_2-Emissionsfaktoren für fossile Brennstoffe", Climate change 27/2016, Umweltbundesamt https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2-emissionsfaktoren_fur_fossile_brennstoffe_korrektur.pdf

4.2 Estimation of transport expenditures

Work travel and cost

In the Microcensus 2016 sample, we have the one-way commuting distance and time to work in categories. We calculate continuous commuting distance and time: we randomly attribute to each worker a specific distance and time to go to work between the lower and upper limits of each category. The maximum distance is capped at 50 km and the maximum time at 1 hour.

On average, workers live 14 km away from their workplace, and spend 23 minutes to go to work. Workers with high income live further away from their workplace, and spend more time commuting. Workers in highest deciles live twice as far from their workplace than workers in lowest deciles (18 km vs 9 km), but spend only 1.5 times as much time commuting (26 minutes vs 18 minutes) (Fig.11a,11b).

To estimate the travel expenses over the year, we need to estimate the total distance traveled to work during a year. Thus, we make assumption on the number of commutes using info on working hours. We assume that full-time workers travel to work 5 days per week, while part-time workers travel to work 3 days per week. This corresponds to 230 working days per year for full-time work and 138 working days for part time work. We then compute the annual number of kilometers traveled to go to work as [2 x distance to work x number of working days per year].

On average, workers travel 6,100 km per year to get to work, and spend 160 hours commuting. Workers in highest income deciles travel 2,5 more than workers from low income deciles, and spend almost twice as much time commuting. The stronger discrepancy between high and low income households in annual aggregate commuting distances and time (compared to a single trip to work) is driven by a higher share of full-time workers (Fig. 13b).[2] 69% of the workers go to work by car (either driving or as passenger), 12% with public transportation, 9% with bicycle and 8% by feet. The use of the car is more common among workers from high income deciles (72%, versus 42% among workers from lowest income deciles) (Fig.13a).

We consider the commuting allowance as an approximation of the transport cost per km that covers in particular the variable costs of car travel. To determine the annual cost for work travel we multiply the annual travel distance by a fixed cost of 0.15 euros per km. Hence, workers spend on average 900 euros for transport expenditure to go to work, ranging from 500 euros for workers from lowest income decile to 1,220 euros for workers from highest income decile (Fig.14a).

Carbon price for transport

To calculate the commuting-related costs of the German carbon price, we multiply the commuting distance with the carbon price and the specific emission factors (in kg CO_2) for each source of energy (Tab.2). We disregard carbon price impacts on other forms of transportation than car commuting as the German carbon price either does not apply or has only a marginal cost contribution. The commuting-related costs of carbon pricing per worker amount, on average, 35 euros per year (Fig.14b).

Table 2: Cost of a carbon price of 25 euros/ton of CO_2 for fuel

	Emission factors (kg CO_2/l)	Fuel consumption (l/100 km)	Energy cost (euros/km)	Carbon price cost (euros/km)	(% of energy cost)
Gasoline	2.37	7.80	0.15	0.0046	3%
Diesel	2.65	7.00	0.15	0.0046	3%

Source for emission factors: "CO_2-Emissionsfaktoren für fossile Brennstoffe", Climate change 27/2016, Umweltbundesamt https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2-emissionsfaktoren_fur_fossile_brennstoffe_korrektur.pdf

[2]For further differences in commuting distances between larger and smaller communities and cities, see the Appendix.

Advantage due to commuting allowance

Finally, we calculate the income tax reliefs from the commuting allowance and recently introduced home-office allowance. As a statutory rule, a lump sum of 1,000 euros per year of income-related expenses is deducted from every employee's taxable income before the taxes are calculated. We assume that each worker has 500 euros of non-travel related work expenses (e.g. contributions to unions, among others). The commuting allowance for 2021 is 0,30 euros/km for distance up to 20 km and 0,35 euros/km from 20 km and above (one-way), with a maximum of 4,500 euros/year for users of public transport. If the sum of non-travel related work expenses and commuting allowance is below 1,000 euros, we attribute a tax deduction of 1,000 euros.

We further consider the new home office allowance for people who telework. This new tax deduction is 5 euros per working day spent, with a maximum deduction of 600 euros per year (equivalent to 120 days of telework per year). The home office allowance also counts towards income-related expenses. We thus apply the same rule as above: if the sum of non-travel related expenses and home office allowance is below 1,000 euros, we attribute a tax deduction of 1,000 euros.

To determine the net advantage of commuting and home-office allowance, we need to multiply the allowance with the marginal income tax rate. As the Microcensus only provides the net income of the household, we associate a marginal tax rate to this net income based on the following steps:

- First, for a range of taxable income from 1 to 500,000 euros, we simulate for singles and couples the income tax, by applying the tax schedule (disregarding the solidarity surcharge as it will be phased out for the vast majority of households). This allows us to associate a marginal tax rate to each taxable income.
- Second, we calculate the gross income as 1.25 x taxable income. This assumption is based on the study by Doerrenberg et al. (2017), who find that on average taxable income is more than 20% lower than reported gross income.
- Third, we assume that social security contributions (SSC) are 21% of gross income (Bach et al., 2016) .
- Finally we can calculate the net income by applying the simplified formula: net income = gross income - SSC - income tax

We thus obtain a range of net incomes with the associate marginal tax rate for singles and couples. Based on this, we can impute the marginal tax rate in the Microcensus based on the net income and the status of the household (Fig.15). In the Microcensus, we consider that the join taxation scheme applies in the following cases:

- Household with more than one person, and partner in the household.

- Household with more than one person, and at least two adults with less than 20 years of age difference.

The resulting average advantage due to commuting and home-office allowance is 340 euros, and varies between 185 euros for workers from lowest decile to 540 euros for workers from highest decile (Fig.14c).

4.3 Estimation of teleworkability of jobs

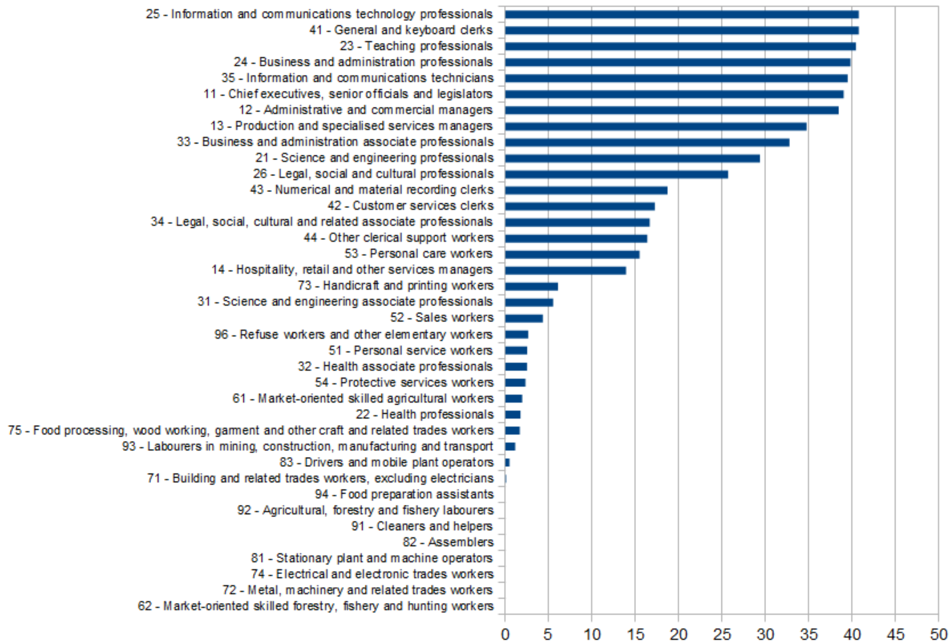
We implement telework in the microcensus based on the share of telework by occupations' groups estimated by Dingel and Neiman (2020). In each of our sample, we randomly select workers in each occupation's group to which we assign telework, with a target of corresponding share of telework by occupation's group. We then obtain two samples for 2014 and 2016 with a global share of telework of 37% among workers, which corresponds to an upper bound for the actual telework potential.

The actual level of telework in the population is below this figure. A recent survey by the Economic and Social Research institute of the Hans Böckler Foundation showed that in April 2020, when restriction measures due to Covid-19 were the highest, 27% of employees were working from home. A new series of restrictions decided from October 2020 led to a new increase from 14% in November 2020 to 17% in December, and 25% in January 2021. Based on this survey, we assume that 15% of people could work full time from home. Thus we reduce proportionally the share of telework in each occupation in our samples.

The share of employees working from home varies significantly across occupations (Fig.1). Managers, educators, and those working in computers, finance and law are largely able to work from home. Farm, construction, and production workers cannot.

To calculate the expenditure implications of teleworking, we assume that the household's energy consumption and expenditure increase by 20% for each day of telework when at least one person of the household teleworks (we base our assumption on Cicala (2020) who find that during Covid-19 pandemics residential electricity consumption increases by 16% during work hours). The additional resulting cost for the household is distributed among the workers of the household who telework. Transport costs are set to zero for all people who telework. People working from home do not benefit from commuting allowance anymore, but they benefit from the home office allowance introduced in 2020.

Figure 1: Share of telework by occupations' groups matched to Microcensus occulation categories (%)



Source: Microcensus 2016, own calculations

5 Results

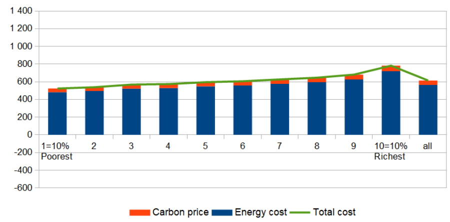
5.1 Distribution of expenditures and teleworkability

The total cost for residential energy are the sum of the cost for energy consumption and the carbon price. We equally distribute the total cost for a household among the workers of the household. We obtain the total costs for commuting as the sum of travel cost and carbon price for fuel, minus the advantage due to commuting and home office allowance.

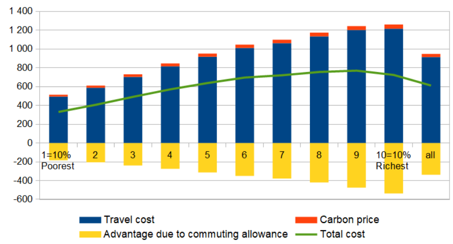
We find that, on average, workers spend similar amounts for work commute and energy expenditure, around 610 euros per year (Fig. 2a–2b). Both expenditures increase with income, but the increase is substantially more pronounced for commuting expenditures (2.2 times higher for high-income workers compared to low-income workers) than for energy expenditure (1.5 times higher for high-income workers compared to low-income workers). These figures suggest that a uniform reduction in commuting due to telework may create stronger cost savings for high-income households since they commute longer distances.

Figure 2: Yearly cost per worker (in euros) and teleworkability, by worker income decile

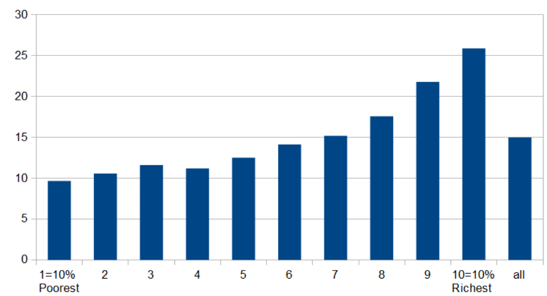
(a) Energy



(b) Transport



(c) Share of people teleworking (in % of workers)



Source: Microcensus 2014 & 2016, own calculations

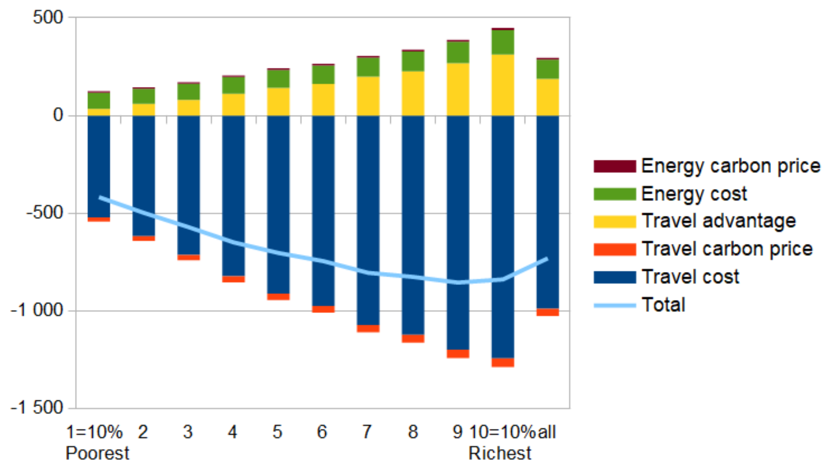
Teleworkability is, however, not uniformly distributed across income as workers in occupations that can be performed at home typically earn more (Fig. 2c). As a result, the share of teleworkers is higher among rich workers: it is 26% for the highest decile, while only 10% for the lowest deciles.

5.2 Financial gains from teleworking are driven by saved commuting expenses

Workers who are teleworking save on average 730 euros per year. Richest workers benefit the most from telework: they save on average 840 euros per year, versus 420 euros for workers from the lowest income decile. These gains are mainly driven by saved commuting expenses. On average the energy expenditure increases by 110 euros per year for teleworker, while the transport expenditure decreases by 840 euros.

Besides the vertical dimension of cost savings over different income groups, there is also large heterogeneity in saved commuting expenses within income

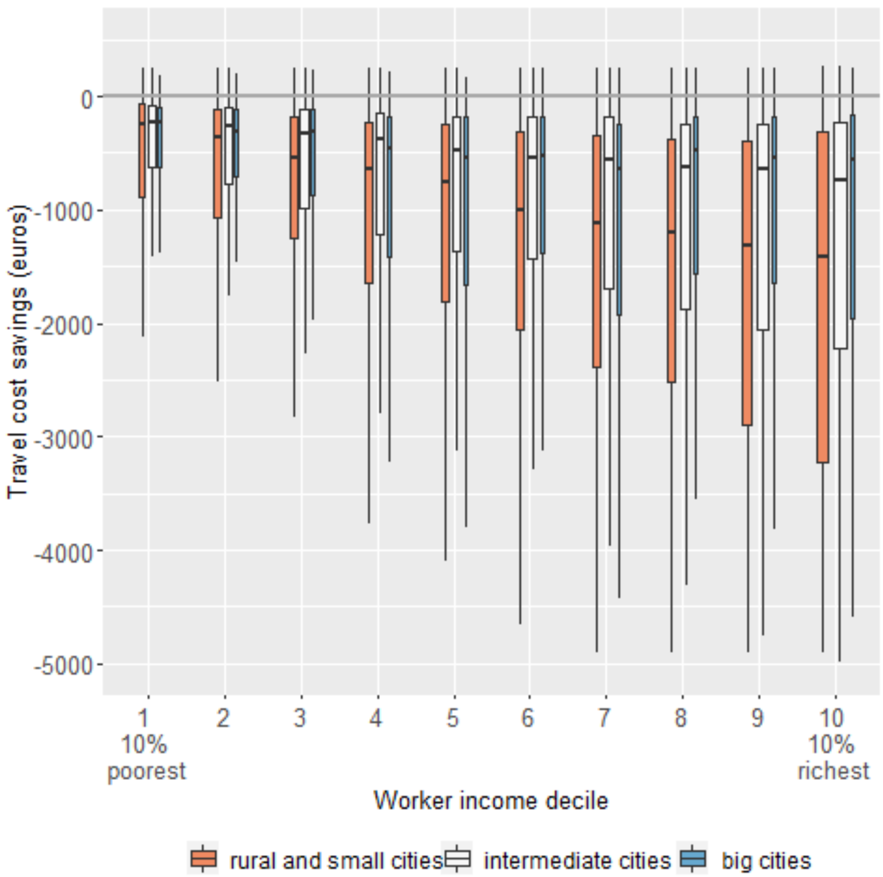
Figure 3: Yearly cost change per teleworker (in euros), by worker income decile



Source: Microcensus 2014 & 2016, own calculations

groups (Fig. 4). Part of this heterogeneity can be explained by agglomeration effects: workers living in rural areas and small towns (less than 20,000 inhabitants) have longer commute to work, and benefit more from teleworking. For this category, the average annual saving on transport expenditure is 35% higher than for workers living in large cities (1,380 euros versus 1,025 euros).

Figure 4: Average yearly transport cost change per teleworker in rural and urban areas (in euros), by worker income decile

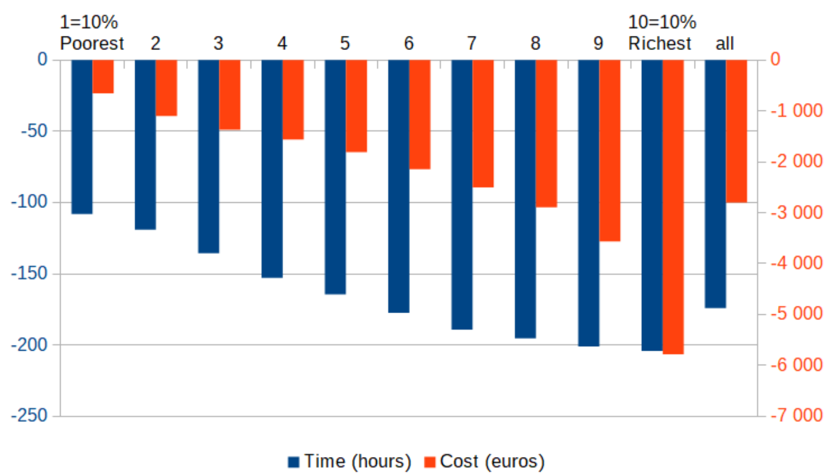


Source: Microcensus 2016, own calculations. The colour-filled area of the bars shows a total of 50 percent of the workers in each decile; the dot shows the average cost; the long vertical lines show the burden for the remaining 25 percent of the workers in each decile. The width of the bars is proportional to the population in each category of cities

5.3 Value of time savings

Additionally to direct financial savings, teleworking reduces commuting time. From our data, we calculate that travel time saved by people who telework is on average 175 hours per year. Time savings are almost twice as high for high-income workers than low-income workers (Fig. 5). If commuting time is valued at the hourly wage earned by the workers who telework, we estimate that savings are almost 9 times higher for higher-income workers than lowest-income workers (5,800 euros vs 650 euros for the lowest income decile). The value of time saving is between 1.3 and 6 times greater than the savings from reduced travel costs.

Figure 5: Yearly travel time and cost saved per teleworker (in hours), by worker income decile



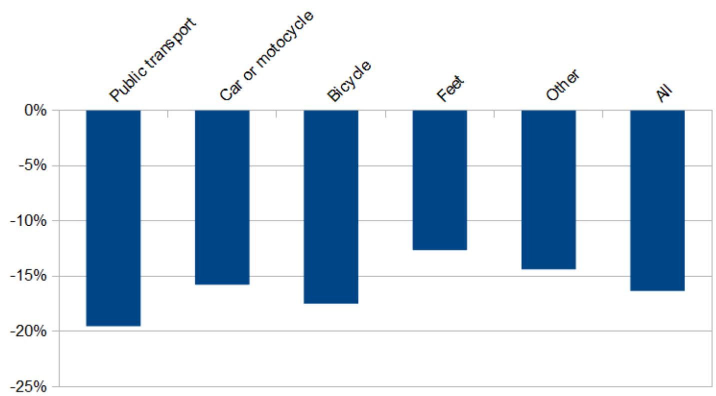
Source: Microcensus 2016, own calculations

5.4 Reductions in aggregate travel distances and carbon emissions

Summing over households allows us to estimate the direct (first-order) aggregate effects of teleworking on travel distances and carbon emissions. The total travel distance decreases by 16% for car and motorcycle commuters (Fig. 6). This corresponds to 24.4 billions fewer kilometres travelled per year, which is equivalent to a reduction of 4.5 millions tons of CO_2 per year.

This decrease could be partially compensated by the rise of CO_2 emissions for residential heating of teleworkers. The total energy consumption of residential energy increases by 3%, with 82% of this increase attributable to the larger

Figure 6: Decrease in total km travelled, by type of transportation



Source: Microcensus 2016, own calculations

demand for gas and heating oil. This, in turn, would correspond to 2.9 millions tons of CO_2 per year. The aggregate carbon emission effect, however, is unclear since heating energy is also saved at the work space when employees work at home. If residential heating systems are more carbon-efficient than the heating system at the work place, teleworking could even reduce aggregate emissions related to heating. Contrary, if energy demand at the work place is unaffected by the share of teleworkers (e.g., as rooms are heated anyway), the increase in residential energy consumption increases aggregate emissions.

6 Conclusion

The COVID pandemic has changed the organisation of work. Teleworking has become more widespread, resulting in fewer work commutes and higher residential energy consumption.
We study the effects of the persistence of telework on transport and energy expenditure. Based on an assumption of 15% of workers working from home, we estimate an annual net gain for workers of 730 euros, mainly due to lower transport expenditure which more than offsets the increase in energy expenditure. Workers with higher revenues who live further away from their workplace benefit the most from telework. Workers in rural areas and small towns, who also travel more kilometres to work, benefit more from teleworking.

Teleworking has a direct and considerable effect on reducing carbon emissions in the transport sector. We estimate that the decrease of travel commute by car leads to a reduction of 4.5 millions tons of CO_2 per year. This number should be considered as an immediate and direct short-run incidence. There are several reasons why these emission reductions may be less pronounced: First, working from home increases residential energy use. The overall impact on emissions would be neutral if domestic energy use just substitutes energy use at the office (due to lighting, heating or electricity use for computers etc.). As we are not aware of any evidence on the magnitude of this substitution effect nor on the carbon intensity of domestic vs. work-site related energy use, we cannot assess the implications for emissions empirically. As the theoretical upper bound of this substitution effect would suggest an increase in 2.9 million tons of CO_2, we would expect only a minor role of residential carbon emissions for the implications on total emissions.

Second, besides substitution effects in energy use, changes in housing and settlement patterns could have more dramatic implications for future energy use and, thus, emissions. Based on a spatial equilibrium model, Delventhal and Parkhomenko (2016) argue that increased teleworking changes the choice of the residential location and of the workplace. Using a similar modeling framework, Larson and Zhao (2016) show that telework causes sprawl, calling into question the idea that telework decreases energy consumption. Depending on wage changes due to telework, land-use regulation, and the telework participation rate, energy consumption may even increase. Hence, while teleworking could help to reduce transport-related carbon emissions, the ultimate magnitude remains highly vulnerable to rebound effects.

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A Energy for residential heating

A.1 Energy prices

Table 3: Energy prices for residential heating

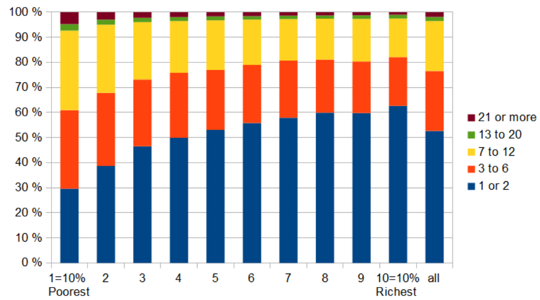
	Prices (euros cent/kWh)
District heating	9.00
Gas	5.97
Electricity	30.43
Heating oil	3.80
Briquettes, lignite	5.00
Coke, hard coal	5.00
Wood, wood pellets	5.00
Biomass, biogas	5.00
Solar energy	11.00
Geothermal	22.10

Source: Dena, Destatis, Fraunhofer ISE, Heizspiegel, own assumption

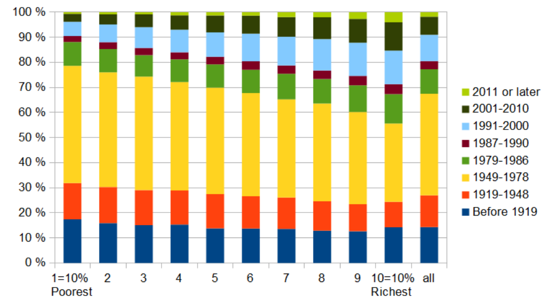
A.2 Characteristics of the dwellings

Figure 7: Characteristics of the dwellings, by household income decile

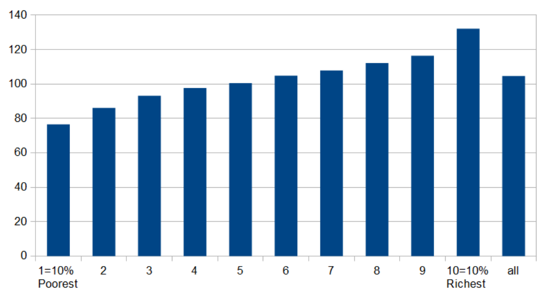
(a) Number of apartments



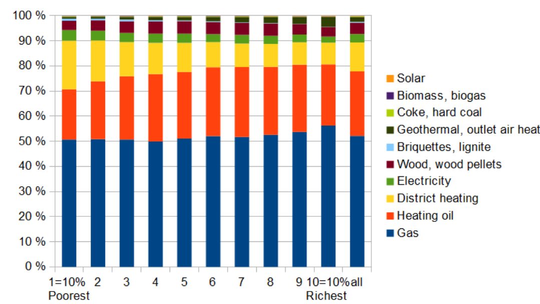
(b) Year of construction



(c) Size (in m^2)



(d) Energy used for heating

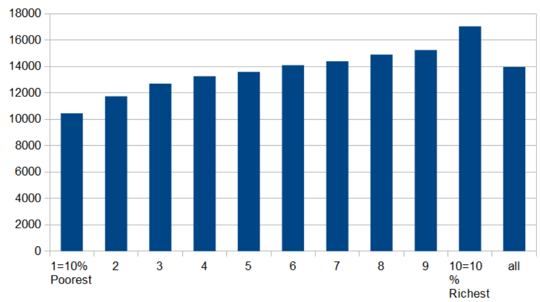


Source: Microcensus 2014, own calculations

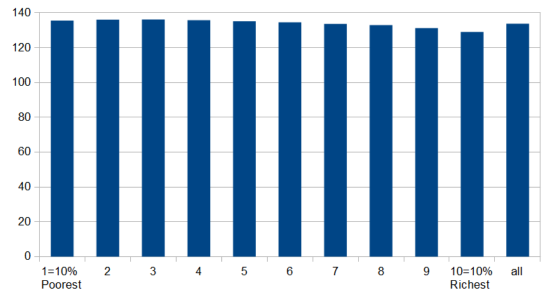
A.3 Energy consumption and expenditure

Figure 8: Energy consumption and expenditure, by household income decile

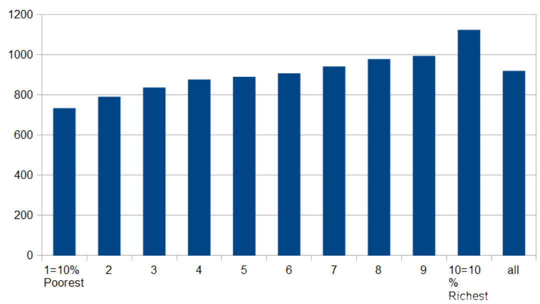
(a) Average yearly energy consumption (in kWh)



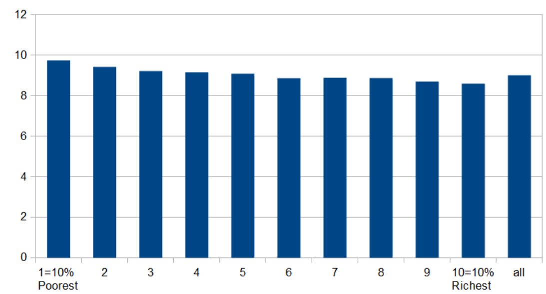
(b) Average yearly energy consumption by square meter (in kWh/m^2)



(c) Average yearly cost of energy (in euros)

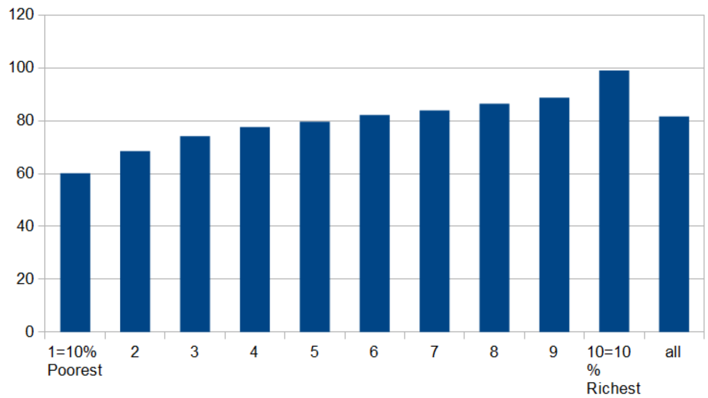


(d) Average yearly cost of energy per m^2 (in euros/m^2)



Source: Microcensus 2014, own calculations

Figure 9: Average yearly cost of carbon price for residential heating with gas and heating oil, per household (in euros), by household income decile



Source: Microcensus 2014, own calculations

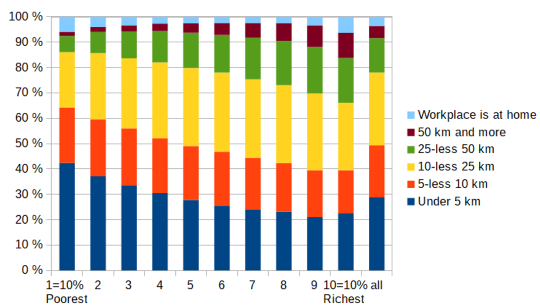
B Travel for commute

B.1 Distance, time and expenditure

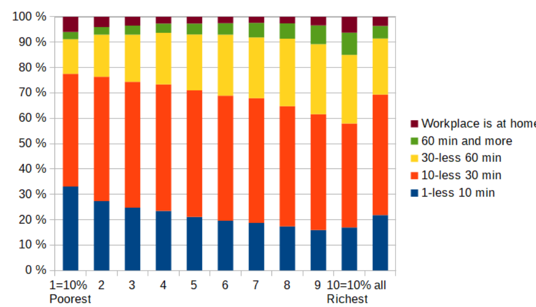
Workers living in rural areas and small cities (less than 20,000 inhabitants) travel more to go to work than workers living in large cities (more than 100,000 inhabitants). The difference increases with the worker income decile: it varies between 8% for the poorest and 15% for the richest.

Figure 10: Distance and time to work per worker in categories, by worker income decile

(a) Distance (in categories)



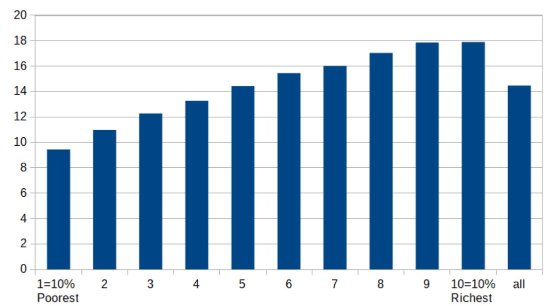
(b) Time (in categories)



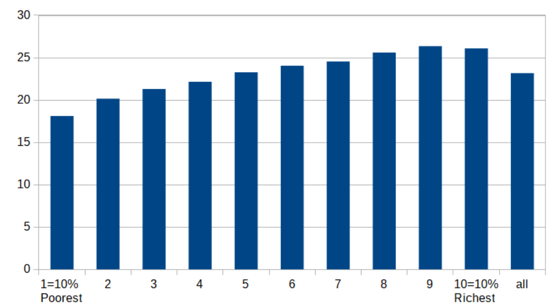
Source: Microcensus 2016, own calculations

Figure 11: Average distance and time to go to work per worker, by worker income decile

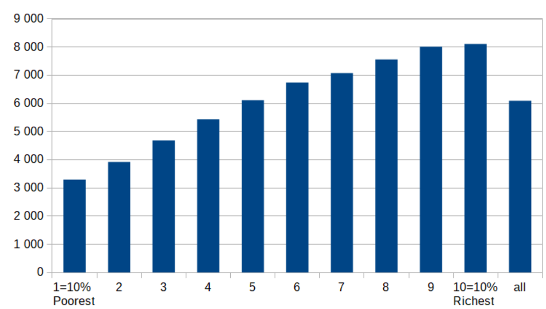
(a) Distance (in km)



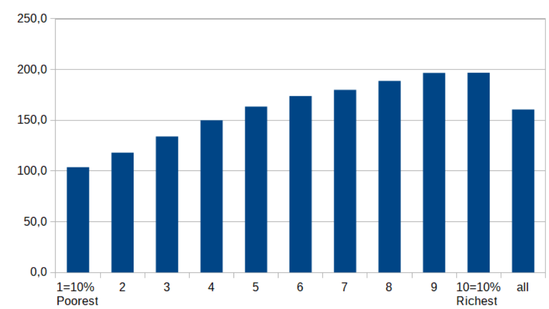
(b) Time (in min)



(c) Yearly travel distance (in km)

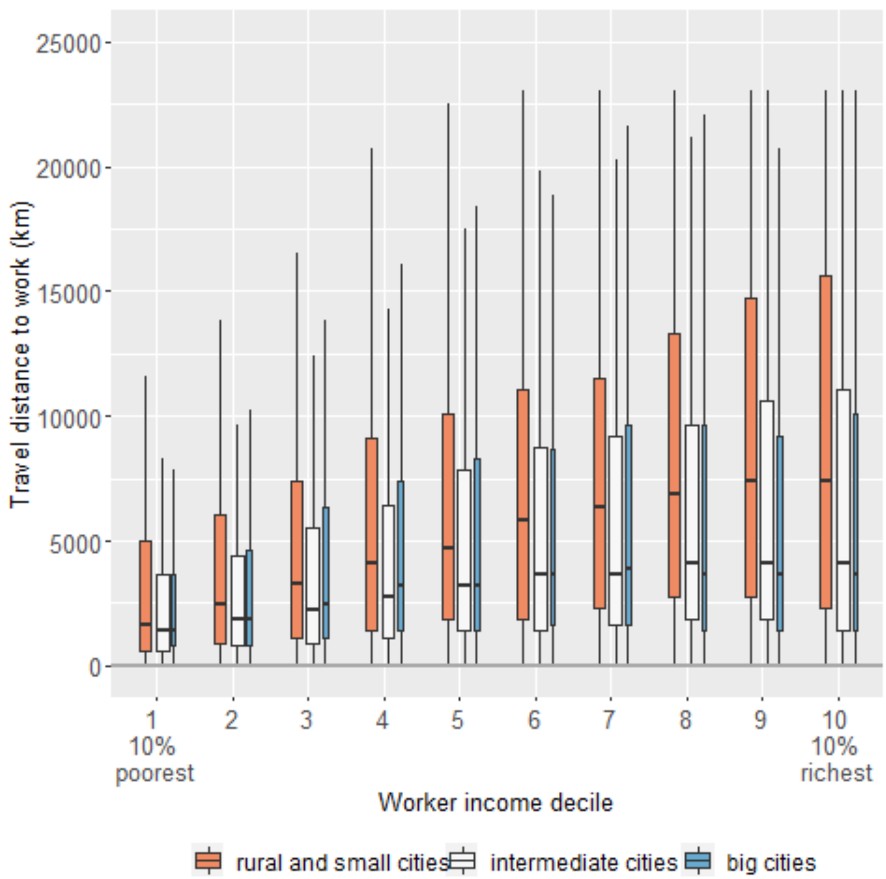


(d) Yearly travel time (in hours)



Source: Microcensus 2016, own calculations

Figure 12: Distribution of yearly travel distance to work per worker living in rural and urban areas (in km), by worker income decile

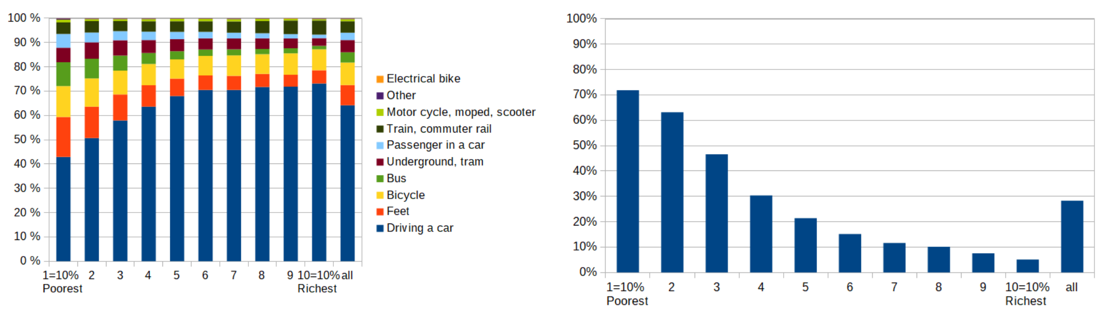


Source: Microcensus 2016, own calculations. The colour-filled area of the bars shows a total of 50 percent of the workers in each decile; the dot shows the average cost; the long vertical lines show the burden for the remaining 25 percent of the workers in each decile. The width of the bars is proportional to the population in each category of cities

Figure 13: Mean of transportation to go to work and part-time work, by worker income decile

(a) Mean of transportation

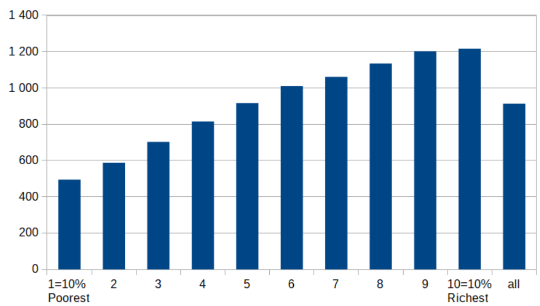
(b) Share of workers working part time



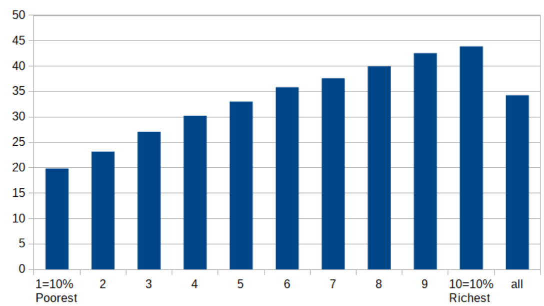
Source: Microcensus 2016, own calculations

Figure 14: Average yearly cost for travel to work per worker (in euros), by worker income decile

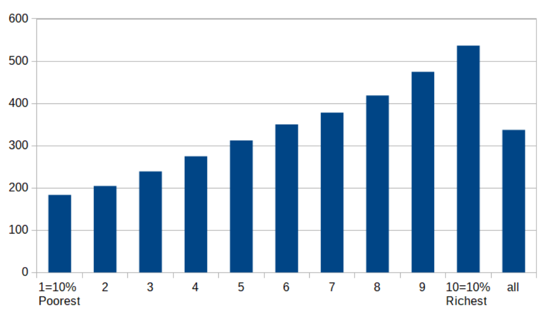
(a) Travel cost



(b) Carbon price cost



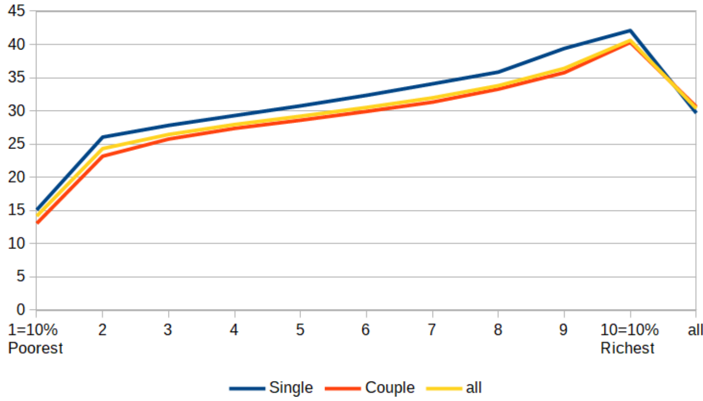
(c) Net advantage for commuting allowance



Source: Microcensus 2016, own calculations

C Marginal tax rate

Figure 15: Average marginal tax rate per household type (in % of taxable income), by household income decile



Source: Microcensus 2016, own calculations