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Effects of Job Accessibility Improved by Public Transport System: Natural Experimental Evidence from the Copenhagen Metro

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This study examines the effect of accessibility to urban jobs via a public transport system on individual earnings and commuting behaviour. The effect of improved public transport based accessibility on these outcomes is determined by exploiting the exogenous variation in access to a public rail and Metro system resulting from the construction of a new terminal Metro station connecting southern townships to Copenhagen city centre. The results show that public transport based job accessibility has a positive and permanent effect on individual earnings. The increase in earnings is associated with a change in commuting patterns as the improved access to public transport facilitates a shift from employment within the township to better paid jobs in the city centre, as well as in other suburbs of the Copenhagen Metropolitan area.

Keywords: *Job accessibility, public transport infrastructure, earnings, commuting behaviour, difference-in-differences.*

1. Introduction

Urban public transport systems aim, among other purposes, to facilitate commuting and hopefully to enhance individual performance on the labour market. Improved job accessibility may raise individual employment rates and earnings by different mechanisms. Workers may not consider relevant job vacancies due to excessive commuting time (Zax and Kain, 1996), may not search for distant jobs efficiently (Wasmer and Zenou, 2002; Selod and Zenou, 2006), or may be screened out by employers in favour of workers with shorter commutes (see the survey by Gobillon *et al*., 2007).

While there is little doubt that these mechanisms may be present in some situations, it is less clear how relevant differences in job accessibility generally are for urban labour markets. The number of relevant job vacancies for many job seekers is reduced due to job differentiation and search frictions, which reduce the impact of improved potential job accessibility by public transport since workers have a limited range of employment opportunities at every moment (Manning, 2003). In addition, job searches are increasingly taking place on the Internet through e-mail and social network websites, significantly reducing the importance of geographical distances between workplaces and residences when searching for employment. Finally, while it is possible that employers discard workers with very long commuting trips, they may not be able to translate

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most job applications into accurate commuting times due to the range of different transport modes and actual public transit accessibility from different locations in the Metropolitan area.

The majority of empirical studies on job accessibility study it in the context of the spatial mismatch in the US urban labour markets (Kain, 1968). These studies usually estimate the effect of (an index of) job accessibility on employment rates among ethnic minorities living in US inner cities (for surveys, see Ihlanfeldt and Sjoquist, 1998; Gobillon *et al*., 2007; Ihlanfeldt, 2006; Zenou, 2009). Earlier studies found evidence in favour of the spatial mismatch hypothesis (for surveys of the early literature, see Kain, 1992 and Ihlanfeldt and Sjoquist, 1998). However, the early literature probably overestimated the role of job accessibility due to residential sorting – processes that have been shown to be important in connection with public transport based access (Voith 1991; Cervero and Duncan, 2002). In addition, errors in the measurement of individual job accessibility may also affect the estimates.

The key challenge in measuring the effects of a public transport innovation is identification. Individuals choose their residence on the basis of housing prices, surrounding employment opportunities and travel preferences. This implies that workers with better access to jobs tend to travel shorter distances than workers residing in more isolated areas, not because they have better access to the labour market, but because they are different. Thus, variation in job accessibility that is not confounded by other factors which also affect earnings is difficult to come by.

The problem of residential self-selection is a common challenge for studies addressing the more general question of the influence of the neighborhood characteristics and built environment[3] on travel behaviour (see Cao *et al*., 2007 and references therein). To identify such effects, Cao *et al*. (2007) compare the changes in travel behaviour of individuals moving to locations with better public transit or pedestrian accessibility with that of individuals that change neighbourhoods without changing their built environments. While comparing the changes in the travel behaviour of movers is a better idea than comparing the behaviour of movers and stayers, it does not solve the problem that individuals moving to neighbourhoods with different features are likely to be different.

The opening of rail and Metro stations provides a more powerful source of identification. The study by Holzer *et al*. (2003) uses the expansion of the San Francisco BART rail system to compare, with the difference-in-differences (DID) method, the hiring of minorities by workplaces located at different distances from the two new stations. They find that accessibility matters only slightly for Latino workers, but not for African American workers.

A limitation of US public transit innovations when investigating the effects of job accessibility is that job accessibility in the US is highly influenced by car ownership (Gautier and Zenou, 2010). Public transport plays a more important role in the job accessibility of European cities, where public transit systems are more reliable and car use is less extensive (Buehler and Pucher, 2012). Gibbons and Machin (2005) evaluate the effect of new rail Metro stations on housing prices in South East London by comparing housing prices just before and after the opening of a new Metro station in areas at different distances from the new infrastructure. This study finds that every 1km reduction in the distance from the property to the London underground increases the house price by 1-4 per cent. However, Gibbons and Machin's estimates may be biased as a result of anticipation if house prices reacted well in advance of the station opening for service (for evidence on anticipation effects on US house prices, see McMillen and McDonald, 2004).

This paper exploits the opening of the new Metro system in Copenhagen and the availability of detailed, micro-level, population time series data to provide empirical evidence for the relevance

[3] The built environment refers to the characteristics of the neighbourhood or zone including buildings, the street network, urban density, connectivity, access to services, etc.

of good access to jobs for earnings in a European Metropolitan area. As far as we know, this is the first empirical analysis to do so. The proposed "natural experiment" has four important advantages over the existing literature. First, it is based on a European public transit innovation. Second, the sample is restricted to a terminal station in the most southern suburb of the Danish capital area. Third, the study area is a homogeneous neighbourhood of single family houses irrespective of distance to the Metro. Fourth, the construction of the station did not induce differences in earnings, employment, or residential mobility of workers residing at different distances to the infrastructure within the selected area.

The paper estimates the pre- and post-treatment effects of improved job accessibility on residential mobility, employment rates, wage earnings and commuting behaviour during the period 1996-2006. Results indicate that the improved public transit accessibility facilitates changes from local jobs to more distant and better paid jobs.

The remainder of the paper is structured as follows: Section 2 presents a description of the natural experiment, which is followed by a description of the data in Section 3. Section 4 describes the econometric approach. Section 5 presents the results. Section 6 concludes.

2. The public transit innovation

The Danish Capital Area is a major city region with about 1.8 million inhabitants, with the majority of workplaces and service facilities being concentrated in the two central municipalities, City of Copenhagen and Frederiksberg (approx. 40 per cent of population and jobs in the urban region). The township located south of the urban area (Island of Amager) is home to Copenhagen international airport, which serves as a workplace for about 700 firms and 23,000 people. With some 3% of regional employment concentrated on one site, the airport is one of the largest sub-centres in the region.

From the early 1970s until 2002, public transport in Copenhagen was based on commuter rail systems (S-trains) connecting the centre to suburbs in the north and west of the city, and a bus network with high service levels on radial arterials. This implied that transit between the township situated south of the urban area (on the island of Amager), and the city centre was only possible by bus service (Ildensborg-Hansen and Vuk, 2006), private modes across two bridges over the Inner Harbour of Copenhagen (Vuk, 2005), and since 2000, by regional train across a bridge connection between the southern part of the urban area and the central station.

The improvement in the public transport connections between Amager and the central parts of the capital area had long been desired and the planning, preparatory work and financing were finally mandated by the Danish Parliament in 1992. In 1996, the city council of Copenhagen approved the location of the Metro lines and stations for the first phases of the new infrastructure. The construction of the Metro started in November 1996. Phase 1 of the Metro connecting the southern part of the capital's urban area with the city centre was inaugurated in October 2002, while phase 2 connecting the city centre with the western part of the city was opened in October 2003. The Metro includes a common section that crosses part of the city centre before splitting into two lines running on the west-central part and eastern part of the island of Amager, respectively (see Figure 1).

The estimated yearly direct cost of commuting by Metro from eastern and central Amager to a job in the city centre in 2002 was around 390 Euros or 0.8 Euros/trip (Trafikstyrelsen, 2012).[4] In addition, the cost of commuting by public transport includes the cost associated with in-vehicle travel time, and the time costs of collection, transfer and distribution. As the reliability of the new

[4] Travel costs to the city centre range from around 0.8 Euros, assuming week-day commuting with a monthly travel pass, to 1.9 Euros for a single ticket in 2002.

Metro is very high, the degree of flexibility depends on headway times and hours of operation. These lines are served by very frequent small Metro trains, which operate continually with a varying headway throughout the day. During rush hour, the headway is two minutes on the central section of the Metro, and four minutes on the single-service sections (central section split into two lines). At night, the headway is between 15 and 20 minutes on all sections (shortest headway nights after Friday and Saturday; night service during weekdays was only introduced in 2009). At all other times, there is three-minute headway on the common section, and six-minute headway on the single service sections.

The Copenhagen Metro has become the primary public transport grid, connecting the island of Amager to the rest of the Metropolitan region. The Metro connects to the commuter rail system via rail hubs in the city centre, and is complemented by a bus line network, thus providing numerous transit connections and many possible destinations. The new infrastructure has increased travel distances for residents of Amager (Vuk, 2005), and has mainly attracted previous bus passengers (70-72 per cent of Metro passengers), but has also reduced the use of private cars (13-18 per cent of Metro passengers).

Whereas most of the northern section of the Metro follows a former S-train line, and some Metro stations are part of existing rail hubs or service centres in the urban fabric, the accessibility of the city centre from the southern stations on the island of Amager was radically improved by the new infrastructure. This paper focuses on the southernmost station 'Vestamager', which is located on a green-field site adjacent to an area with a low urban density, where the effects of the new access can be measured and analysed based on the distance of residents' homes to the station without proximity to other Metro or train stations substantially limiting the data. This station provides enough variation in terms of the distance of residences to the Metro entrance, and is located in a homogeneous single family housing neighbourhood.

Vestamager Metro station is 14 minutes (in Metro transit time) from Nørreport Metro station, which is a major public transport node in the city centre. In terms of frequency and connectivity, the station and Metro line together form one of the backbones of public transport in the township. Prior to 2002, the area was much more remote, as airport runways to the south, and nature areas to the east limited private and public transport connectivity. Travel time by bus or by bike to the city centre was approximately 30 minutes, while services were infrequent (20 min. headway) and provided poor connections to regional transit hubs.

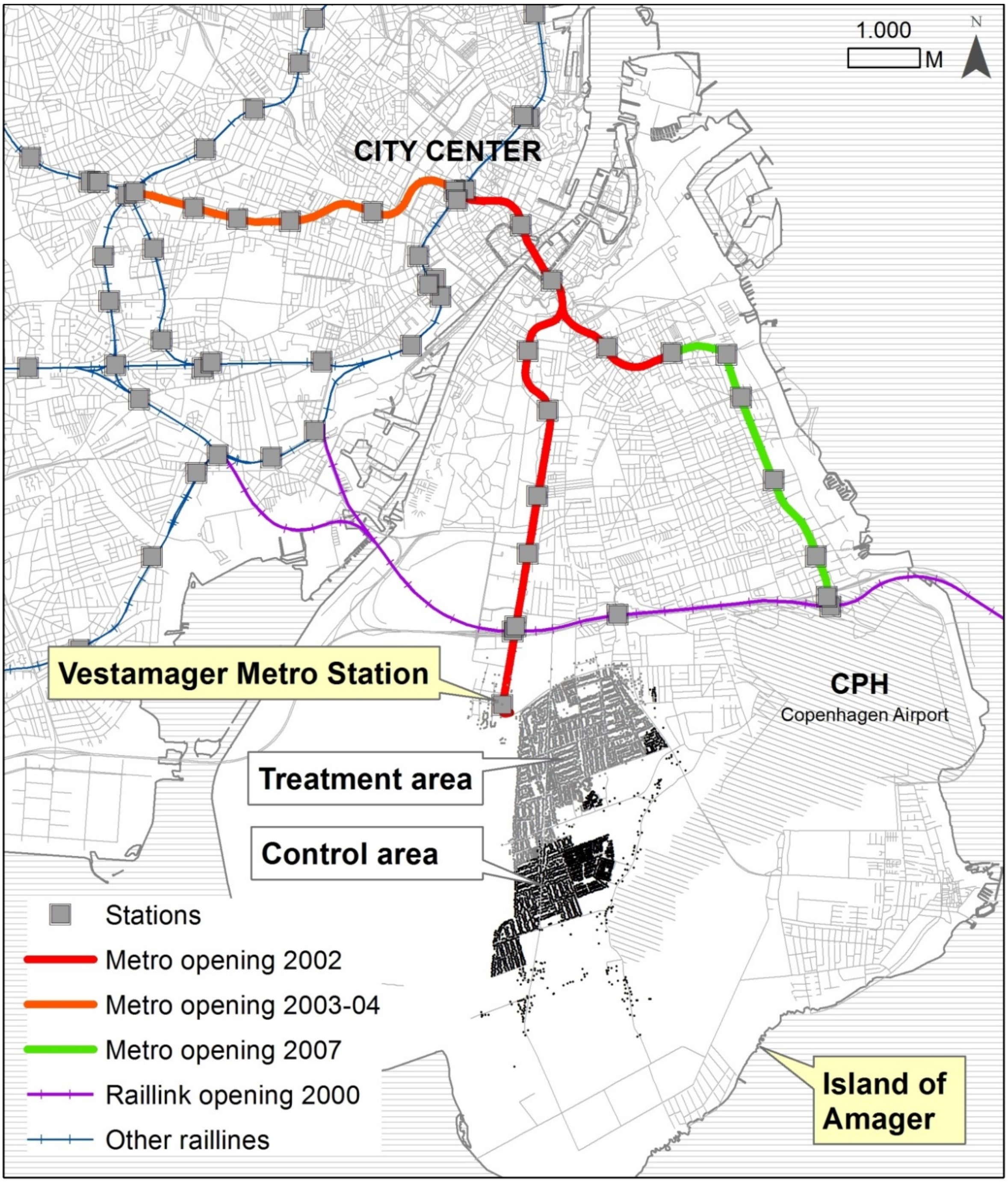

Figure 1. Vestamager Metro Station and addresses within the treatment and control areas

3. Data

The empirical analysis uses micro-data on working-age individuals living in homes located between 0.5 and 6.2 km from Vestamager station. The data include information on the minimum street distance between the dwelling and the Metro station, and yearly information on individual addresses. This is an important innovation of the data set compared to previous studies such as Holzer et al. (2003) whom stratified geographical areas on the basis of postal codes, or Gibbons and Machin (2005) and McMillen and McDonald (2004) who used Euclidian distances between postcode area centroids of properties and their nearest Network Rail or London

Underground/DLR station. Our residence-station distance measure is based on minimum street distance, which ensures that the definition of control and treatment groups encompasses residents with similar access to Vestamager station.

Thus, the data facilitate the identification of those individuals who, in different years of the period 1995-2006, were living at different distances from the Metro station. Minimum street distance to the station was computed for 100 per cent of residences/addresses on 01.01.2011 and, therefore, includes residences which did not exist in 2002. Since we link residence to individuals on a yearly basis from 1995 to 2006, it is possible to identify the individuals residing in the neighbourhood of Vestamager Metro station back in time.

Figure 2 shows the distribution of residences for all individuals aged 18-65 within 6.2 km of Vestamager station and with residence in the municipality of Tårnby.[5] The figure shows that there are no residences within 0.5 km of the station, and that the number of individuals living more than 4.5 km from the station is very low, which is due to the presence of airport infrastructure. The terrain in the area is quite flat with a maximum elevation of 8 metres above sea level.

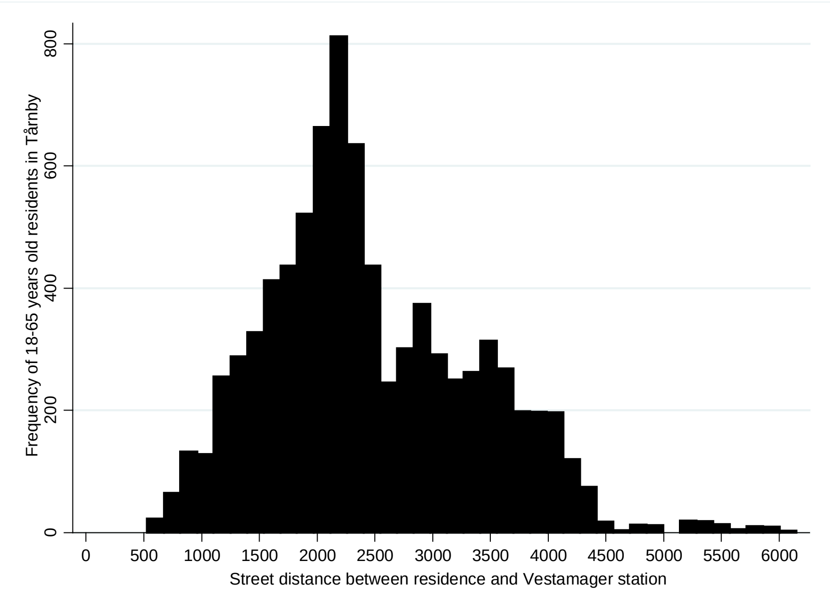

Figure 2. Distribution of distances between residence and the under-construction Vestamager station in 2001

The public register-based micro-data provide a wide range of socio-economic, demographic and dwelling characteristics.[6] Table 1 presents a comparison of several characteristics of working age individuals and their residences located respectively between 0.5 and 2.7 km and between 2.7 and 6.2 km of Vestamager Metro in 2001, when the station was still under construction. The homes of residents in the closer of the two neighbourhoods are located on average 1.9 km (street

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5 Residents from the southern municipality of Dragør between 2.7 km and 6.2 km are not included in the sample to improve homogeneity of residents and avoid unnecessary sources of time variant unobservable heterogeneity treated (only from Tårnby) and control persons. For example, the municipality implements active labour market policy, which implies that caseworkers from Dragør may implement labour programs differently and may have contact with local networks of employers than may affect employment, earnings or commuting behaviour in ways uncontrollable with a DID approach.
6 See Table 1 for the complete list of variables.

distance) from the Metro station, while residents in the distant neighbourhood live on average 3.5 km away from the entrance to the transport infrastructure.

Table 1. Summary statistics for adult working age residents by distance to the under-construction Vestamager station in 2001

Variable	Residence 0.5-2.7 km from station	Residence 2.7-6.2 km from station
Minimum street distance from residence to Vestamager station (km)	1.9(0.5)	3.5(0.6)
Age	43.7(12.0)	43.5(12.2)
Female (per cent)	49.5	48.7
Basic or high school education (per cent)	37.9	39.8
Professionally oriented education (per cent)	47.0	47.1
Shorter or medium higher education (per cent)	11.7	9.7
Bachelor or long higher education (per cent)	2.2	2.1
Danish ethnic background (per cent)	97.0	96.3
Number of people in the family	2.5(1.1)	2.4(1.1)
Number of adults in the family	1.8(0.4)	1.8(0.4)
Children in the family (per cent)	44.6	42.4
Number of infants in the family	0.0(0.2)	0.0(0.2)
Partner (per cent)	80.3	81.8
Employment (per cent)	84.7	84.0
Unemployment level (between 0-1,000)	30(130)	30(128)
Years in employment since 1980	16.6(6.6)	16.0(6.9)
Earnings (1,000 Danish kroner)	234(163)	231(160)
Commuting distance (km)	5.7 (17.9)	7.1(19.3)
Employed in manufacturing or construction sector (per cent)	12.5	13.4
Employed in trade, transport, restaurants or hotel (per cent)	28.7	30.7
Employed in financial, insurance, real estate or other bus. services (per cent)	13.8	12.3
Employed in public, education, health or social sector (per cent)	22.5	23.1
Detached house (per cent)	88.3	90.7
Number of rooms	4.3(1.1)	4.5(1.1)
Living space (m^2)	124.7	128.5
Residential mobility (per cent)	8.7	8.5
Observations	5,392	2,982

Notes: Standard deviations in parentheses. All variables are measured at the start of 2001. 1) Female is a dummy variable indicating the gender of the individual. 2) Basic or high school education is a dummy indicating the level of education achieved by the individual. 3) Professionally oriented education is a dummy indicating that the individual has completed an education at a vocational college. 4) Shorter or medium higher education denotes that the individual has completed 1-4.5 years of education at a vocational university. 5) Bachelor or long higher education denotes a dummy variable indicating that the individual has completed a university education of 4-6 years. 6) Danish ethnic background indicates whether the individual was born in Denmark and at least one of the parents was also born in Denmark or is a Danish citizen. 7) Partner is a dummy indicating that the individual lives together with a partner. 8) Employment indicates whether the individual has positive wage earnings. 9) Unemployment level is an indicator between 0 and 1000 of the number of unemployed hours a year for the individual. 10) Employment in xx sector is a dummy indicating the sector where the individual is primarily employed. 11) Detached house is a dummy indicating whether the individual resides in a single-family detached house. 12) Residential mobility is a dummy indicating whether the individual has changed residential address since the preceding year.

The residents of both areas have very similar characteristics, with the exception of longer commuting distances and slightly lower education and higher employment in trade, transport, restaurants and the hotel sector for the residents living further away from the Metro station, since this group is slightly closer to the airport than the remaining Metropolitan area. The difference in commuting distance caused by the different geographical location of residences of the control group motivates the application of the DID approach to control for unobservable time invariant characteristics.

The main outcomes of interest in this study are earnings and commuting behaviour. In addition, we check the validity of the empirical approach by testing for the absence of pre-treatment effects on additional outcomes including residential mobility and employment. We also estimate post-treatment effects on residential mobility and employment to rule out that earnings and commuting effects are in fact a result of the improved accessibility and not changes in local employment or residential choices.

Residential mobility is measured with a dummy which indicates whether the individual lives at a different address compared to the preceding year.[7] Employment is measured with a dummy which is equal to 1 if the individual has positive wage earnings. Earnings are defined as the annual sum of all wage earnings (as reported by employers and banks to the tax office). We use two different measures of commuting behaviour: commuting distance and area commuting indicators. If job vacancies were uniformly distributed over the metropolitan area, then commuting distance would properly capture any change in commuting patterns motivated by improved job accessibility. However, employment is highly concentrated in particular parts of the Copenhagen urban and suburban areas and, therefore, we use area commuting dummies to better capture job transitions across the metropolitan area. Area commuting indicators are dummy variables indicating whether the individual commutes between 0 and 5 km, between 5 and 10 km, between 10 and 25 km or distances above 25 km.[8] These variables capture whether individuals work in the suburban labour market on the island of Amager (0-5 km commute), in the centre of the city of Copenhagen (5-10 km commute), or at distant workplaces (commutes of 10-25 km and above 25 km).

4. Empirical strategy

This section describes the empirical approach. The aim of this analysis is to compare the variation in earnings and commuting behaviour before and after the infrastructure was operative for adult working-age individuals residing at different distances from the Metro station. To do so, we apply a multiple period DID regression (Imbens and Wooldridge, 2009).

The inauguration of the Metro on October 2002 represents an exogenous change in the accessibility of residences in the southern township (the island of Amager) to central and other suburban employment centres. However, differences in the productivity, travel behaviour and residential mobility of the individuals residing at different distances from the new Metro station potentially confound a rough comparison of the mean outcomes for individuals with better access to the new Metro station, e.g. the estimated effect of improved access to jobs if residents were randomly distributed at different distances to the entrance of the station.

In order to control for unobservable confounding variables, we apply a DID approach to the sample of residents in areas surrounding Vestamager station. To implement the DID estimation,

[7] Danish citizens must report a change of address to the National Registry/Citizen's Service at the latest 14 days after moving or a punishment will be issued. Address changes may, however, already be reported up to a month before the actual move.

[8] Ideally, we would like to measure travel time and travel distance by private means and public transport, but such data were not available at the individual level for the sample.

we group all adult working age individuals *i* from the study area into a treatment and a control group depending on whether their residence is located within 0.5 and 2.7 km or between 2.7 and 6.2 km street distance from Vestamager Metro station, respectively.[9] The estimated effect of improved job accessibility is obtained by subtracting the average outcome variation over time in the more distant (control) group of residents from the average outcome variation over time of the treatment group. This double differencing removes the bias that may be the result of average outcome level differences specific to the treatment group and not related to the Metro.

The causal effect of improved access to jobs is consistently estimated with a multiple time periods DID regression (Imbens and Wooldridge, 2009):

$$Y_{it} = \alpha + \gamma \cdot M_{it}^{m} + \sum_{j=1996}^{2006} \lambda_j \cdot 1\{t = j\} + \sum_{j=1996}^{2006} \beta_j \cdot M_{it}^{m} \cdot 1\{t = j\} + X_{it}{}'\vartheta + \varepsilon_{it}; \quad (1)$$

where Y_{it} is the outcome variable of individual *i* in year *t*=1995,…, 2006;[10,11] M_{it}^{m} is a dummy that indicates that the individual *i* resides within the distance threshold of *m* km from the Metro station in year *t*, $1\{t = j\}$ is a dummy variable that equals 1 when the individual observations corresponds to year *j*, X_{it} is a set of conditioning variables measured at the start of the observation year *t*. ε_{it} is an error term representing the unobservable characteristics of the individual *i* in year *t*.

The parameter γ measures the difference (given covariates) between treated and control individuals in 1995, and the parameters λ_j measure time effects common to both control and treatment groups. The coefficients β_j (*j* = 1996, …, 2001) capture the effects of anticipated job accessibility gain resulting from the new Metro. The post-treatment effects are given by year specific coefficients β_j (*j* = 2002, …, 2006), such that different coefficients β_j may capture eventual accumulating effects of improved access to jobs.

The identification of the parameters of interest requires several conditions. First, there are no relevant interactions between the members of the studied population due to, for example, congestion of the new Metro station or other spill-over effects. This is a realistic assumption given the low density of the area surrounding the new station of Vestamager.

Second, the conditioning variables X are exogenous, in the sense that they are not affected by distance between dwelling and Metro. The role of X in the DID approach is to remove differences in outcome time trends between treatment and control groups (Lechner, 2011). In the empirical analysis, we include age, gender, education, family composition, ethnic background, number of rooms in dwelling, living space, and type of house, all of which are variables which may affect trending behaviour and are not likely to be affected by improved accessibility.

The DID approach identifies the causal effect of the new station based on deviations in the outcome trend of the treated group from the outcome trend of the control group. Thus, the key identifying assumption in our analysis is that the outcomes of both the treatment and control group would have experienced the same trends in the absence of the Metro station. The common

[9] We report estimates for different thresholds around 2.7 km to assess the robustness of the effects on the definition of the treatment variable.
[10] The baseline year is the first one for which data is available for the given outcome. It is 1995 in the case of earnings and employment, 1996 in the case of residential mobility and 2000 in the case of commuting-type outcomes.
[11] We use a linear probability model when the outcome is binary —residential mobility, employment and commuting area indicators. This model has well known disadvantage because it has no confining predicted probabilities within the [0;1] interval. This could be a problem when the object of interest is prediction. However, as the object of interest is a treatment effect and the sample is large, the DiD coefficient of the linear probability model identifies the treatment effect, is readily interpretable and can be easily estimated

trend assumption would not be realistic if the new Metro station had pre-treatment effects prior to its opening. If residents anticipated job accessibility gains by changing jobs to more distant areas before the new infrastructure became operative, then commuting and earnings trends would have converged or diverged just before the Metro became operative.

In addition, the common trend hypothesis will not hold if treatment and control groups are different in time varying unobservable characteristics. In this regard, residential selection behaviour is a critical issue in our identification strategy. If choosing a residence within 0.5 and 2.7 km from the station (and not between 2.7 and 6.2 km) is based on time-varying omitted variables associated with the outcomes of interest, individuals living near the Metro will be different from those living further away with regards to characteristics left uncontrolled by the DID method, which will bias our estimated effects. As an indirect test for uncontrolled time-varying unobservable characteristics, we test whether there is a different propensity to residential mobility between the treatment and control groups.

5. Empirical results

This section presents evidence for the validity of the proposed empirical strategy and discusses the empirical results. In subsection 5.1, we assess the validity of the proposed method by testing for the absence of pre- and post-treatment effects on residential mobility, and for the absence of pre-treatment effects on labour market outcomes. In subsection 5.2, we present the main results and demonstrate their robustness.

5.1 Validity of the research design

This section tests the validity of the DID strategy, e.g. common trend assumption, through a test for statistical insignificance of the pre-treatment effects ($\beta_j = 0$ for j < 2002) on residential mobility, employment rates, earnings and commuting during 1996-2001, data permitting. Since neither group experienced improved public transport before 2002, but had been aware of the precise location of Vestamager station since 1996, ruling out the presence of non-common trends or anticipatory effects is a central issue for our empirical strategy. Figure 3 presents informal evidence for the validity of the DID design and the effects of improved job accessibility. By comparing the trajectories of employment, residential mobility, earnings and commuting distances before the Metro opened in 2002, these figures provide informal evidence for common trends. By comparing the trajectories of earnings and commuting distances after the Metro became operative, these graphs suggest the presence of positive earnings effects.

Table 2 reports formal evidence of the appropriateness of use of the DID approach. The table presents the estimated coefficients for $\beta_j = 0$ for $j < 2002$ for the outcomes of interest. In the case of earnings and employment, the data set includes information back to 1995. In the case of residential mobility, the data set includes information back to 1996, while in the case of commuting behaviour, the data set only includes commuting distances since 2000. We use the DID approach to estimating these pre-treatment effects because this method allows us to control for unobservable time invariant differences between the treatment and control groups. The data available permits us to estimate the effect on earnings and employment between 1996-2001, on residential mobility between 1997 and 2001, and on commuting behaviour in 2001. The standard errors are clustered at the household level. Despite the fact that pre-treatment trends (uncontrolled for covariates) are very similar, we control for potential small deviations in the trends by including the covariates in the DID regression.[12] The inclusion of covariates permits a slightly more precise estimation of the effects. These estimates are presented for several distance thresholds for the separation of treatment and control areas. Table 2 shows that the common

[12] See section 5.

trends condition is plausible since none of the pre-treatment estimated effects are statistically significant. In other words, the propensity to change residence, the labour market behaviour and commuting patterns of persons residing within 0.5 and 2.7 km from the Metro station does not seem to deviate from that of those residing between 2.7 and 6.2 km. This finding is not surprising given the great deal of uncertainty about the immediate impact of the new infrastructure before 2002.[13]

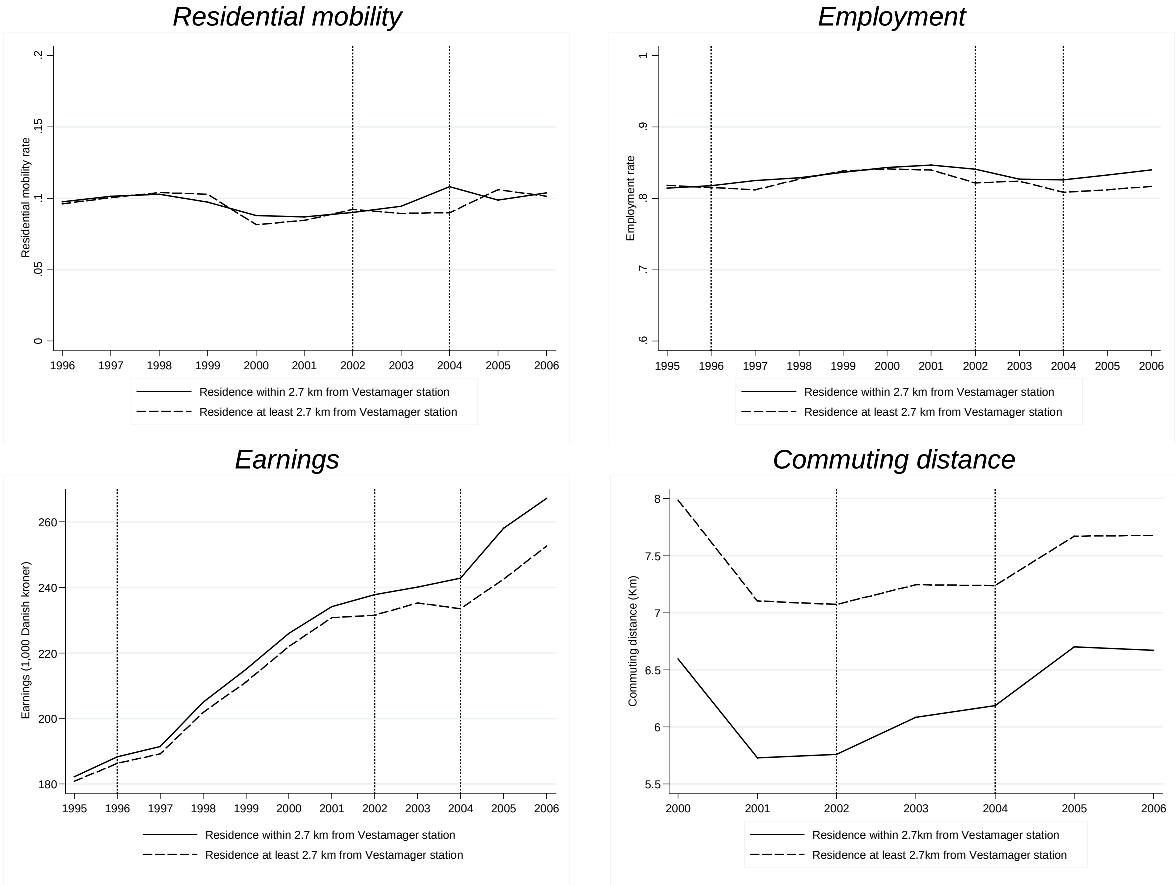

Figure 3. Residential mobility, labour market outcomes and commuting in 1995-2006

Notes: The vertical dashed lines in years 1996, 2002 and 2004 indicate the announcement of the construction of the Metro, the inauguration of Vestamager station with Phase 1, and the expansion of the Metro with Phase 2 respectively.

[13] See section 2.

Table 2. Estimated pre-treatment effects of improved job accessibility

Year	m = 2.5 km	m = 2.6 km	m = 2.7 km	m = 2.8 km	m = 2.9 km
	Residential mobility				
1997	0.007 (0.011)	0.004 (0.011)	0.001 (0.011)	0.006 (0.011)	-0.009 (0.011)
1998	-0.003 (0.011)	-0.003 (0.011)	-0.001 (0.011)	0.001 (0.011)	-0.008 (0.011)
1999	-0.012 (0.011)	-0.008 (0.011)	-0.007 (0.011)	-0.006 (0.011)	-0.015 (0.011)
2000	0.003 (0.010)	0.003 (0.010)	0.002 (0.010)	0.005 (0.011)	-0.004 (0.011)
2001	0.001 (0.010)	0.001 (0.010)	-0.001 (0.010)	0.000 (0.011)	-0.001 (0.011)
	Employment				
1996	0.003 (0.006)	0.006 (0.006)	0.004 (0.006)	0.005 (0.007)	0.008 (0.007)
1997	0.011 (0.008)	0.016 (0.008)	0.016 (0.008)	0.017 (0.008)	0.020 (0.008)
1998	0.005 (0.008)	0.008 (0.008)	0.005 (0.008)	0.006 (0.009)	0.008 (0.009)
1999	0.001 (0.009)	0.006 (0.009)	0.004 (0.009)	0.003 (0.009)	0.004 (0.009)
2000	0.004 (0.009)	0.008 (0.009)	0.006 (0.009)	0.006 (0.010)	0.004 (0.010)
2001	0.011 (0.010)	0.015 (0.010)	0.013 (0.010)	0.014 (0.010)	0.016 (0.010)
	Earnings				
1996	-1,377 (1,694)	-285 (1,723)	-826 (1,739)	284 (1,777)	-185 (1,795)
1997	-1,267 (2,149)	796 (2,178)	-56 (2,203)	1,448 (2,238)	2,671 (2,260)
1998	-364 (2,587)	1,167 (2,606)	623 (2,630)	2,077 (2,683)	3,283 (2,720)
1999	1,483 (2,871)	2,657 (2,896)	2443 (2,924)	3,808 (2,975)	3,858 (3,026)
2000	1,554 (3,115)	2,655 (3,136)	2,692 (3,161)	4,643 (3,214)	4,779 (3,276)
2001	1,125 (3,035)	2,708 (3,002)	2,446 (2,785)	4,691 (3,055)	5,755 (3,100)
	Area commute in 2001				
0-5 km	0.001 (0.008)	-0.001 (0.009)	-0.001 (0.009)	0.002 (0.008)	0.003 (0.009)
5-10 km	-0.001 (0.008)	-0.001 (0.007)	-0.001 (0.008)	0.000 (0.008)	0.002 (0.008)
10-25 km	0.002 (0.007)	0.002 (0.007)	0.002 (0.007)	-0.001 (0.008)	0.000 (0.008)
25- km	0.002 (0.005)	-0.001 (0.005)	0.001 (0.005)	0.002 (0.005)	0.001 (0.005)

Notes: Columns report estimates for different distance thresholds *m* (see (1)). Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent, respectively. *N*=92,519 observations for mobility effect analysis, *N*=100,829 observations for labour market effect analysis, and *N*=58,197 observations for commuting effect analysis.

5.2 Econometric results

This section presents the main results. The analysis proceeds in two steps. First, we investigate the effect of improved access to jobs on mobility and employment. Secondly, we estimate the effects of improved job accessibility on earnings and commuting behaviour.

In order to interpret the impact of improved job accessibility on earnings and commuting behaviour, it is important to assess whether the new infrastructure has a relevant effect on post-treatment residential mobility and employment rates. Figure 3 shows that the effect of the improvement in access to jobs on residential mobility and employment is rather limited. This implies that the diverging earnings appreciated in figure 3 can be attributed to wage enhancing job transitions for residents closer to the station, and not to residential mobility of more productive workers closer to the Metro or increased employment participation of persons residing closer to the new station.

We now turn to a more formal approach by estimating the effects of improved accessibility on employment and residential mobility following the opening of the Metro in 2002 and up till 2006. The interpretation of the effects of Metro proximity following its opening in 2002 as job accessibility effects requires that the Metro does not affect the residential mobility of the treatment and control groups differently. Table A1 of the appendix reports these estimates. The table shows that after the completion of the new infrastructure, residents in the proximity of the Metro have a slightly higher tendency to stay in their homes than those individuals residing further away from the Metro station. However, these estimates are not statistically different from zero. The table also shows that the improvement in access to jobs has a moderately positive effect of around 2 per cent on employment rates, which is too moderate an effect to completely drive the effect of the new Metro station on earnings and commuting.

We now turn our focus to the effect on earnings. Improved access to the labour market via public transport should progressively enhance individuals' earnings if the new station facilitates job-to-job transitions to other areas of the local labour market, especially in the inner city. Table 3 provides evidence of the positive effect of living closer to station on earnings, especially since 2004-5 when phase 2 of the Metro system was completed. The table suggests that the shorter distances to the Metro had almost no effect during the first two years, but the effect increased and stabilized during 2006 at about 10,471-13,821 Danish Crowns.

Table 3. Estimated post-treatment effect of improved job accessibility on earnings

Year	m = 2.5 km	m = 2.6 km	m = 2.7 km	m = 2.8 km	m = 2.9 km
2002	4,295 (3,702)	5,241 (3,731)	4,915 (3,768)	7,047* (3,834)	7,108* (3,924)
2003	3,134 (3,892)	4,365 (3,912)	3,981 (3,953)	5,237 (4,011)	5,141 (4,105)
2004	7,768* (4,127)	10,140*** (4,178)	9,184** (4,248)	9,544** (4,330)	13,048*** (4,280)
2005	11,074** (4,273)	13,902*** (4,300)	13,195*** (4,360)	12,617*** (4,417)	15,315*** (4,487)
2006	10,471** (4,397)	12,909*** (4,438)	13,559*** (4,507)	13,494*** (4,578)	13,821*** (4,683)

Notes: Columns report estimates for different distance thresholds *m* (see (1)). Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent, respectively. *N*=100,829 observations.

The effect of a shorter street distance to the Metro on earnings is a necessary, but insufficient result to be able to conclude that such effects are a consequence of improved access to jobs. The new infrastructure may selectively attract workplaces to the neighbourhoods closest to the Metro station, which would generate positive earnings if the new firms favour local workers. To discard this possibility and other possibilities, we now investigate the effect on commuting behaviour.

Table 4 shows the average effects on commuting distances. The table shows that the new Metro apparently does not change the commuting distances of those living in the vicinity of the Metro. However, as commuting distance is a Euclidean distance measure between residences and workplaces, it provides an imperfect measurement of the impact of improved access on commuting across the public transport network characterised by providing access to very different nodes (Scheurer, 2013). In addition, the new infrastructure may have a non-linear

Table 4. Estimated post-treatment effect of improved job accessibility on commuting distance

Year	m = 2.5 km	m = 2.6 km	m = 2.7 km	m = 2.8 km	m = 2.9 km
2002	-262 (531)	-91 (531)	115 (535)	224 (533)	49 (546)
2003	-256 (552)	-415 (560)	-76 (560)	-8 (568)	-1 (580)
2004	72 (568)	-185 (578)	-45 (588)	-262 (603)	-431 (630)
2005	545 (527)	477 (531)	804 (534)	709 (540)	376 (559)
2006	-636 (651)	-619 (664)	-205 (673)	166 (680)	-159 (710)

Notes: Columns report estimates for different distance thresholds *m* (see (1)). Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent respectively. *N*=58,197 observations.

impact on commuting distance in the sense that it may reduce the commuting trips to closest workplaces and to most distant destinations in favour of workplaces in the city centre or other urban employment centres.

The analysis of effects on binomial indicators for area commuting provide a more powerful tool for detecting potential changes in commuting behaviour as a consequence of improved job accessibility. We now report estimates on the probability of commuting different geographical distances. Table 5 shows that improved access to the new Metro station reduces short commuting trips (between 0 and 5 km) by 2-4 percent. The table also shows that this effect is statistically significant from 2005. As can be seen in the table, the shorter distance to the Metro station increases short-to-medium commuting trips (between 5 and 10 km and between 10 and 25 km), while it tends to have a negative, but statistically insignificant effect on the longest commuting trips, a result that may explain the insignificant average effect on commuting distances. The positive effects on commuting trips between 5 and 10 km are manifested for all thresholds and are very similar for 2005-2006, while the longer commuting trips are only significant in 2006. This pattern suggests that the effect of improved access to jobs only becomes fully manifested after several years, and that, as in the case of the effect on earnings, the impact on commuting is permanent. The shift from commuting between 0 and 5 km to distances between 5 and 10 km discards the possibility that the earnings effect is driven by the relocation of firms to the vicinity of the new station, which could favour the employment of local workers.

As shown in table A2 of the appendix, the estimated effects on earnings and commuting are robust to excluding the covariate set from the DID regression. Such robustness of the estimates to control for baseline covariates suggests that the double-difference approach that removes time invariant unobservable characteristics is sufficient to identify the effects. This result also suggests that the use of a linear parametric model for the binary area commuting rate outcomes does not affect the results in comparison with the non-parametric DID without covariates.

Table 5. Estimated post-treatment effect of improved access on area-commuting rates

Year	m = 2.5 km	m = 2.6 km	m = 2.7 km	m = 2.8 km	m = 2.9 km
	0-5 km commute				
2002	-0.005 (0.008)	-0.003 (0.009)	-0.003 (0.009)	0.001 (0.009)	0.003 (0.009)
2003	-0.008 (0.010)	0.000 (0.011)	-0.002 (0.011)	-0.001 (0.011)	-0.007 (0.011)
2004	-0.023 (0.011)	-0.016 (0.012)	-0.019 (0.012)	-0.013 (0.012)	-0.017 (0.012)
2005	-0.030** (0.012)	-0.026** (0.013)	-0.034*** (0.013)	-0.030** (0.013)	-0.027** (0.013)
2006	-0.036*** (0.013)	-0.031** (0.013)	-0.038*** (0.013)	-0.040*** (0.014)	-0.033** (0.014)
	5-10 km commute				
2002	-0.001 (0.007)	-0.001 (0.007)	-0.001 (0.008)	-0.002 (0.008)	0.000 (0.008)
2003	0.000 (0.010)	-0.007 (0.010)	-0.007 (0.010)	-0.006 (0.010)	-0.001 (0.010)
2004	0.017 (0.011)	0.011 (0.011)	0.010 (0.011)	0.009 (0.011)	0.012 (0.011)
2005	0.026** (0.011)	0.021* (0.012)	0.021* (0.012)	0.019 (0.012)	0.021* (0.012)
2006	0.028** (0.012)	0.023* (0.012)	0.023* (0.012)	0.022* (0.012)	0.021* (0.013)
	10-25 km commute				
2002	0.007 (0.007)	0.004 (0.007)	0.005 (0.007)	0.001 (0.008)	0.000 (0.008)
2003	0.006 (0.009)	0.007 (0.009)	0.008 (0.009)	0.005 (0.009)	0.008 (0.010)
2004	0.007 (0.010)	0.008 (0.010)	0.012 (0.010)	0.009 (0.010)	0.013 (0.011)
2005	0.007 (0.011)	0.009 (0.011)	0.015 (0.011)	0.014 (0.011)	0.017 (0.012)
2006	0.013 (0.011)	0.014 (0.011)	0.020* (0.012)	0.020* (0.012)	0.021* (0.012)
	25- km commute				
2002	0.000 (0.005)	-0.001 (0.005)	0.000 (0.005)	0.000 (0.005)	-0.003 (0.005)
2003	0.002 (0.006)	0.000 (0.006)	0.001 (0.006)	0.002 (0.006)	-0.001 (0.006)
2004	-0.001 (0.006)	-0.003 (0.006)	-0.003 (0.007)	-0.005 (0.007)	-0.008 (0.007)
2005	-0.003 (0.007)	-0.004 (0.007)	-0.003 (0.007)	-0.003 (0.007)	-0.011 (0.007)
2006	-0.004 (0.007)	-0.006 (0.007)	-0.004 (0.007)	-0.002 (0.007)	-0.009 (0.007)

Notes: Columns report estimates for different distance thresholds *m* (see (1)). Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent, respectively. *N*=58,197 observations.

Table 6 compares the effects of Metro access on earnings and short commuting trips (0-5 km) for workers employed in different sectors.[14] The main motivation for doing this is that job vacancies within different sectors have a different spatial distribution across the Copenhagen Metropolitan area. Employment in the trade, transport, restaurant or hotel sectors is highly concentrated in the inner city and the international airport located next to the study area. Thus, the new Metro substantially reduces travelling time to similar workplaces located in the centre. Employment within the manufacturing or construction sector is mostly concentrated in other suburban employment centres far away from the study area. Therefore, the new station does not involve a very significant change in the otherwise longer commuting trips of workers employed in these sectors.

Employment in the private sector is mostly concentrated in the city centre, while employment in the public sector is concentrated in the city centre, but is also more uniformly distributed across the Metropolitan area. The table shows that the effect of improved access to jobs is only significant for individuals employed in the trade, transport, restaurant or hotel sectors. The effects on short commuting trips demonstrate that improved access to public transport changes the commuting patterns for these types of workers, who, as a consequence of improved access, change their local jobs for better paid jobs elsewhere in the Metropolitan area, but especially in the city centre where most of the employment in this sector is concentrated. Thus, workers employed in these sectors, for whom the new transport infrastructure implies the most important change in job accessibility, were able to make transitions from local to more distant jobs which improved their earnings. In the case of improved commuting opportunities, job-to-job transitions are more likely to be characterised by a wage increase because the set of opportunities the worker faces improves (for evidence of earnings drop in job-to-job transitions without improved access to jobs, see Postel-Vinay and Robin, 2002).

Table 6. Estimated post-treatment effect of improved job accessibility by employment sector

Year	Manufacturing or construction		Trade, transport, restaurant or hotel		Financial, insurance, real estate or other business services		Public, education, health or social work sector	
	Earnings	0-5 km commute	Earnings	0-5 km commute	Earnings	0-5 km commute	Earnings	0-5 km commute
2002	3,224 (10,921)	-0.037 (0.029)	3,169 (6,199)	0.007 (0.017)	2,696 (11,732)	-0.039 (0.028)	2,342 (4,974)	0.026 (0.018)
2003	4,477 (11,106)	-0.021 (0.032)	7,913 (6,529)	-0.018 (0.021)	4,084 (12,445)	-0.020 (0.031)	-2,336 (5,271)	0.041** (0.020)
2004	-3,363 (11,188)	-0.030 (0.034)	13,803* (7,839)	-0.037 (0.023)	11,946 (13,076)	-0.023 (0.032)	3,375 (5,633)	0.029 (0.021)
2005	5,949 (12,465)	-0.045 (0.036)	20,791*** (7,179)	-0.080*** (0.024)	17,700 (13,394)	-0.033 (0.033)	-816 (5,760)	0.019 (0.022)
2006	1,808 (12,550)	-0.033 (0.035)	21,490*** (7,451)	-0.058** (0.025)	4,238 (14,124)	-0.041 (0.034)	990 (6,024)	-0.015 (0.023)
N	13,075	6,198	28,705	14,047	13,049	6,817	27,138	13,619

Notes: Columns report estimates for distance threshold m = 2.7 km. Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent, respectively.

[14] The estimated effects on the remaining area commuting indicators are available upon request.

As workers from the sector with poorer access to jobs in the city centre are more likely to make residential moves closer to the new Metro station, and these residential moves may be hidden by the statistically insignificant average effect on the residential moves of unemployed individuals and individuals employed in other sectors, the final analysis of this paper investigates whether the detected effects on earnings and commuting are caused by effects of Metro access on residential mobility. Table A3 shows that residential mobility for workers facing the greatest improvement in access were not affected by the new infrastructure.

6. Conclusion

This study has analysed the construction of a terminal Metro station, which connected a relatively isolated township to the city centre of Copenhagen to obtain empirical evidence of the effect of improved access to jobs on individual earnings. The study of the effect on earnings is an important contribution to the literature on the effect of improved accessibility which tends to rely on the more indirect methodology of hedonic pricing. The paper has compared the effect of proximity to the new Metro on earnings and commuting behaviour for all working age individuals and for workers employed in different sectors residing in the treatment and control areas from 7 years before the opening of the station to 4 years after.

The findings indicate that good access to the Metro is associated with a wage increase which first became detectable two years after opening and reached the level of 10,471-13,821 Danish kroner 4 years after opening.

Commuting destinations have been redistributed following the opening of the Metro. The probability of commuting a short distance (<5 km) within the township had reduced 3-4 years after the opening of the new station, whereas the probability of commuting a slightly longer distance (5-10 km) had increased. 4 years after opening, the probably of commuting longer distances (10-25 km) had increased, but longer time series will be required to fully determine how commuting patterns have changed.

When looking at the changes in earnings and commuting distances, the findings suggest that an effect on earnings mainly applies to those individuals most affected by improved access to jobs. The effects of improved access to jobs on earnings are only significant for those individuals who were employed in the township prior to the opening of the new Metro (commuting 0-5 km). The new public transit infrastructure greatly increased access to the city centre and this change seems to be driving short term changes in commuting (shift from 0-5 km to 5-10 km) as well as earnings.

Ending the time series 4 years after the opening of the Metro station is of course a limitation of this study and the findings should be considered as short term effects. Future studies on longer term effects should, however, be possible based on the use of Danish register data, but they would also require elaborate modelling of other environmental and infrastructural changes over time.

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Appendix: Additional tables

Table A1. Estimated post-treatment effect of improved job accessibility on residential mobility and employment

Year	m = 2.5	m = 2.6	m = 2.7	m = 2.8	m = 2.9
	Residential mobility				
2002	-0.013 (0.010)	-0.011 (0.010)	-0.008 (0.011)	-0.005 (0.011)	-0.015 (0.011)
2003	-0.013 (0.010)	-0.010 (0.011)	-0.002 (0.011)	-0.002 (0.011)	-0.007 (0.011)
2004	0.006 (0.011)	0.003 (0.011)	0.007 (0.011)	0.008 (0.011)	0.000 (0.011)
2005	-0.015 (0.011)	-0.016 (0.011)	-0.013 (0.011)	-0.006 (0.011)	-0.014 (0.011)
2006	-0.009 (0.011)	-0.009 (0.011)	-0.006 (0.011)	-0.003 (0.011)	-0.010 (0.011)
	Employment				
2002	0.019 (0.010)	0.024** (0.010)	0.022** (0.010)	0.024 (0.011)	0.023** (0.011)
2003	0.001 (0.011)	0.006 (0.011)	0.006 (0.011)	0.007 (0.011)	0.006 (0.011)
2004	0.014 (0.011)	0.022** (0.011)	0.021* (0.011)	0.019* (0.011)	0.021 (0.012)
2005	0.016 (0.011)	0.023** (0.011)	0.022* (0.011)	0.016 (0.012)	0.021* (0.012)
2006	0.020* (0.011)	0.024** (0.011)	0.026** (0.011)	0.020* (0.012)	0.022* (0.012)

Notes: Columns report estimates for different distance thresholds *m* (see (1)). Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent, respectively. *N*=92,519 observations to mobility effect analysis, and *N*=100,829 observations to employment effect analysis.

Table A2. Robustness of post-treatment effects of improved job accessibility to excluding covariate set[15]

Year	Earnings		0-5 km commute		5-10 km commute		10-25 km commute		25- km commute	
	Cov.	Cov. excl	Cov.	Cov. excl	Cov.	Cov. excl	Cov.	Cov. excl	Cov.	Cov. excl
2002	4,930 (3,765)	4,837 (4,025)	-0.003 (0.009)	-0.006 (0.009)	-0.001 (0.008)	0.000 (0.007)	0.005 (0.007)	0.006 (0.007)	0.000 (0.005)	0.000 (0.005)
2003	3,973 (3,951)	3,489 (4,218)	-0.002 (0.011)	-0.004 (0.011)	-0.007 (0.010)	-0.006 (0.010)	0.008 (0.009)	0.009 (0.009)	0.001 (0.006)	0.001 (0.006)
2004	9,195** (4,245)	7,930* (4,567)	-0.019 (0.012)	-0.021* (0.012)	0.010 (0.011)	0.010 (0.011)	0.012 (0.010)	0.013 (0.010)	-0.003 (0.007)	-0.003 (0.007)
2005	13,204*** (4,358)	14,140*** (4,678)	-0.033*** (0.013)	-0.037*** (0.013)	0.021* (0.012)	0.022* (0.012)	0.015 (0.011)	0.017 (0.011)	-0.003 (0.007)	-0.003 (0.007)
2006	13,572*** (4,505)	13,162*** (4,856)	-0.038*** (0.013)	-0.040*** (0.014)	0.023* (0.012)	0.022* (0.012)	0.020* (0.012)	0.021* (0.012)	-0.005 (0.007)	-0.004 (0.007)
R^2	0.1918	0.0254	0.0703	0.0038	0.0179	0.0013	0.0315	0.0066	0.0135	0.0003
N	100,829	100,829	58,197	58,197	58,197	58,197	58,197	58,197	58,197	58,197

Notes: Columns report estimates for distance threshold m = 2.7 km (see (1)).Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent, respectively.

[15] The estimated effects on the remaining area commuting indicators are available upon request.

Table A3. Estimated pre- and post-treatment effects of improved job accessibility on mobility of individuals employed in the trade, transport, restaurant or hotel sectors.

Year	Residential mobility
1996	
1997	-0.004 (0.019)
1998	-0.003 (0.019)
1999	-0.016 (0.019)
2000	-0.014 (0.018)
2001	-0.004 (0.018)
2002	-0.006 (0.019)
2003	-0.014 (0.019)
2004	0.003 (0.019)
2005	-0.012 (0.019)
2006	-0.002 (0.019)

Notes: Columns report estimates for distance threshold *m*=2.7 km (see (1)). Standard errors clustered at the household level in parentheses. ***, **, * denote statistical significance at 1 per cent, 5 per cent and 10 per cent, respectively. *N*=26,296 observations