Teleworking Effect on Traffic and Air Pollution

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Abstract

Traffic congestion is one of the foremost problems confronted by the urban and suburban tenants of today. Traffic congestion increases vehicle emissions and degrades air quality. Urban planners and policy makers have consequently been always investigating choices to alleviate traffic congestion and to enhance air quality. Teleworking is one option that has received significant consideration and has been studied in the recent past. The aim of the study is to explore the relationship between teleworking, air quality and traffic in Switzerland. The analysis relies on panel individual and household level data over the period 2002-2013. We examine five main air pollutants; the sulphur dioxide (SO_2), the ground-level ozone (O_3) the nitrogen dioxide (NO_2), the carbon monoxide (CO) and the particulate matter less than 10 microns (PM_{10}). Based on the fixed effects estimates, teleworking reduces traffic volume by 1.9 per cent. Furthermore, the reduction observed on air pollution is higher for NO_2, CO and PM_{10} ranging between 3.3-3.7 per cent, followed by O_3 at 2.3 per cent and SO_2 at 2.1 per cent. According to instrumental variable (IV) approach and the two stage least squares (2SLS) method, the effect is higher ranging between 2.6-4.1 per cent. The respective reduction on traffic becomes 2.7 per cent. Overall, the main concluding remark of the study is that teleworking can be a promising tool for urban planning and development, focusing at the traffic volume reduction, and the air quality improvement. Additional policy implications of teleworking and its beneficial effects for the society are further discussed.

Keywords: Air Quality; Fixed Effects; Instrumental Variables; Panel Data; Teleworking; Traffic

1. Introduction

With surging population and urbanisation, air contamination and traffic congestion have turned out to be pressing issues in the modern societies. This can be especially ascribed to the increasing number of private cars. There are few strategies that can be utilised to relieve the levels of traffic volume and reduce the air pollution, including fuel pricing and investments on public transportation infrastructure. Another possible tool is teleworking, which is explored in this study. Work conditions and schedules, especially within the last 10 years, followed with the fast enhancement and boost of the technology, have been disconnected from the traditional place, such as the employers' premises. It is possible nowadays for the employees to carry out their duties and job obligations in other locations, including their home, the clients' premises, while travelling or in other remote locations (Bailyn, 1988; Perin 1991; Perlow 1997; Sullivan and Lewis 2001; Madsen, 2006).

Since the 1980s an increasing part of the labour force has been teleworking at home or in any location other than employer's premises at least one day a week. Earlier studies have outlined the reasons of teleworking growth due to the fast and impressive boost of technology and specifically the information and communication technology (ICT), and due to the perceived benefits of teleworking. These benefits include job satisfaction improvement, increase on productivity and employee loyalty, and the need for couples to balance work-family life. In addition, employers are able to cut costs in terms of saving space office and equipment among others (Potter, 2003; Golden, 2006). Therefore, as the technology and public telecommunications services have been advanced, interest in teleworking has increased remarkably in recent years.

Teleworking can have positive environmental effects, including reduction in traffic and air pollution. According to a study conducted by the Texas Transportation Institute, Americans are spending more time in traffic than ever before (Schrank and Lomax, 2005). As the time lost in traffic in America's largest cities threatens to surpass two working weeks per year, it comes as little surprise that teleworking is promoted as a mean to recover time lost because of the commuting and to improve the productivity of the workers in USA. Therefore, the alleviation of traffic congestion and the reduction in air pollution are reported as the leading benefits of teleworking (Vittersø et al., 2004; Golden and Veiga 2005; Vega et al., 2015; Anderson et al., 2015; Bentley et al., 2016).

The fast enhancement in ICT, especially in the last years, including electronic mail, fax machines, computer networks and data systems and storage, such as icloud, have dramatically widened the workplace options for employees, self-employed and freelancers, that allow them to

work wherever these tools are available, including at home. In USA it is found that teleworking and working at home allows the employees to avoid the rising frustration from the irritation and the time loss associated with commuting. Roughly 30 per cent of the employees work at home and an estimated two million are full-time employees who otherwise would commute daily to the employer's premises.

The objective and motivation of this study is to contribute to the teleworking, urban planning and air quality literature analysing the impact of the teleworking, as an alternative tool, on traffic and air quality with further beneficial effects on the environment and public health. The analysis relies on detailed micro-level data derived from the Swiss Household Panel (SHP) survey, which provides information on personal and household characteristics, over the period 2002-2013. First, we apply a fixed effects model and we propose a seemingly unrelated regression (SUR) system as robustness check, which allows for the simultaneous estimation between teleworking, traffic and air pollution. Fixed effects account for endogeneity coming from the omitted variables bias. However, we also apply an instrumental variable (IV) approach using two stage least squares (2SLS) method, in order to solve for possible reverse causality between teleworking, traffic and air pollution.

The structure of this study is the following: In the next section, we describe the methodology followed and the data used in the empirical work, while in the section 3 we report the empirical results. In the last section, we discuss the concluding remarks of the study and the possible policy implications of teleworking.

2. Literature Review

Earlier studies explored the effects of teleworking on various outcomes, including household allocation, work-family life balance, productivity, job satisfaction, traffic and air quality among others (Mokhtarian and Salomon, 1997; Mokhtarian et al., 2004; Vittersø et al., 2004; Vega et al., 2015; Anderson et al., 2015; Giovanis, 2017). However, this study contributes to the earlier literature by exploring the relationship amongst teleworking, air pollution and traffic, using detailed individual and household level data and mapping the traffic and air quality data in a small geographical area, such as the municipality.

From a national and policy making perspective, teleworking is an important tool, because of its potential benefits and transportation implications, especially with respect to traffic congestion and air quality. The public cost of the urban traffic congestion is not limited only to employee and corporate productivity losses, costs of delays and personal delays due to commuting at work, but also to the congestion during the peak hours of the day, which is a major source of air pollution.

Therefore, teleworking is seen by policy makers as an important tool in transportation management. In addition, besides its potential benefits to air pollution and traffic congestion reduction, other benefits of teleworking include the reduced national petroleum and benzene use, a less number of accidents and eased transportation infrastructure requirements. Finally, teleworking can also expand opportunities for part time workers who have responsibilities at home and household, including caring of children, elder or disabled people, and it allows people with impaired mobility and disability to work from home. The studies by Sinha and Bhattacharya (2016, 2017) explored the relationship between NO2 and SO2 and classification of income into low, medium and high levels. Moreover, they consider the electricity and petroleum consumption and they found that the Environmental Kuznets Curve (EKC) hypothesis holds emphasizing the importance of the economic growth impact on environment.

The effects of teleworking on travel behaviour have been extensively documented, largely through the efforts of Mokhtarian and Salomon and their colleagues. The reviews of these studies are provided by Handy and Mokhtarian (1995), Mokhtarian (1991, 1998), Mokhtarian and Salomon (1997) and Mokhtarian et al. (2004). The results derived from earlier studies are mixed. A number of studies found that teleworkers reduce their number of trips and distance travelled over the teleworking days (Niles, 1988; Pendyala, 1991; Mokhtarian, 1998; Wells, et al., 2001), while other studies provide empirical evidence suggesting travel stimulation or generation (Niles, 1994; Mokhtarian, 1991; Mokhtarian and Salomon, 1997) sometimes only on non-teleworking days. The majority of the research literature is based on qualitative or descriptive statistics. Some of them have adopted behavioural approaches to explain the decisions of individuals to engage in teleworking (Mokhtarian and Salomon, 1996). However, very few studies have explored the effects of teleworking on traffic and air quality. This study attempts to fill this gap in the previous literature by applying regression analysis, controlling for possible confounders and individual and household characteristics.

Shafizadeh et al (1998), who focused on previous macro-scale studies found that the average savings per teleworker ranges between 1,500 and 3,500 vehicle miles travelled (VMT) per year. Banister and Marshall (2000) found that teleworkers in Netherlands decreased the total number of trips by 50 per cent during the teleworking days and the distance travelled by 10 per cent. The authors found a significant decrease in the total number of trips because of teleworking, by 17 per cent and a peak-hour traffic reduction by 26 per cent. Glogger et al. (2008), employed descriptive statistics using data from 37 telecommuters and 29 household members derived from a study that was carried out amongst teleworkers in the Greater Munich Area of Germany as part of a project called Mobility Centres Network (MOBiNET). The authors found that teleworkers reduced their

total trips by 19 per cent and their work trips by 43 per cent, while the households cut their total trips and work trips by 14 and 29 per cent respectively. On the other hand the number of car trips for leisure purposes nearly doubled, and the total distance for leisure trips increased. However, the household members' share of car trips-for leisure purposes decreased from 64 to 48 per cent. A different approach is followed by Choo et al. (2005) who used national aggregate data to estimate an econometric time-series model of VMT as a function of economic variables and employ a 2SLS method. Then they take the residuals from this regression and they regress them on the teleworking data. In the first stage regression the authors consider gross domestic product (GDP) per capita, the price of gasoline, average miles per gallon of the vehicle fleet, a consumer price index (CPI) for all commodities, and a CPI for transportation as explanatory variables over the period 1966-1999, while the dependent variable is the VMT per capita. Their findings suggest that VMT during the sample period they examined would have been approximately 2.12 per cent higher than the observed VMT in the absence of teleworking.

While a number of studies explored the relationship between teleworking, travel behaviour and VMT, very few studies explored the effects of teleworking on air pollution. Moreover, these studies examined mainly US case studies, while there is no comprehensive study in Europe, especially in Switzerland. Moreover, no study used so far detailed data from micro-level household surveys within a panel framework. Mokhtarian and Varma (1998) used data from another teleworking program implemented in California, the Neighborhood Telecenters Project, which established 15 centers. They found that total VMT was 53 lower on teleworking days than on non-teleworking days, but the number of trips increased, because people apparently drive home from the telecenter for lunch. Next the authors used the EMFAC7 emissions model and found that emissions on teleworking days were 15 per cent less than on non-teleworking days for the reactive organic gases, 21.5 per cent for CO, 35 per cent for NOX and 51.5 for PM. Pflueger et al. (2016) explored the impact of the Dell's Connected Workplace on envirnoment. Dell's Connected Workplace includes flexible employment schemes, such as variable work hours and working from home. More specficaily the authors found that with the implmentation of this program 6,700 metric tons of greenhouse gas emissions were avoided in 2013 and additional $12 millions were saved in the same year. Almost the 20 per cent of Dell's workforce participate officially in Dell's Connected Workplace program and the expectations is to bring the target at 50 per cent global participation by 2020. The Smart 2020 report calculated that teleworking could reduce global carbon emissions by around 0.5 per cent by 2020. Considering USA, if the number of teleworkers rose to 30 million, it is estimated that the emissions reduction could reach the 75-100 million tonnes of carbon dioxide equivalent (The Climate Group 2008).

In United Kingdom, British Telecom (BT) has implemented a teleworking program for its employees. The effect of homeworking was the reduction of CO_2 emissions at 6,980 tonnes, on a net yearly basis, between 2012-2015. As an even larger number of unregistered staff are known to work at home, the actual level of savings is probably substantially higher, and even perhaps double (Carbon Trust, 2016). Pérez et al. (2004), explored the impact of teleworking on traffic and air quality to a Spanish metropolitan area: the city of Zaragoza located in the northeast of Spain. The authors found that the annual savings in air pollution range between 541.1 and 3,246.9 thousands of Euros for a teleworking penetration ranging between 2.5 and 15 per cent. The respective traffic annual savings are estimated at 5,232.6 and 31,395.9 thousands of Euros.

Although teleworking is conceptually simple, its implications can be various in many areas of life, as we discussed earlier, and important questions are rising, which are not fully yet been answered. For instance, the form and the degree that teleworking can take, and the public benefits depend on the peoples' attitudes, the nature and tasks of the work performed, the adaptability of corporate culture and the changes in the travel behaviour. This study attempts to answer the possible implications of teleworking on air quality and traffic; however, there is a wide variation of prediction of the future of teleworking and its impact on transportation and air quality, since this study explores the case of Switzerland, using a representative national survey. Thus, the effects of teleworking can vary depending also on the country explored, its culture and infrastructure among other factors.

On the other hand, teleworking and home-based working are associated with negative effects for both employees and employers. In earlier studies, concerns have been expressed that include conversion of employees into contract and casual workers, lacking benefits, job security and protection. Also previous studies support that the face-to-face interaction is associated with positive outcomes (Olson et al., 2002). Social interaction at work can facilitate social presence and improve communication quality (Short et al., 1976; Burgoon et al., 2002). Thus, employees who face less social presence at work and increased reliance on technology based job activities, may experience lower levels of communication richness and quality, leading to lower productivity (Lowry et al., 2006). From the employer's perspective, issues include the cost and effort that are necessary to implement a program and the challenge of remote supervision. Nevertheless, this is not the main topic of the current study, but the main objective is to explore the effects of teleworking on traffic volume and air pollution, while its impact on other aspects of life can be considered for future research.

3. Material and Methods

3.1 Fixed effects

In this section we present the main methods employed in the analysis. The first regression is estimated using fixed effects and it is:

$$TV_{j,t} = \beta_0 + \beta_1 tel_{i,j,t} + \beta' z_{i,j,t} + \gamma W_{j,t} + \mu_i + M_j + \theta_t + M_j T + \varepsilon_{i,j,t} \tag{1}$$

TV denotes the monthly traffic volume in location (municipality zip code) *j* and in time *t*. The variable *tel* is a dummy variable taking value 1 whether the individual *i* is teleworker and 0 otherwise. Vector *z* includes personal and household characteristics, such as age, marital status, education level, the household size and house tenure. Vector *W* denotes the weather conditions. Set μ_i is the individual fixed effects, M_j is the location fixed effects and set θ_t is a time-specific vector of indicators for the month and the year that the interview took place. $M_j T$ is a set of area-specific time trends, which controls for unobservable, time-varying characteristics in the area. Finally, $\varepsilon_{i,j,t}$ expresses the error term which is assumed to be *iid*. Standard errors are clustered at the area-location level. Since the traffic volume is skewed, the logarithms are considered. The second model explores the relationship between teleworking and air pollution and is defined as:

$$e_{j,t} = \beta_0 + \beta_1 tel_{i,j,t} + \beta_{21} TV_{j,t} + \beta' z_{i,j,t} + \gamma W_{j,t} + \mu_i + M_j + \theta_t + M_j T + \varepsilon_{i,j,t} \tag{2}$$

Relation (2) is similar with (1) with the difference that the dependent variable is the air pollutant, while traffic volume (TV) becomes now an independent variable, since it can cause air pollution while the opposite is not implied. The dependent variable *e* denotes the air pollutant examined in location *j* and time *t*. As we mentioned earlier, since the data availability of the traffic volume is only based on monthly frequency, we convert the air pollutants and weather conditions into monthly frequency, by taking the their averages over this period. Using the fixed effects method, which is group dummies for municipalities, we can control for the average differences across municipalities in any observable or unobservable predictors. These differences include vanpooling, industrial activity, transportation infrastructure, and other observable and unobservable factors that may affect the main outcomes of interest- traffic volume and air pollution. Therefore, when we estimate the regressions with plain ordinary least squares (OLS), there is a great possibility that the

omitted variable bias would result, because unobservable factors can be correlated with the variables that are included in the regression. The fixed effect coefficients soak up all the across-group action and what is left is the within-group action, which is what is desirable and the threat of omitted variable bias is considerably reduced.

The main issue of the regression models discussed above is the unit level of analysis. More specifically, the main dependent variable of interest is the teleworking which is measured at individual level, while traffic and air quality are measured on regional level. One option is to use hierarchical models where the obervation units are nested in observation units of a higher level. Examples include students enrolled at schools, employees in sectors and other. In this case the dependent variable is measured at individual level, while the independent variables are based on a higher level, such as municipalities or regions. However, in regression models (2)-(3) the dependent variable is the traffic and air quality measured at municipality level, while teleworking and other independent variables are based on individual units. Therefore, hierarchical model are inapplicable. In this case we take the following steps. Regarding the continuous variables, such as age and household income, we calculate their average values on municipality level, while for the categorical variables we obtain the proportions, again on municipality level. Concluding, in models (1)-(2) we estimate fixed effects using a panel of municipalities and not individuals. Therefore, the set μ_i denoting the individual fixed effects will be removed.

Additionally, as robustness check, we apply the seemingly unrelated regression (SUR) system. The basic idea of employing a SUR system is that the individual relationships for the air pollutants may be linked and therefore, their disturbance term can be correlated. One important motivation of using SUR is to gain efficiency in estimation by combining information on different equations, since the air pollutants we explore, are inserted in different equations as outcomes and it is not possible to estimate them simultaneously otherwise, like using single econometric estimation. According to earlier studies we implement fixed effects models since we have location-municipality fixed effects and using the control variables that we explore in more details in the data section (Jones, 2009; Lavain, 2015; Giovanis and Ozdamar, 2016; Sinha and Bhattacharya, 2016, 2017).

3.2 Two Stage Least Squares (2SLS)

As we discussed in the previous section, fixed effects may reduce the endogeneity coming from possible omitted variables bias. However, the endogeneity derived from reverse causality is not

solved. More specifically, a plausible degree of reverse causality between traffic and teleworking, and between air pollution and teleworking may be present. Regarding the former relationship, we argue that teleworking may reduce traffic, since people decide to work at home some days of the week. However, the individuals may decide to choose the teleworking scheme if there are affected by traffic and congestion. Therefore, a causal effect from traffic to teleworking may exist. Similarly, the second aim of this study is to explore the effect of teleworking on air pollution. While teleworking may have a positive effect on air quality, the individuals may also be willing to choose the specific employment scheme if they are negatively affected by the air pollution, especially those who have health problems. For this reason, we propose the instrumental variable (IV) approach using two stage least squares (2SLS) method, to solve the endogeneity coming from a plausible degree of reverse causality between teleworking and the main outcomes of interest.

Three factors are used as instrumental variables for teleworking. The first is the job position which refers to whether the individual is on a management position, production position or training-supervising position. This variable can be correlated with the teleworking, since managers or supervisors, are older, more educated and more flexible to work at home some days of the week or month. In addition, we argue that the job position cannot have a direct effect on air pollution and traffic, but the effect can go only indirectly through teleworking. The second variable is whether the individual has a computer at home or not. This can be significantly correlated with the teleworking scheme, since technology, computing and internet is the major determinant of using this employment scheme. As we mentioned before, the possession of the computer at home cannot cause directly the traffic volume or the air pollution. The social class of the individual is the third variable used as an instrument. More specifically, the social-professional class refers to whether the individual belongs in one of the following categories: Legislators; senior officials; managers; professionals; technicians and associate professionals; clerical officers; service workers; market sales workers; skilled agricultural and fishery worker; craft and related trades workers; plant and machine operator assemblers; and elementary occupations. This variable can be correlated with teleworking, since managers, clerical officers and service workers for instance, are more likely to participate in the teleworking scheme than those who belong to plant and machine operator assemblers and the elementary occupations. More details on the variables employed in the analysis, and, the correlation amongst teleworking and the main outcomes of interest-air pollution and traffic-are described and discussed in the next section.

Our choice of instrumental variables is based on two sources. According to the data availability and the information on the survey we decided to use the specific variables as instruments for teleworking. The argument is that while income, education, household size and area

can be directly related to air pollution and traffic, these variables are not associated directly, but they may have an indirect effect only through teleworking. Similar with the approach followed by Choo et al. (2005) these factors may influence the decision or propensity to telework and then the fitted values are considered for the second stage regression. Second, we follow earlier studies about the selection of those instrumental variables. The studies by de Graaff and Rietveld (2004), Jiang (2008), Dettling (2013) and Rupietta and Beckmann (2016), employed the possession of computer, internet-modem and social class as instruments for teleworking. Their argument lies on the fact that the these factors should capture the exogenous teleworking opportunities for individuals, but should not affect the air quality and traffic.

3.3 Data

The data used in this study are derived from the Swiss Household Panel (SHP) Survey which has started in 1999 with slightly more than 5,000 households and consists of 15 waves in total, during the period 1999-2013. However due to the availability of the traffic volume data, we make use of 12 waves over the period 2002-2013. The survey interviews respondents older than 15 years, about the aspects of their lives, such as household conditions, household composition, residential mobility, education, health and usage of health services, employment, socio-economic values, income from employment, benefits and other sources, marriage, cohabitation, children and parenting, ageing, retirement, quality of life and well-being measures among others. The main objective of the SHP survey is to further understand the social and economic change at the individual and household level in Switzerland, to identify, model and forecast such changes, their causes and consequences in relation to a range of socio-economic variables.

We employ two dependent variables; the traffic volume and the air pollutants, while the main independent variable of interest is the teleworking. The relevant regressors are chosen based on the earlier literature (Koenig et al., 1996; Henderson and Mokhtarian, 1996; Mokhtarian et al., 2004), including demographic and household variables, such as household income, age, household size, job status, house tenure, marital status, education level, municipalities and community typology indicating whether the area is urban, sub-urban, peripheral sub-urban, rural, agricultural and industrial among others. The reasons of using these factors as possible determinants of air quality and traffic are various. Regarding the job status can be a significant confounder for traffic, air quality and teleworking. More specifically, it is possible that part-time employees are more likely to telework or work at home and therefore, to use less often transportation. In this way also the air

pollution is indirectly reduced. A similar explanation can be given for the education level and age, where the older, more educated and more experienced workers are more likely to telework. Income is an important factor, according to the environmental Kuznets curve (EKC) hypothesis, where the air quality is deteriorated up to a certain point and after this point is improved (Grossman and Krueger, 1991, 1995; Panayotou, 1997; Selden and Song, 2004; Vollebergh et al., 2009; Giovanis and Ozdamar, 2016; Sinha and Bhattacharya, 2016, 2017). Household size and marital status can be related to traffic, as larger households may make more use of transportation leading to higher levels of air pollution. The area characteristics can be important, since teleworking and traffic mainly depend on the distance between work and home location and the available transportation infrastructure, including roads and public transit.

Additionally, the regressions control for the day of the week, month of the year, the wave of the survey, and an area-specific trend to capture the effects of unobservable characteristics of the municipality that may be correlated with pollution, traffic and teleworking which may vary over time. Another set of significant factors for both traffic and air quality is the weather conditions, such as the minimum, maximum and average temperature, precipitation and wind speed. Earlier research studies show that weather conditions are significantly associated with the air pollution (Roberts, 2004; Tai et al., 2010, 2012; Barmpadimos et al., 2012; Lecoeur et al., 2012). In this study we examine the five most critical air pollutants; ground level ozone (O_3), sulphur dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO) and Particulate Matter of 10 micrometres or less in size (PM_{10}).

In a study by Salvador et al. (2007) it was found that the highest incidence of local anthropogenic emissions on PM levels is observed during the winter months. This incidence is mostly related to deep surface thermal inversions and low rainfall rates, which favour the accumulation of pollutants from local sources and mainly NO_X. Similarly Iorga et al. (2015) and other studies found a positive correlation among CO, SO_2, NO_X and PM (Chaloulakou et al., 2005; Vardoulakis et al., 2008) On the other hand, the correlation between PM and O_3 is negative indicating that lower O_3 concentrations being associated with higher particulates concentrations, and associated with increased NO_X, which leads to lower O_3 concentrations (Chaloulakou et al., 2005; Vardoulakis et al., 2008; Iorga et al., 2015). However, the correlation between air pollution and meteorological conditions is mixed. Iorga et al. (2015) found a positive correlation between both PM_{10} and $PM_{2.5}$ and temperature with higher coefficients appeared in the warm season, which is related with instable atmospheric conditions, such as atmospheric pressure or it may be due to a positive correlation with solar radiation, increased oxidation during summer months. On the contrary a negative correlation with temperature could be due to increased emissions from space

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heating combustion appliances. Regarding the association between wind speed, humidity and air pollution the earlier studies suggest a negative correlation. In humid days the pollutants may be lurked by fog and deposited onto surfaces or air pollution levels decrease as wind speed and atmospheric concoction increase leading to lower air pollution concentrations. This results to a cleaner atmosphere (Cusack, et al., 2012; Iorga et al., 2015). Earlier studies also found a positive correlation between traffic and air pollution (Vallius et al., 2003; Chaloulakou et al., 2005; Salvador et al., 2007; Koçak et al., 2007; Vardoulakis et al., 2008; Iorga et al., 2015). According to these studies, the positive correlation is due to the fact that traffic emissions contain as contain large loadings of typical vehicle exhaust products such as NOX, Lead (P_b), Zinc (Z_n) and nitrate (NO_3^-).

Overall, the choice of the pollutants is based on earlier studies exploring the various determinants of air pollution. Moreover, the air pollutants explored in this study are considered the most harmful for the public health and the environment, and can be affected also by anthropogenic sources. Therefore, their investigation can be very important if the target of policy makers and environmental agreements is the improvement on environment. The findings can provide valuable insights to the policy makers about decisions about anthropogenic actions that may influence and impact the environment. Furthermore, there is no detailed recording for other pollutants in every monitoring station and along the period examined, including P_b, Z_n and NO_3^-. For example the studies by Grossman and Krueger (1991, 1995), Panayotou (1997), Selden and Song (2004), Vollebergh et al. (2009), Giovanis and Ozdamar (2016), Sinha and Bhattacharya (2016, 2017), include income and population density as main factors of air pollution. Since our variables are based on individual and household level, household size is used as a proxy for the population density, as we have mapped the air pollution on municipality level. Furthermore, earlier studies support that more educated people are usually wealthier, better informed about the impact of air pollution and traffic on environment and have more potential for higher earnings, which the latter contributes positively in the air quality according to the evidence on the EKC hypothesis. Previous studies also explored the relationship between the air pollution levels and socio-economic characteristics, as we employ in this study. The study by Lavaine (2015) included socio-economic characteristics to explore the relationship between air pollution and mortality rates. In another study by Xing et al. (2017), it was found that income, education and household size are major drivers of energy transition in the residential sector and therefore have an impact on air pollution, while other studies found that female share in households has an impact on household energy choice in Bolivia, Guatemala and some Asian countries (Sathaye and Tyler ; Israel, 2002; Heltberg, 2005; Gupta and Kohlin, 2006). Based on the literature we presented so far we include in our regression estimates the most important socio-economic factors. As we mentioned earlier socio-

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economic characteristics can be considered as confounders and therefore it is important to include them into the regression models. Studies have shown that air pollutants in the area of residence and the socio-economic status of an individual can be associated, so when epidemiological, economic, environmental and other studies are conducted, the socio-economic factors should be accounted for, as they may act as confounding factors (Stroh et al., 2005).

The air pollutants are based on daily frequency and measured in micrograms per cubic meter (ug/m^3). The data were provided by the National Air Pollution Monitoring Network (NABEL) and the available values are the averages. In order to map and match the air pollution and traffic volume data with the individuals' municipality zip codes we follow the following steps: In the first step we obtain the exact location of air and traffic monitoring stations in latitude and longitude coordinates which are available in the Das Bundesamt für Umwelt (BAFU) website (bafu.admin.ch). Second, we take the centroids of municipalities provided by the Federal Office of Topography (www.swisstopo.admin.ch). Then, in the third step we convert the point data from the monitoring stations into data up to municipality level, employing the inverse distance weighting (IDW) which is one of the most popular GIS-based interpolation methods. In IDW, the weight of a sampled data point is inversely proportional to its distance from the estimated value. In other words, we calculate the centroid of each municipality and then we measure the distance between the monitors and the centre of each municipality using the Haversine distance formula. Then we apply the IDW method to map the air pollution and traffic volume (for more details on the IDW see Franke and Nielson, 1980). There are 459 traffic and 16 air pollution monitoring stations. The air pollution and traffic mapping is taken place within a radius of 10 km and for robustness checks a mapping within a radius of 5 km is obtained. Since the traffic volume is available only on monthly frequency, we convert the air pollutants and weather variables on monthly basis, by taking the monthly averages.

4. Results

4.1 Summary Statistics

In this section we present and discuss the main results. In table 1 we present the summary statistics for the main variables of interest. In addition, we report a sample of other characteristics, including the weather conditions, the household income and the age. We should notice that teleworking is a binary variable and not continuous; however the average value which is 0.0843 shows also the proportion of the sample that is involved in teleworking and this is 8.43 per cent. From table 1 we observe that the values among the air pollutants vary, since their nature is quite different. Regarding the traffic volume, the only available information provided is the total number

of vehicles. Therefore, information related to the type of vehicle, such as lorry, private car, bus or small vans is unavailable.

(Insert Table 1)

As we can see in table 2, the correlation among the four air pollutants is positive and significant, while their association with O_3 becomes negative. This is consistent with previous studies. One possible explanation for this association is the seasonal variations in the occurrence of those pollutants. More specifically, O_3 is mainly formed as a result of chemical reactions between nitrogen oxides (NO_X) and volcanic compounds (VOCs) in the presence of sunlight and under high temperature and high levels of solar radiation, which occur, especially during the hot months of spring and summer (Wennberg et al., 1998; Bauer and Langmann, 2002; Toro et al., 2006). O_3 is a colourless gas and it is one of the major components of the atmospheric smog. It causes irritation to the respiratory system and eyes, causing coughing and wheezing and chest tightness, especially amongst those with respiratory and heart problems. Furthermore, it is harmful to plants, as it reduces their growth and it affects the buildings (Harrison and Yin, 2000; Harrison, 2001). Similarly, CO is a colourless, but also poisonous and odourless gas and its largest sources come from vehicles, especially when they are moving slowly. The NO_2 is a reddish, brown gas that is poisonous in high concentrations and in urban areas mainly comes from exhaust emissions. It can increase the likelihood of respiratory problems and can reduce immunity to lung infections, causing problems such as wheezing, coughing, colds, flu and bronchitis (Harrison and Yin, 2000; Harrison¸2001). SO_2 is another major pollutant. The main source comes from the fuel burning process that contain sulphur, such as coal and oil, and it can cause breathing difficulties if inhaled into the body, and acid rain when it reacts with moisture in the air (Harrison and Yin, 2000; Harrison¸2001). Particulate matter comes from various sources, such as vehicle exhausts, industrial sites, unpaved roads, and construction sites and it can consist of hundreds of different chemicals, including carbon, sulphur and nitrogen compounds. Its adverse effects on health are well documented, including respiratory and cardiovascular morbidity, such as aggravation of asthma, respiratory symptoms and an increase in hospital admissions, and mortality from cardiovascular and respiratory diseases and lung cancer (Harrison and Yin, 2000; Harrison¸2001). While the weather conditions may also determine the levels of the remained air pollutants, pollution is also caused from other factors, mainly from traffic, power plants and industry and especially from fuel vehicles that include CO and NO_2. (Charron and Harrison, 2003; Toro et al., 2006). The positive correlation between CO and NO_2 can be explained due to the effect of CO which slowly burns nitrogen

monoxide (NO) to NO_2 (Vingarzan, 2004). Previous studies also found a positive relationship between CO, NO_2, PM_{10}, and SO_2 (Wang et al., 2002).

As it was expected, traffic is positively correlated with the air pollutants, while teleworking is negatively associated with traffic volume and air pollution. Traffic is also positively correlated with maximum temperature and wind speed and negatively associated with precipitation. Regarding minimum and average temperature, their association with traffic volume is insignificant. One explanation the majority of the cars includes air conditioners and this contributes to the people's decision to travel, irrelevant from the atmospheric temperatures. The negative association between traffic and precipitation may be due the fact that increases on rainfall and snow may cause reduction in traffic. Regarding teleworking its association with the weather conditions is insignificant, while its relationship with wind speed becomes positive and significant without a clear explanation. In addition, teleworking and household income are negatively associated at 10 per cent of significance level.

The relationship between household income and air pollutants is negative and significant; however, this correlation does not allow us to conclude anything about the actual association. More specifically, the Environmental Kuznets Curve (EKC) hypothesis, which has been influenced by Kuznets' study (1955), suggests that the relationship between income inequality and per-capita income is characterised by an inverted U-shaped curve. This suggests that as the income is increased, the income inequality initially is increased as well up to a certain point and thereafter pollution starts to decline. The majority of the studies exploited panel data based on country level and they found that the EKC hypothesis holds (Grossman and Krueger, 1991, 1995; Panayotou, 1997; Selden and Song, 2004; Vollebergh et al., 2009; Giovanis, 2013; Bölük and Mert, 2014; Giovanis and Ozdamar, 2016; Sinha, 2006; Sinha and Sudipta, 2016 Sinha and Bhattacharya, 2016, 2017). Thus, the correlation standalone is not enough to reveal the relationship between income and pollution, where a quadratic relationship between air pollution and income may be present. Nevertheless, this is not explored in details, since it is out of the current's study topic.

Age is positively correlated with teleworking indicating that the older employees are more likely to participate in teleworking schemes. This can be also explained by the fact that older employees are more experienced, more likely to be employed in high positions, as supervisors and managers and therefore more able and flexible to use teleworking schemes. On the other hand, the relationship between age and household income is negative, while it was expected to be positive for the reasons mentioned above. However, a different specification or an alternative functional form can be more appropriate, including quadratic terms of age, similar to the case of the EKC hypothesis discussed before. Finally, a negative association between age and air pollutants is

presented, except for O_3, which may imply that the older people pollute less. However, this is not the main point of this study, but it can be investigated in future research studies.

In all cases, the average temperature and the maximum temperature are positively associated with the air pollutants, while a negative and significant correlation between the air pollutants and minimum temperature and wind speed is observed. This is explained by the fact that extreme high temperature increases the air pollution levels (Roberts, 2004; Tai et al., 2010, 2012; Barmpadimos et al., 2012; Lecoeur et al., 2012). Similarly, the negative relationship between the air pollutants and precipitation, except for O_3, is owned to the fact that rainfall is able to absorb them in the air so they are washed out of the air and then they fall to the ground. However, this creates another issue, which is the shift of the pollution to the soil and water. Therefore, while on the one hand precipitation may wash out the pollution, on the other hand the air pollutants may increase rainfall and precipitation. In a study by Rosenfeld et al. (2008) pollution may increase or decrease precipitation depending on other environmental factors, indicating that the relationship is not still clear. Overall, a positive relation between maximum and average temperature and air pollution is documented in earlier studies, while a negative relationship between minimum temperature and wind speed is found (Roberts, 2004; Tai et al., 2010, 2012; Barmpadimos et al., 2012; Lecoeur et al., 2012; Zhou et al., 2014; Price et al., 2014).

(Insert Table 2)

4.2 Regression Estimates

Next we present and discuss the regression estimates. In table 3 we show the estimated fixed effects regressions using models (1) and (2). In the first column the dependent variable is the logarithm of the traffic volume, while in the remained columns the dependent variables are the logarithms of the main air pollutants explored. While the air pollution in levels could have been considered, the logarithms are taken in order to see the percentage change of traffic and air pollution due to teleworking, instead of a change on pollution levels. Moreover, since in table 1 we have shown that the levels between air pollutants vary significantly, the percentage change can be more proper. In addition, an alternative approach could be the consideration of standardised air pollutants.

According to the estimates in the first column of table 3, teleworking reduces the traffic volume on average by 1.9 per cent. Regarding the air pollutants, the largest change is observed for NO_2 at 3.6 per cent followed by CO at 3.4 per cent, PM_{10} at 3.3 per cent and then by O_3 and SO_2, ranging

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between 2.1-2.3 per cent. In addition, a 1 per cent increase of traffic leads to an increase of air pollution in the range of 3.2-4.3. The estimates are consistent with earlier findings, where the largest part of the pollution due to traffic is observed to NO_2, PM_{10} and CO, since these pollutants are linked more with the traffic and vehicle travelling (Henderson and Mokhtarian, 1996; Mokhtarian and Varma, 1998). The same holds for the relationship between teleworking and air pollution. In other words, since teleworking leads to traffic reduction, the largest drop is observed in the above mentioned air pollutants. Regarding the household income, the EKC hypothesis seems to hold, as there is a quadratic relationship between household income, air pollution and traffic. The exception is O_3 and CO, where the household income is significant only in linear terms and negative. This shows that as the income increases after a certain point, the air pollution and traffic are reduced. Nevertheless, this does not imply any causation, but rather may show that those who are richer, are more likely to be located in cleaner areas with less traffic congestion. The turning points are 24,350, 27,450 and 25,600 Swiss Francs respectively for SO_2, NO_2 and $PM_{10.}$

Age is negatively associated to traffic and air pollution, which may show that older people drive fewer miles. However, other explanations include alternative functional forms, such as a quadratic term on age, or the fact that older people are more inclined to opt teleworking, because they are more experienced, educated and may hold higher administrative, managerial and academic positions. Nevertheless, this is not explored in this study, but we suggest is as a topic for future research. A similar conclusion can be derived for the education, where the more educated people are more likely to drive less, adopt teleworking employment scheme than those with incomplete compulsory school. The association between household size and pollution is positive, indicating that large households use more often transportation; for instance driving the children to school and employed people in the household that may make more frequent use of car and transportation overall. Lastly, house tenure, is an insignificant factor of traffic and air pollution.

Regarding, the weather factors, a positive relationship between average, minimum, maximum temperature and traffic is observed. One explanation for this positive relationship is that high temperature may be related to clean weather, which increases the visibility and the ability of people to drive. In addition, high temperature is associated with better weather conditions and may increase the driving and journeys for leisure purposes where people are more likely to spend more time outdoors (Leard and Roth, 2015).

On the other hand, the negative relationship between precipitation and traffic can be explained due the fact that high levels of rainfall and snowfall may decrease the visibility, create problems in road infrastructure and thus may discourage people to drive or use transportation. Furthermore, people may prefer to use public transit to go to work, instead of private transportation reducing this

way the average traffic volume and congestion. This information is unavailable; however, the substitution effects of public and private transit due to weather conditions could be further explored. Hanbali and Kuemmel (1993) the traffic volume reductions up to 56 per cent may occur, depending on the adversity of the snow storm.

We show that the effect of wind speed on air pollution is significant and negative which can be attributed to two channels. First, as we mentioned in the first section, wind speed may clean the air by transferring the air pollutants to other areas. Second, as the wind speed reduces traffic, the air pollution is indirectly declined through traffic reduction. A similar interpretation, can also be given for the temperature, as decreases in temperature, which may be associated with cold weather, high wind speed or with high levels of rainfall, lead to traffic reduction and thus to air quality improvement. On the other hand, temperature, may increase pollution, especially, for O_3, since is formed under sunlight, associated with high levels of solar radiation and temperature (Brook et al., 1993; Tai et al., 2010; Han et al., 2011; Barmpadimos et al., 2012; Kim et al., 2014; Zhang et al., 2015). However, the coefficient of the average temperature was found significant and positive only in the case of CO and O_3.

However, as the previous studies explored the effects of weather on air pollution, including precipitation and temperature, other studies found that there might be a reverse causality where air pollution prevents snowfall, rainfall and therefore precipitation, because pollution particles may prevent cloud water form condensing into snowflakes and raindrops (Rosenfeld, 2000; Jirak and Cotton, 2006).

Overall, the relationship between weather conditions, traffic and air pollution is not trivial at all and it can be actually much more complicated, but this is not the main point of this study. However weather factors are employed as possible confounders for teleworking and the outcomes of interest. For instance, people who are located in more isolated areas, with rough and poor weather conditions, may choose to telework, which also affects traffic and air quality. Furthermore, there are also other weather conditions and factors that may affect traffic and air pollution, such as wind direction, but it is more desirable to consider variables as confounders that are associated with both the factor of interest-teleworking- and the outcomes explored. However, we should notice that wind direction could be relevant in our analysis in connection with long-range transport of air pollutants. Nevertheless, we suggest for future research applications.

(Insert Table 3)

The estimates in table 3 are based on the air pollution mapping within a radius of 10 km. In table 4 we show the same regressions (1)-(2) using 2SLS and instrumenting teleworking with the variables discussed in the previous section; whether the respondent has a computer at home, the respondent's job position and social-professional class. We observe that teleworking reduces the traffic by 2.7 per cent on average. The causal effect also on air pollution is higher than the one found in table 3 and it ranges between 2.6-4.1 per cent. According to the weak instrument test the null hypothesis is rejected. Furthermore, the null hypothesis of no endogeneity is accepted based on the Hansen statistic and its associated p-values. The remained estimated coefficients are not reported, since the concluding remarks are the same with those presented in table 3.

(Insert Table 4)

In table 5 we present the regressions for traffic and air pollution where the air pollution mapping is based on a radius of 5 km and therefore, the number of observations is smaller. The estimates are consistent with those found in tables 3-4, where the largest effects are observed for NO_2, CO and PM_{10}, followed by O_3 and SO_2. We also observe that the impact is higher, since the radius is shorter and closer to air monitoring stations. Furthermore, according to weak instrument and Hansen endogeneity tests, the instrumental variables employed in the analysis are proper. In table 6 we illustrate the SUR system estimates using the air pollution mapping within 10 km radius, confirming the estimates found in table 3. However, SUR does not account for the endogeneity issue, and our favourable estimates are those derived by the 2SLS, as there is a possible degree of reverse causality between teleworking and the main outcomes of interest-traffic and air pollution.

(Insert Tables 5-6)

5.   Conclusions and policy recommendations

This study explored the impact of teleworking on air pollution and traffic volume using a detailed micro-level panel dataset, the Swiss Household Panel (SHP) Survey, over the period 2002-2013. The findings support the beneficial effects of teleworking, as its implementation leads to traffic and air pollution reduction. Therefore, there are various policy implications derived from

teleworking, not only to air quality and traffic, but also to other factors, which can be examined in future research studies and applications.

There are four limitations and gaps in earlier studies that this paper attempted to cover. First, the majority of the studies used cross-sectional data and not longitudinal, and therefore the same individual is not followed across time. This limitation does not allow us for the investigation of the individual's propensity to telework and the travelling behaviour and thus the impact of teleworking on air quality. This study uses a panel data analysis that allows to include the individual's history into a fixed effects model and to account for omitted variables bias. The second limitation is that earlier studies explored either the relationship between traffic and teleworking or the impact of teleworking on air quality, without considering both associations into a panel data framework. The interrelationship among teleworking, traffic and air pollution into a longitudinal framework analysis allows the dynamic exploration of the teleworking impact on traffic and air quality. Third, while previous studies made use of IV approaches, the analysis is limited to the impact of teleworking on other outcomes, including well-being, job satisfaction, productivity and employee loyalty among others. So far there is no study using IV approaches to solve for the possible reverse causality between teleworking, air pollution and traffic. Fourth, the air pollution mapping methodology is not applied and the reduction on air pollution and greenhouse gas emissions is developed theoretically, according to the traffic and miles travelled reduction. On the contrary, in this study we use air pollution data in a rather high disaggregated area level and we employ real historical air pollution data. However, the disaggregation level is jot precise if we could implement the air quality mapping at post code level of the respondent's residence. Therefore, we suggest the consideration of higher disaggregation level of the air quality for future research applications that will lead to even more robust and precise estimates. The main concluding remark is that teleworking has a positive impact on air quality, even this effect is low, in a European country, which is Switzerland. The results may significantly vary according to the country, the cultural factors, socio-economic characteristics, and other regional factors of the place explored. Thus, teleworking is suggested as one of the measures for urban planning and development and air quality improvement.

Overall, by implementing teleworking, the number of people driving alone is decreased, which is a key for traffic and air pollution reduction, and a factor that reduces fuel consumption. In this case teleworking can be a viable short- and long-term solution to emissions, fuel consumption and traffic congestion reduction, especially in the urban areas and an important tool for the quality of life improvement. Other solutions include road and mass public transit improvements, which require large financial investments, long and extended periods of time in order to be constructed and often are bogged down by political and financial interests (as it was the case of the London Congestion

Zone before its implementation and congestion zones in other cities that did not take place). Compared to these solutions, teleworking can be an effective solution for traffic reduction and air quality improvement, which can be implemented immediately and at a fraction of the cost with short- and long-term benefits for the society. The distance travelled for business can be also lower through the increased use of teleconferencing and video conferencing, which are parts of the teleworking. In addition, the reduction of traffic and air pollution can have positive effects on environment and public health. Moreover, air quality improvement reduces the hospital admissions and the related inpatient and outpatient costs, through the improvement of health status.

Furthermore, future studies can explore the possible benefits of teleworking on employers and employees. For instance, firms and business may gain significant profits, as teleworking can be a way of cutting costs and at the same time it can be a way to increase employee's productivity and loyalty and consequently firm's performance. Employing more people at home, employers can afford to lease or purchase smaller, less expensive facilities, pay less for energy and electricity and purchase fewer supplies. From the employee's side the plausible effects of teleworking include the work-life balance and it may allow them to cope with the family obligations and household production, such as household chores and childcare. Even though this study explored the effects of teleworking on traffic and air pollution, future research studies can explore its possible additional effects on employees, employers and the society overall, as the environment and public health, hospital admissions, productivity, and well-being.

Acknowledgements

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Table 1. Summary Statistics

	Average	Standard deviation	Minimum	Maximum
Teleworking	0.0843	0.2267	0	1
Ground Level ozone (O_3)	62.077	29.668	1.43	199.85
Sulphur Dioxide (SO_2)	1.599	2.703	0.01	24.58
Nitrogen Dioxide (NO_2)	26.067	17.113	0.01	91.59
Carbon Monoxide (CO)	262.713	325.310	0.1	1,951.67
Particulate Matter (PM_{10})	18.593	14.336	0.4	110
Traffic Volume	38,825.72	28,723.47	100	147,614
Average Temperature	7.81	11.10	-10.3	23.8
Minimum Temperature	4.46	11.30	-26.7	20.6
Maximum Temperature	11.55	13.78	15.22	32
Precipitation	6.09	1.52	0	13.71
Wind Speed	0.25	0.26	0	2.119
Household Income	113,066.8	98,870.85	0	6,185,400
Age	46.785	17.724	16	96

The air pollutants are measured in micrograms per cubic meter (ug/m^3), the temperature is measured in Celcius.
Wind speed is measured in meters per second. Precipitation is measured in centimeters (cm). Household income is expressed in Franc (₣).

Table 2. Correlation Matrix

	Teleworking	CO	SO_2	O_3	NO_2	PM_{10}	Traffic Volume	Age	Income	Temp	Wind Speed	Max Temp	Min Temp
CO	-0.0016 (0.2549)												
SO_2	-0.0107*** (0.0000)	0.1623*** (0.0000)											
O_3	-0.0126* (0.0495)	-0.4242*** (0.0000)	-0.1778*** (0.0000)										
NO_2	-0.0450*** (0.000)	0.6281*** (0.0000)	0.3717*** (0.0000)	-0.4962*** (0.0000)									
PM_{10}	-0.0414*** (0.0000)	0.5655*** (0.0000)	0.3550*** (0.0000)	-0.4156*** (0.0000)	0.7346*** (0.0000)								
Traffic Volume	-0.0175** (0.0136)	0.0947*** (0.0000)	0.1234*** (0.0000)	0.0851*** (0.0000)	0.0975*** (0.0000)	0.0732*** (0.0000)							
Age	0.0310** (0.0369)	-0.0149*** (0.0000)	-0.0437*** (0.0000)	0.0744*** (0.0000)	-0.0165*** (0.0001)	-0.0205*** (0.0001)	0.0102*** (0.0053)						
Household Income	-0.0269* (0.0822)	-0.0111*** (0.0000)	-0.0098*** (0.0000)	-0.0229*** (0.0000)	-0.0214*** (0.0000)	-0.0107** (0.0345)	-0.0069* (0.0916)	-0.0971*** (0.0000)					
Temperature	0.0588*** (0.0083)	0.1446*** (0.0000)	0.0430*** (0.0000)	0.3292*** (0.0000)	0.0954*** (0.0000)	0.0655*** (0.0000)	0.0451 (0.9878)	0.1360*** (0.0000)	0.0103*** (0.0043)				
Wind Speed	0.0086** (0.0347)	-0.1624*** (0.0000)	-0.1339*** (0.0000)	-0.1075*** (0.0000)	-0.0286*** (0.0000)	-0.0196*** (0.0000)	0.0296*** (0.0000)	-0.0297*** (0.0000)	-0.0023 (0.5234)	-0.3198*** (0.0000)			
Maximum Temperature	0.0303* (0.0767)	0.1588*** (0.0000)	0.0386*** (0.0000)	0.3377*** (0.0000)	0.1051*** (0.0000)	0.0700*** (0.0000)	0.0073* (0.0688)	0.1350*** (0.0000)	-0.0119*** (0.0010)	0.9717*** (0.0000)	-0.3422*** (0.0000)		
Minimum Temperature	-0.0019 (0.6386)	0.1456*** (0.0000)	0.0328*** (0.0000)	0.3013*** (0.0000)	0.0857*** (0.0000)	0.0555*** (0.0000)	0.0052 (0.2123)	0.1300*** (0.0000)	-0.0077** (0.0337)	-0.9642*** (0.0000)	-0.2905*** (0.0000)	-0.8947*** (0.0000)	
Precipitation	-0.0062 (0.1393)	-0.0305*** (0.0000)	-0.0697*** (0.0000)	0.0795*** (0.0000)	-0.0459*** (0.0000)	-0.0650*** (0.0000)	-0.0135*** (0.0016)	0.0312*** (0.0000)	-0.0114*** (0.0021)	0.0485*** (0.0000)	0.1188*** (0.0000)	-0.0009 (0.7908)	0.0994*** (0.0000)

p-values within brackets, ***, ** and * indicate significant at 1%, 5% and 10% level

Table 3. Fixed Effects for Traffic and Air Pollution

	DV: Log of Traffic Volume	DV: Log of O_3	DV: Log of SO_2	DV: Log of NO_2	DV: Log of CO	DV: Log of PM_{10}
Log of Traffic Volume		0.0360*** (0.0079)	0.0312*** (0.0019)	0.0434** (0.0205)	0.0419** (0.0204)	0.0389*** (0.0046)
Teleworker	-0.0188** (0.0074)	-0.0232** (0.0105)	-0.0213* (0.0109)	-0.0363** (0.0172)	-0.0345* (0.0194)	-0.0329** (0.0135)
Log of Household Income	0.3643* (0.1961)	-0.1595** (0.0731)	0.3677** (0.0754)	1.151* (0.0628)	-0.3155** (0.1449)	0.3941** (0.1733)
Log of Household Income Square	-0.0166* (0.0088)	0.0180 (0.0133)	-0.0182** (0.0085)	-0.0563* (0.0289)	-0.0205 (0.0745)	-0.0194** (0.0083)
Age	-0.0194*** (0.0043)	0.00094 (0.0042)	-0.1040*** (0.0130)	-0.0347*** (0.0095)	-0.0871*** (0.0126)	-0.0344*** (0.0087)
Employment (Part Time)	-0.0031*** (0.0009)	0.0018 (0.0027)	-0.1052 (0.1601)	-0.0340** (0.0151)	-0.0237** (0.0106)	-0.0071 (0.0078)
Education (reference= incomplete compulsory school)						
Education- compulsory	-0.0104*** (0.0031)	-0.0073** (0.0031)	-0.0042** (0.0016)	-0.0114 (0.0095)	-0.0134 (0.0087)	-0.0082 (0.0074)
Education- vocational school	-0.0078* (0.0041)	-0.0099* (0.0052)	-0.0667 (0.0551)	-0.0128 (0.0135)	-0.0053** (0.0026)	-0.0057 (0.0046)
Education- high school	-0.0069*** (0.0011)	-0.0023*** (0.0006)	-0.0044*** (0.0014)	-0.0041* (0.0021)	-0.0054*** (0.0018)	-0.0062** (0.0028)
Education- University and higher)	-0.0030*** (0.0006)	-0.0021*** (0.0009)	-0.0052*** (0.0018)	0.0058* (0.0030)	-0.0087* (0.0046)	-0.0036** (0.0016)
Marital Status (reference=single)						
Marital Status-Married	0.0116** (0.0053)	0.0041 (0.0032)	0.0148*** (0.0043)	0.0154* (0.0081)	0.0419*** (0.0156)	0.0144 (0.0112)
Marital Status- Divorced	0.0004 (0.0018)	-0.0255 (0.0554)	0.0054 (0.0066)	-0.0067 (0.0054)	-0.0176* (0.0105)	-0.0102* (0.0056)
Marital Status- Widowed	-0.0118*** (0.0017)	-0.0020* (0.0011)	-0.0094* (0.0053)	-0.0116* (0.0061)	-0.0082* (0.0049)	-0.0143*** (0.0032)
Household Size	0.0217** (0.0089)	0.0016* (0.0009)	0.0307** (0.0125)	0.0308* (0.0179)	0.0141 (0.0215)	0.0186** (0.0087)
House Tenure (reference =tenant)						
House Tenure-owner	0.0017 (0.0042)	0.0052 (0.0042)	-0.0129 (0.0084)	-0.0458 (0.0372)	0.0055 (0.0108)	0.0116 (0.0089)
Average Temperature	0.0360*** (0.0036)	0.0055*** (0.0013)	0.0031 (0.0040)	0.0021 (0.0086)	0.0625*** (0.0068)	0.0049 (0.0057)
Minimum Temperature	0.0242*** (0.0019)	0.0027 (0.0074)	0.0045** (0.0022)	0.0089* (0.0054)	0.0389*** (0.0039)	0.0077** (0.0029)
Maximum Temperature	0.0096*** (0.0019)	0.0090*** (0.0007)	0.0114*** (0.0023)	0.0066 (0.0182)	0.0391*** (0.0035)	0.0070** (0.0032)
Wind Speed	-0.0072*** (0.0006)	-0.0042*** (0.0004)	-0.0056** (0.0024)	-0.0199*** (0.0052)	-0.0146*** (0.0022)	-0.0041** (0.0019)
Precipitation	-0.0743** (0.0188)	0.1340*** (0.0109)	-0.1662*** (0.0309)	-0.1158 (0.0796)	-0.1838*** (0.0402)	-0.1022*** (0.0393)
No. observations	9,776	7,504	6,712	7,681	6,748	7,235
R Square	0.1472	0.1775	0.1812	0.1829	0.1874	0.1593

Robust standard errors within brackets, ***, ** and * indicate significant at 1%, 5% and 10% level

Table 4. Two Stage Least Squares (2SLS) Fixed Effects for Traffic and Air Pollution

	DV: Log of Traffic Volume	DV: Log of O_3	DV: Log of SO_2	DV: Log of NO_2	DV: Log of CO	DV: Log of PM_{10}
Log of Traffic Volume		0.0372*** (0.0074)	0.0337** (0.0157)	0.0469*** (0.0102)	0.0444*** (0.0108)	0.0404** (0.0187)
Teleworker	-0.0270** (0.0132)	-0.0277* (0.0143)	-0.0258** (0.0116)	-0.0407** (0.0188)	-0.0377** (0.0174)	-0.0358** (0.0166)
Hansen Statistic for endogeneity	6.195 [0.8600]	8.576 [0.6610]	12.694 [0.3138]	9.589 [0.5989]	17.251 [0.1007]	13.493 [0.2623]
Weak instrument test	34.386 [0.0000]	32.290 [0.0000]	29.775 [0.0000]	35.577 [0.0000]	31.093 [0.0000]	32.479 [0.0000]
No. observations	9,236	7,186	6,326	7,298	6,369	6,889
R Square	0.1088	0.1659	0.1699	0.1535	0.1645	0.1267

Robust standard errors within brackets, p-values within square brackets, ***, ** and * indicate significant at 1%, 5% and 10% level

Table 5. Fixed Effects and 2SLS for Air Pollution within 5 km Radius

	DV: Log of O_3	DV: Log of SO_2	DV: Log of NO_2	DV: Log of CO	DV: Log of PM_{10}
Panel A: Fixed Effects					
Log of Traffic Volume	0.0388*** (0.0021)	0.0351*** (0.0064)	0.0447** (0.0209)	0.0452*** (0.0067)	0.0413*** (0.0039)
Teleworker	-0.0279* (0.0146)	-0.0236** (0.0114)	-0.0401** (0.0182)	-0.0383** (0.0169)	-0.0374** (0.0177)
No. observations	7,254	6,545	7,569	6,589	7,157
R Square	0.1412	0.1504	0.1683	0.1284	0.1814
Panel B: 2SLS					
Log of Traffic Volume	0.0397** (0.0182)	0.0371** (0.0167)	0.0466*** (0.0142)	0.0473** (0.0226)	0.0442** (0.0215)
Teleworker	-0.0291** (0.0142)	-0.0283* (0.0154)	-0.0442*** (0.0075)	-0.0405* (0.0221)	-0.0385** (0.0135)
Sargan Statistic for endogeneity	7.378 [0.7832]	8.341 [0.6825]	2.685 [0.9879]	5.713 [0.8918]	3.059 [0.9719]
Weak instrument test	28.896 [0.0000]	27.283 [0.0000]	29.051 [0.0000]	30.258 [0.0000]	29.843 [0.0000]
No. observations	6,955	6,112	7,082	6,153	6,677
R Square	0.2540	0.2368	0.2208	0.2418	0.1526

Robust standard errors within brackets, p-values within square brackets, ***, ** and * indicate significant at 1%, 5% and 10% level

Table 6. Seemingly Unrelated Regression (SUR) System Random Effects within a radius of 10 km

	DV: Log of O_3	DV: Log of SO_2	DV: Log of NO_2	DV: Log of CO	DV: Log of PM_{10}
Log of Traffic Volume	0.0353** (0.0118)	0.0310* (0.0164)	0.0425** (0.0185)	0.0406* (0.0209)	0.0392* (0.0198)
Teleworker	-0.0203* (0.0103)	-0.0240** (0.0115)	-0.0344** (0.0145)	-0.0324* (0.0170)	-0.0314* (0.0161)
No. observations	6,575				
R Square	0.3982	0.4569	0.3472	0.4038	0.3555

Robust standard errors within brackets, ** and * indicate significant at 5% and 10% level