Working from home: Forecasting 2050

Antonin Danalet, Matthias Balmer, Andreas Justen, Nicole A. Mathys

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Abstract

This paper presents a discrete choice model for working from home. The model is jointly estimated on data from Switzerland collected in 2015 and 2020 and is internally validated. It is also externally validated using a synthetic population of Switzerland for 2017. In particular, the alternative specific constant is calibrated so that the observed market shares of working from home are reproduced using the synthetic population of 2017. The calibrated model is then applied to a projected synthetic population for 2030, 2040 and 2050, forecasting work from home for these years in Switzerland.

Introduction

Telecommuting imposes lower costs to the users and takes a shorter time to be implemented as other congestion and pollution mitigation strategies, such as switching to alternative fuel vehicles, promoting public transport and shared mobility services (car-sharing, ride-sourcing, and bike-sharing) or implementing a congestion pricing [Shabanpour et al., 2018, Kim, 2017, Zhu and Mason, 2014, Choo et al., 2005]. In particular, it directly impacts peak period traffic [Paleti, 2016]. However, working from home might induce other trips e.g. for leisure (rebound effect, see e.g., Ravalet and Rérat [2019], Shabanpour et al. [2018], Zhu and Mason [2014], Koenig et al. [1996], Nilles [1991]) and increase the distance traveled [Chakrabarti, 2018] (but maybe not, see Andreev et al. [2010]).

In this paper, we focus on home-based telecommuting. Working from home is not the only way of telecommuting: one might work from other people's home, from cafés and librairies or from vehicles [Stiles and Smart, 2020].

Our goal is to forecast who will work from home among the Swiss resident population in 2050. For this, we estimate a choice model using the data of the Swiss travel survey, the Mobility and Transport

Microcensus (MTMC), that took place in 2015 and (partially) in 2020. These are revealed data on the actual behaviour at a national level. Then, we validate this model internally. We also validate the choice model externally by applying it to a synthetic population of 2017 calibrated on retrospective data [Bodenmann et al., 2019]. Finally, we apply the model to a forecasted synthetic population of 2050 in order to predict the proportion of the population doing home office.

Such results are important for the prediction of the number of trips to work. More generally, a synthetic population 2050 containing the probability for each individual to work from home and its impact on the number of trips to work and for other purposes allows us to develop better transport models, such as the Swiss national passenger transport model [Justen et al., 2020, `www.are.admin.ch/npvm`] and transport forecast, such as the Transport Outlook 2050 (`www.are.admin.ch/transport-outlook`). Hence the results make it possible to test the impact of teleworking in the future on the Swiss transport system. This in turns allows to guide transport policy and focus infrastructure investments.

Chapter 1 presents a review of the literature on data, models, influencing factors, forecasting and impact on transport demand and location choice. In chapter 2, we then present the data used in this article: the Mobility and Transport Microcensus and Synthetic Populations for 2017, 2030, 2040 and 2050. The model is presented in chapter 3, including a description of the model attributes and specification, the estimation results using the data of 2015, the internal validation, the test of the temporal stability of the model and a joint estimation of the model using both the data of 2015 and 2020. Then, an external validation using a synthetic population is presented in chapter 4. Finally, the forecasts for 2030, 2040 and 2050 are presented in chapter 5, followed by a discussion of the limitation of the model (chapter 6), possible future work (chapter 7) and a conclusion (chapter 8).

1 Literature review

The link between teleworking and trip generation [Drucker and Khattak, 2000] or activity-based modelling [Shabanpour et al., 2018] is mentioned in several papers.

1.1 Data

According to Asgari and Jin [2015], there was a shift in the literature in the mid-1990s from stated preference data [Sullivan et al., 1993, Bernardino et al., 1993, Yen and Mahmassani, 1997, Yen, 2000] to revealed preference data [Olszewski and Mokhtarian, 1994, Manner-

ing and Mokhtarian, 1995, Mokhtarian and Salomon, 1997, Drucker and Khattak, 2000, Pouri and Bhat, 2003] on telecommuting. Asgari and Jin [2015] define two types of surveys: "small organization-specific surveys and large data sets at national or statewide level". Small organisation-specific surveys are often related to a telecommuting program [Kitamura et al., 1990, Mannering and Mokhtarian, 1995]. The Mobility and Transport Microcensus [Federal Statistical Office / Federal Office for Spatial Development, 2017] is the largest national survey about travel behaviour in Switzerland, running every five years since 1974. In it, questions about telecommuting have been asked in 2005, 2010, 2015 and briefly in 2020, and are currently being asked in 2021. In other European countries, questions about telecommuting are present in national travel surveys in England's "National Travel Survey" (with frequency in the week, month or year) and in the Danish national travel survey (on full-day telecommuting only) [Crawford, 2021]. In the Netherlands, there are no questions related to telecommuting in the national travel survey, but there is one in a mobility panel; in Germany's "Mobilität in Deutschland" and in Norway, there is a question to people travelling less than what should correspond to their work percentage, asking about the reason, which can be working from home. Ireland does not ask about telecommuting [Crawford, 2021].

The questions can ask about the preferences to telecommute, actual telecommuting (behaviour on a particular day), the frequency of telecommuting [Mannering and Mokhtarian, 1995, Drucker and Khattak, 2000] or a combination of these [Mokhtarian and Salomon, 1996b, Pouri and Bhat, 2003]. Asgari and Jin [2015] suggest to ask about the choice of telecommuting on a specific, random day, and about work-related trips that might be done on this specific day even if the person telecommutes. Similarly, Deng et al. [2015] suggest decomposing home-based teleworking in three categories: full-day (resulting in the elimination of trips), part-day (resulting in shifts in commuting time), and overtime telecommuting - defined as working from home, e.g., in the evening, while still commuting on peak hours (resulting in no change in commuting behavior). Time use surveys show that working from home is the most common non-office work location, but people also work from third places, which might be dedicated (co-working spaces) or not (cafés, librairies, ...), or could do "itinerant telework" (working from their car or in the train) [Thomsin, 2002, Ravalet and Rérat, 2019, Stiles and Smart, 2020].

1.2 Models

Logit models [Sullivan et al., 1993, Bernardino et al., 1993, Mannering and Mokhtarian, 1995, Drucker and Khattak, 2000, Walls et al., 2007],

ordinal probit models [Yen and Mahmassani, 1997, Yen, 2000, Drucker and Khattak, 2000, Shabanpour et al., 2018], binary probit models [Mokhtarian and Salomon, 1996a,b], orderd logit [Drucker and Khattak, 2000], Generalized Extreme Value models [Paleti, 2016] and count models [Singh et al., 2013] were used to analyse commuting behaviour.

The unit of observation are mostly individual employees, but also sometimes the dual-earner household [Paleti and Vukovic, 2017] or of the employer [Yen and Mahmassani, 1997]. Pouri and Bhat [2003] jointly model the adoption and frequency of home-based telecommuting, while Asgari et al. [2014] sequentially model telecommuting choice, frequency and daily engagement.

Constraints were incorporated into the utility function or used to define the choice set (see below, Section "Influencing factors"). Models incorporating constraints in the utility function appear to be superior according to Mokhtarian and Salomon [1996b].

1.3 Influencing factors

Mokhtarian and Salomon [1994] define two types of influencing factors: constraints/facilitators ("external factors related to awareness, the organisation, and the job, and internal psychosocial factors") and drives ("work, family, leisure, ideology, and travel"). Among the observed constraints, Mokhtarian and Salomon [1996a] cite lack of awareness, job unsuitability and manager disapproval.

The influencing factors mentioned in the literature are presented in Table 1. These factors influence telecommuting participation, telecommuting frequency or both (see e.g., Paleti [2016]).

1.4 Forecasts & impact on transport demand and location choice

Forecasts of telecommuting rates The need for "analysing factors affecting the individual choice to telecommute" and integrating telecommuting into transport models has long been recognised [Handy and Mokhtarian, 1996]. The rate of employees working from home is nowadays sometime an input for transport models. This rate is usually defined in input scenarios (e.g., 25% or 50% of employees work from home) [Shabanpour et al., 2018].

Impact on transport demand and location choice For a given individual living in a given place, full-day telecommuting directly decreases the number of trips to work, while part-day telecommuting might decrease the number of trips to work during peak hours.

Overall, when taking into account all trips, including, e.g., leisure trips, the net effect of telecommuting on the number of trips is unclear. According to Mokhtarian [2008], short-term studies show substitution

Table 1: Influencing factors mentioned in the literature

Influencing factors	**References**
Presence of small children in the household	Mannering and Mokhtarian [1995], Drucker and Khattak [2000]
Number of people in the household	Mannering and Mokhtarian [1995], Shabanpour et al. [2018]
Gender of respondent	Mannering and Mokhtarian [1995], Drucker and Khattak [2000], Singh et al. [2013], Paleti and Vukovic [2017], Shabanpour et al. [2018]
Number of vehicles in the household	Mannering and Mokhtarian [1995], Paleti [2016], Paleti and Vukovic [2017], Shabanpour et al. [2018]
Access to vehicles	Shabanpour et al. [2018]
Being a driver	Drucker and Khattak [2000]
Whether the respondent recently changed departure time for personal reasons	Mannering and Mokhtarian [1995]
Flexibility of work schedule	Mannering and Mokhtarian [1995], Sener and Bhat [2011], Paleti [2016], Shabanpour et al. [2018]
Being a manager	Mannering and Mokhtarian [1995], Shabanpour et al. [2018]
Ability to borrow a computer from work if necessary	Mannering and Mokhtarian [1995]
Family orientation	Mannering and Mokhtarian [1995]
Price of telecommuting (small living space, costs incurred by employees)	Yen [2000]
Income	Yen [2000], Peters et al. [2004], Paleti [2016], Shabanpour et al. [2018]
Locational and accessibility variables	Drucker and Khattak [2000]
Educational attainment	Drucker and Khattak [2000], Peters et al. [2004], Paleti and Vukovic [2017], Shabanpour et al. [2018]
Lack of free parking	Drucker and Khattak [2000]
Occupation type (e.g. health care, social assistance services, manufacturing, construction maintenance, communication industry, government employees, agriculture, clerical and administrative)	Walls et al. [2007], Zhou et al. [2009], Moeckel [2017], Paleti and Vukovic [2017], Shabanpour et al. [2018]
Home-work distance	Mokhtarian and Meenakshisundaram [2002], Paleti [2016], Shabanpour et al. [2018]
Home-work travel time	Shabanpour et al. [2018]
Population and employment density	Shabanpour et al. [2018]
Immigration status	Paleti [2016], Paleti and Vukovic [2017]

effects (i.e., less trips when telecommuting), but analyses taking into account long-term and indirect effects show complementary effects (i.e., more trips when telecommuting). The author foresees a faster growth of telecommunications-based interactions than in travel. According to Hu and He [2016], telecommuting is associated with longer total daily trip duration on the days that telecommuters go to their workplaces. Working only from home is associated with a reduction in overall travel time according to Lachapelle et al. [2018]. Working a full day from home decreases daily travel duration, while working only part time from home and going to the office on the same day but later does not [Stiles and Smart, 2020]. Using the Mobility and Transport Microcensus (MTMC), the same dataset as we do in this paper, Ravalet and Rérat [2019] show that people telecommuting are making more trips for other purposes, hence a rebound effect takes place. These non-work trips are shorter.

If in the short term, telecommuting decreases the number of trips to work and might decrease the overall daily travel distance, in the long term, telecommuting might decrease the propensity for residential relocation and increase tolerance for long distance commuting [Ravalet and Rérat, 2019]. Hu and He [2016] shows that less-frequent telecommuters (and their households) tend to undertake longer distances to work than frequent telecommuters and non-telecommuters. In Switzerland, teleworkers live further away from the workplace than their colleagues [Ravalet and Rérat, 2019].

2 Data

In this section, we present the three main data sources used in this paper: the Mobility and Transport Microcensus 2010, 2015 and 2020 (chapter 2.1) and synthetic populations of Switzerland calibrated to real data for 2017 (chapter 2.2) and projections for 2030, 2040 and 2050 (chapter 2.3).

2.1 Mobility and Transport Microcensus

For the estimation of the model, we use the data of the Mobility and Transport Microcensus (MTMC) [Federal Statistical Office / Federal Office for Spatial Development, 2017]. The MTMC (`https://www.are.admin.ch/mtmc`) is the Swiss national travel survey. It is conducted every five years. Data were collected in 2010, in 2015, at the beginning of 2020, and in 2021. A full year of data collection was originally planned in 2020. It was interrupted and postponed due to the coronavirus pandemic. In 2015, 57'090 persons were interviewed by telephone (CATI) about their travel behaviour (from 57'090 different

households). In 2020, because of the interruption due to the pandemic, 6903 interviews took place between January 12th and March 7th. Data of 2021 will first be available for researchers in 2023 and are therefore not available for the present paper. The Mobility and Transport Microcensus contains information about the socioeconomic characteristics of households and individuals, mobility resources (vehicles and public transport season tickets), daily mobility (trips on a given reference day), occasional journeys (day trips and trips with overnight stays) and attitudes towards transport policy in Switzerland.

On top of the questions asked to the full sample, four groups of questions are asked only to a portion of the sample. 30% of randomly selected respondents who were working in the week preceding the interview[1] were asked about working from home, in particular "Can you do some of your work at home?"[2] and "What percentage of your professional activity do you carry out at home?"[3].

2.2 Synthetic Population 2017

A synthetic population calibrated to retrospective data for the reference year 2017 was developed as an input into the transport models of the Swiss government [Vrtic et al., 2020] and the Swiss Federal Railways [Bodenmann et al., 2019]. It contains a georeferenced dataset of the full Swiss resident population grouped in households. The demographic and socio-economic attributes include among other age, sex, education level, nationality, income, mobility tools - such as car availability and possession of public transport season tickets, work location and business sector. The 10 business sectors are an aggregation of the General Classification of Economic Activities (NOGA 2008) defined by the Swiss Federal Statistical Office (FSO).

The synthetic population is based on the Population and Households Statistics (STATPOP) and the Structural Business Statistics (STATENT) of the Swiss Federal Statistical Office (FSO, `https://www.bfs.admin.ch/`). These register data contain the geocoordinates of households and businesses, the age and sex of individuals, the size of the household and the number of employees of businesses. Additional attributes are added by simulating and calibrating an agent-based land

[1] Note that people in apprenticeship were not asked the question on home-based telecommuting in the MTMC.

[2] "Pouvez-vous effectuer une partie de votre travail à la maison ?" in French; "Dürfen oder können Sie einen Teil von Ihrer Arbeit zuhause erledigen?" in German. See the full questionnaire: `https://www.bfs.admin.ch/bfs/de/home/statistiken/mobilitaet-verkehr/erhebungen/mzmv.assetdetail.5606052.html`.

[3] "Quel pourcentage de votre activité professionnelle effectuez-vous à domicile ?" in French; "Wie viele Stellenprozente pro Woche schaffen Sie zuhause für Ihren Beruf" in German. See the full questionnaire.

use model, "Facility Location Choice Simulation" (FaLC), reproducing available aggregate data on language, education level, work percentage, business sectors, position in the company, assignment of employed individuals to businesses, training status (pupils or students), income of individuals and households, mobility resources (car and public transport season tickets, also sometimes referred to as "mobility tools"), and owning or renting the place of living.

2.3 Synthetic Population 2030, 2040 and 2050

Using the official population scenarios for Switzerland and Swiss cantons up to 2050 by the Swiss Federal Statistical Office, the land use model FaLC was applied to forecast synthetic populations. It generates populations for 2030, 2040 and 2050 with the same data structure as in the synthetic population 2017. These forecasts are used as input for the Swiss transport outlook 2050 [Justen et al., 2021].

3 Choice model

The choice model is a binary logit model. The two alternatives are "some home-based telecommuting" or "not working from home at all". We define "some home-based telecommuting" as answering "yes" or "sometimes" to the question on working from home and answering a work percentage higher than 0. People answering "no" to the first question or "yes" to the first question, then "0%" to the second one are considered as not doing some home-based telecommuting. People who did not get the question or who did get the question but did not provide an answer to both questions are excluded from the sample. With this definition, we get a sample of 8997 answers in 2015 and of 1289 answers in 2020. Only one person was interviewed by household, so all answers come from different households. In 2015, 28.1% of Swiss residents working were doing part of it from home ($\pm$0.9%, 95% confidence interval).

In Section 3.1, we first present the attributes that were tested and the specification of the model, i.e., how the attributes were integrated in the utility function. Then, in Section 3.2, we show the estimation results based on the data of 2015, and in particular which parameter are included in the final model. Some attributes mentioned in Section 3.1 (e.g., structure of the household) are not in the final estimation results (Section 3.2), since they were not significant.

3.1 Model attributes and specification

We have tested the attributes presented in Table 2.

Table 2: Attributes tested in the model

Attribute	**Levels (number of levels in parentheses if relevant)**
Level of education	No post school, secondary, tertiary, university (4)
Sex	Women, men (2)
Structure of the household	Single household, couple with/without children, single parent with children, not family household (5)
Public transport connection quality of the place of living	A/very good, B/good, C/moderate, D/low, none (5)
Public transport connection quality of the place of working	A/very good, B/good, C/moderate, D/low, none (5)
Urban/rural typology of the place of living	Urban, intermediate, rural (3)
Urban/rural typology of the place of working	Urban, intermediate, rural (3)
Crow-fly distance from home to work	Up to 280 km
Business sector in which the person works	Agriculture, retail, gastronomy, finance, production, wholesale, services for companies, other services, "non movers", others (10) (see chapter 2.2 and 3.2.1 for more details)
Having several part time jobs	Yes, no (2), only available in 2015
Income of the household	Below 2000 CHF, 2000 up to 4000, 4001 up to 6000, ..., 14'001 up to 16'000, more than 16'000, not known/NA (10)
Function in the company	Executives, no management position, not known/NA (3)
Rate of part-time work	From 0 to 100%
Language of the interview	German, French, Italian (3)
Age	From 15 to 84
Public transport season ticket: General abonnement	Yes, no (2)
Public transport season ticket: Regional abonnement	Yes, no, not known/NA (3)
Public transport season ticket: Half fare abonnement	Yes, no, not known/NA (3)
Car availability	Yes (always, on demand), no, not known/NA (3)
Combinations of mobility resources (see Danalet [2019])	Combinations of (1) car and no car and (2) general abo., regional abo., half fare abo., and both half fare and regional abo., and not known/NA (11)

Age, commuting distance and rate of part-time work are included in the model as piecewise linear specification. The income levels were tested separately and then grouped in one category including all households with 8000 CHF or less per month. The nationalities were tested separately and then grouped in one category including Swiss, German, French, Italian, Northwestern Europe and Eastern Europe nationals.

The fact of having several part time jobs was significant in the model, but was removed because this information is not available in the synthetic population. Similarly, being of Swiss, German, French, Italian and North Western Europe nationality (one single variable) was significantly positive, but we have decided to remove this attribute from the model, since it most probably represents a proxy for higher education, higher income and tertiary-sector jobs. It would thus not perform well for forecasting. Native citizen telecommuting more has been observed in other studies [Paleti, 2016, Paleti and Vukovic, 2017].

3.2 Estimation results, 2015

The model has been estimated using PandasBiogeme [Bierlaire, 2020]. Table 3 shows general statistics and Table 4 shows the parameter estimates. We observe that the decision to work from home is influenced

by work related factors, such as the business sector and the function in the company (chapter 3.2.1), by socio-economic characteristics, such as age and income (chapter 3.2.2) and by spatial factors (chapter 3.2.3).

Table 3: General statistics about the estimation for 2015

Number of estimated parameters	30
Init log likelihood	-6236.245
Final log likelihood	-4208.787
Rho-square for the init. model	0.325
Rho-square-bar for the init. model	0.32
Akaike Information Criterion	8477.575
Bayesian Information Criterion	8690.714

3.2.1 Work related: Business sector, function in the company & rate of part-time work

The parameters for people working in agriculture was first set as a reference value. People working in services for companies do not significantly work more or less from home than some working in agriculture. This parameter was also fixed to zero. Services for companies include scientific and technical activities, media production (cinema, video, television, sound recording), real estate, health, creative, artistic and performing activities, casinos, sports, recreation and leisure activities, and voluntary organisations.

The results of the estimation of the model show that people working in finance, production, wholesale, accommodation and food service activities ("gastronomy") and services for companies and private individuals ("services") and in other business sectors not defined in other categories ("others") are less likely to work from home in comparison to people working in agriculture and services for companies. A similar effect has already been observed for manufacturing [Walls et al., 2007, Zhou et al., 2009, Paleti and Vukovic, 2017, Shabanpour et al., 2018] and administration [Paleti and Vukovic, 2017]. It might be explained by the fact that these persons perform personal services and physical activities at their workplace. Hence a digital substitution is not possible.

People working in public administration, defence and education ("public administration & education") are more likely to work from home in comparison to people working in agriculture and services for companies. This contradicts some results from Chicago showing that "government employees are among the least frequent telecommuters"

	Value	Rob. Std err	Rob. t-test	Rob. p-value	
Alternative specific constant$_{\text{Working from home}}$	0.849	0.579	1.47	0.142	
$\beta_{\text{Business sector: agriculture, etc. (ref.)}}$	0	-	-	-	
$\beta_{\text{Business sector: finance}}$	-0.368	0.127	-2.9	0.00369	**
$\beta_{\text{Business sector: gastronomy}}$	-1.02	0.213	-4.82	1.47e-06	***
$\beta_{\text{Business sector: public administration \& education}}$	0.403	0.0872	4.62	3.86e-06	***
$\beta_{\text{Business sector: services}}$	-0.701	0.0859	-8.16	4.44e-16	***
$\beta_{\text{Business sector: production}}$	-0.84	0.0866	-9.7	0.0	***
$\beta_{\text{Business sector: retail}}$	-1.02	0.15	-6.76	1.43e-11	***
$\beta_{\text{Business sector: wholesale}}$	-0.555	0.104	-5.32	1.05e-07	***
$\beta_{\text{Business sector: others}}$	-2.79	1.02	-2.73	0.00635	**
$\beta_{\text{Household structure: other household types (ref.)}}$	0	-	-	-	
$\beta_{\text{Household structure: couples without children}}$	-0.162	0.0621	-2.61	0.00895	**
$\beta_{\text{No management position (ref.)}}$	0	-	-	-	
$\beta_{\text{Executives}}$	0.842	0.0599	14.1	0.0	***
$\beta_{\text{Language of interview: Italian, French (ref.)}}$	0	-	-	-	
$\beta_{\text{Language of interview: German}}$	0.24	0.0609	3.93	8.51e-05	***
$\beta_{\text{Household income: more than 8000 (ref.)}}$	0	-	-	-	
$\beta_{\text{Household income: 8000 or less}}$	-0.578	0.0648	-8.91	0.0	***
$\beta_{\text{Household income: NA}}$	-0.405	0.0871	-4.65	3.3e-06	
$\beta_{\text{Home-work distance: } > 0}$	1.29	0.16	8.06	6.66e-16	***
$\beta_{\text{Home-work distance: 0}}$	2.06	0.123	16.7	0.0	***
$\beta_{\text{Home-work distance: NA}}$	0.0485	0.223	0.217	0.828	
$\beta_{\text{PT quality, home: very good to weak (A, B, C, D) (ref.)}}$	0	-	-	-	
$\beta_{\text{PT quality, home: worst}}$	0.185	0.0718	2.57	0.01	**
$\beta_{\text{University education (ref.)}}$	0	-	-	-	
$\beta_{\text{No post school education}}$	-1.88	0.145	-12.9	0.0	***
	-1.01	0.0674	-14.9	0.00	***
$\beta_{\text{Tertiary education}}$	-0.568	0.0827	-6.87	6.59e-12	***
$\beta_{\text{Age [15, 18]}}$	-0.591	0.155	-3.82	0.000136	***
$\beta_{\text{Age [19, 30]}}$	0.13	0.0165	7.89	2.89e-15	***
$\beta_{\text{Age [31, 78]}}$	0.00459	0.00298	1.54	0.123	
$\beta_{\text{Age [79, 84]}}$	-0.618	0.39	-1.59	0.113	
$\beta_{\text{Rate of part-time work [1, 89]}}$	-0.0104	0.00175	-5.98	2.29e-09	***
$\beta_{\text{Rate of part-time work [90, 100]}}$	0.0259	0.00916	2.83	0.00464	**
$\beta_{\text{Owning a GA travelcard}}$	0.228	0.1	2.27	0.0231	*
$\beta_{\text{Mobility resources: other categories (ref.)}}$	0	-	-	-	
$\beta_{\text{Mobility resources: car \& half fare abonnement}}$	0.422	0.0622	6.78	1.17e-11	***
$\beta_{\text{Mobility resources: NA}}$	-0.626	0.634	-0.988	0.323	

Table 4: Parameter estimates

[Shabanpour et al., 2018]. This might be related to different policies regarding telecommuting for public employees and different ratios of public employees in defence between Switzerland and Chicago.

Independent workers, owners of their own company, people working in their own family business, and employees with management position (managing a team) or members of the direction of the company (all grouped in attribute "executives") tend to work more from home than workers without management position in the company. This partially contradicts previous results from Chicago, showing that "managers of companies or enterprises are less likely to participate in telecommuting" [Shabanpour et al., 2018].

Both regarding government employees and management position, the contradictions with Shabanpour et al. [2018] might be related to the time when they collected their data (2008). Behaviour and social norms might have change with time.

The higher percentage people work, the more they tend to work from home, until 89%. Between 90% and 100%, this effect is negative.

3.2.2 Socio-economic factors: Language, income, education, household structure, mobility resources & age

(1) People who did the interview on the phone in German, (2) living in households whose income is above 8000 CHF per month, (3) owning a GA travelcard[4] and (4) both owning a half fare travelcard and having a car available (always or on demand) tend to work more from home than people (1) who did the interview in French or Italian, (2) from poorer households, (3) not owning a GA travelcard and (4) people having other combinations of mobility resources. These findings regarding income have been observed in previous studies [Paleti, 2016, Shabanpour et al., 2018].

The level of education also has an impact. People without a diploma are the least likely to work from home, followed by people with a primary education, and then by people with a tertiary but non university education, compared to people with a university diploma (fixed to 0 in the model, as reference value). Such effects have been observed in other estimation results [Paleti and Vukovic, 2017].

We observe a negative effect of age until 19. Then between 20 and 31, people tend to work more from home with age. Finally, starting at 32, we do not observe an effect of age. When older than 79, the value of the parameter is still different, even though still not significant (reminder: there are only people working in the sample; this is not a proxy effect for being retired).

We don't observe a significant effect of gender on working from home in our model.

3.2.3 Spatial factors: Distances and public transport quality

People with a larger crow-fly (non-zero) distance between home and work and with the worst quality of public transport on a 5 level-scale (as defined by the Swiss Federal Office for Spatial Development) at their home location tend to work more from home. Similar effects have been observed in Mokhtarian and Meenakshisundaram [2002],

[4]The GA travelcard allows the owner to travel by public transport throughout Switzerland for free.

Paleti [2016] and Shabanpour et al. [2018]. People with no commuting distance work more from home, obviously. This confirms the data quality.

3.3 Internal validation

We have estimated the model on 80% of the data and applied it to the remaining 20%. The 80-20% decomposition of the data was random. This process was repeated 10 times. The observed proportion of people doing home office in the subsample of 20% of the observations is 29.1% on average on the 10 runs (min: 28.0%, max: 30.2%), while the predicted proportion of people doing home office in the same subsample of 20% is 29.3% on average (min: 28.7%, max: 29.7%). Among the 10 runs, the largest difference is 1.4 points of percentage and the smallest 0.1. We consider these results as good enough to use the model for a test of temporal stability and an external validation.

3.4 Testing temporal stability using the Mobility and Transport Microcensus 2020

We have used the model estimated with the data of 2015 to forecast the decision to work from home in the data of 2020. In the data of 2020, we observe a proportion of 33.7% of respondents working from home (unweighted results, thus representing the sample and not the Swiss resident population). Our model predicts that 32.2% of these respondents work from home. We consider these results as good enough to use our model for forecasting.

3.5 Estimating model using the Mobility and Transport Microcensus 2015 & 2020

We have estimated a model using the joint data of 2015 and 2020, including a scale parameter for the data of 2020. We have decided not to estimate a model on the data of 2020 alone, since the sample is smaller in 2020 (only 1289 observations) than in 2015 (8997) and some attributes might have been not significantly different from zero when using only the data of 2020 just because of the sample size.

For each original parameter of the model of 2015, we have tested a specification with two parameters, one for 2015 and one for 2020. When year-specific parameters were significantly different from one another, we have kept both if they were both significantly different from zero (only for couples without children) and only the one of 2015 otherwise (only for public transport connection quality of the place of living). If parameters for 2015 and 2020 were not significantly different from one

another, we have estimated one single parameter for both years (all other parameters).

We have then tested all non significant parameters in 2015 with the data of 2020. Two were significantly different from zero in 2020 only. People working in the intermediate area, between rural and urban areas in the 3-level "urban/rural typology" of the Swiss Federal Statistical Office, tend to work less from home than people working in rural or urban areas. People owning a GA travelcard and not having a car available tend to work more from home than people with other combinations of mobility resources, even when the effect of owning a GA travelcard in general, with or without having a car available, is already in the model and significant. The fact that only two parameters are significant in 2020 and were not in 2015 shows a certain stability of behaviour between 2015 and 2020. It might however also be related to the relatively smaller sample size in 2020.

The complete results of the joint estimation are presented in Tables 5 and 6. Table 7 describes the main differences between the estimation based on the data of 2015 and the joint estimation.

Table 5: General statistics about the estimation of the joint model with pooled data of 2015 and 2020

Number of estimated parameters	34
Init log likelihood	-7129.712
Final log likelihood	-4851.794
Rho-square for the init. model	0.319
Rho-square-bar for the init. model	0.315
Akaike Information Criterion	9771.589
Bayesian Information Criterion	10017.7

The joint estimates are very similar in the joint estimation as in the 2015 model. The difference observed for "couples without children" between 2015 and 2020 cannot be easily interpreted. Similarly, it is difficult to explain why living in a place with a bad public transport offer had an impact in 2015 and not anymore in 2020. Newly significant estimates in 2020, having a general abonnement without having a car available and working in an intermediate area, not in the city center and not in rural areas, is difficult to explain.

	Value	Rob. Std err	Rob. t-test	Rob. p-value	
Alternative specific constant$_{\text{Working from home}}$	0.652	0.587	1.11	0.267	
$\beta_{\text{Business sector: agriculture, etc. (ref.)}}$	0	-	-	-	
$\beta_{\text{Business sector: finance}}$	-0.256	0.118	-2.17	0.0298	*
$\beta_{\text{Business sector: gastronomy}}$	-0.944	0.196	-4.83	1.39e-06	***
$\beta_{\text{Business sector: public administration \& education}}$	0.41	0.082	5.0	5.66e-07	***
$\beta_{\text{Business sector: services}}$	-0.733	0.081	-9.05	0.0	***
$\beta_{\text{Business sector: production}}$	-0.773	0.0814	-9.5	0.0	***
$\beta_{\text{Business sector: retail}}$	-1.02	0.142	-7.22	5.27e-13	***
$\beta_{\text{Business sector: wholesale}}$	-0.513	0.0977	-5.25	1.56e-07	***
$\beta_{\text{Business sector: others}}$	-3.11	1.02	-3.06	0.00222	**
$\beta_{\text{Household structure: other household types (ref.)}}$	0	-	-	-	
$\beta_{\text{Household structure: couples without children 2015}}$	-0.159	0.0608	-2.61	0.00912	**
$\beta_{\text{Household structure: couples without children 2020}}$	0.412	0.14	2.93	0.00336	**
$\beta_{\text{No management position (ref.)}}$	0	-	-	-	
$\beta_{\text{Executives}}$	0.827	0.0569	14.5	0.0	***
$\beta_{\text{Language of interview: Italian, French (ref.)}}$	0	-	-	-	
$\beta_{\text{Language of interview: German}}$	0.26	0.0571	4.56	5.11e-06	***
$\beta_{\text{Household income: more than 8000 (ref.)}}$	0	-	-	-	
$\beta_{\text{Household income: 8000 or less}}$	-0.552	0.0608	-9.08	0.0	***
$\beta_{\text{Household income: NA}}$	-0.398	0.0813	-4.89	1.02e-06	
$\beta_{\text{Home-work distance: } > 0}$	1.33	0.151	8.87	0.0	***
$\beta_{\text{Home-work distance: 0}}$	2.12	0.116	18.3	0.0	***
$\beta_{\text{Home-work distance: NA}}$	0.0658	0.208	0.317	0.751	
$\beta_{\text{PT quality, home: very good to weak (A, B, C, D) 2015 (ref.)}}$	0	-	-	-	
$\beta_{\text{PT quality, home: worst 2015}}$	0.185	0.0712	2.6	0.00927	**
$\beta_{\text{University education (ref.)}}$	0	-	-	-	
$\beta_{\text{No post school education}}$	-1.93	0.14	-13.7	0.0	***
$\beta_{\text{Secondary education}}$	-1.02	0.0631	-16.2	0.0	***
$\beta_{\text{Tertiary education}}$	-0.609	0.0772	-7.88	3.11e-15	***
$\beta_{\text{Age [15, 18]}}$	-0.561	0.156	-3.59	0.00033	***
$\beta_{\text{Age [19, 30]}}$	0.133	0.0156	8.51	0.0	***
$\beta_{\text{Age [31, 78]}}$	0.00326	0.00278	1.17	0.241	
$\beta_{\text{Age [79, 84]}}$	-0.485	0.307	-1.58	0.114	
$\beta_{\text{Rate of part-time work [1, 89]}}$	-0.00951	0.00163	-5.84	5.21e-09	***
$\beta_{\text{Rate of part-time work [90, 100]}}$	0.0211	0.0085	2.48	0.013	
$\beta_{\text{Owning a GA travelcard}}$	0.263	0.0938	2.81	0.00497	**
$\beta_{\text{Mobility resources: other categories (ref.)}}$	0	-	-	-	
$\beta_{\text{Mobility resources: car \& half fare abonnement}}$	0.421	0.0584	7.21	5.49e-13	***
$\beta_{\text{Mobility resources: GA travelcard \& no car 2020}}$	1.03	0.434	2.38	0.0175	*
$\beta_{\text{Mobility resources: NA}}$	-0.382	0.534	-0.716	0.474	
$\beta_{\text{Workplace location: urban or rural 2020 (ref.)}}$	0	-	-	-	
$\beta_{\text{Workplace location: intermediate 2020}}$	-0.435	0.208	-2.09	0.0368	*
Scale 2020	0.949	0.0594	16.0	0.0	

Table 6: Parameter estimates of the joint model with data of 2015 and 2020

4 External validation using a synthetic population 2017

In this chapter, we present the results of applying the choice model jointly estimated with the data of the Mobility and Transport Microcensus 2015 and 2020 to the synthetic population 2017. The goal is to validate the approach before applying the model to the synthetic populations 2030, 2040 and 2050.

	Estimation 2015	Joint estimation 2015/2020	
	Value 2015	Value 2015	Value 2020
βHousehold structure: Couples without children	-0.16 **	-0.16 **	0.41 **
βPT quality, home: worst	0.19 **	0.19 **	0 (fixed)
βMobility resources: GA travelcard & no car	0 (fixed)	0 (fixed)	1.03 *
βWorkplace location: intermediate	0 (fixed)	0 (fixed)	-0.44 *
All other parameters	1 estimate	1 joint estimate	

Table 7: Main differences between the 2015 only estimation and the 2015/2020 joint estimation. Some values have been fixed to zero, since they were not significantly different from zero.

We use the "the most recent" estimates, i.e., (1) the joint estimates (when only one variable for 2015 and 2020), the 2020 estimates (when differentiated between 2015 and 2020 (i.e., couples without children 2020), (3) nothing/zero if only significant in 2015 and not in 2020 (for public transport quality at home) and (4) the newly significant parameters for 2020 (i.e., mobility resources: GA & no car, workplace located in an intermediate area).

4.1 Calibration of the constant by simulating results for the Mobility and Transport Microcensus

The alternative specific constant is calibrated against the observed proportion of people doing home office in the Mobility and Transport Microcensus. The constant is empirically adjusted by using the heuristic method suggested by Train [2003, ch. 2.8 "Recalibration of constants", p. 39]. An iterative process is used to recalibrate the constants. The estimated alternative-specific constant (ASC_0) for the telecommuting alternative is iteratively modified so that the predicted share of decision-makers telecommuting $\hat{S}_n$ (computed using the alternative specific constant ASC_n from the n-th iteration) is equal to the observed share of decision-makers telecommuting S. We have applied Train's adjustment:

$$ASC_{n+1} = ASC_n + \ln(S/\hat{S}_n)$$

In this process, the alternative specific constant changes from 0.61 to 0.80. With this change, the model predicts almost exactly (tolerance: 0.001) the observed shares of people working from home in the full sample of the Mobility and Transport Microcensus, when it is applied to the full sample of (employees of) the Mobility and Transport Microcensus.

Data and code availability

The data of the Mobility and Transport Microcensus 2015 are available to researchers after signing a data protection contract. Some costs might be associated with the request. The request can be done through the following form: `https://www.are.admin.ch/are/de/home/mobilitaet/grundlagen-und-daten/mzmv/datenzugang.html`.

The data of the synthetic populations 2017 and 2050 are very sensitive (it includes the exact - not synthetic - coordinates of Swiss households) and it is not possible to share it with researchers. The 2017 aggregated data are available for each zone of the Swiss national transport model after digitally signing a data protection contract on FORSbase: `https://forsbase.unil.ch/project/study-public-overview/16671/0/`.

The code of the model is available on GitHub: `https://github.com/antonindanalet/home_office_in_microcensus`.

Appendix

8.1 Data

8.1.1 Mobility and Transport Microcensus

We observe that almost half (48%) of the people working from home did it 10% of their time or less in 2015. 9% of people working from home did it full time (see Fig. 2).

The reason to work from home, as stated by respondents, is presented in Figure 3. It shows that 25% of people working from home have their workplace at home. This is often the case with small family companies, where the place of work and living are the same. The most frequent answer is "Other". It might show that the reason to work from home is complex and cannot be identified by a single category during a phone interview.

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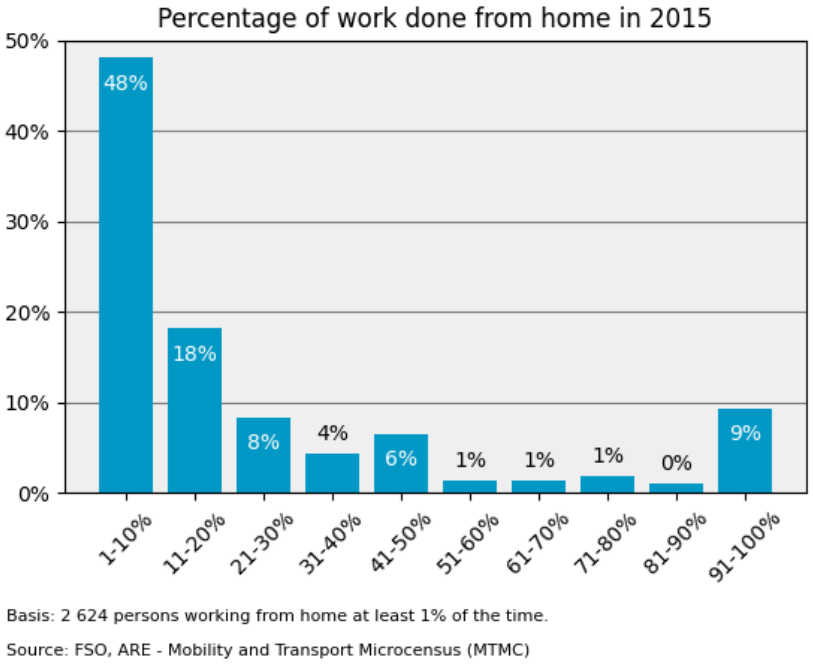

Figure 2: Percentage of work done from home in 2015

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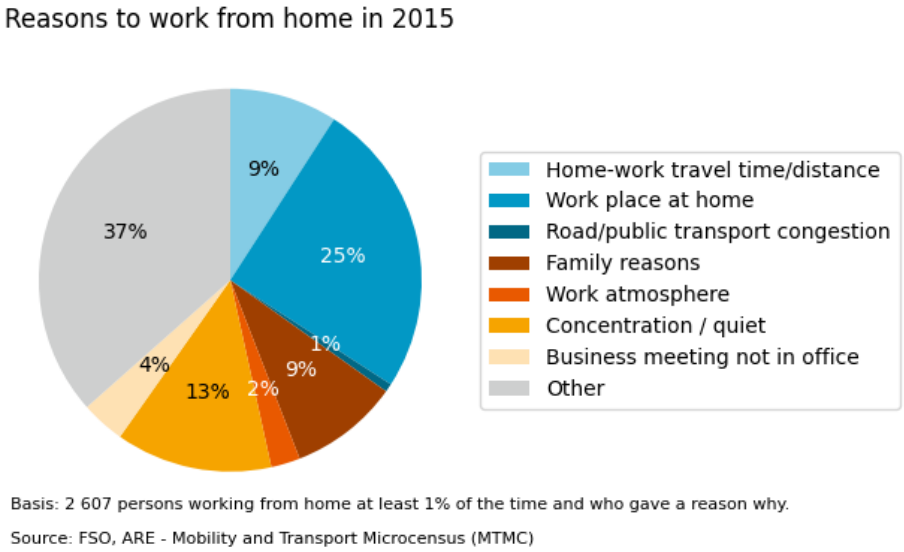

Figure 3: Reasons for working from home in 2015

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