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**Working Paper**

# A spatial choice model based on random utility

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# DISKUSSIONSBEITRÄGE AUS DEM INSTITUT FÜR WIRTSCHAFT UND VERKEHR

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SVEN MÜLLER

# A SPATIAL CHOICE MODEL BASED ON RANDOM UTILITY

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# A Spatial Choice Model Based on Random Utility

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Working Paper

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# A Spatial Choice Model Based on Random Utility

**Summary**
Decreasing number of students in Germany lead to the closures of schools due to lack of utilization. Hence, competition between schools will increase. We use a mixed multinomial logit model in order to identify influencing factors of school choice and to regard realistic substitution patterns within the context of forecasting school choice probabilities with changing choice sets over time. Results yield commuting distance as the most important factor, but school characteristics like profiles (math or languages, e.g.) and spatial attributes like centrality have remarkable impact, too. Moreover, the analysis shows heterogeneity in population. For our sample we identify authority responsible (private/public school) as the most important variable to specify substitution patterns. Using the results, we simulate the effects of school closings and openings in realistic scenarios.

**Keywords**: School choice, secondary schools, mixed multinomial logit, school closure, school openings, urban areas

## 1 Introduction

More and more regions in Europe are confronted with declining school enrollment due to low fertility rates or negative net migration or even both. Consequently, authorities are forced to reduce the number of school locations. Future generations of students have to choose a certain school location from a reduced set of remaining schools and may face a longer commute to school. Within the framework of long term school network planning it is important to know how students disperse under a changing choice set of schools over time (Müller, 2008). We expect that commuting distance and the school specific characteristics (profiles, centrality, school size and authority responsible) are important and sufficient factors determining the choice of a certain school location in Saxony, Germany (Speiser, 1993; Mahr-George, 1999; Schneider, 2004; Müller, 2006; Müller et al., 2008). We differentiate between schools with a common profile and schools with a unique profile. A school with a common profile provides a service (mathematics/science for example) which is comparable to a lot of other schools. Usually, schools offer a combination of two common profiles. In contrast, a unique profile is offered by one school only. For example: If a school offers remarkable more languages than most of the other schools we name this profile *core languages*. Moreover, we name a school offering a unique profile *magnet school* since it is the only one in a particular region offering such an educational service. So students are attracted by this school over a broad geography.
In Germany tuition fees only occur at some private schools. They are at a low level usually. So, we do not explicitly pay respect to tuition fees in this study. Also, the confessional affiliation are neglected here as an explanatory variable. Particularly in Dresden, there are no confessional constraints concerning enrollment and again just a few private schools have a strict confessional affiliation. Note that the number of private schools is increasing recently. In future, tuition fees and confessional affiliation will have a much greater impact on school choice (Barthels, 2007b). It is valuable to know which combination of profiles increases the choice probability of a certain school and whether there is heterogeneity in the sensitivity of individuals to the influencing factors. Particularly in a spatial choice situation one has to consider substitution patterns

between different alternatives (Haynes et al., 1988), notably if the choice set differs over time (Müller et al., 2009). With declining enrollment the competition between schools will increase. Easy accessible schools with an attractive combination of profiles will gain more students than others. This in turn leads to a reduced risk of being closed by school authorities.
In this contribution we utilize a mixed multinomial logit model (MMNL) to describe the process of school choice and analyse the consequences of opening and closing schools in the City of Dresden, Saxony. For this, the remainder of this article is as follows: Section 2 covers an overview of the literature and the theoretical model determining the school choice probabilities. In section 3 we describe the data used followed by the estimation of a series of models (section 4). In section 5 we simulate the choice probabilities for different scenarios, which cover school openings and closures. Some final remarks can be found in the 6th section.

## 2 School choice modelling

This section deals with the student's individual choice probability for each school, dependent on commuting distance and school specific characteristics. There are no school districts in Saxony so students are free to choose a certain school location. Deterministic approaches which yield spatially consistent school districts are not appropriate here. We assume that each student chooses the school with the highest utility. A probalistic approach with respect to individual utility should be used. The multinomial logit model (MNL) has been well established within the context of destination or location choice modelling (McFadden, 1973; Ben-Akiva and Lerman, 1985; Hansen, 1987; Gabriel and Rosenthal, 1989; Hunt and Teply, 1993; Bhat, 1997; Drezner et al., 1998; Greene, 2003; Becker et al., 2005). Recent studies on school choice - partly applying MNL - were focused on the discrimination between the choice of private and public schools (Figlio and Stone, 1997; Alderman et al., 2000) or the question whether students will take part in higher education. For example: whether they enroll on a college (Brinkmann and Leslie, 1987; Kane and Spizman, 1994; Schneider, 2004)? Lankford and Wyckoff (2000) study the relationship between racial composition of schools and school choice. Their results show that the racial composition of schools and neighborhoods are very important within the context of choosing between private and public schools. The choice between voucher and non-voucher schools in Chile has been studied by Contreras (2002). He finds that school choice is gender based. Females more often choose voucher schools, while males more often choose private, non-voucher schools. The results of Nguyen and Taylor (2003) seem to evidence that a full choice set is superior to combinations of sub-sets for the modelling of college choice. Montgomery (2002) used the logit-approach to model the choice process of universities using cost variables mostly. Hoxby (2003) mainly discusses the economic benefits of free school choice such as increase in productivity and welfare but less which variables determine the process of school choice. The most influencing factors for parental choice of school location seem to be proximity and academic quality (Glazerman, 1997; Goldring and Bauch, 1995; Kleitz et al., 1998; Peterson and Hassel, 1998).
In eastern german cities the share of ethnic minorities is very low (except Berlin) and so we assume that the racial composition does not have a strong influence on school choice here. There exist no voucher schools in Germany and there are just a few private schools. Nevertheless, the latter are emerging recently (see section 1). So most of the studies mentioned before focus on attributes which seem to be of less interest concerning school choice in Germany, particularly Saxony. We assume that school choice is related to profile, authority and proximity (Müller, 2006; Müller and Haase, 2009).
We model the school choice behavior in order to predict choice probabilities within scenarios

of school closures and openings. Therefore we consider substitution patterns between schools. Also, we like to consider individual heterogeneity to explore taste variation within the population. Here the MNL is not appropriate because its restrictive assumptions concerning the stochastic utility component (Train, 2003, p.46-56), for example it exhibits independence from irrelevant alternatives (IIA) and yields unrealistic substitution patterns. Concerning school choice modelling, Borgers et al. (1999) point out that a standard/conventional logit model is not appropriate to include substitution effects. In this case it appears to be that the more general mixed multinomial logit model (MMNL) is superior to MNL due to its flexibility concerning substitution patterns and individual heterogeneity (Brownstone and Train, 1999; Dow and Endersby, 2004; Gottlieb and Joseph, 2006). Besides empirical experience with this kind of discrete choice model from other fields of research (Rouwendal and Meijer, 2001; Hensher and Greene, 2003; Bhat and Gossen, 2004; Smith, 2005) particularly Hastings et al. (2005) use a MMNL to identify parental preferences and school competition. They analyze how demand disperses in a situation of free school choice for elementary and middle schools. Using data from a stated preference survey they discover proximity, ethnicity and academic quality as the most influencing factors. These variables show significant variation in individual heterogeneity. We therefore revert to the MMNL as well.

**MMNL structure**

The mixed logit probabilities are the integrals of the well-known logit probabilities over a density [1] of parameters (Bhat, 2000). Generally, the model takes the structure:

$$P_{is}(\theta) = \int L_{is}(\beta) f(\beta|\theta) d(\beta) \tag{1}$$

with

$$L_{is}(\beta) = \frac{\exp(\beta' x_{is})}{\sum_{\tilde{s}} \exp(\beta' x_{i\tilde{s}})} \tag{2}$$

where $P_{is}$ is the probability that student $i$ chooses school $s$. Here, $x_{is}$ is a vector of alternative-related observed variables, while $\beta$ represents parameters that are random realizations from a density function $f(\cdot)$ characterized by a vector of underlying moment parameters $\theta$, which are normally distributed in our case. Here, the overall random term associated with the utility of each alternative is divided into two components. In order to capture individual heterogeneity and correlation across alternatives, the utility function for student $i$ and school $s$ is specified as:

$$U_{is} = \gamma' y_{is} + \xi_{is} = \gamma' y_{is} + \mu_i' z_{is} + \varepsilon_{is} \tag{3}$$

where $y_{is}$ and $z_{is}$ are vectors of observed variables related to school $s$ and student $i$, $\gamma$ is a vector of coefficients of the systematic component of utility, $\mu_i$ is a random vector with zero mean and $\varepsilon_{is}$ is independent and identically extreme value distributed (IID). The terms in $z_{is}$ are error components that, along with $\varepsilon_{is}$, define the stochastic component of utility $\xi_{is}$, which can be correlated over alternatives depending on the specification of $z_{is}$. Here, $z_{is}$ is a subvector

[1] This density is also called the mixing distribution. The name mixed multinomial logit model is dispositional on this.

of $y_{is}$ primarily containing variables of the school attributes (like the schools' authority). The stochastic part of utility yields tastes not observed by the researcher are used by the student to evaluate schools (random taste variation), and since we do not observe these tastes completely, this portion of utility is correlated over schools (unobserved attributes). The covariance of two schools $s$ and $l$ is denoted by $\text{Cov}(\xi_{is}, \xi_{il}) = E(\mu_i' z_{is} + \varepsilon_{is})(\mu_i' z_{il} + \varepsilon_{il})$. We expect $E(\mu_i) = E(\varepsilon_{is}) = E(\varepsilon_{il}) = 0$. Let us denote the covariance of $\mu_i$ as $W$. So $E(\mu_i \mu_i') = W$. For a given $i$:

$$W = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} & \cdots \\ \sigma_{21} & \sigma_{22} & \sigma_{23} & \cdots \\ \sigma_{31} & \sigma_{32} & \sigma_{33} & \cdots \\ \cdots & \cdots & \cdots & \cdots \end{pmatrix}$$

with $\sigma_{11} = E(\mu_1 \mu_1)$ and $\sigma_{12} = E(\mu_1 \mu_2)$ and so on. If we consider the covariance of two different schools $\text{Cov}(\xi_{is}, \xi_{il})$, then

$$\begin{aligned} & E(\mu_i' z_{is} + \varepsilon_{is})(\mu_i' z_{il} + \varepsilon_{il}) \\ = \; & E(\mu_i' z_{is} \mu_i' z_{il} + \mu_i' z_{is} \varepsilon_{il} + \mu_i' z_{il} \varepsilon_{is} + \varepsilon_{is} \varepsilon_{il}) \\ = \; & E(\mu_i' z_{is} \mu_i' z_{il}) \\ & \text{Since } z_{is} \text{ and } z_{il} \text{ are known rather than expected it follows} \\ = \; & z_{is}' E(\mu_i \mu_i') z_{il} \\ = \; & z_{is}' W z_{il}. \end{aligned}$$

If we consider $z_{is}$ as a dummy variable which indicates whether the school $s$ is private (=1) or not (=0) then this last term determines whether the two schools $s$ and $l$ are correlated ($z_{is} = z_{il} = 1$) or not. The degree of correlation is defined by $W$. Hence, the MMNL can handle the IIA problem automatically if the error components are spcified in a sufficient way. Note, that the probabilities of (1) are approximated through simulation for any given value of $\theta$ (Train, 2003). A short description of the estimation method is given in the appendix.

# 3 Data

The spatial data set includes geographies (blocks [2], wards and districts), the school locations and the street network of Dresden. Using a shortest path algorithm we determine the street network distances between all blocks (round 6,400) and school locations (23). In this study we focus on colleges (german: "Gymnasium"). Figure 1 displays the spatial distribution of all colleges and college students in Dresden for the years 2004, 2008 and 2012 (see section 5). We do not consider the colleges Sportgymnasium and Abendgymnasium, because they are supra-regional colleges or rather special boarding schools. They are not representative and would distort the modelling. The school size $V_s$, is the number of classes per class-level (synonyms: year, grade) [3]. Furthermore, we obtain information on the profiles offered by each college as well as the authority responsible. We assume that unobserved attributes of colleges are associated with authority responsible. For example, it is likely to assume that private schools have a better academic quality than public schools because of a better teacher-student ratio. Private schools

[2] A block is the smallest geographical unit for administrative issues in Germany. A ward contains at least one block, while a district consists of one ward, leastwise.

[3] *http://www.dresden.de/de/03/c_04.php*

often have a confessional affiliation (Barthels, 2007a). As mentioned in section 2 tastes of the students to these unobserved attributes are correlated over schools.

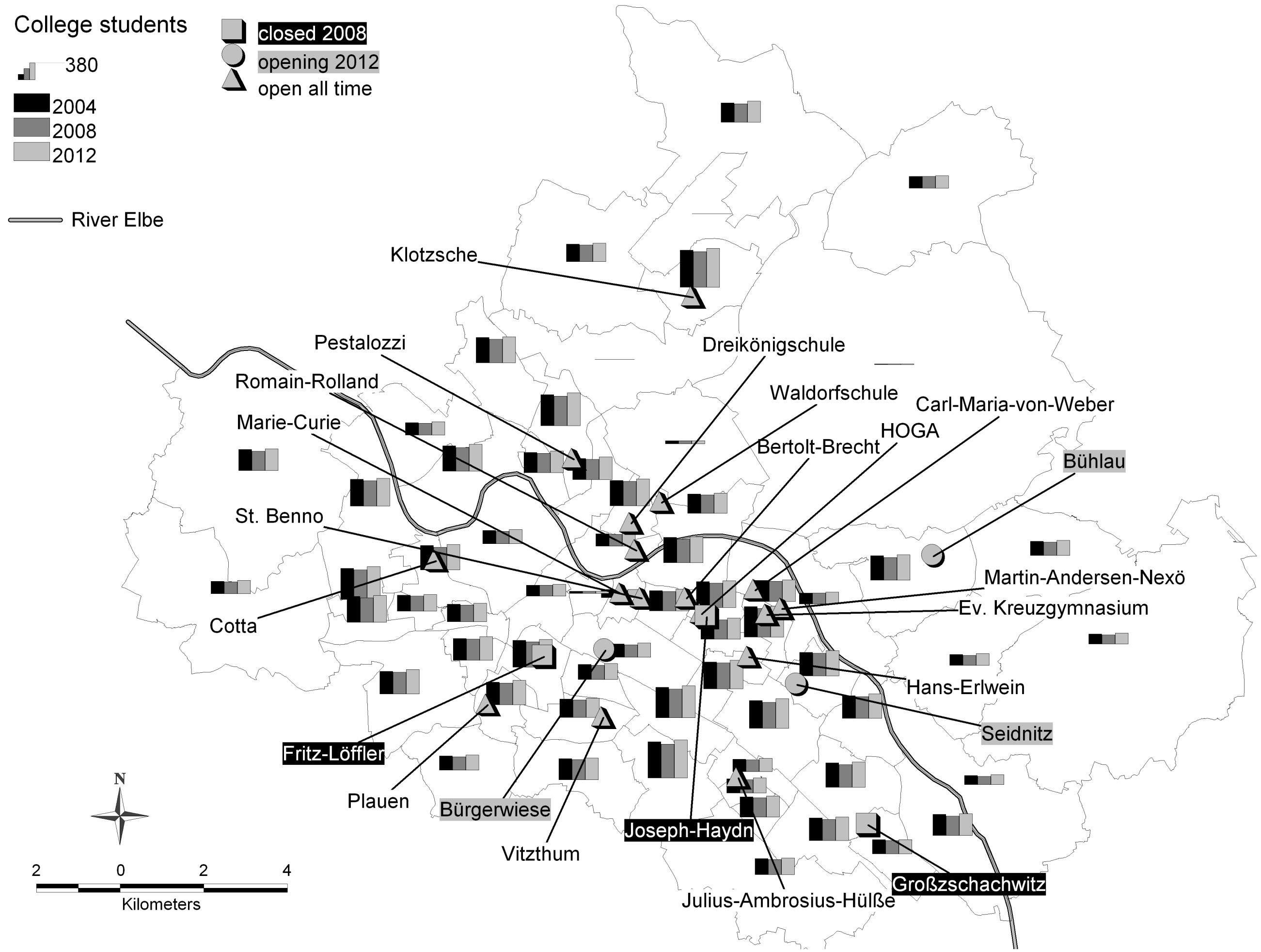


Figure 1: Colleges and college students in the City of Dresden

In 2004 we have carried out a survey covering nearly 4,700 of 12,000 college students at 13 of 20 colleges. One outcome of this survey is the revealed preferences of students to school choice. Unfortunately, we just have information which school a given student attends. We do not know which school the student prefers basically. We assume that a student who is not allowed to attend the school with the highest utility - due to capacity reasons for example - the student is willing to attend the school with second highest utility and so on. So, for every student our sample provides information about the chosen school, which is the school with highest utility and the student is "allowed" to enroll on.[4]
Forthcoming information of each student are the block where the student is located (home) and the attended school among other information (Müller et al., 2008). College students are aged between 10 and 18 years. Colleges in Saxony, Germany, cover 5th - 12th class-level. For each school our data set includes information on $V_s$, profile, authority responsible (=1 private school, =0 public schools) and the distance $d_{is}$ travelled to school $s$ by student $i$ (see table 1). We use distance instead of travel-time because we consider future scenarios of a school network (see section 5). But some of the school locations of future school network scenarios are not existing at the moment. Therefore, it is not possible to compute exact public transport travel-times for those school locations.[5] However, we assume a student evaluates distance with the travel-time of an appropriate transport mode. So, in the choice situation distance serves as a proxy for travel-time implicitly.
Since we expect a nonlinear influence by distance on students school choice, we consider a log-distance measure besides the simple distance measure. It is reckoned that the location of a school in the meaning of centrality has influence on school choice as well. The centrality of a school $C_s$ is measured in distance (km) from school $s$ to the city center[6]. Schools located close to the city center are more easy to access by public transport and car than those located at the outskirts. We assume that it is more attractive for a student located at a outskirts-district to attend a school located close to the city center (low value of $C_s$) than to attend a school located at a different outskirts-district (high values of $C_s$). More central schools are supposed to obtain a higher utility than others. We consider a dummy variable which indicates whether the closest school is a magnet school (=1) or not (=0). Regarding the average distance in table 1 it is conjecturable that there will be a relatively high proportion of students choosing a magnet school even when located far away. Since the utility function is linear-in-parameters, enumeration maybe leads to unrealistic high probabilities for students located close to magnet schools - all other variables constant. Thus, the expected sign of this "compensation" coefficient will be negative.
We have eliminated the colleges Großzschachwitz, Joseph-Haydn and Fritz-Löffler from the data set in order to avoid distortion. These colleges are already closed for enrollment in 2004 (year of the survey). For example, in 2004 there are students - especially at lower class-levels - attending Julius-Ambrosius-Hülße College which is next to Großzschachwitz just because they are not allowed to enroll on the closest college Großzschachwitz (Müller et al., 2008).

[4] Note that it is supposable that the decision which school to choose is mainly influenced by parents.
[5] One has to consider new lines and schedules e.g.
[6] Here, the functional city center is located close to the topological centroid of the city area.

| **College** | private school | p1 | p2 | p3 | p4 | p5 | Number of chosen alt. | weighting factor (WESML) | distance [m] aver. | std.dev. | min. | max. | $C_s$ km | $V_s$ classes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pestalozzi* | 0 | 1 | 0 | 0 | 0 | 0 | | | | | | | 3.518824 | 3 |
| Großzschachwitz | 0 | 1 | 0 | 0 | 0 | 0 | | | 2695.59 | 2579.33 | 615.64 | 13923.15 | 8.193287 | 4 |
| Marie-Curie | 0 | 1 | 0 | 0 | 0 | 0 | 201 | 2.005 | 4672.77 | 3180.37 | 100.00 | 16124.22 | 0.396577 | 4 |
| Bürgerwiese** | 0 | 1 | 0 | 0 | 0 | 0 | | | | | | | 1.140956 | 3 |
| Seidnitz** | 0 | 1 | 0 | 0 | 0 | 0 | | | | | | | 4.945167 | 3 |
| Cotta | 0 | 1 | 0 | 0 | 0 | 1 | 629 | 0.867 | 2970.62 | 1687.09 | 100.00 | 9495.55 | 4.218586 | 5 |
| Joseph-Haydn | 0 | 1 | 0 | 0 | 0 | 1 | | | 5031.26 | 3117.52 | 232.00 | 12293.00 | 2.401082 | 4 |
| Dreikönigsschule | 0 | 1 | 0 | 0 | 0 | 1 | 152 | 0.948 | 4141.44 | 3554.82 | 69.80 | 12097.99 | 1.979044 | 3 |
| Vitzthum | 0 | 1 | 0 | 0 | 0 | 1 | 266 | 0.869 | 2412.88 | 1708.30 | 70.00 | 12462.66 | 2.746265 | 4 |
| Bühlau** | 0 | 1 | 0 | 0 | 0 | 1 | | | | | | | 7.881512 | 3 |
| Bertold-Brecht* | 0 | 1 | 0 | 1 | 0 | 0 | | | | | | | 1.899466 | 4 |
| Fritz-Löffler | 0 | 1 | 0 | 1 | 0 | 0 | | | 2415.43 | 2262.12 | 123.81 | 10440.70 | 1.991180 | 3 |
| J.-A.-Hülße | 0 | 1 | 0 | 1 | 0 | 0 | 620 | 0.853 | 2503.82 | 1966.8 | 130.00 | 17800.59 | 5.238133 | 4 |
| Klotzsche | 0 | 1 | 0 | 1 | 0 | 0 | 343 | 1.116 | 2240.11 | 1960.47 | 36.79 | 13039.69 | 7.581799 | 3 |
| Plauen | 0 | 1 | 0 | 1 | 0 | 0 | 441 | 1.099 | 2255.03 | 1875.78 | 123.78 | 16924.68 | 3.761541 | 5 |
| Hans-Erlwein* | 0 | 1 | 0 | 1 | 0 | 0 | | | | | | | 3.630464 | 5 |
| **Carl-Maria-von-Weber*** | 0 | 0 | 0 | 0 | 0 | 1 | | | | | | | 3.553827 | 1 |
| St. Benno | 1 | 1 | 0 | 1 | 0 | 1 | 418 | 0.977 | 5554.11 | 2676.83 | 150.00 | 14688.66 | 0.832203 | 3 |
| Evangelisches Kreuzgymnasium* | 1 | 1 | 0 | 1 | 0 | 1 | | | | | | | 3.827819 | 3 |
| **Martin-Andersen-Nexö** | 0 | 1 | 1 | 0 | 0 | 0 | 261 | 0.961 | 3827.84 | 2578.77 | 273.76 | 14305.00 | 4.181314 | 3 |
| **Romain-Rolland** | 0 | 0 | 0 | 1 | 1 | 0 | 373 | 0.867 | 4649.81 | 3094.52 | 90.00 | 14851.61 | 1.427663 | 3 |
| Waldorfschule* | 1 | 0 | 0 | 0 | 0 | 0 | | | | | | | 2.725931 | 2 |
| Gymnasium der HOGA* | 1 | 0 | 0 | 0 | 0 | 0 | | | | | | | 2.271985 | 1 |
| **average** | | | | | | | 370,4 | | 3382.76 | 2646.63 | 36.79 | 17800.59 | 3.3188495 | 3.35 |

p1: mathematics/science (common)
p2: mathematics/science (core)
p3: languages (common)
p4: languages (core)
p5: music/arts (common)

* colleges not within geocoded sample
** colleges opened in 2012
Colleges written **bold** are magnet schools (unique profile)

Table 1: Data

## 4 Results

In this section we present and discuss the results of several model specifications. Although a Hausmann-McFadden test proved our suggestion, that the IIA assumption holds not true for our sample, we estimate a MNL in order to show the advantages of the MMNL for this specific study. The choice of variables to enter utility were determined through exploration. It turns out that the dummy variable for profile mathematics/science is not significant because nearly every college offers this profile. The log of $d_{is}$ yields a remarkable lower pseudo-$R^2$ and we remove this variable. Experiments with different model specifications concerning the stochastic utility component show that profile 5 has to be removed from the set of variables as well. This variable distorts modelling (high final gradient norm, non-convergence) using MMNL. On the basis of these pre-examinations, the variables distance, closest school is a magnet school (dummy), $C_s$, $V_s$, private school (dummy), profile 2, profile 3 and profile 4 (all dummies) seem to be most promising and have to be considered for estimation and choice probabilities simulation. All three MMNL models have to be interpreted within an error components structure motivation, which is formally equivalent to random components structure and differs only concerning the interpretation of the utility function (Train, 2003, p.144). The three different model specifications (MMNL 1-3) are due to testing for heterogeneity in population and possible substitution patterns. In other words: Which variables enter the stochastic utility part significantly. Surprisingly, the students tastes concerning the profiles do not vary. Pre-examination show mostly insignificant standard deviation for the profiles. This suggests a distinct discrimination of tastes concerning school profiles by the dummy specification. The results of the most promising model specifications can be found in table 2.

| | | MNL | | | MMNL1 | | | MMNL2 | | | MMNL3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | | Estimate | SE | t-test | Estimate | SE | t-test | Estimate | SE | t-test | Estimate | SE | t-test |
| $d_{is}$ | mean | -.700 | .014 | -48.28 | -.726 | .014 | -51.44 | -.899 | .034 | -26.35 | -.798 | .019 | -40.05 |
| | Std. Dev. | | | | | | | .274 | .045 | 6.09 | | | |
| Centrality $C_s$ | mean | -.043* | .031 | -1.34 | -.194 | .021 | -9.35 | -.190 | .028 | -6.48 | -.158 | .026 | -5.81 |
| | Std. Dev. | | | | | | | .422 | .040 | 10.40 | .382 | .039 | 9.65 |
| Closest school is a magnet | mean | -1.150 | .155 | -7.42 | -1.090 | .157 | -6.93 | -1.676 | .236 | -7.11 | -1.384 | .190 | -7.32 |
| school (unique profile) | Std. Dev. | | | | | | | | | | | | |
| Profile 2 | mean | .496 | .163 | 3.04 | .415 | .108 | 3.84 | .459 | .134 | 3.41 | .435 | .122 | 3.53 |
| (math/science core) | Std. Dev. | | | | | | | | | | | | |
| Profile 3 | mean | .095* | .143 | 0.67 | .222 | .066 | 3.35 | .200 | .073 | 2.69 | .180 | .068 | 2.65 |
| (languages) | Std. Dev. | | | | | | | | | | | | |
| Profile 4 | mean | 1.190 | .127 | 9.35 | .504 | .107 | 4.72 | .656 | .119 | 5.48 | .634 | .115 | 5.49 |
| (languages core) | Std. Dev. | | | | | | | | | | | | |
| Profile 5 | mean | .144* | .115 | 1.26 | | | | | | | | | |
| (music/arts) | Std. Dev. | | | | | | | | | | | | |
| School size $V_s$ | mean | .554 | .049 | 11.31 | .536 | .047 | 11.24 | .527 | .056 | 9.42 | .522 | .055 | 9.57 |
| | Std. Dev. | | | | | | | | | | | | |
| Authority responsible | mean | 1.010 | .221 | 4.59 | -.736 | .319 | -2.31 | -.762 | .380 | -2.00 | -.660* | .367 | -1.79 |
| (=1, if private school) | Std. Dev. | | | | 2.280 | .320 | 7.14 | 2.538 | .402 | 6.29 | 2.358 | .390 | 6.04 |
| Log likelihood | | | -4641.13 | | | -4846.02 | | | -4800.74 | | | -4813.57 | |
| Likelihood ratio statistic | | | 7775.29 | | | 7365.50 | | | 7456.06 | | | 7430.41 | |
| pseudo-$R^2$ | | | .455 | | | 0.431 | | | .436 | | | .434 | |
| Correct predicted observations in % | | | 58.25 | | | 58.64 | | | 58.69 | | | 58.64 | |
| All variables are significant on .95 level, except * (non-significant) | | | | | | | | | | | | | |
| The number of observations is 3704 for all models. | | | | | | | | | | | | | |
| Likelihood ratio test ($\chi^2$) | | | | | | | | | | | | | |
| MNL | | | - | | | 409.78 | | | 319.22 | | | 344.88 | |
| MMNL1 | | | | | | - | | | 90.56 | | | 64.91 | |
| MMNL2 | | | | | | | | | - | | | 25.66 | |

Table 2: Estimation results

If we look at the four models we see that the coefficients of the spatial variables ($d_{is}$, $C_s$ and closest school is a magnet school) are larger for the MMNL models than for the standard logit model. The evaluation of the profiles differs between the MNL and the mixed logit models while there is no remarkable difference between the three mixed logit models. The parameter for the school size is very similar over all four models. Authority responsible shows the most striking difference between MNL (positive sign) and MMNL (negative sign) specification.

The negative sign of distance indicates a decrease in utility with increasing commuting distance. MMNL2 discovers taste variation of students evaluating commuting distance. The negative sign for centrality $C_s$ means that, ceteris paribus, colleges closer to the city center have a higher utility than those ones at the outskirts: it is most likely to assume that most individuals obtain highest utility from the closest school. Nevertheless, for some individuals the school characteristics (profiles, authority for instance) of the closest school might not be desirable and they probably choose an alternative school. Mostly, this alternative school is not within walking or biking distance. The schools located near the city center are rather good accessible by public transport or car. Moreover, the high spatial density of school locations near the city center implicates a lot of alternatives within a given distance interval. So, usually students prefer colleges close to the city center. However, the specifications for which centrality enters the stochastic part show heterogeneity. Dependent on model specification, round 31-34 per cent of the population evaluate $C_s$ positive. If so, schools located at the outskirts yield higher utility (high values of $C_s$, see table 1 and figure 1). This is because students who prefer the closest school and who are located at the outskirts gain highest utility from the closest outskirts school. As expected, all profiles increase utility, particularly the unique profiles (2 and 4) offered by magnet schools. The preferences for the profiles are ordered: The most preferred profile is "languages core" (profile 4) followed by "math/science core" (profile 2) and third "languages" (profile 3). This order is independent from model specification. The variable, which indicates whether the closest school is a magnet school, shows the expected negative sign and enters significant for all specifications. As assumed the variable compensates unrealistic high utility due to linear distance measure for those students located very close to magnet schools.

The parameter of school size $V_s$ is consistent over all model specifications. It was foreseeable that the sign would be positive, since larger schools obtain scale effects (they offer more extracurricular courses, for example) and the probability that a students application of enrollment will be rejected is lower than for smaller schools. The sign for authority responsible is positive for MNL specification. In contrast, for the MMNL specifications the sign is always negative. The standard deviation is quite huge (2.538 for example). It means that this parameter can take many values (the 95 per cent interval is [-4.94,3.41], and the 90 per cent is [-4.01,2.49]). This makes interpretation difficult to some extent. However, some information is given by this parameter. The mean is negative while 37-39 per cent of all students would evaluate private schools positive. This latent surplus could be conditional on the properties of most of the private schools, like confessional affiliation, elitist student community because of admission test and to some extent specific teaching conditions, which are different from public colleges (ecological subjects for instance). The majority of students regard these properties as repellent. According to this, the choice probability of a private school will be mostly lower than for a public school, especially for those ones far away from students home. But table 1 indicates for the private school (St. Benno) an average commuting distance which is remarkable above the overall average. So, students are willing to seek private schools over a relatively broad geography. In contrast the MNL suggests all students evaluate private schools very positive (1.01) and therefore it neglects that some students dislike private schools. So MNL does not consider taste variation which is observable using MMNL (see figure 2).

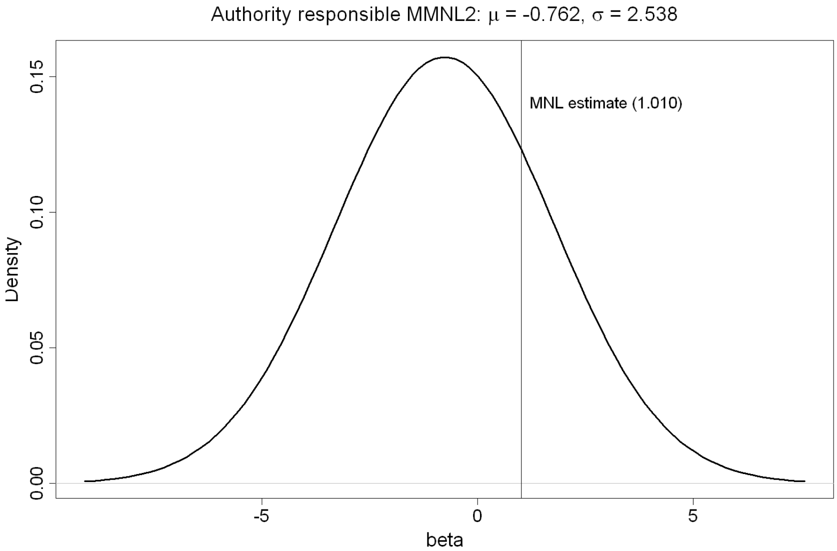


Figure 2: Estimated normal distribution for the variable "Authority responsible" of MMNL2

The substitution patterns that are implied by the models can be shown by an easy example. Suppose a private school "C" offering profile 2 (math/science core) is introduced to a base situation consisting of

- a private school "A" offering profile 3 (languages),
- a public school "B" offering profile 3.

The MNL, because of the IIA property, implies that the new school C will draw proportionately from all both schools A and B offering profile 3. In contrast, the mixed logits predict that school C will draw more proportionately from school A than from school B. Using the estimates of MNL the ratio of choice probabilities of A and B is 2.746 for the base situation and the situation with three schools. Using MMNL1 with 10 draws we get a ratio of 1.378 for the base situation and 1.030 for the situation with three schools. If we compute the relative deviation between the two situations for both models this yields .523 for A and B using MNL and .458 for A and .275 for B using the MMNL. Since we want to map substitution patterns in future school network scenarios the MNL is not appropriate here. Although the MNL has a better goodness-of-fit. All three MMNL differ significantly (see table 2). MMNL2 will be used for simulation of scenarios in the next section, because it has best explanatory quality.
Our analysis reveals that the size of a school and its service in terms of offered profiles as well as spatial patterns (here: centrality) influence school choice, besides the known attributes as stated i the literature like racial composition, academic quality, sex, proximity and authority responsible (see section 2). Moreover, our results suggest that MMNL is appropriate to regard substitution patterns between schools.

## 5 Simulation of choice probabilities

The local school authority of Dresden decided in 2000 to close three colleges in 2008 due to low student numbers. In 2006 the decision has been made to establish three new school locations in 2012 because of new college student number forecasts, which show a slight increase. In this section we utilize MMNL2 to simulate choice probabilities for three different scenarios: In 2004 - the year when the survey was accomplished - there are 20 colleges open (first scenario). In 2008, the second scenario, the colleges Joseph-Haydn, Fritz-Löffler and Großzschachwitz will be closed. This yields a reduced choice set (17 colleges) for simulation. In the third scenario (2012) the new colleges Bühlau, Seidnitz and Bürgerwiese will be opened (see fig. 1). So the choice set consists of 20 available schools in 2012. Although small scale data (block level) on student numbers and commuting distances are available, the choice probabilities for each scenario are simulated on district level for visualization purposes. No data is available for the surrounding districts of Dresden. Admittedly, there are no colleges located in the surrounding districts close to the city limit. So the simulated choice probabilities are expected to be realistic, since no colleges outside Dresden would attract students from within the city limits. We employ BIOSIM for simulation (Bierlaire, 2005). The number of draws is set to 1000 to derogate variance.

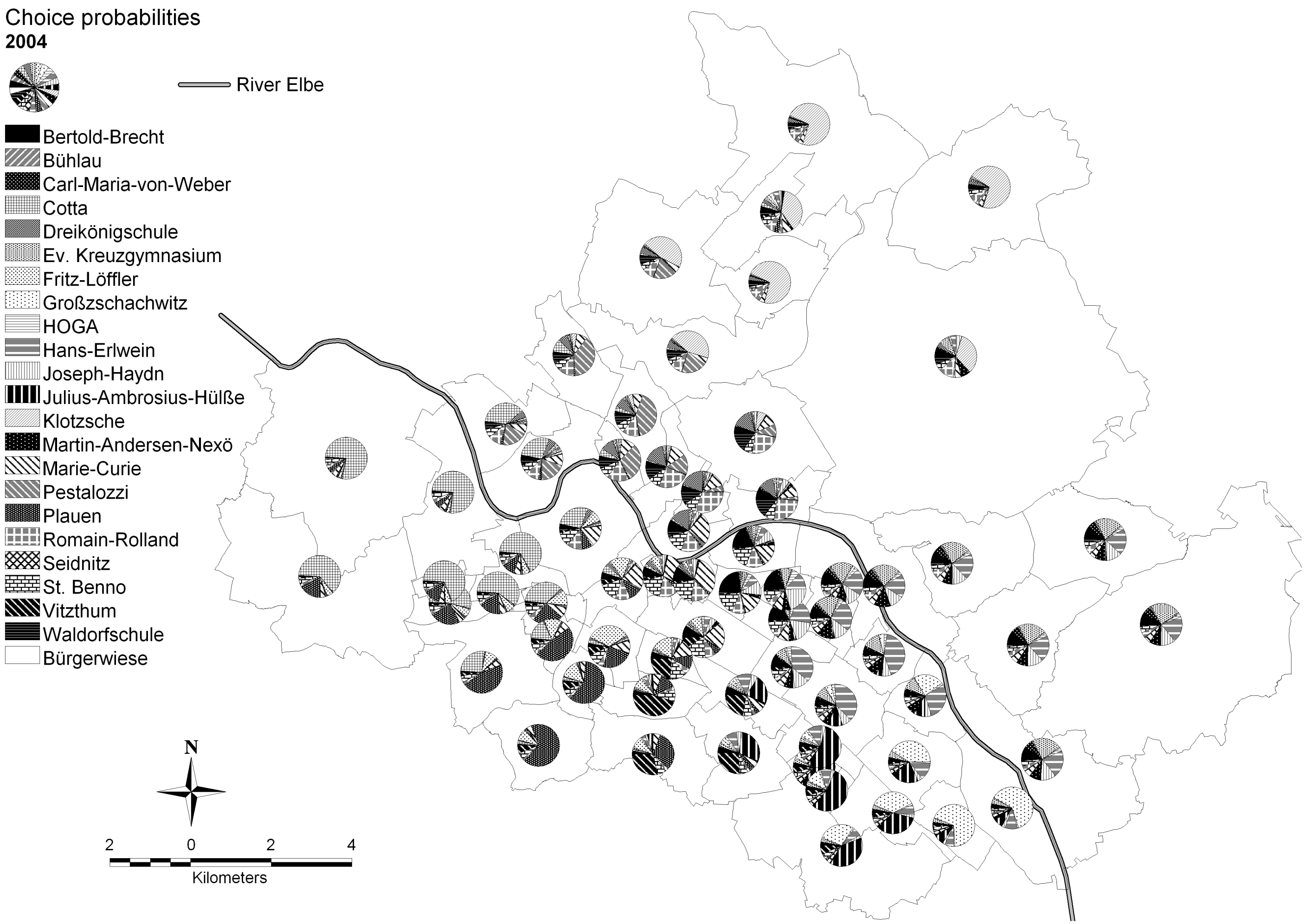


Figure 3: Scenario 1 - 2004

Figure 3 displays the simulated choice probabilities for 2004. Expectedly, districts located at the outskirts show high choice probabilities for just one particular college, which is the closest school location due to the generally long commuting distances to other college locations for these districts. This is Klotzsche College in the north and Cotta College in the west for instance. Districts located closer to the city center show a diversified choice probability pattern, because of significantly more schools within a given distance interval. It is noteworthy, that the districts in the south-east (north of the river Elbe) have a diversified choice pattern, too, although they are located at the outskirts. This is conditional on the lack of river crossings within this area and no college is located here. Due to missing ferries or bridges, the river has a spatially strong separating impact in this area. Comparing the choice probabilities of the two most south-eastern districts both sides the river, this impact becomes apparent. The closest bridge is located round 10 kilometers away from the south-eastern edge following the river toward the city center. At this point exists access to a spatial cluster of colleges (for example: Martin-Andersen-Nexö, Carl-Maria-von-Weber, Ev. Kreuzgymnasium, see fig. 1). This spatial characteristic leads to the observed diversified choice probabilities.
Besides these spatial distinctions of choice probabilities there are patterns observable, which are more alternative specific. For many districts there is a relatively high choice probability of Romain-Rolland College, which is a magnet school. This college is very attractive for many students throughout the city due to the combination of profile 3 and 4. The location close to the city center implies good accessibility, especially by public transport. Particularly, for the northern outskirts there is a remarkable choice probability of this college. The dummy variable which identifies the closest school as a magnet school yields the desired effect: the districts close to Romain-Rolland College do not show unrealistic high probabilities.
The most noticeable difference between scenario 1 and 2 (see figure 4) is the increase in choice probability of Julius-Ambrosius-Hülße College for the districts in the south-east conditional on the closure of Großzschachwitz College. A comparable phenomenon can be seen in the south-east/central districts. Here, the closure of Fritz-Löffler College leads to increased choice probabilities of Plauen and Vitzthum College. The shift in choice probability due to the closing of Joseph-Haydn College are not really discernible compared to the ones mentioned before. The location of Joseph-Haydn within a spatial cluster of several other colleges offering the same profile (Carl-Maria-von-Weber, Bertold-Brecht, for example) leads to only marginal changes in probabilities. The opening of Bühlau College in 2012 (see figure 5) results in a dramatic shift of probabilities in the eastern districts north of the river Elbe. In 2012 these districts show the same pattern like districts in the north and south-west outskirts. The probability of Bürgerwiese College in the (south-) central districts and the probability of Seidnitz College (south of river Elbe) are less flashy but still well noticeable. All together, the most significant changes in choice probabilities occur in the south-east of Dresden, particular due to the closure of Großzschachwitz College and the opening of Seidnitz and Bühlau College.

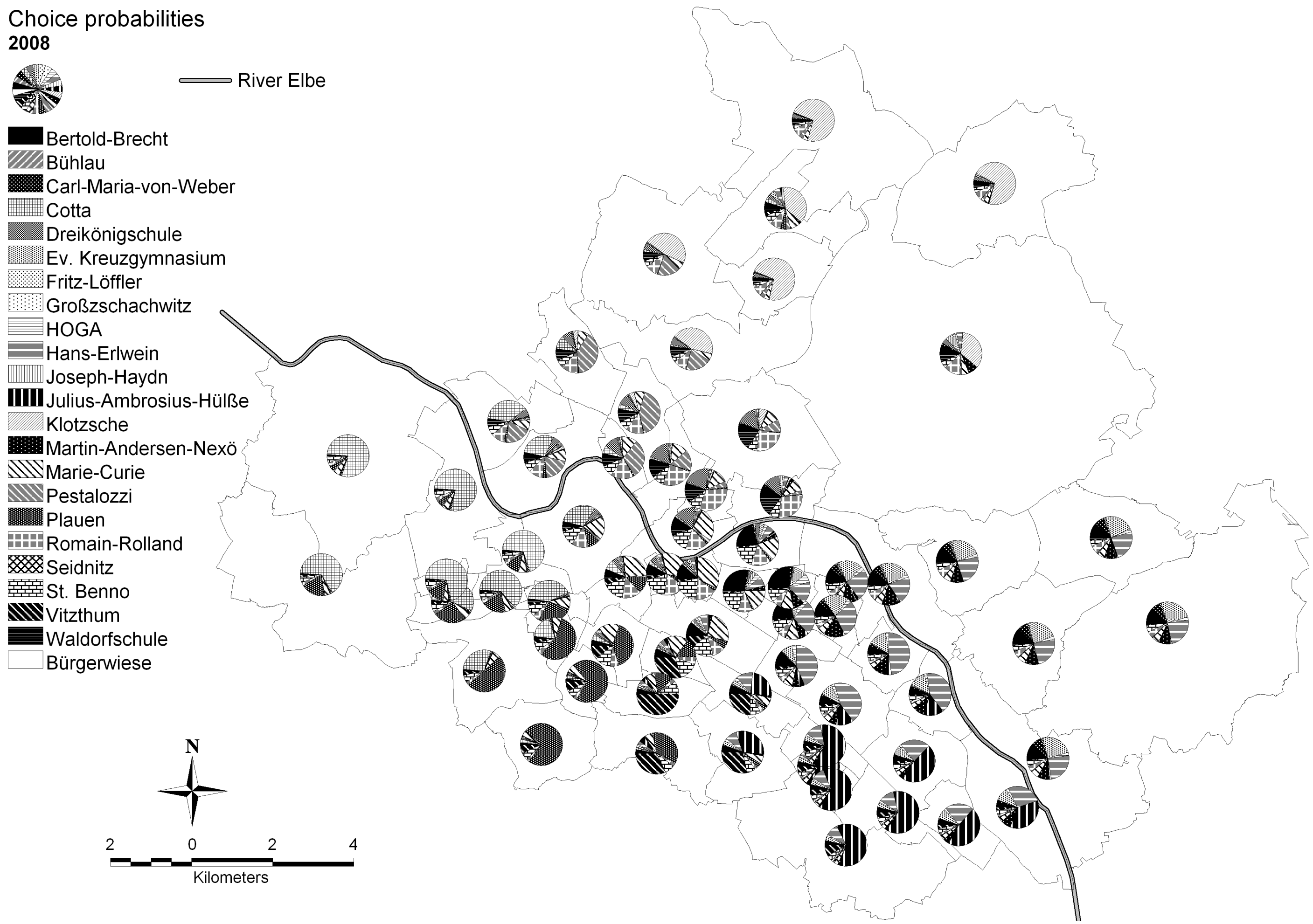


Figure 4: Scenario 2 - 2008

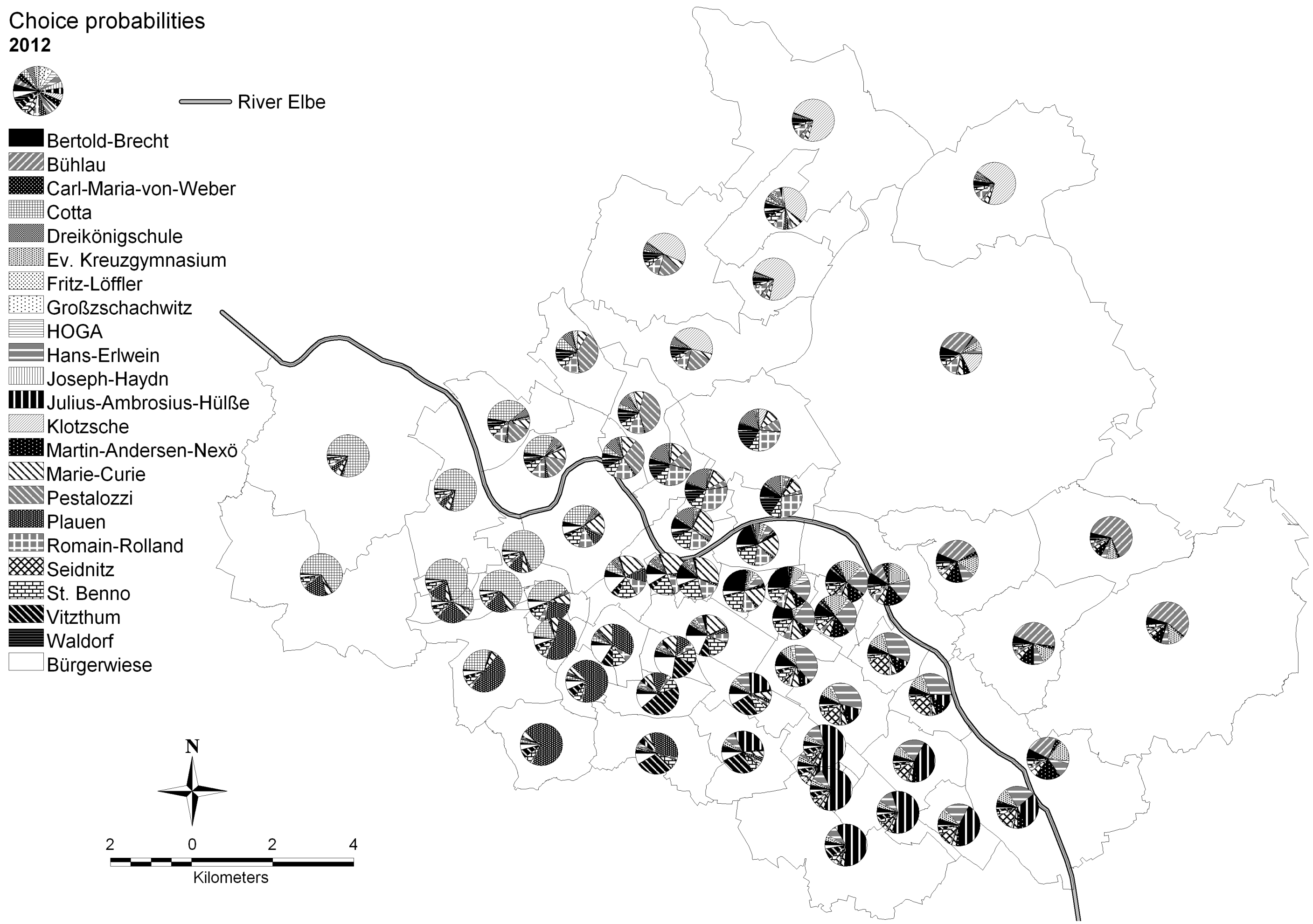


Figure 5: Scenario 3 - 2012

Figure 6 displays the share of students for each college in the years 2004, 2008 and 2012. "Shares" have to be interpreted as potential of students, since capacity is not considered. Therefore, students will not be rejected attending a certain college.[7] Unfortunately, there is no data available about the actual shares. The local school authority provides the number of students attending a given school. But there is no distinction between students located in Dresden and students not located in Dresden. Moreover, the forecast of student numbers does not tell us about the proportion of college students. We approximate this proportion from our survey. For these two reasons we do not compare actual shares with those computed here.
Schools located in the city center exhibit a relatively high share of students due to $C_s$ and school size (Marie-Curie) or combination of profiles (St. Benno, Romain-Rolland) as well as the relative large number of students located near the city center. For some colleges (Klotzsche, Pestalozzi, for example) the changing choice sets do not have a great impact, because they are located far away from areas affected by school closures/openings. It is striking, that the shares of the colleges Julius-Ambrosius-Hülße, Hans-Erlwein, Vitzthum and Plauen are very fluctuant. The net gain or loss of each college for the whole time span is given by figure 7. The colleges Julius-Ambrosius-Hülße, Plauen, Cotta and Vitzthum gain student shares, because of the school closures in their proximate surroundings. The increase of student shares for Marie-Curie and St. Benno is conditional on the attractive location, while the gain of shares for Romain-Rolland College is due to its combination of profiles. Colleges Cotta and Martin-Andersen-Nexö have gained shares although colleges Bürgerwiese and Bühlau have been opened within their surrounding. This is due to size (Cotta) and profiles (Martin-Andersen-Nexö). In contrast to this, colleges Ev. Kreuzgymnasium and Carl-Maria-von-Weber loose more students to the new colleges than they have gained from the closed ones. These two schools are located in the center close to the three new schools. They do not maintain large capacity nor do they offer unique profiles.

[7] Even public colleges could reject students due to capacity reasons.

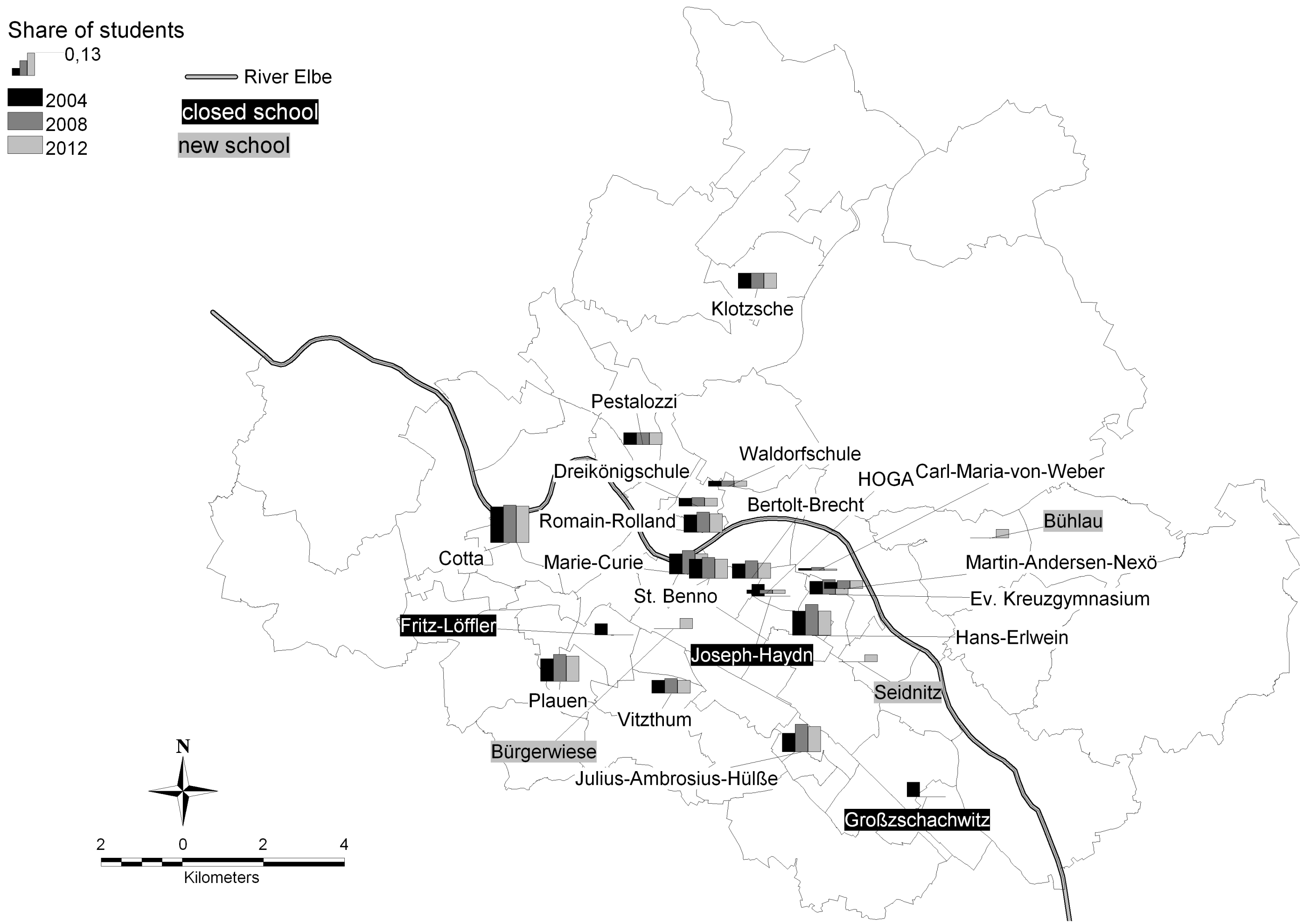


Figure 6: Share of attending students for scenarios 2004, 2008 and 2012

## 6 Conclusion

With declining student numbers school authorities are forced to close school locations accompanied by changing choice sets for students. So it is worthwhile to know about the impacts on school choice behavior. As already stated in the literature we found that distance has the strongest influence on school choice. But our analysis yields significant influence of profiles, authority responsible, centrality and capacity on school choice as well. Unique profiles and school size cause a remarkable surplus in utility. Hence, a specialization on a certain subject (like languages) will increase choice probability. While competition rises with declining student numbers, the consequence of these results is to focus on specific profiles. However, from the point of view of educational policy it is questionable whether such development is desirable.
By reason of changing choice sets over time it is important to model realistic substitution patterns. Therefore, we have used the flexible MMNL, which enables to analyse heterogeneity within population. Our analysis revealed significant taste variation for private schools, distance and centrality. The unobserved students preferences on the specific properties of private and public schools act as a nesting structure. Concerning distance and centrality there is taste variation for some students due to the spatial patterns of the school locations.
It was foreseeable that the surrounding districts of closed or opened school locations show plainest changes in choice probabilities. Nevertheless, the scenario simulation detected changes in probability for more distant districts. The net gain and loss of student share for each college is associated with these results. Even colleges located far away from closed or opened colleges show a significant variation of student share over time. Thus, an approach which assumes each student chooses the closest school location is not appropriate for dynamic school network planning.
In summary, school choice is strong influenced by spatial factors. Educational contents are more subordinate while still important. Future research determining school choice behavior should incorporate individual-specific data, particularly spatial dependencies of individuals, and school characteristics (alternative specific).

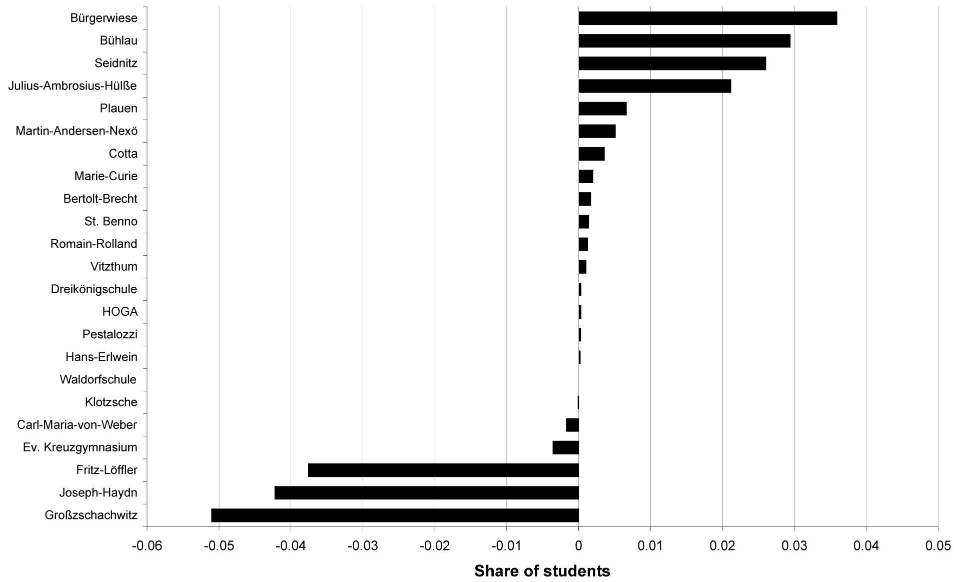


Figure 7: Net gain and loss in student share 2004 - 2012

# 7 Appendix

The simulated probabilities are computed as follows:

(1) Draw a value of $\beta$ from $f(\beta|\theta)$ and label it $\beta^r$ with superscript $r = 1$ referring to the first draw.

(2) Calculate $L_{is}(\beta^r)$ with this draw.

(3) Repeat steps 1 and 2 $R$ times and average the results as $\check{P}_{is} = 1/R * \sum_r^R L_{is}(\beta^r)$.

$\check{P}_{is}$ is the unconditional probability used to calculate the simulated likelihood function. $\check{P}_{is}$ is strictly positive and an unbiased estimator of $P_{is}$ by construction. Its variance decreases as $R$ increases. As Bierlaire (2003) recommended we set $R = 1000$. We use BIOGEME 1.4 for estimation with implemented Unix's pseudo random number generator. Other possible methods are Halton sequences and Modified Latin Hypercube Sampling. A deeper discussion is not covered within this paper. $\check{P}_{is}$ is smooth in $\theta$ and all variables and it sums to one over all alternatives. So the simulated probabilities are inserted into the log-likelihood function to give a simulated log likelihood:

$$SLL = \sum_{i=1}^{I} \sum_{s=1}^{S} y_{is} ln \check{P}_{is} \tag{4}$$

where $y_{is} = 1$ if student $i$ chooses school $s$ and zero otherwise. The maximum simulated likelihood estimator (MSLE) are the values of $\beta$ and $\theta$ that maximize SLL by iteration. The properties of this estimator are discussed in (Train, 2003, p.253-260). A trust-region algorithm (Conn et al., 2000) named BIO is used for optimization (Bierlaire, 2005). The number of students attending a given school within our choice-based sample do not represent the actual numbers. So we have to use the weighted exogenous sampling maximum likelihood (WESML) estimator to obtain consistent estimators for the MMNL. Since we do not consider alternative specific constants we use ESML for the MNL.

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