A plea for microsimulation

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KEYWORDS

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ABSTRACT

German demographic or educational projections are conventionally based on macrosimulations. Macrosimulation models use average values of the simulation parameters to compute the updating process. Additionally, the proportions of educational graduate rates stay constant in these models. In this paper I introduce a discrete event microsimulation model which is designed to project the graduate rates of the German population. With this simulation model it was demonstrated that the development of the graduation rates can become the subject of the simulation.

INTRODUCTION

Since the late 1950s, a similar development can be observed in all western industrial countries. This development can be described as an increase of the educational demand and, as a consequence, an increase of the educational level of the society (Hradil 2006; Allmendinger et al. 2010; Geißler 2008). The proportion of students with a lower educational attainment decreased between 1955 and 2000, whereas the proportion of students with an intermediate and high educational attainment increased (Allmendinger et al., 2010). Afterwards, the development can be described as a polarization of educational attainment. The proportion of students with an intermediate educational attainment stagnates whereas the development of the rest continues as the patterns before (Hannappel, 2015). In the political and scientific discourse, this development is usually called "the educational expansion".

Germany occupies a middle rank in the PISA study (The Programme for International Student Assessment) (Deutsches PISA-Konsortium, 2001) which lead to a public and political controversy about the structure, the aims and the curriculum of the German education system. Hence, education policy becomes more and more important. Whereas the sociopolitical point of view focused on the development of the educational level of the population[1], the educational policy focused on the educational participation of the next generation, e.g. the transition rates within the education system and the graduation rates. Therefore, a main point for policymakers is to provide an adequate educational infrastructure and a sufficient number of teachers (Klemm, 2012). However, educational reforms and teacher-training need time. Hence, education planning needs an anticipatory approach. To calculate the potential demand, policy makers need information about possible (or most likely) future developments of educational attainment. Educational projections of those developments are usually used as an information tool (Kultusministerkonferenz, 2002).

Problem: The German 'Kultusministerkonferenz' (KMK)[2] regularly calculates educational projections since 1963 (Kultusministerkonferenz, 2002). The projection of the graduates of the education system are not calculated completely by the KMK. The calculation is based on a population projection of the German Statistical Office (GSO). The GSO uses macrosimulation for the population projections (Statistisches Bundesamt, 2009). Macrosimulation models use mean values of certain parameters to project a system status (in the case of a population projection it is the age structure of a society) into the "future". The parameters of the population projection are *fertility*, *migration* und *mortality*. The KMK uses these results to calculate the future graduates of the german education system (Kultusministerkonferenz, 2013). Additionally, the KMK uses current education transition rates and applies them to the calculated future population. At this point, however, there is a structural problem. The transition rates which are used for the calculation are percentage proportions of students who leave the school with a certain graduation. These proportions remain constant during the macrosimulation. Nevertheless, the previous development of the graduation rates never remain constant. From this point of view, the problem of this kind of projection is the structural separation of population projection and education projection.

Objectives: In this paper I present a simulation method which solves the problem of the separation. Instead of a macrosimulation model, I use a microsimulation model to project possible developments of educational attainment. Whereas an expansion of microsimulation models and techniques can be observed during the last decade (Li and O'Donoghue, 2013), a similar development is not recognizable for Germany.

Approach & Method: The projection of the educational attainment is based on an event-oriented dynamic microsimulation approach. Microsimulation models calculate single bio-

[1] A widespread assumption is that an increase of the educational level leads to an increase of prosperity and social innovation capability (Anger et al. 2006; Becker 1994; Bildungsberichterstattung 2006; Picht 1964).

[2] The KMK is a conference of the education ministers of the different German federal states.

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graphic events (e. g. *birth*, *partnership*, *education*, *death*, etc.) for every agent[3]. This method allows to implement different kinds of calculations, which determine time as an interval until an event will occur. All operations within the simulation are regarded as chronological sequences and every event occurs at a discrete time. The probability of single events can be calculated by conventional statistic methods. Furthermore, transition probabilities of a single event can be calculated depending on other events (independent variables), e.g. sex, age, educational status (Hannappel and Troitzsch, 2015). The calculations are based on macro-structural analyses, e.g. the calculation of the probability of women to give birth to a first child depending on age and educational status. This structure enables to analyze interaction effect between macro phenomena like the influence of demographic processes on educational attainment. Whereas the graduate rates remain constant in the macrosimulation model of the KMK, these rates are the subject of the microsimulation model.

Contributions: The construction of a microsimulation model needs time, manpower and money. As a consequence, the usage of microsimulation models is usually a privilege of larger (commercial) research institutes. The methodological discussions about different approaches and techniques takes place rather in the so called 'method reports' or 'discussion papers' than in scientific Journals (Axelrod 1997; Hannappel and Troitzsch 2015)[4]. This is unfortunate, because microsimulation models have a special analytical potential and can be used as an addition to conventional statistical methods. In particular, the current political situations make models necessary which are able to consider complex social phenomena in order to test possible future scenarios and to help policy makers make their decisions (Mannion et al., 2012).

Structure: Within microsimulation models, biographical events have to be modeled. It is necessary to have some knowledge about the factors the single events are influenced by. The first section discusses the main factors of the important events. Afterwards, I present the module structure and with the example of the event *first transition*, I will give an introduction to the operation mode of the simulation algorithm.

THEORY

As mentioned above, the microsimulation model, which will be discussed in the method section, cancels the separation between population projection and education projection. The microsimulation model considers educational processes and demographic processes. To construct a theory based model, assumptions from an educational theory as well as from demography theory are necessary. The main findings of the simulation are presented in the section "result" and discussed in the last section.

[3]Agents are simulated individuals or cases/actors from the starting dataset.

[4]Exeaptions are "The Journal of Artificial Societies and Social Simulation (JASS) http://jasss.soc.surrey.ac.uk/JASSS.html and the "International Journal of Microsimulation" http://www.microsimulation.org/ijm/

Educational sociology:

It is well known from numerous national and international studies that individual educational decisions are dependent on an individual‘s social origin (Boudon 1974; Bourdieu 1982; Becker 2000; Becker 2010; Geißler 2005). The international comparison shows that the correlation between social origin and school performance is especially high for Germany (Deutsches PISA-Konsortium, 2001). The German education system is characterized by a horizontal stratification. After primary school the parents have to decide whether their children will go to a lower secondary, middle or higher secondary school. Basically, there are three main transitions: 1) the transition from primary school to secondary school, 2) transitions within secondary school (from one school type to another) and 3) the transition after secondary school to university or to vocational training or job.

1) The transition from primary school to secondary school is the most important transition for individual educational careers (Becker 2000; Becker and Lauterbach 2010; Ditton 2010; Henz and Maas 1995; Solga and Wagner 2010). This is mainly caused by two reasons: a) only a small number of students change the initially selected school type and b) a high correlation between educational graduation and occupational careers. 2) Transitions within secondary schools are rare; most transitions are downgradings (e.g. from high secondary schools to middle secondary schools) (Baumert et al. 2003; Solga and Wagner 2010). 3) Finally, a lot of studies show that the transition to university is dependent on the social origin as well(Middendorff et al. 2013; Müller et al. 2011).

Demography:

In the demographic research, two main factors have crystallized as important for fertility behavior: 1) region and 2) education.

1) Even 25 years after the German reunification, there are stable differences in the fertility behavior between West(ern) and East(ern) Germany. Women from West-Germany give birth to their first child later, have a higher rate of childlessness and generally have a lower number of children (Kreyenfeld and Konietzka, 2004).

2) Furthermore, it is well-known that the probability to give birth to a child varies between women with different educational status. The higher the educational level of women, the lower the probability to give birth to a child (Blossfeld et al. 1991; Brüderl and Klein 2003; Herlyn et al. 2002; Klein and Lauterbach 1994; Wirth 2007). Other factors like class, employment and religious denomination are less important (Höpflinger, 2012)

These findings were considered by the construction of the microsimulation model[5].

[5]The points listed above are rather empirical than theoretical findings. However, this paper is not the place for a detailed reception of the theoretical explanations. Boudon (1974) and Bourdieu (1982) give a deep insight into the relation between the social phenomena which are discussed above.

Fig. 1. Elements of microsimulation models

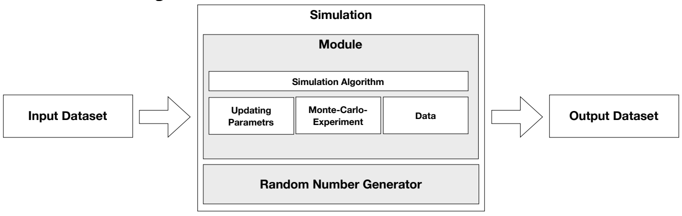
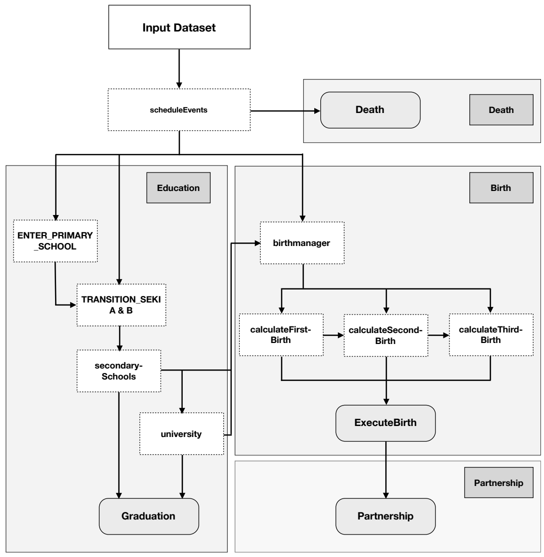


Fig. 2. Overview: Modules



METHOD

Microsimulation:

Figure 1 shows the main elements of a microsimulation. At first, a dataset is necessary. During the simulation, the dataset will be updated to a certain time point (t_T) depending on decision rules which are implemented in the model (Gilbert and Troitzsch 2005; Spielauer 2009). Dynamic microsimulation models can either be modelled with a period approach or with an event-orientated approach. Whereas the former ones model time as a process between determined time intervals (mostly one year), event oriented simulations model time as a random variable which is simulated as the time between two events. In period-oriented models, the simulation runs from one time step to another. In event-oriented models, the simulation runs from event to event. The events like *birth*, *school enrolement*, *marriage*, etc. are organized in single simulation modules. The main item of a simulation module is the simulation algorithm. Simulation algorithms are formalized program codes which structure the order of the modules. In combination with Monte-Carlo-Experiments (Galler 1997; van Immhoff and Post 1998), the simulation algorithms decide whether an event occurs to an agent or not. Finally, the result of a simulation model is a fictitious dataset which includes the simulated population. The advantage of microsimulation is that the outcome of these models has the same structure as the input dataset. Consequently, the dataset can be analyzed with the conventional statistical methods and software.

The model:

Figure 2 gives an overview of the model structure. I used the Scientific Use File (SUF) 2008 as the input dataset. The SUF is a 70% subsample of the microcensus which includes 477 239 individuals. The microcensus is a 1% annual census of the German population which includes a lot of questions about socio-economic issues. The simulation starts with a *scheduleEvent*. All actors from the starting population and all agents[6] have to pass this event. Within this event, a simulation algorithm checks the characteristics of the agents and decides what will happen next to the agent.

In contrast to conventional statistical methods, microsimulation models are more complex. The description of the single modules, the simulation algorithms, the calculation of the transition rates and the description of the different datasets, which are the basis of the calculations, is too complex for this paper. Hence, I will describe the single modules in a simplified way and will then describe how the simulation works by the example of a single event[7].

Death: The module *Death* is the first module the individuals have to pass. The simulation algorithm calculates the exact time of death for every individual. The time of death is a result of a comparison between a survival function value which is taken from the life tables of the German Statistical Office and a random number, which is drawn for every individual, i. e. the calculation of the date of death is the result of a Monte-Carlo-Experiment.

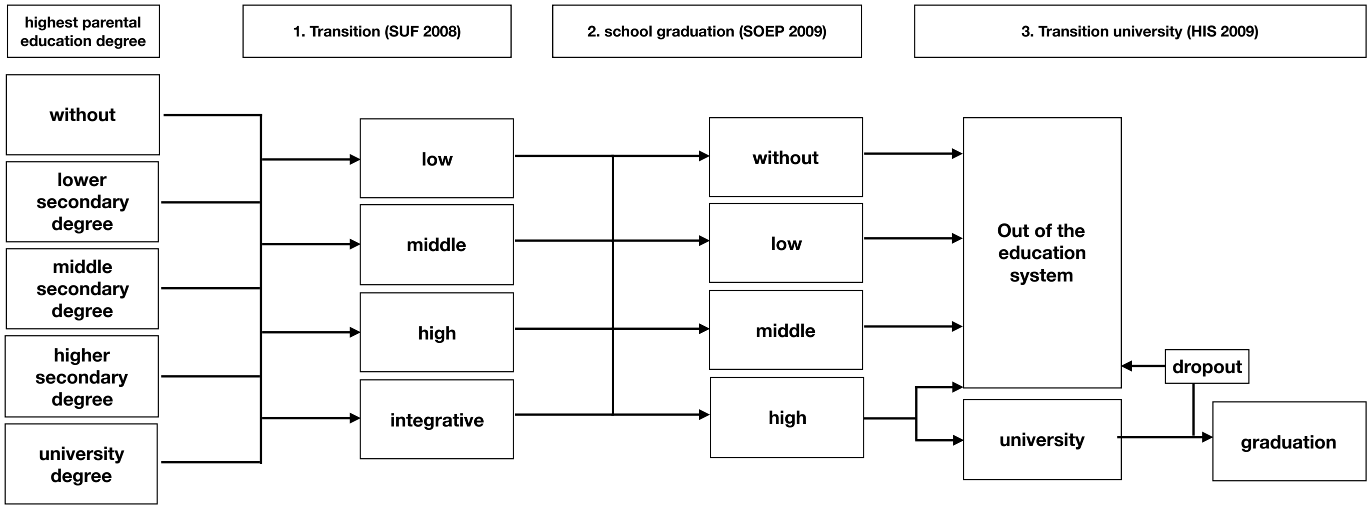
Education: Within the module *Education*, the simulation algorithm decides which kind of educational attainment will be assigned to an agent considering his or her "parents". This module takes into account the different social selectivity mechanisms within the German education system (see the section 'Education model').

Birth: The module *Birth* consists of three different submodules (*calculateFirstbirth*, *calculateSecondtbirth* and *calculatethirdbirth*. The submodule *calculateFirstbirth* calculates the day when a certain women will give birth to her first child depending on her educational status, age and whether she lives in West or East Germany. The submodule *calculateSecondtbirth* and *calculateFirstbirth* calculates the day of birth of the second and the third child as well. However, whereas the first birth is calculated as the age of the women by her first birth, the second and third birth is calculated as the distance between

[6]The input dataset includes information from real persons. These cases are called 'actors'. During the simulation the simulation model creates new cases (e. g. if a "child" is born). Cases which are created by the simulation are called 'agents'

[7]For a detailed description of the complete simulation see (Hannappel, 2015)

Fig. 3. Modul: Education



first and second and second and third birth[8].

Partnership: Finally, when a woman gives birth to a child, a partner is matched by education and age. As a consequence, fertility is modeled independently of partnership. This approach is oriented towards an approach that Martin Spielauer (2003) used in a model for the Austrian society.

The module education:

Figure 3 shows the empirical model of educational decisions. The education module considers three transitions. The first transition is the transition from primary to secondary school. The second transition calculates the school graduations of the agents and the third transition is the transition to university. This structure is based on the main empirical findings from the educational sociological research.

The first transition is calculated depending on the social origin of the students. I calculated the probability of a transition decision depending on the highest parental educational degree. For the calculation I used the SUF 2008. This dataset is used for the simulation as well. The school graduation is calculated depending on the school type of the secondary school in Germany. Principally, it is possible to catch up a school graduation. Therefore, I calculated the probability to get a certain graduation depending on the school form the students visit during secondary school. For those calculations, a panel dataset is necessary. Hence, I used the Socioeconomic panel (SOEP) from the German Institute of Economics (DIW) (Siegel et al., 2010). As mentioned above, the transition to a university is highly correlated with the social origin of the students. For this calculation, I used another panel dataset, the "Studienberechtigtenpanel" (Spangenberg et al., 2011) from the Hochschulinformationssystem (HIS). With this dataset, it is also possible to calculate the probability of the transition to university depending on the social origin of the students.

Example: the first transition

Table I lists the probabilities for the first transition depending on the social origin of the students. The probability for children from parents without an education degree to visit an integrative school[9] amounts to 10,4%. It is also shown that the transition rates vary between the parental education categories. The higher the parental education degree, the higher the probability to visit a high school type. Using the example of students from parents without an education degree, it will be shown how the simulation algorithm of the first transition works.

TABLE I
TRANSITION RATES OF THE FIRST TRANISTION DEPENDING ON THE HIGHEST PARENTAL EDUCATION DEGREE (IN PERCENT)

	highest parental education degree				
school type	Without	low	middle	high	university
integrative	16,1	10,4	10,2	10,3	8,8
high	6,3	11,3	27,6	45,2	67,3
middle	22,3	34,6	43,4	31,5	18,6
low	55,3	43,6	18,8	43,6	5,3
N	415	3248	4766	1722	2875

Source: FDZ der Statistischen Ämter des Bundes und der Länder, Scientific Use File 2008, own calculations, weighted with EF952, [2]unweighted

The simulation algorithm operates with integers between 0 and 100 000. Therefore, the percentage values have to be converted into integer values. Table II lists the percentage values (for students from parents without an education degree), the cumulative frequencies, the values for 1 - the cumulative

[8]The calculation method is described in a previous paper of the ECMS conference (Hannappel et al., 2012), see also (Hannappel and Troitzsch, 2015) or (Hannappel, 2015).

[9]Integrative schools in Germany are schools which integrate all school types, i. e. students from this school type can reach all kinds of school leaving qualifications.

frequencies and the simulation values. The simulation values are the values vor 1 - the cumulative frequencies multiplied by 10 000. These are the values which are used in the simulation.

TABLE II
CALCULATION OF THE SIMULATION VALUES

school type	Percent	Cum. Frequencies	1-Cum. Frequencies	Simulation Values
integrative	10,4	10,4	0,9	100 000
high	11,3	21,8	0,78	89 569
middle	34,6	56,4	0,44	78 247
low	43,6	100	0	43 628
N[2]	3248			

Source: FDZ der Statistischen Ämter des Bundes und der Länder, Scientific Use File 2008, own calculations, weighted with EF952, [2]unweighted

First of all, the random number generator draws a random number between 0 and 100 000. The simulation algorithm compares this random number with the number of the second row from the column "Simulation". If the random number is larger than 89 569, the agent will sign as a student on an integrative school form. Otherwise the random number will be compared with the value of the third row (category "middle"). If the random number is larger than 78 247, the agent will sign as a student on a high school type. This process will be repeated until a suitable category is found. This approach is called "Monte-Carlo-Simulation" and is based on the probabilistic assumption that a large number of Monte-Carlo-Experiments leads to an approximation of the empirical values to the simulated cases.

$$lim_{n \to \infty} P(|p(A) - P(A)| \leq \varepsilon) = 1 \quad (1)$$

(Kühnel and Krebs, 2001, S. 132 f.)
The transitions of agents from the category "parents without an education degree" during the simulation should be similar to the implemented values from table II.

Verification

The probabilistic design of microsimulation models leads to the problem that the results of microsimulations vary from simulation run to simulation run. Additionally, prospective simulations can not be validated[10]. One possibility to test the correctness of the simulation model is to verify[11] the model. Hence, to verify the model, the divergence of the output values from the input values have to be analyzed. Figure III shows the results of the chi-square test.

Besides only a few exceptions, the chi-square test shows that the model works in a desirable way. The main modules

TABLE III
VERIFICATION: CHI-SQUARE-TEST & R^2

		χ2	df	Sig	R2			χ2	df	Sig	R2
Bildung	OA	4,6	4	0,33	0,998	Geburten (West)	OA	3,8	3	0,28	0,998
	HS	4,4	4	0,35	0,999		HS	1,2	3	0,75	0,999
	RS	7,1	4	0,13	0,999		RS	4,6	3	0,20	0,999
	Abi	0,2	4	0,71	0,999		Abi	4,3	3	0,23	0,998
	Uni	0,4	4	0,63	0,999		Uni	6,9	3	0,07	0,996
Partnerschaft	HS	195,9	4	0,00	0,997	Tod	Männer	89,25	100	0,77	0,999
	RS	620,2	4	0,00	0,930		Frauen	103,6	100	0,28	0,999
	Abi	280,5	4	0,00	0,952						
	Uni	170,8	4	0,00	0,999						

(*Birth* and *Education*) show (nearly) no significant deviations. The goodness of fit (R^2) is almos above 90 % and mostly above 99 %. Only the module *partnership* shows significant deviations[12]

RESULTS

Figure 4 shows the development of the real educational attainment until the year 2012 and the results of the simulation for 2013 to 2050. The simulation results are based on the analysis of the agents from the age group from 26 – 35 years. Because of the low number of cases the analyses of the ALLBUS dataset are based on the 30 – 40-year-old population. The age when the agents get a certain graduation depends on the simulated educational career. Agents with a low school career get their graduation at the age of 15, with a middle graduation at the age of 16, with a high graduation at the age of 19 and with a university graduation at the age of 25. Therefore, the analysis of the simulation results can only be calculated for the agents from the age of $\geq$ 26.

The simulation results show a plausible development. The proportion of agents with at least a high graduation increases from 42,5% to 46,6%. Hence, the simulation continues the educational expansion. Interestingly, the proportion of agents without a school graduation remain constant over the simulation time. This is remarkable because the population without a school graduation is characterized by a very high birth rate. The results show that different fertility rates are overcompensated by educational mobility.

The development until the year 2025 may seem very plausible at the first sight. However, the reduction of the percentage of agents with at least a high graduation needs an explanation. The problem is caused by a problematic heuristic for the calculation of the transition for people in vocational training. These students where handled like students on an integrative school. This leads to an overestimation of the agents with a high graduation at the beginning of the simulation. This needs to be corrected in further simulation models. Therefore, new analyses with other datasets are necessary.

Despite the slight bias, the simulation results show:

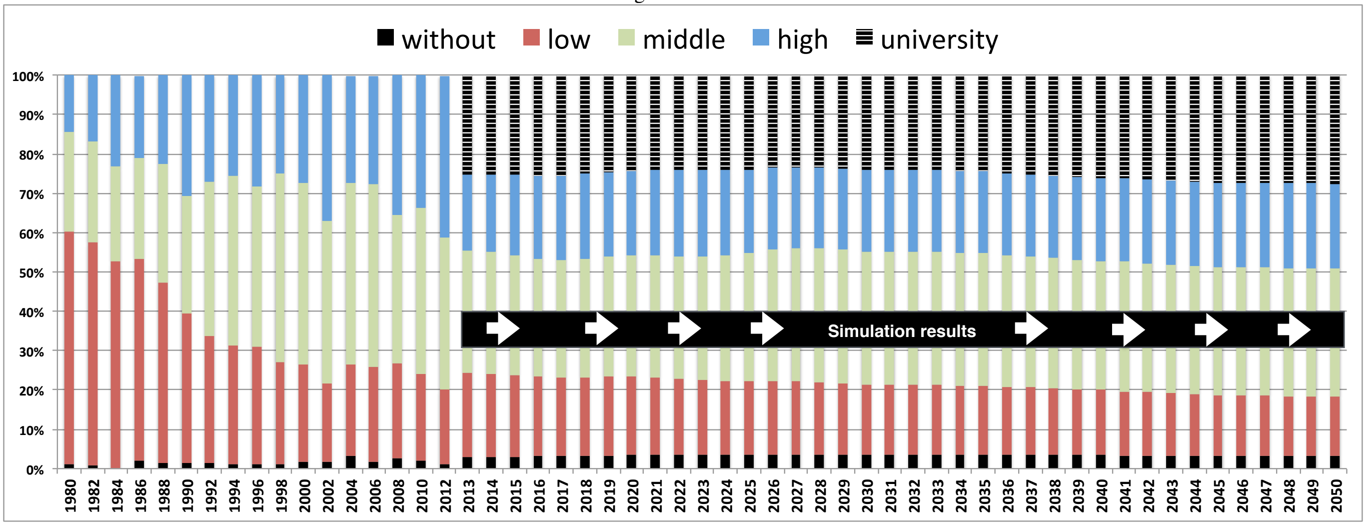
- A continuation of the educational expansion in the upcoming years.

[10]The only possibility to validate prospective simulations is to wait until the real time has reached the end of the simulation time to compare the simulation results with the real development. It is clear that this is no constructive approach.

[11]Verification in the context of simulation models means the "process of checking that a program does what it was planned to do" (Gilbert and Troitzsch, 2005).

[12]Further analysis with percentage deviations, which cannot be described in this paper, shows that the differences between implemented values and the simulation results are very small (Hannappel, 2015).

Fig. 4. Results



Source: 1980 – 2012: ALLBUS 1980 – 2012 (adjusted version of the variable *v668*), 2013 – 2050: simulation results

- However, the increase of this expansion will loose momentum.
- The expansion is largely constituted by educational mobility.

CONCLUSIONS

Conventionally, macrosimulations are used to project possible developments of the educational attainment (Kultusministerkonferenz 2002; Kultusministerkonferenz 2013). Macrosimulation models use average values of the simulation parameters to compute the updating process. This prevents the possibility of interaction effects. Additionally, the proportions of educational graduate rates stay constant in these models.

With this simulation model it could be demonstrated that the development of the graduation rates can become the subject of the simulation. Although the transition rates remain constant in this model as well (indeed on a more detailed level), the graduate rates did not. The interaction between demographic educational parameters (education model & transition rates) leads to a variation of the graduation rates during the simulation. This is the main advantage of microsimulation over macrosimulation.

Especially in times of great changes, such models are helpful in order to get a better understanding for complex developments and contexts. It would be regrettable to renounce these models.

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