# Chapter 12

# THE DYNAMICS OF EDUCATIONAL EXPANSION: A SIMULATION MODEL

**Cor van Dijkum, Niek Lam & Harry B.G. Ganzeboom**

## INTRODUCTION

Human societies generally do not develop according to a linear evolutionary pattern. Whether we look at wealth, inequality, or political institutions, a universal pattern of societal development is hardly discernible. However, there appears to be one major exception to the lack of a universal pattern: in all societies and at all times, the educational distribution seems to be expanding upward. Wherever we go and whenever we look, more recently born cohorts always have a higher level of education than previous ones. For example, in a previous study by one of the authors, comparing educational distributions of cohorts in thirty countries throughout the twentieth century (Ganzeboom & Treiman, 1993), it was found that in each society the trend in educational levels was generally upward, with very few exceptions for wartime cohorts in lower developed countries like Turkey and India.

In this chapter, we set out to investigate the mechanisms behind educational expansion. Several mechanisms can be suggested. At the macrolevel, there are two competing views of the causes of educational expansion. Neoclassical theories in economics as well as functionalistic theories in sociology tend to attribute the rising levels of education to a rising demand in the labor market for higher educated, more productive workers. According to these theories, one would expect a strong and causal relationship between industrial and economic restructuring on the one hand, and educational expansion on the other, while educational expansion should follow patterns of industrial development. This "modernism thesis" has been criticized by many: ample research shows that occupational distributions tend to react to variations in the educational stock (instead of the other way around), and even that only at some distance.

There is strong evidence for the existence of an autonomous mechanism of educational expansion, which is not directly related to demand in the labor market. Radical suggestions allude to status competition between countries and imitation between countries as the primary drives behind educational expansion. While such suggestions have their merits, they are difficult to test quantitatively. At the microlevel, a more acceptable view holds that educational expansion is the unintended consequence of what economists (Thurow, 1975) refer to as job competition, and sociologists as status competition. In each version, the basic underlying mechanism is that students observe the economic or social value of certain diplomas in society, and decide that it is rational for them to push on to a subsequent level in order to compete effectively with the existing educational stock. Whether this explanation is phrased in terms of job competition or status competition makes very little difference for the result that for members of the next cohort it is always rational to continue school longer than for the previous cohort.

Our long-term project aims to investigate and understand the mechanics of educational expansion. Research on educational expansion should address the main explanatory questions on the development of the educational distribution. Three main issues stand out in this context. First, countries—and episodes—vary in the speed of educational expansion. In some countries educational expansion takes place rapidly, in others it emerges more slowly. Under which conditions can a high speed of development or near stability be expected? Second, an important observation is that as the distribution of the population over educational levels in a society expands, the form—and in particular the dispersion—of the distribution may change. In some countries, educational expansion implies that the distribution rolls up from the bottom (i.e., in each new cohort a smaller number of lower educated appears, while the number of higher educated does not rise proportionally). In other countries, the pattern is the opposite: educational expansion implies that the number of higher educated expands faster than the number of lower educated. As a consequence, the dispersion of the educational distribution declines in the first case, and increases in the second case. A model of educational expansion should be able to account for these different patterns of development. Finally, there is the issue about who gets better access to higher education when education expands. A general pattern, found around the world, is that the children of higher status background (often best indicated by parental education) are better equipped to make a grade. An obvious question then is, does educational expansion change the chances of success of children from high-status background relative to those of less-privileged background?

Our long-term aim is to elucidate and cover all these issues by following a dual-track analytic strategy. First, variations in educational expansion are assessed in a data-analytical model by comparing survey results from a large number of countries and by relating the cohort-wise differences to empirical macroindicators. Second, we want to understand the underlying mechanics of educational expansion in a simulation model that mimics the real world closely, but introduces only a limited number of simple assumptions to reproduce the real world. While our final aim is to combine data-analytic and simulation models into one analysis and use this model to deal with all three issues on educational expansion outline above, the aim of this chapter is much more modest. We build a simulation model for educational expansion that exploits the simple assumption that expansion occurs because students, who are in school, compare their expected final outcomes to the existing stock in their society, and try to compete with the older cohorts by staying in school for a longer period. The basic drive behind educational expansion is a simple process of status comparison. The aim of this chapter is to codify this assumption in a simulation model that can account for at least one empirical result, namely the changes in the educational distribution of the Netherlands over the past century.

The data we use to calibrate our model are taken from some twenty surveys that are part of the International Stratification and Mobility File (ISMF) (Ganzeboom & Treiman, 1993). This "superfile" collects and standardizes survey data on social mobility (i.e., data on occupations and educations of parents and children) from countries around the world. The subsample for the Netherlands in the ISMF is particularly large, due to the fact that more than twenty surveys have become available for comparison. These surveys were conducted between 1958 and 1997. However, the birth cohorts contained in the

**Table 12.1**
**Percentage of Achieved Education in Different Birth-Cohorts in The Netherlands, 1900-1975**

| Cohort | Primary % | Presecondary % | Secondary % | Tertiary % | N |
|---|---|---|---|---|---|
| 1900 – 1904 | 67.1 | 18.9 | 8.4 | 5.6 | 579 |
| 1905 – 1909 | 61.0 | 20.0 | 10.9 | 8.0 | 792 |
| 1910 - 1914 | 61.1 | 23.9 | 8.5 | 6.5 | 1,268 |
| 1915 – 1919 | 49.8 | 28.6 | 12.6 | 9.1 | 1,675 |
| 1920 – 1924 | 44.6 | 29.8 | 15.5 | 10.1 | 2,479 |
| 1925 – 1929 | 38.0 | 32.2 | 18.8 | 11.0 | 2,998 |
| 1930 – 1934 | 33.6 | 34.1 | 18.8 | 13.5 | 3,386 |
| 1935 – 1939 | 27.8 | 35.6 | 21.4 | 15.2 | 3,619 |
| 1940 – 1944 | 20.2 | 39.4 | 23.4 | 17.0 | 3,923 |
| 1945 – 1949 | 14.5 | 40.4 | 25.5 | 19.6 | 5,170 |
| 1950 – 1954 | 13.5 | 36.1 | 27.7 | 22.7 | 5,308 |
| 1955 – 1959 | 10.3 | 33.3 | 31.7 | 24.7 | 4,987 |
| 1960 – 1964 | 6.8 | 28.8 | 39.0 | 25.5 | 3,602 |
| 1965 – 1969 | 4.8 | 26.7 | 43.5 | 25.0 | 2,406 |
| 1970 – 1974 | 2.9 | 21.2 | 45.8 | 30.0 | 1,170 |
| 1975 – 1979 | 2.5 | 17.8 | 44.8 | 35.0 | 326 |
| N | 10,043 | 14,389 | 11,232 | 8,023 | 43,687 |

educational expansion, which is not directly related to demand in the labor market. Radical suggestions allude to status competition between countries and imitation between countries as the primary drives behind educational expansion. While such suggestions have their merits, they are difficult to test quantitatively. At the microlevel, a more acceptable view holds that educational expansion is the unintended consequence of what economists (Thurow, 1975) refer to as job competition, and sociologists as status competition. In each version, the basic underlying mechanism is that students observe the economic or social value of certain diplomas in society, and decide that it is rational for them to push on to a subsequent level in order to compete effectively with the existing educational stock. Whether this explanation is phrased in terms of job competition or status competition makes very little difference for the result that for members of the next cohort it is always rational to continue school longer than for the previous cohort.

Our long-term project aims to investigate and understand the mechanics of educational expansion. Research on educational expansion should address the main explanatory questions on the development of the educational distribution. Three main issues stand out in this context. First, countries—and episodes—vary in the speed of educational expansion. In some countries educational expansion takes place rapidly, in others it emerges more slowly. Under which conditions can a high speed of development or near stability be expected? Second, an important observation is that as the distribution of the population over educational levels in a society expands, the form—and in particular the dispersion—of the distribution may change. In some countries, educational expansion implies that the distribution rolls up from the bottom (i.e., in each new cohort a smaller number of lower educated appears, while the number of higher educated does not rise proportionally). In other countries, the pattern is the opposite: educational expansion implies that the number of higher educated expands faster than the number of lower educated. As a consequence, the dispersion of the educational distribution declines in the first case, and increases in the second case. A model of educational expansion should be able to account for these different patterns of development. Finally, there is the issue about who gets better access to higher education when education expands. A general pattern, found around the world, is that the children of higher status background (often best indicated by parental education) are better equipped to make a grade. An obvious question then is, does educational expansion change the chances of success of children from high-status background relative to those of less-privileged background?

Our long-term aim is to elucidate and cover all these issues by following a dual-track analytic strategy. First, variations in educational expansion are assessed in a data-analytical model by comparing survey results from a large number of countries and by relating the cohort-wise differences to empirical macroindicators. Second, we want to understand the underlying mechanics of educational expansion in a simulation model that mimics the real world closely, but introduces only a limited number of ... real world. While our final aim is to combine data-analytic and simulation models into one analysis and use this model to deal with all three issues on educational expansion outline above, the aim of this chapter is much more modest. We build a simulation model for educational expansion that exploits the simple assumption that expansion occurs because students, who are in school, compare their expected final outcomes to the existing stock in their society, and try to compete with the older cohorts by staying in school for a longer period. The basic drive behind educational expansion is a simple process of status comparison. The aim of this chapter is to codify this assumption in a simulation model that can account for at least one empirical result, namely the changes in the educational distribution of the Netherlands over the past century.

The data we use to calibrate our model are taken from some twenty surveys that are part of the International Stratification and Mobility File (ISMF) (Ganzeboom & Treiman, 1993). This "superfile" collects and standardizes survey data on social mobility (i.e., data on occupations and educations of parents and children) from countries around the world. The subsample for the Netherlands in the ISMF is particularly large, due to the fact that more than twenty surveys have become available for comparison. These surveys were conducted between 1958 and 1997. However, the birth cohorts contained in the

**Table 12.1**
**Percentage of Achieved Education in Different Birth-Cohorts in The Netherlands, 1900-1975**

| Cohort | Primary % | Presecondary % | Secondary % | Tertiary % | N |
|---|---|---|---|---|---|
| 1900 – 1904 | 67.1 | 18.9 | 8.4 | 5.6 | 579 |
| 1905 – 1909 | 61.0 | 20.0 | 10.9 | 8.0 | 792 |
| 1910 - 1914 | 61.1 | 23.9 | 8.5 | 6.5 | 1,268 |
| 1915 – 1919 | 49.8 | 28.6 | 12.6 | 9.1 | 1,675 |
| 1920 – 1924 | 44.6 | 29.8 | 15.5 | 10.1 | 2,479 |
| 1925 – 1929 | 38.0 | 32.2 | 18.8 | 11.0 | 2,998 |
| 1930 – 1934 | 33.6 | 34.1 | 18.8 | 13.5 | 3,386 |
| 1935 – 1939 | 27.8 | 35.6 | 21.4 | 15.2 | 3,619 |
| 1940 – 1944 | 20.2 | 39.4 | 23.4 | 17.0 | 3,923 |
| 1945 – 1949 | 14.5 | 40.4 | 25.5 | 19.6 | 5,170 |
| 1950 – 1954 | 13.5 | 36.1 | 27.7 | 22.7 | 5,308 |
| 1955 – 1959 | 10.3 | 33.3 | 31.7 | 24.7 | 4,987 |
| 1960 – 1964 | 6.8 | 28.8 | 39.0 | 25.5 | 3,602 |
| 1965 – 1969 | 4.8 | 26.7 | 43.5 | 25.0 | 2,406 |
| 1970 – 1974 | 2.9 | 21.2 | 45.8 | 30.0 | 1,170 |
| 1975 – 1979 | 2.5 | 17.8 | 44.8 | 35.0 | 326 |
| N | 10,043 | 14,389 | 11,232 | 8,023 | 43,687 |

educational expansion, which is not directly related to demand in the labor market. Radical suggestions allude to status competition between countries and imitation between countries as the primary drives behind educational expansion. While such suggestions have their merits, they are difficult to test quantitatively. At the microlevel, a more acceptable view holds that educational expansion is the unintended consequence of what economists (Thurow, 1975) refer to as job competition, and sociologists as status competition. In each version, the basic underlying mechanism is that students observe the economic or social value of certain diplomas in society, and decide that it is rational for them to push on to a subsequent level in order to compete effectively with the existing educational stock. Whether this explanation is phrased in terms of job competition or status competition makes very little difference for the result that for members of the next cohort it is always rational to continue school longer than for the previous cohort.

Our long-term project aims to investigate and understand the mechanics of educational expansion. Research on educational expansion should address the main explanatory questions on the development of the educational distribution. Three main issues stand out in this context. First, countries—and episodes—vary in the speed of educational expansion. In some countries educational expansion takes place rapidly, in others it emerges more slowly. Under which conditions can a high speed of development or near stability be expected? Second, an important observation is that as the distribution of the population over educational levels in a society expands, the form—and in particular the dispersion—of the distribution may change. In some countries, educational expansion implies that the distribution rolls up from the bottom (i.e., in each new cohort a smaller number of lower educated appears, while the number of higher educated does not rise proportionally). In other countries, the pattern is the opposite: educational expansion implies that the number of higher educated expands faster than the number of lower educated. As a consequence, the dispersion of the educational distribution declines in the first case, and increases in the second case. A model of educational expansion should be able to account for these different patterns of development. Finally, there is the issue about who gets better access to higher education when education expands. A general pattern, found around the world, is that the children of higher status background (often best indicated by parental education) are better equipped to make a grade. An obvious question then is, does educational expansion change the chances of success of children from high-status background relative to those of less-privileged background?

Our long-term aim is to elucidate and cover all these issues by following a dual-track analytic strategy. First, variations in educational expansion are assessed in a data-analytical model by comparing survey results from a large number of countries and by relating the cohort-wise differences to empirical macroindicators. Second, we want to understand the underlying mechanics of educational expansion in a simulation model that mimics the real world closely,

real world. While our final aim is to combine data-analytic and simulation models into one analysis and use this model to deal with all three issues on educational expansion outline above, the aim of this chapter is much more modest. We build a simulation model for educational expansion that exploits the simple assumption that expansion occurs because students, who are in school, compare their expected final outcomes to the existing stock in their society, and try to compete with the older cohorts by staying in school for a longer period. The basic drive behind educational expansion is a simple process of status comparison. The aim of this chapter is to codify this assumption in a simulation model that can account for at least one empirical result, namely the changes in the educational distribution of the Netherlands over the past century.

The data we use to calibrate our model are taken from some twenty surveys that are part of the International Stratification and Mobility File (ISMF) (Ganzeboom & Treiman, 1993). This "superfile" collects and standardizes survey data on social mobility (i.e., data on occupations and educations of parents and children) from countries around the world. The subsample for the Netherlands in the ISMF is particularly large, due to the fact that more than twenty surveys have become available for comparison. These surveys were conducted between 1958 and 1997. However, the birth cohorts contained in the

**Table 12.1**
**Percentage of Achieved Education in Different Birth-Cohorts in The Netherlands, 1900-1975**

| Cohort | Primary % | Presecondary % | Secondary % | Tertiary % | N |
|---|---|---|---|---|---|
| 1900 – 1904 | 67.1 | 18.9 | 8.4 | 5.6 | 579 |
| 1905 – 1909 | 61.0 | 20.0 | 10.9 | 8.0 | 792 |
| 1910 - 1914 | 61.1 | 23.9 | 8.5 | 6.5 | 1,268 |
| 1915 – 1919 | 49.8 | 28.6 | 12.6 | 9.1 | 1,675 |
| 1920 – 1924 | 44.6 | 29.8 | 15.5 | 10.1 | 2,479 |
| 1925 – 1929 | 38.0 | 32.2 | 18.8 | 11.0 | 2,998 |
| 1930 – 1934 | 33.6 | 34.1 | 18.8 | 13.5 | 3,386 |
| 1935 – 1939 | 27.8 | 35.6 | 21.4 | 15.2 | 3,619 |
| 1940 – 1944 | 20.2 | 39.4 | 23.4 | 17.0 | 3,923 |
| 1945 – 1949 | 14.5 | 40.4 | 25.5 | 19.6 | 5,170 |
| 1950 – 1954 | 13.5 | 36.1 | 27.7 | 22.7 | 5,308 |
| 1955 – 1959 | 10.3 | 33.3 | 31.7 | 24.7 | 4,987 |
| 1960 – 1964 | 6.8 | 28.8 | 39.0 | 25.5 | 3,602 |
| 1965 – 1969 | 4.8 | 26.7 | 43.5 | 25.0 | 2,406 |
| 1970 – 1974 | 2.9 | 21.2 | 45.8 | 30.0 | 1,170 |
| 1975 – 1979 | 2.5 | 17.8 | 44.8 | 35.0 | 326 |
| N | 10,043 | 14,389 | 11,232 | 8,023 | 43,687 |

survey cover the whole period, as the older interviewees in the older surveys were in school even as early as 1910. After standardizing the educations, categorizing them in four classes (primary, presecondary, secondary, and tertiary), and organizing the birth cohorts by five year widths, Table 12.1 shows the pattern of educational expansion for the Netherlands in this century (for men): we see a sharp decline in the number of lower educated and a considerable increase of the number of higher educated. These simple data are our main benchmark here: how can we account for the specific pattern of educational expansion that has occurred in the Netherlands in the twentieth century?

## A SYSTEM DYNAMICS MODEL

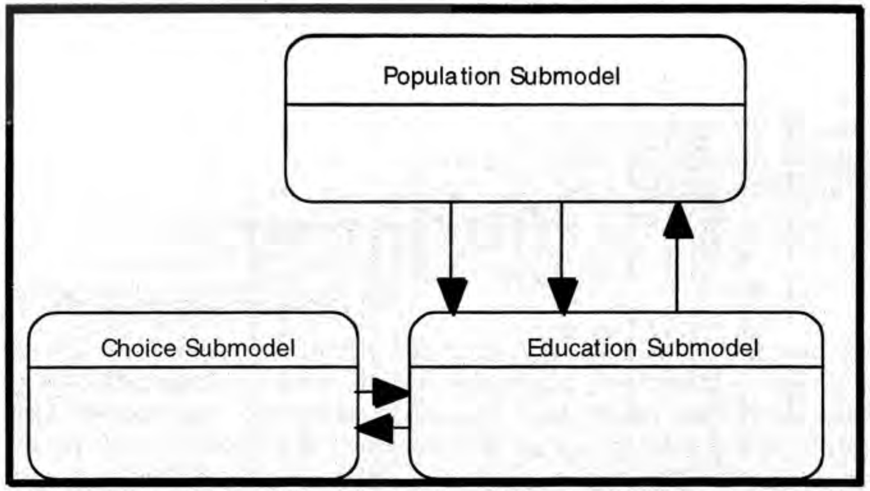
By simulating social phenomena researchers in the social sciences make fruitful use of the idea of systems science (Von Bertalanffy, 1952; Boulding, 1956; Klir, 1991) that social phenomena can be analyzed as (social) systems. Especially the time-dependent interaction between the parts of a system can be made explicit in this way. To deal with the complexity of this interaction system, researchers make use of computer-aided model building. The logical basic for such tools is laid down in the theory of dynamic systems. In this theory the concept of feedback (Wiener, 1948) is used to express the idea that the interaction between parts of a system is reciprocal—that is, that a part of a system influences at time $t_0$ another part, and at time $t_1$ the other way around. These feedback-regulated models can be mathematically expressed in recursive difference (i.e., differential) equations and then formalized in computer algorithm's (Forrester, 1968; Hanneman, 1988; Levine & Fitzgerald, 1992; Van Dijkum, 1997; Haefner, 1996). User-friendly software such as ITHINK (Peterson & Richmond, 1994) can be used to handle the computer models, while software like MADONNA (Zahnley, 1996) makes it possible to engage in advanced simulation experiments.

With the aid of this software we can thus develop a sophisticated dynamic model of educational expansion which seems to respect its complexity. Our system dynamics model in Figure 12.1 consists of three submodels which mimic the population system, the education system, and the choice system. A set of starting values of parameters represents the state of affairs (of the society) at the macro level. In the simulation model, four levels of education are distinguished: primary, presecondary, secondary, and tertiary. The levels are elements of the population submodel, the education submodel and the choice submodel. In the next sections the submodels are explained.

### Society Parameters

To start with: the society parameters represent preset starting values. The population of the Netherlands in 1900 was, for example, four million people.

**Figure 12.1**
**The Population Submodel, the Education Submodel, and the Choice Submodel**




The simulation covers the period from 1900 to 2020. In this period the compulsory primary education in the Netherlands is supposed to be six school years. The average duration of the primary, presecondary, secondary, and tertiary education are 6, 3, 3 and 6 years, respectively. As a consequence the average ages on which one leaves school receptively are 12 (primary), 15 (high school), 18 (college), and 24 (university). The last (highly artificial model) assumption was that nobody has a child before the age of 25. In this way the minimal duration of the period people live without a child is determined: 13 years for people with only primary education, 10 years for people with presecondary education, 7 years for the college student, and 1 year for a university student.

### The Population and Education Submodels

The population and education submodels form the core of the simulation model, also because of the interaction between these submodels. The population model is the input for the education model, whereas the output of the education model is the input for the population model. Figure 12.2 is used to describe these submodels in detail.

In this figure three parts are to be identified: the population submodel, the education submodel, and in-between the six years of age (four ellipses). Viewed in more detail the figure consists of many rectangles and arrows. Each numbered rectangle represents a category of a group. As an example: number 21 represents a group of children (of a primary educated father) leaving school with only

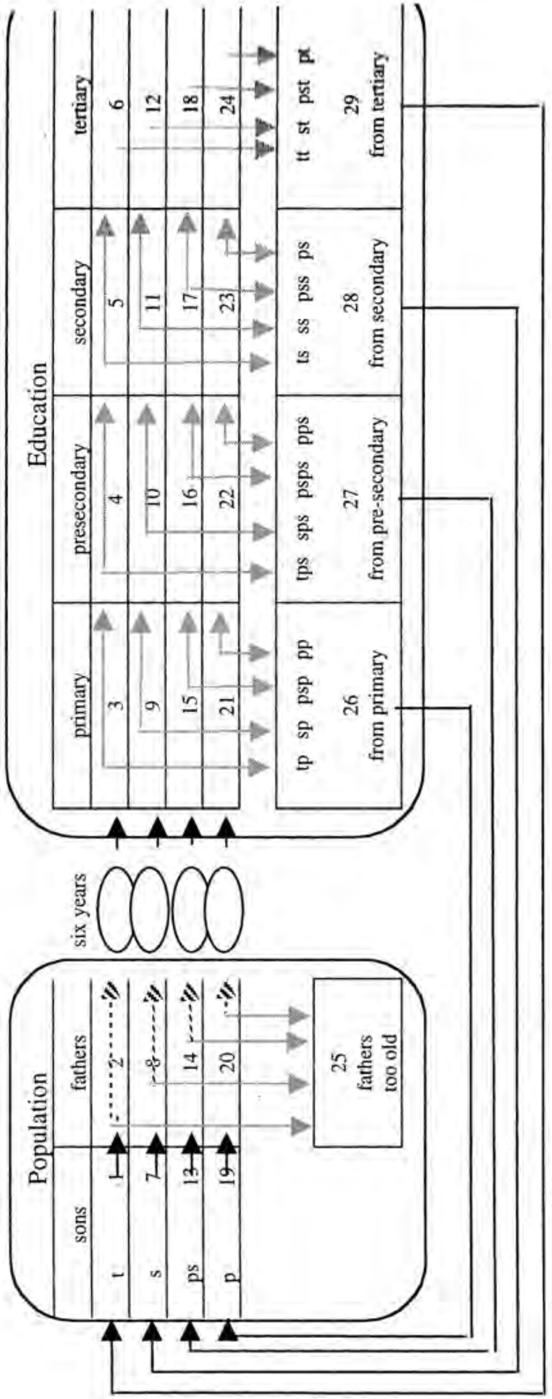



**Figure 12.2**
**The Population and Education Submodels in Detail**

primary school as a qualification. In this rectangle one can also find abbreviations of subgroups in each category. For example tp stands for those children who have a father with tertiary education, who themselves did not reach further than primary education. These subgroups are important to analyze mobility between classes.

There are three kinds of arrows: solid, shaded and dashed. Solid and shaded arrows represents throughputs. A solid arrow indicates that the whole group flows from one group to another (for example group 1 to group 2). A shaded arrow indicates a splitting, one part flows to group A, another part flows to group B. Dashed arrows represent the origin of a flow.

### The Population Submodel

We start with the description of the population submodel. Three groups are to be distinguished in this model: sons, fathers, and "fathers who are too old to give birth to a son." The groups of fathers and sons are split into four education classes: primary, presecondary, secondary, and tertiary. In between these classes function three flows: (1) the inflow from the education model; (2) the throughput from sons to fathers; (3) the outflow of fathers to "fathers who are too old."

The first inflow, from the education model, feeds the population model with sons of different degrees of education. Those sons will mature, and after their childless period they will become fathers in turn. The duration of this period is determined by the preset society parameters. When sons become fathers they move a column to the right and then belong to the population of fathers.

From each category of fathers two arrows start. The shaded arrow refers to the group of "fathers too old," because there will be a time that fathers do not get a son anymore. The dashed arrows are the sons of the fathers who are six years of age, and represent the input of the education system.

The number of fathers together with the degree of their fertility determine the number of six-year olds. Our (arbitrary) assumption is that the average number of sons a father has, is the same for each level and is to be estimated by 1.82, that is each year (during the twenty years fathers do get sons) the chance to get a son is 0.09.

### The Education Submodel

These sons mature and will enter the education system at age six. This means that the education system is coupled to the population system with a delay of six years.

Mobility between classes is in our model only possible in the education system. At birth sons belong to their father's class, but after leaving the education system their achieved class depends solely on their highest diploma. Thus, for instance, sons from the highest class may achieve less education than their fathers, and drop out of their class (e.g., from tertiary born to presecondary educated).

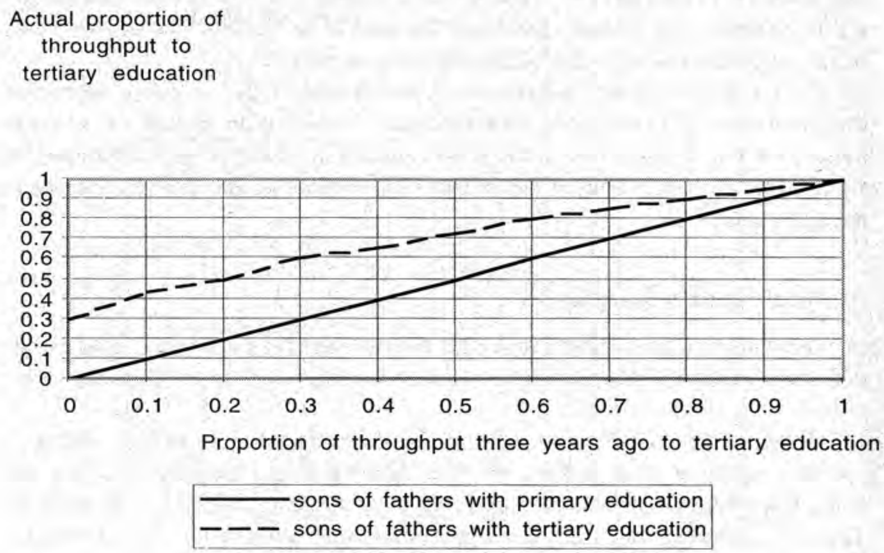
At the age of six they enroll in the education system. Their first opportunity for leaving it is after graduating primary school at the age of twelve. In Dutch history, this graduation produced for a long period the difference between classes. However, because of the long period of compulsory education in the Netherlands, the majority nowadays will seek further education. Thus, after finishing presecondary education at age fifteen one has to choose again. Graduating from secondary education gives the opportunity to enroll in tertiary education levels at age eighteen. At the age of twenty-four students (in this model) leave the education system. There are no opportunities for further education, which reflects the structure of the Dutch education system.

The outflows of the education system are the inflows of the population system. For example, students who stop after a secondary education are the inflow of the secondary class of the education system, and will after some delay become fathers. The same is true for the other types of education, and thus the circle will be closed: the education system influences the population system and the population system influences the education system.

### The Choice Submodel

There are three moments of choice in the simulation model: (1) after primary education the choice for presecondary education; (2) after presecondary education the choice for secondary education; (3) and finally after secondary education the choice for tertiary education.

**Figure 12.3**
**Proportion of Throughput Related to the Throughput Three Years Ago for Sons of Fathers with Primary Education and for Sons of Fathers with Tertiary Education**




Our first assumption is that there are differences in throughput for each education class. Probably more sons of high class will enter tertiary education than sons belonging to low classes. That assumption leads to 3 (choices) x 4 (educational classes) = 12 choice submodels. Our second assumption is that former cohorts will influence the choice of the next cohort. That assumption can be entered in these submodels as shown in Figure 12.3.

The parameter which is modeled is the proportion (in Figure 12.3 "throughput to tertiary school") that "flows" in a year to the next level of education. Our first assumption implicates that for each class a different graph has to be used. As a consequence two class graphs are plotted in Figure 12.3: one for the primary class and one for the tertiary class. The second assumption has as a consequence that from the (throughput) proportion of a former cohort (arbitrarily determined as three years ago) plotted on the horizontal dimension, the graph will determine what (throughput) proportion will result for the current cohort. For the primary class we have plotted, as an example, that the throughput will remain the same. In the graph for tertiary education our third assumption is pictured. That assumption is that the next cohort will try to reach as far or farther than the former cohort.

## WHICH CHOICE MODEL IS ADEQUATE?

**Figure 12.4**
**Proportion with Only Primary Education of Birth Cohorts in the Netherlands, 1900-1975**

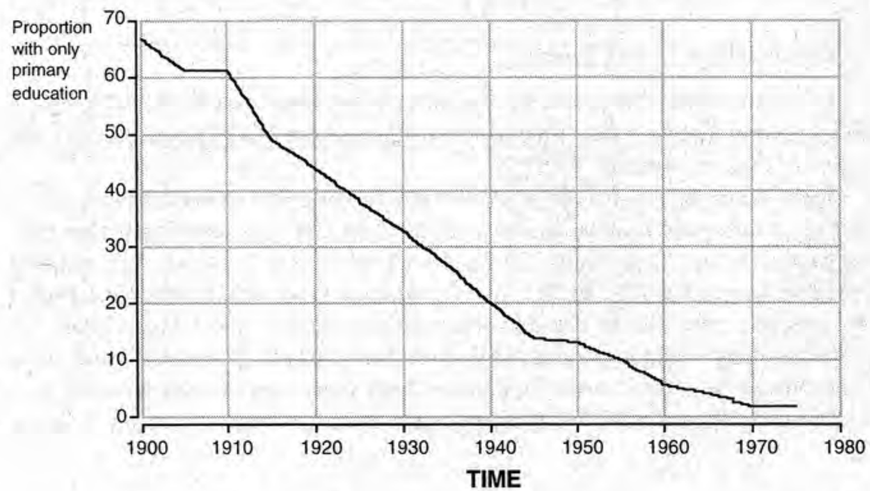
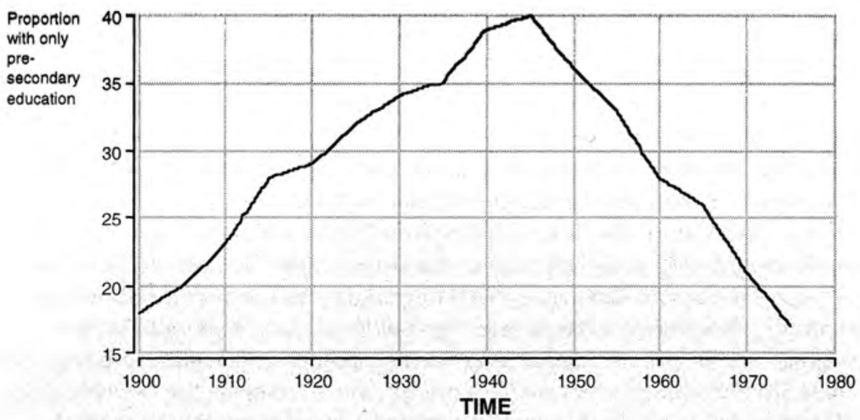


**Figure 12.5**
**Proportion with Only Presecondary Education of Birth Cohorts in the Netherlands, 1900-1975**




It is of course crucial which graphs we select for our choice model. To get a realistic model we confront the outcome of the selected choice model with empirical date from the Netherlands. For the period 1900-1975 these data represent the distribution of education levels and are characterized with graphs such as are shown in Figures 12.4 and 12.5 (these figures are based on the numbers as presented in Table 12.1).

### Fitting with a Linear Model

In a first series of experiments we selected the most simple type of graph: a linear relation between the "proportions of throughput." That linear relation can vary, as is shown in Figure 12.6.

If the throughput stays the same we can use the graph in the diagonal (y=x). But we assume that in most of the cases the next cohort is reaching higher than the former cohort. That means that graphs are selected in the upper diagonal area of the rectangle {(0,0),(1,0),(1,1),(0,1)}. Moreover, we assumed that the higher the class the stronger the drive to reach farther—that is, for a higher class we took the graph which started higher in the vertical dimension, and as a consequence was less steep. Finally, we have done experiments with the rule that coming higher in the level of education makes the drive stronger to move up.

**Figure 12.6**
**Several Linear Relations Between New and Old Throughput**

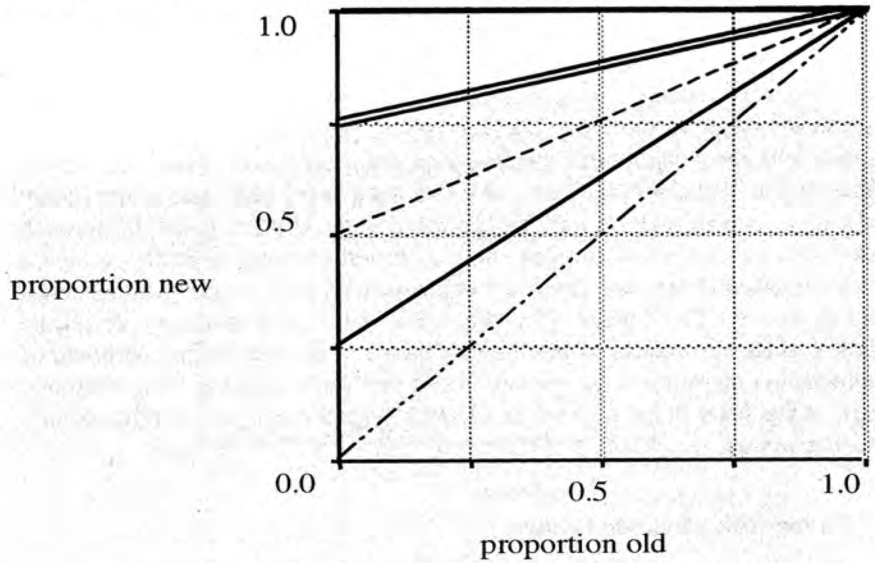
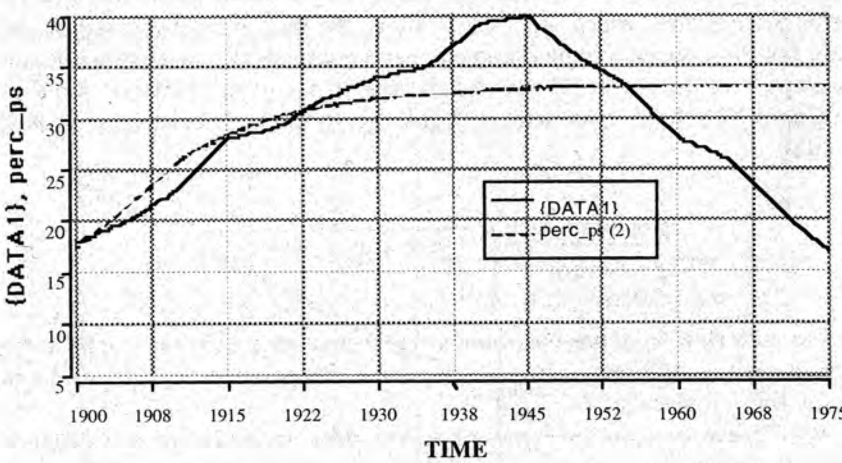



**Figure 12.7**
**Fitting Presecondary Education with a Linear Choice Model**



To test all these assumptions we compared the outcome of those experiments with the portrayed empirical data. A typical outcome of such comparisons is given in Figure 12.7.

It is at the same time the most difficult data to fit. Contrary to the other time-dependent proportions, which are monotonously decreasing or increasing, this proportion is going up and down (i.e., is passing a maximum). To choose values of parameters which produce outcomes (shown as perc_ps) which are reasonably close to the data (DATA1) seems possible. However one cannot realize with those values that the model passes *a maximum*[1]. Moreover, the fit between data and other proportion variables, such as the participation in primary education, is poor and can only be optimized at the expense of the fit between other data and variables. Besides, this conclusion does not take into account a possible ordering between the different parameters, such as has been discussed in the section "The Choice Submodel." But that is not necessary: It can be shown whatever ordering is presupposed between parameters, the optimum of combination of values of parameters cannot produce the passing of a maximum such as has been found in the data. Herewith our linear model is falsified in a qualitative way.

### Fitting with a Logistic Relation

That leads us to the idea that the graphs in our choice model have to be nonlinear. Reasoning about the dynamics of our model, in which the growth of the population is exponential, we thought that the most adequate graph is the logistic one (see Figure 12.8).

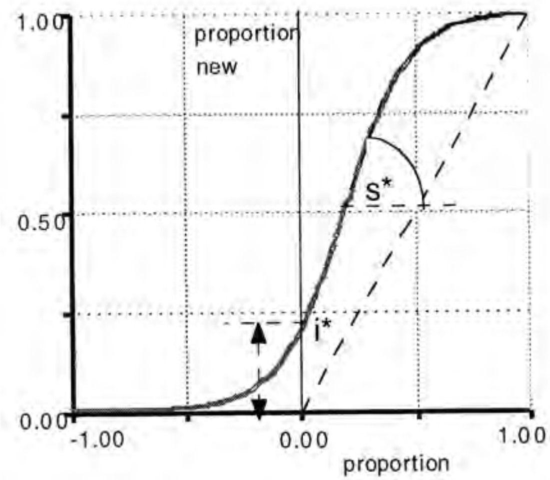
The development of the logistic curve can be seen in the rectangle {(-1,0),(1,0),(1,1),(-1,1)}. We use the right part of this rectangle and in this area we prefer those graphs which are located above the diagonal between (0,0) and (1,1). For those logistic graphs two parameters are used: (1) s is an indication of the slope $s^*$ of the graph; (2) i is an indication of the point of intersection $i^*$ of the graph. With these parameters our logistic graph can be calculated by the next formula:

$$\text{proportion\_new} = \frac{1}{\left(e^{(s*\text{proportion\_old}+i)} + 1\right)}$$

For each flow from one education group to another a different graph can be used as well as different values of the related two parameters. This results in twenty-four parameters.

With these parameters experiments are done to minimize the distance between the outcome of our model and the mentioned data. However, the values of the parameters cannot be arbitrarily chosen. Some values make sense for our reasoning about the model; other parameter values which could minimize the

**Figure 12.8**
**A Logistic Relation Between Old and New Proportion of Throughput**




distance cannot be justified so easily, for example, because there is no throughput at all during the simulation period, and thus have to be rejected. According to the fitting experiments, and in line with acceptable graphs, the best parameters give rise to the following fitting situations, as shown in two examples, pictured in Figures 12.9 and 12.10.

**Figure 12.9**
**Proportion Primary Throughput in Model (perc_p) and Data (data1)**

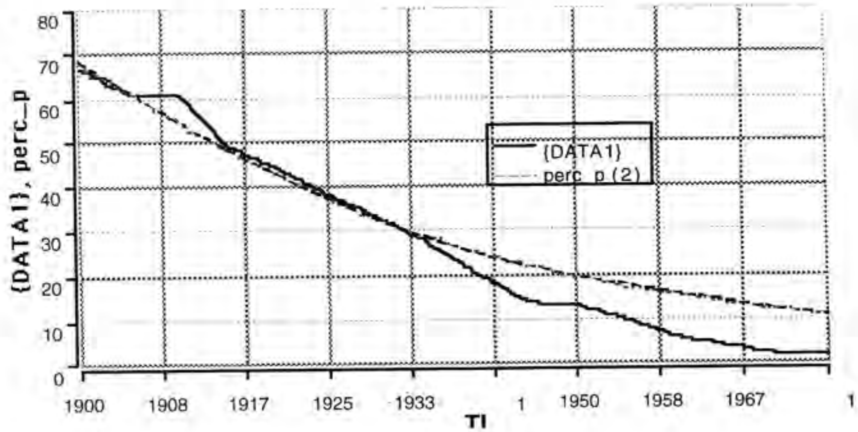
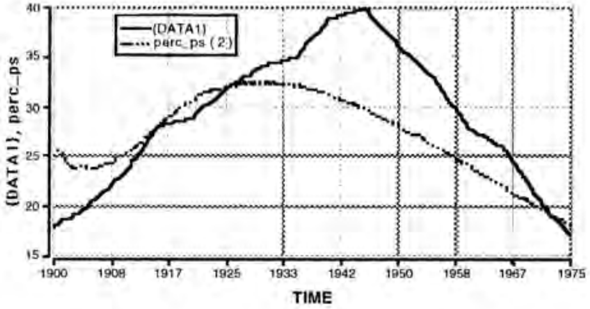


**Figure 12.10**

**Proportion Presecondary Throughput in Model (perc_ps) and Data (data1)**



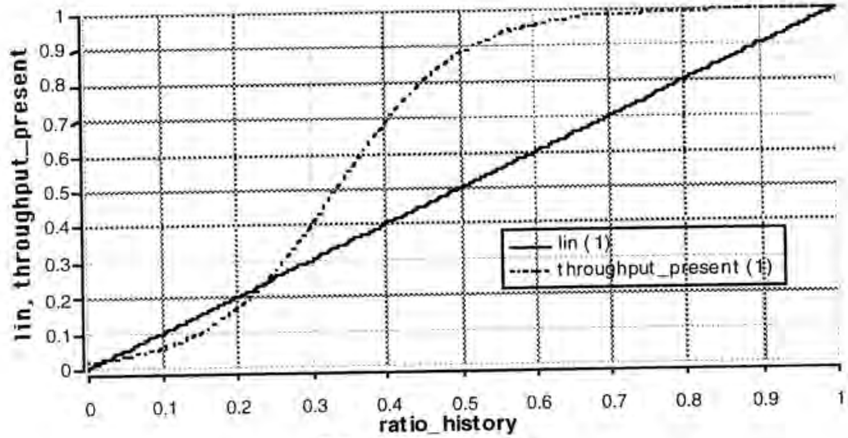

Different values of parameters lead to a set of choice graphs. Most of these graphs are according to our idea that each generation tries to come further than the previous generation. The graphs are located in the area above the diagonal in Figure 12.8. Moreover, there seems to be a system in the ordering of the graphs. The slope of the graphs (its indicator s, respectively -9, -13, -41, -70)[2] representing the throughput to presecondary is steeper the higher the class of the father. That can be interpreted as the idea that the higher the class the more chance to reach presecondary education. For the next education level the same interpretation can be used. However in this case it is not because of the slope of the graphs (s is constant at -12), but because of the moving of the graph to a more favorable area (i as indicator, respectively 4, 2, 1.4, 0). For the tertiary education level the point of intersection also moves more to the right (i as indicator, respectively -3, -2, 2.7, 5), thus also in this stage of an education career, the higher the class the higher the chance to attain a university education.

However there are two interesting exceptions to our line of reasoning so far: the graph of the throughput of primary to secondary; and the graph of the throughput of tertiary to tertiary (see Figure 12.11). Here are periods in which the throughput is less than it was before.

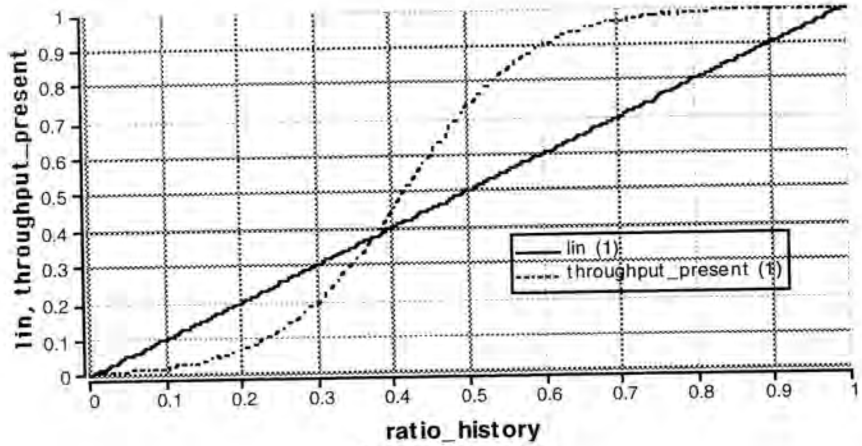
The first hypothesis to explain this result is: it is an artifact of our model. It seems unlikely, but we cannot completely eliminate this possibility. However, another system-dynamics-oriented hypothesis is thinkable. To come to a system in which an in-between-class—such as the presecondary class—at first rises to a maximum and subsequently goes down to a lower stationary value, negative feedback is necessary. An empirical interpretation of the result is that for the lowest class the achievement of the presecondary level is historically viewed successful, but for the next step, to the secondary level, the educational career is initially inhibited because a threshold is working. However, when enough members of the primary class have overcome that barrier, the educational career will be enhanced by positive feedback. For the highest class the interpretation can be that, historically viewed, achieving the tertiary level was initially not stimulated.

**Figure 12.11**

**Two Exceptions to the Rule that Each Cohort Tries to Reach Further Than the Previous Cohort**




*Primary to secondary*

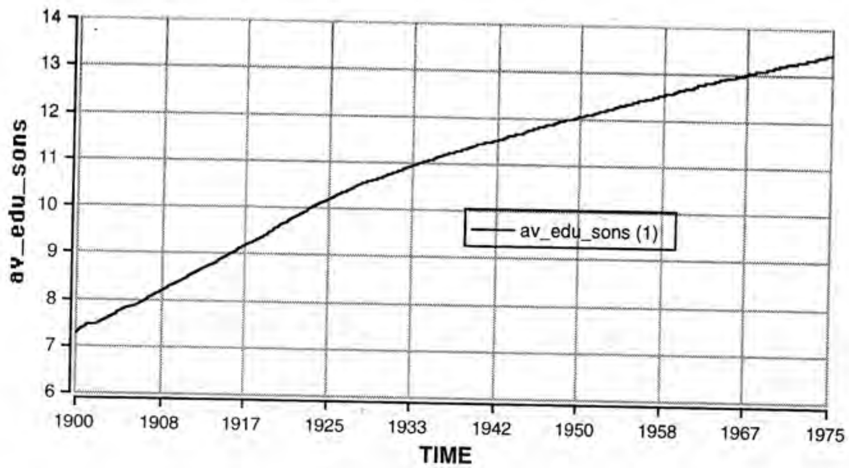



*Tertiary to tertiary*

## Other Relevant Outcomes of the Model

There are other relevant outcomes of the model. One of these is the achieved average education in years (Figure 12.12). The increase is between seven and fourteen years, according to the empirical study of Ganzeboom & Treiman (1993). In this way our model adequately produces the speed of educational expansion.

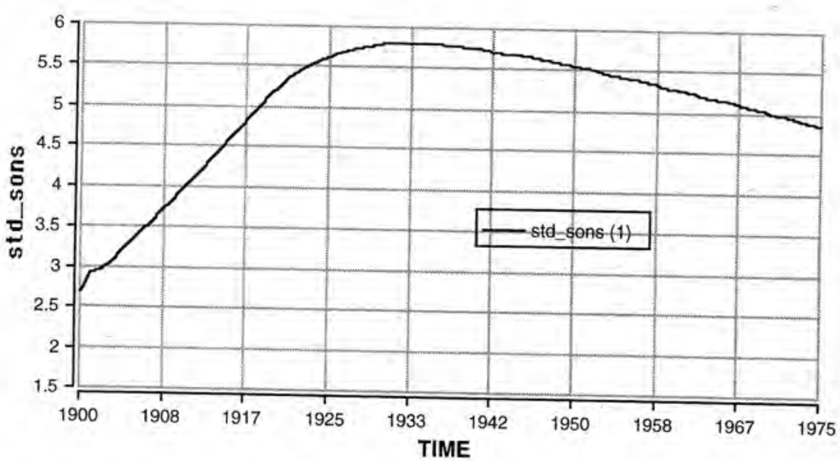
**Average Achieved Education in Years for Sons, 1900-1975**




Another aspect of educational expansion is the dispersion of the achieved education in the course of time. Concerning that variable our fitted model produces the outcome such as has been pictured in Figure 12.13. As a pattern it gives the rise and fall of the standard deviation and in this way it adequately represents the empirically found educational inequality (Ganzeboom & Treiman, 1993). Our model is thus verified in a qualitative way.

**Figure 12.13**

**Development of the Standard Deviation of the Achieved Education in Years, 1900-1975**




## WHAT NEXT?

Our model can be viewed as a qualitative step towards understanding the mechanism of educational expansion and its complexity. However, some of our ideas are still rather speculative and have to be explored by better simulation studies. More empirical reference is needed and the model has to be falsified or verified with the aid of quantitative measures of fit—measures which allow a better discussion of the parsimony of a model than was possible in this chapter.

The next step in our study is also to include more than one country in our empirical data as well as other variables of interest. We are optimistic about the possibility to generate with our model the empirically found variety in (the speed of) educational expansion of other countries. We also think it possible with our simulation model to produce other variables of interest, such as realistic mobility tables.

## NOTES

1. The software we used for those fitting experiments, MADONNA, can automatically adjust the values of selected parameters—in our case the slope of the linear function—to reach an optimal fit. The algorithm which achieves that is the Down-Hill Simplex Algorithm (see Press et al., 1992).

2. The intersection point is about the same and does not make a difference.

## REFERENCES


Bertalanffy, L. von (1952). *Problems of Life*. London: Watts.

Boulding, K.E. (1956). General Systems Theory: The Skeleton of Science. *Management Science, 2*, 197-208.

Dijkum, C. van (1997). From Cybernetics to the Science of Complexity. *Kybernetes, 26*, 725-738.

Forrester, J. (1968). *Principles of Systems*. Cambridge: Wright Allen Press.

Ganzeboom, H.B.G. & Treiman, D.J. (1993). Preliminary Results on Educational Expansion and Educational Achievement in Comparative Perspective. Unpublished Paper, Utrecht University.

Haefner, J.W. (1996). *Modeling Biological Systems: Principles and Applications*. New York: Chapman & Hall.

Hanneman, R.A (1988). *Computer-assisted Theory Building: Modeling Dynamic Social Systems*. Newbury Park, CA: Sage.

Klir, G. (1991). *Facets of Systems Science*. New York: Plenum Press.

Levine, R.L. & Fitzgerald, H.E. (Eds.) (1992). *Analysis of Dynamical Psychological Systems and Cybernetics*. New York: Plenum Press.

Peterson, S. & Richmond B. (1994). *Introduction to System Dynamics Modeling. ITHINK: the Visual Tool for the 90's. Software from High Performance Systems*. Hanover: High Performance Systems.

Press, H., Flannery, B.P., Teukolsky, S.A. & Vetterling, W.T. (Eds.) (1992). *Numerical Recipes, the Art of Scientific Computing*. Cambridge: Cambridge University Press.
Thurow, L. (1975). *Generating Inequality: Mechanism of Distribution in the U.S. Economy*. New York: Basic Books.
Wiener, N. (1948). *Cybernetics or Control and Communication in the Animal and the Machine*. Cambridge, MA: MIT Press.
Zahnley, T. (1996). MADONNA Software. Berkeley: University of California.

# Chapter 13

# TOWARDS A METHODOLOGY FOR THE EMPIRICAL TESTING OF COMPLEX SOCIAL CYBERNETIC MODELS

**Johannes van der Zouwen & Cor van Dijkum**

## CYBERNETICS AND SOCIAL SCIENCE

### The First Applications of Cybernetics in Social Science

From the beginning of general systems theory—or its twin, cybernetics—attempts were made to apply its concepts and ideas to the study of social processes. The "father of cybernetics," Norbert Wiener, wrote his book on *The Human Use of Human Beings: Cybernetics and Society* (1950), only two years after the publication of his foundational work *Cybernetics, or Control and Communication in the Animal and the Machine* (1948; cf. Geyer and van der Zouwen, 1994). Other well-known early applications of cybernetics and systems theory are those of Talcott Parsons (1952) in sociology and Karl Deutsch (1963) in political science.

One of the criticisms voiced against these early applications of cybernetics, was that the authors did not sufficiently take into account the specific nature of social systems, systems that are essentially different from equilibrium-maintaining systems like the thermostat. One of the first applications of ideas from general systems theory in which the particular characteristics of social systems are explicitly reckoned with, is Walter Buckley's book *Sociology and Modern Systems Theory*, published in 1967.

Since the publication of this book, over thirty years have passed. Classical, or first-order, cybernetics is succeeded by a modern, second-order cybernetics. And analogous to this development, the classical "social cybernetics" is succeeded by the modern "sociocybernetics" (Geyer & van der Zouwen, 1991). In modern sociocybernetics it is well understood that social systems are more than boundary-maintaining, goal-seeking, input-output machines. We all know