Assessing Global Change from a Regional Perspective:

An Economic Close-Up of Climate Change and Migration

Markus Zimmer

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An Economic Close-Up of

Climate Change and Migration

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Markus Zimmer

Referent: Prof. Dr. Peter Egger
Korreferent: Prof. Dr. Dr. h.c. Hans-Werner Sinn

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Unless we change direction, we are likely to end up where we are going.

Chinese proverb

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Preface

Global change has become eminent in our everyday lives. Slowly, but noticeably, the faces surrounding us represent the international global community. Climate doomsday is as present as ethnical and religious controversy. The press reports how eastern German women to flee the catastrophic economic conditions that prevail after the fall of socialism, while catastrophic flooding is haunting the eastern German men who quail in solitude and welfare transfers. And to top it all, this flooding – resulting from global climate change – determines the outcome of national elections. Listening to politicians, global terrorism seems to be a worse threat to the wellbeing of the German citizens than demographic change, and the population is still indecisive if some additional days of beer garden weather aren't worth the little bit of desertification in the third world.

In this work I attempt to highlight some of these issues and to catch a glimpse of the local effects of global change. I will particularly focus on industrial water usage and domestic migration. This work has been funded by the German Federal Office for Education and Research as part of the GLOWA project. This interdisciplinary project aims to explore the effects of global change on the water cycles in different regions of the world. This thesis is devoted to the GLOWA-Danube sub-project which investigates the Upper-Danube Catchment Area. Part of the funds are bound to supporting graduate students and should as a result, facilitate the development of the GLOWA project by the successful completion of relevant dissertations.

My special thanks goes to my supervisors Prof. Peter Egger and Prof. Hans Werner Sinn, not only for supporting me during the work on my thesis, but in particular for being colleagues rather than superiors. I truly enjoyed these years of being guided wisely and treated as a friend. I also wish to thank Prof. Ray Rees for inspiring me as an undergraduate student and awakening my interest for the economic profession. I would also like to thank those involved in the GLOWA-Danube project, especially Dr. Matthias Egerer for being my fellow sufferer and for jointly crawling through the water cycles, theoretically and in practice. Finally I extend my thanks to Andreas Rogge-Solti for being an exceptional programmer, and without whom, I would probably still be trying to implement all of the JAVA-code by myself.

Part One

Climate and the Industry

Chapter 1.1

Does Climate Change Matter?

Regional Water-Related Environmental Issues of

Climate Change from the Perspective of a Corporation

If something is sustainable, it means we can go on doing it indefinitely.

If we can't, it isn't.

Jonathon Porritt (Environmentalist and Writer)

Introduction

We can easily reach our natural lifespan without oil but can only survive a few days without water. Water is the most important natural resource that is both restrictable in access and indispensable to sustain social, economic and ecological human needs. The functioning of material cycles strongly depends on a sustainable usage of the water resources. Efficiency implies that social, ecological and economic functions compete with each other and have to be balanced and limited in their scale to avoid water scarcity or an overuse of the resource.

While in arid regions water scarcity is a well-discussed issue, it has only just recently become the focus of increased awareness in the more humid regions of our planet. In particular, the exceptionally dry and hot weather conditions in 2003 led to an increased sensitivity to this topic in Germany. In some regions water threatened to become scarce; a few communities in south-eastern Bavaria even had to be supplied with water by truck for some days or weeks.

But scarcity is more broadly defined than just lack of the resource. It is rather a lack in the usable amount of the resource, and this scarcity, ironically, can also be caused by an excess of water. Besides this excess being an obvious problem in itself, as in the case of a flood, it can also lead to water shortages. Recall the recent tsunami in the Indian Ocean or Hurricane Katrina in New Orleans, where one of the biggest problems was the poisoning of drinking water through the flooding. However, these are extreme cases and such events are rather unlikely to occur often.

In 1987, the World Commission on Environment and Development (WCED), which had been set up in 1983, published a report with the title “Our Common Future” (World Commission on Environment and Development, 1987). This report became generally known as the “Brundtland Report”, named after the Commission’s chairwoman, Gro Harlem Brundtland. The basis for this report, and for the numerous other conceptions of sustainable development referring to it, is an anthropocentric view of the world. According to it, nature has no intrinsic value but serves to satisfy human needs. But since all human needs directly or indirectly depend on it, human needs alone dictate that nature must be protected for future generations.

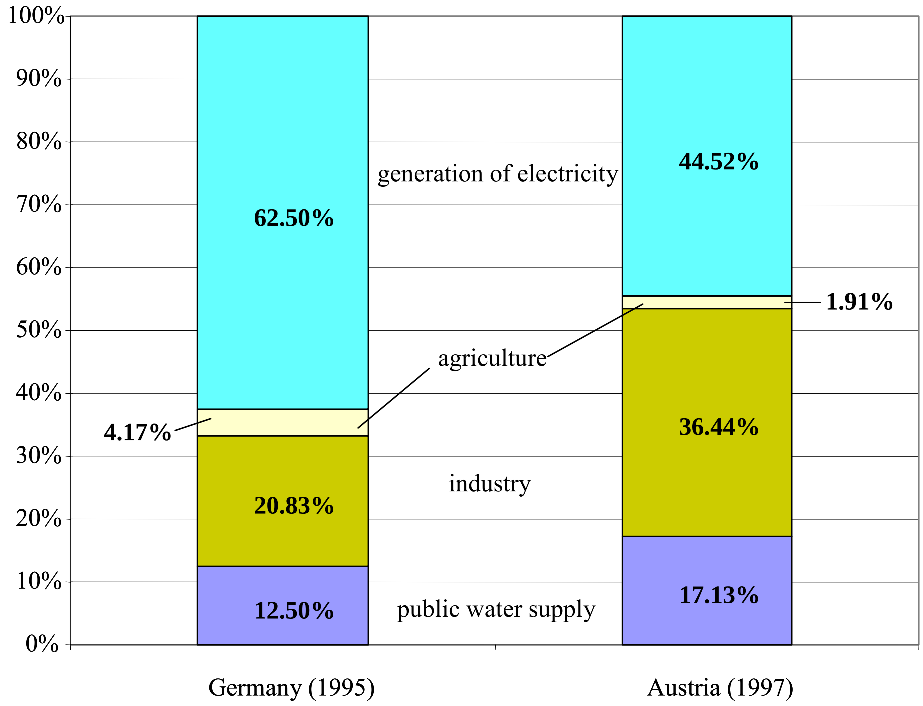

Fig. 1.1.1: Water users in Germany and Austria
(German Federal Environmental Agency, 2000; Statistical Office of Austria, 2002).

The following discussion centres on the sustainable use of water in its economic function, and in this function it spotlights the issues and problems expressed by the prime use of the resource in the observed area: industrial production and power generation. While drinking water supply and agricultural irrigation have been widely discussed, industrial water demand plays a much lesser role in the literature (Griffin, 2006). This applies especially to the humid regions of the world, like the Upper Danube catchment area. This region primarily includes parts of Bavaria and Baden-

Wurttemberg in Germany and Tyrol in Austria. The minor role of industrial water use in the literature is astonishing, especially because the industrial sector (incl. power generating plants) - in some developed countries - is by far the largest water user (European Environment Agency, 2000). For a comparison between different users in Germany and Austria, see figure 1.1.1 . Mines, power generating plants, industrial production and manufacturing firms form the group of industrial water users. The major industrial water users are typically self-supplied. In Bavaria and Baden-Wurttemberg this proportion accounts for 95.4% and 99.1% of industrial water demand (Federal Statistical Office Germany, 2003).

Big users in water-intensive industries use water mainly for three reasons. First, water is used as an input in the production process, which includes cleaning and transporting intermediate goods. Second, water is used for cooling of manufacturing and power generating plants and third, it is used to produce steam. Third, water is used for personal sanitation. Sanitary water is usually obtained from the local public water supplier. In contrast to other forms of water use - such as irrigation - power plants and manufacturing firms re-use or circulate the water. Re-usage of water means that it is used again for another purpose, for example first as a part of the production process, and then as cooling fluid. Circulation means that the water is used for the same purpose several times, which is mostly the case when used for cooling or heating. The average utilization coefficient in Bavaria and Baden-Wurttemberg for all branches is 3.8 and 2.4, respectively (Federal Statistical Office Germany, 2003).

An accessible introduction into the general subject of the economics of water use can be found in the recently published textbook, Water Resource Economics (Griffin, 2006). A comprehensive collection of significant papers regarding the specific topic of industrial water use is given in The Economics of Industrial Water Use (Renzetti, 2002). A further overview is given by Gispert (2004), focusing especially on the empirical literature of estimating price elasticities of industrial water demand in different countries and sectors. Two further studies not mentioned by Gispert estimate price elasticities for France (Reynaud, 2003) and Canada (Dupont, Renzentti, 2000).

Our contribution to research on water-related problems in humid regions is an analysis of apparent and possible future problems caused by global change for industrial water users in the Upper Danube catchment area. Since the available statistical data contain no information about these problems and secondary literature is hardly available, a three-step inquiry process was used to acquire this primary information from the industrial users. The results presented here are, nevertheless, not representative for the observed industries but are intended as a contribution to the academic discussion and presentation of some important aspects of industrial water use. While some of the results might seem obvious, the problems specific to humid regions enrich the discussion on industrial water use.

GLOWA-Danube and DANUBIA:

A Multidisciplinary Environmental Decision Support System

The main goal of the GLOWA-Danube project is the creation of DANUBIA, a computer-based multidisciplinary Environmental Decision Support System (EDSS) to evaluate the effects of global change on the water cycle in the Upper Danube Catchment area. A major problem in this quest is the impossibility to evaluate the effects of global change by observing the evidence of individual scientific disciplines. By themselves, they cannot develop strategies for the management of sustainable water use under changing boundary conditions (Ludwig, Mauser et al., 2003). To grasp the complexity of these interrelations, interdisciplinary science is often called on to solve future problems and answer the urgent questions concerning global change in the context of sustainable development. Unfortunately, no common methods have yet been developed to fully describe the integrative interactions between natural and socio-economic processes. This is not least due to the radically different methods by which the individual disciplines describe and formalize their working processes. Major difficulties of combined research are often the different scales of space and time. Diverse projects have been launched in recent years to overcome these problems of conjoint research.

To ensure the integration of socio-economic and natural sciences for an analysis of a sustainable use of water resources, researchers of various sciences have gathered within the framework of the project GLOWA-Danube (www.glowa-danube.de). These sciences include hydrology, meteorology, water resource engineering, geography, glaciology, ecology, environmental economics, environmental psychology, agricultural economics, tourist sciences, and computer sciences. The overall aim of the project is to develop and validate integration techniques, integrated models, and integrated monitoring procedures for the functional type of a catchment area in mountain forelands of the humid latitudes and to implement them in the network-based integrated environmental decision support system DANUBIA. The single models cover the socio-economic and physical processes that are essential to model the water cycles in mountain-foreland situations (Ludwig, Mauser et al., 2003).

The single models are adjusted to the upper Danube catchment basin, which covers an area of approximately 80,000 km², mainly including parts of Bavaria but also smaller parts of Baden-Wurttemberg, Austria, and Grisons in Switzerland (figure 1.1.2). By simulating scenarios that consider different socio-economic and climatic boundary conditions within DANUBIA, it is intended to deliver a basis for reviewing alternatives concerning water management and sustainable development.

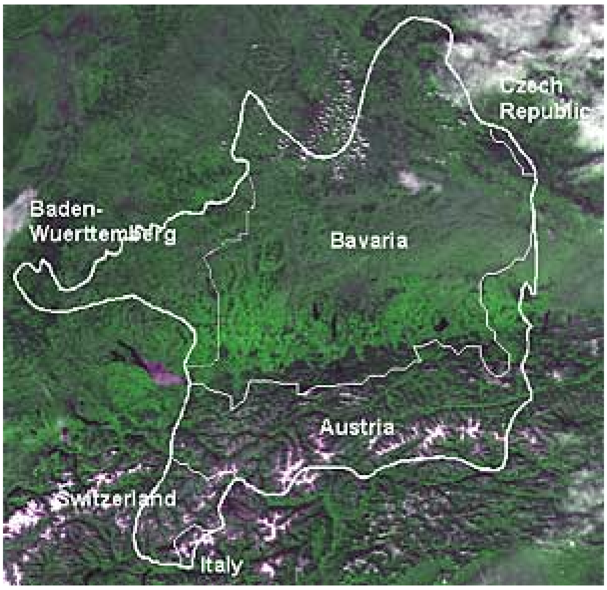

Figure 1.1.2: The Upper Danube Catchment Area

Integration in DANUBIA means that each scientist can keep his core competence in terms of the best possible sectoral results. Following Egerer (2005) this integrative approach is based on four essential assumptions:

- Integration only takes place based on numerical models, because they alone are able to produce results that are transparent for all other groups.
- The area of competence of each model is clearly defined. No one else is able to solve sectoral questions better than the experts in that field.
- Integration takes place between the cores of the disciplines and is first enabled by adequate data-interfaces between the single models.
- Each variable is modelled only once by a given discipline. But the corresponding results must be incorporated into a communications network connecting all disciplines in order to link the different processes with each other (Mauser, 2003). The single models run parallel on separate network-linked computers (Barth et al., 2004).

To enable the integration of the different models, a formal meta-modelling language called unified modelling language (UML) was developed by software engineers. UML describes the single models in a standardized way that is independent of the particular discipline. This language has become the standard for projects with heterogeneous disciplines (Booch et al., 1999). UML is used by all sub-groups to define their models and interfaces between each other in a diagrammatic, simple way. The data between the single models is shared through the negotiated interfaces that are formalized in UML. The models themselves are developed in JAVA in an object-oriented manner[1].

Figure 1.1.3 shows a simplified UML-class diagram of the DANUBIA system. These diagrams will be used throughout this work to illustrate the implemented JAVA code. The models of the socio-economic disciplines are linked to each other by the Actor Controller, which is an interface to export and import data. The socio-economic disciplines are bundled into the Actor component. They communicate via the Actor Controller with the models of the natural sciences within the DANUBIA framework. Each model consequently plays two roles. The first is to supply information to the other models and the second is to simulate the discipline-specific output given the imported information from other models.

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[1] A brief introduction to the UML-terminology can be found later in this work in the description of the demography module in chapter 2.1 .

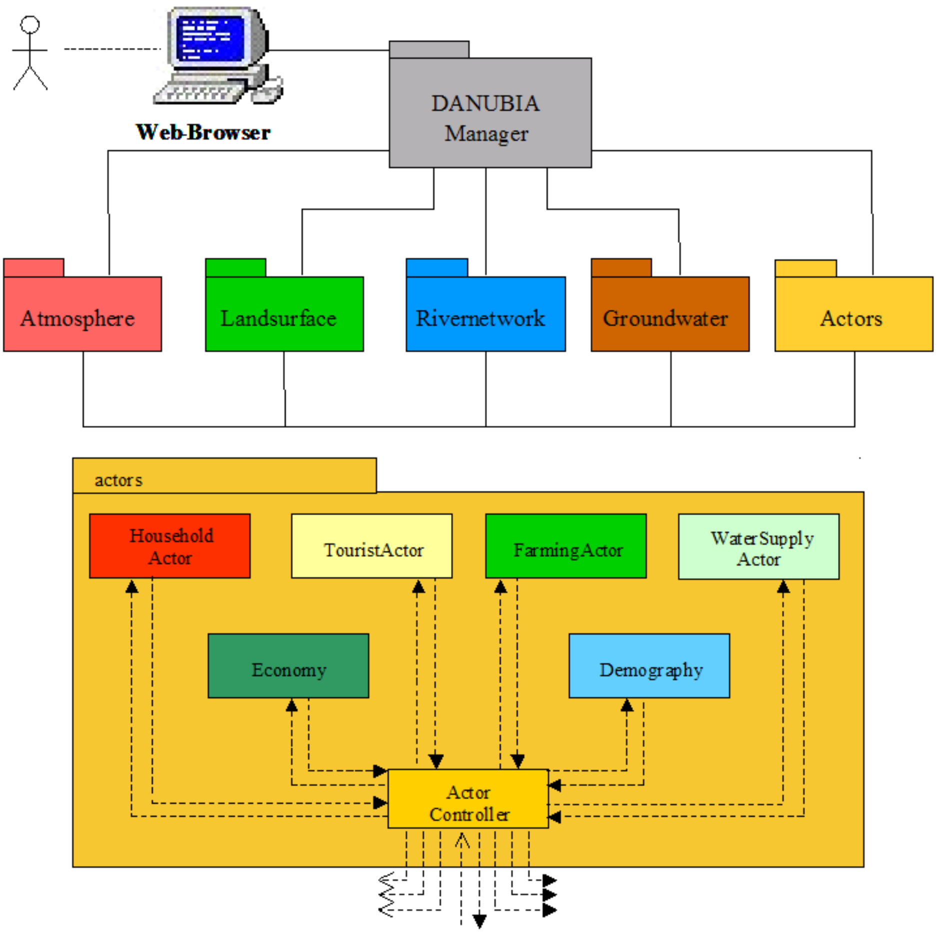

Figure 1.1.3: The integrative approach in DANUBIA.

The Proxel Concept

In order to design independent interfaces between the models which allow to exchange the simulated data, it is necessary to define a standardised spatial solution for the shared data. DANUBIA uses the concept of the so-called proxels (process pixel) as a box in which processes occur. One proxel is equivalent to a floor space of one square kilometre and a height extending from the bottom of the water tables to the upper edge of the atmosphere. The modelled catchment area consists of 182,750 proxels (or square kilometres), containing 425 proxel-columns and 430 proxel-rows. But not every proxel is part of the catchment area. The number of all relevant proxels - resulting from a quadrangle placed over the whole area (figure 1.1.4) - adds up to an area of about 77,000 square kilometres.

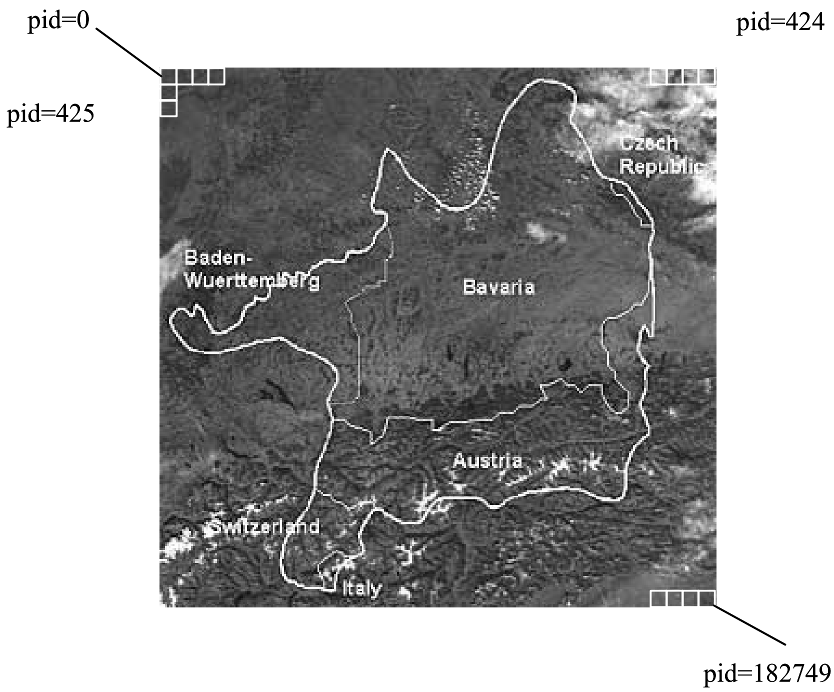

Figure 1.1.4: The catchment is subdivided in proxels (GLOWA-Danube).

The fundamental characteristics of a proxel are identical for all sub-groups. They contain basic information such as a unique ID number, its positioning, topographic data and the land use composition. This information forms the base proxel. Based on this, each group extends the proxel information with the data generated by their models (figure 1.1.5). The aggregate information from all groups describes one proxel, and all proxels together describe the actual state of the catchment area.

The spread of the intra-model spatial solutions varies from a few square meters to several hundred square kilometres and distinguishes between administrative and natural borders. The conceptual design implies that all these differently scaled data must be translated into proxel values if they are to be exchanged between two models. This implies that all the data that is calculated by the macroeconomic model (based on administrative borders) has to be converted into proxel values in order to be exchanged by the export interface. This concerns predominantly two variables which are needed by other models, the industrial water demand and gross domestic product.

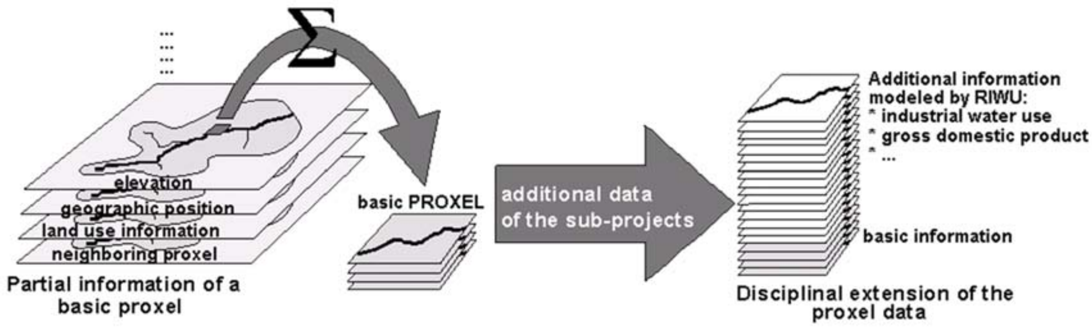

Figure 1.1.5: The proxel concept.

The unusual generation of grid-based proxel values from administrative data is done by using remote sensing procedures. Remote sensing images help to identify areas of industrial production. Based on CORINE Land Cover data[2], the sub-project hydrology/remote sensing developed a database that contains the percentage distribution of land use type per proxel (Mauser, 2002). For the economic modelling purposes, of the identified land-use categories (for instance wetlands, water bodies, or agricultural areas) the industrial / commercial / transport units category is relevant. It is used to divide the computed administrative data into proxel values. We assume

[2] CORINE Land Cover (also CLC) is a project that originated from an initiative of the European Commission. CORINE is the abbreviation for Coordinated Information on the European Environment. It analyses satellite images with regard to land use changes and environmental issues since the middle of the 1980s.

that gross domestic product is produced only on proxels that contain this relevant land-use class. Accordingly, industrial water demand is limited to these proxels. The administrative data is distributed in proportion to the share of the land-use class of a proxel in the sum of all proxels in the district[3]. Thus, the proxel value of the administrative district is calculated as the quotient of the share of the land-use class of that proxel in the aggregate for all proxels of the district multiplied by the district value generated by the economic model. Finally, the industrialized proxels are characterized by the possibility to extract river water or groundwater. All proxels that contain a river (known from the land use classification) or are directly adjacent to a "river proxel" have - in addition to extracting groundwater - the option to extract river water. The industrial water demands are communicated to the natural scientific models. To standardize exchange between the sub-models all water flows are measured in m^3/sec.

The results presented here establish a basis for the economic component of DANUBIA.[4] The role of the economic component is to model and forecast the companies' quantities of industrial water demand as well as other impacts on the environment, like pollution and warming up of the waste water and cooling water[5]. This is done dynamically for ground- and surface water on the scale of a representative production site per proxel. This production facility mutually interacts with the other socio-economic and natural-science components of the project. The microeconomic data that is necessary to model each single site in the observed area

[3] A proxel with a 0% share has no GDP and no industrial water demand, whereas a proxel with a 50% share has five times as much GDP or industrial water demand as one with a 10% share.

[4] For a more detailed, general overview of the project GLOWA-Danube, consult Ludwig, Mauser et al. (2003). A more detailed look at the very important applied informatics aspects of DANUBIA can be found in Barth, Hennicker et al. (2004).

[5] In addition to biological and chemical pollution the warming up of effluents is commonly denoted as thermal pollution.

is provided mainly by the German Date Research Centre[6]. These data provide information about each site's current economic indicators, water demands, water usage and pollution discharges.

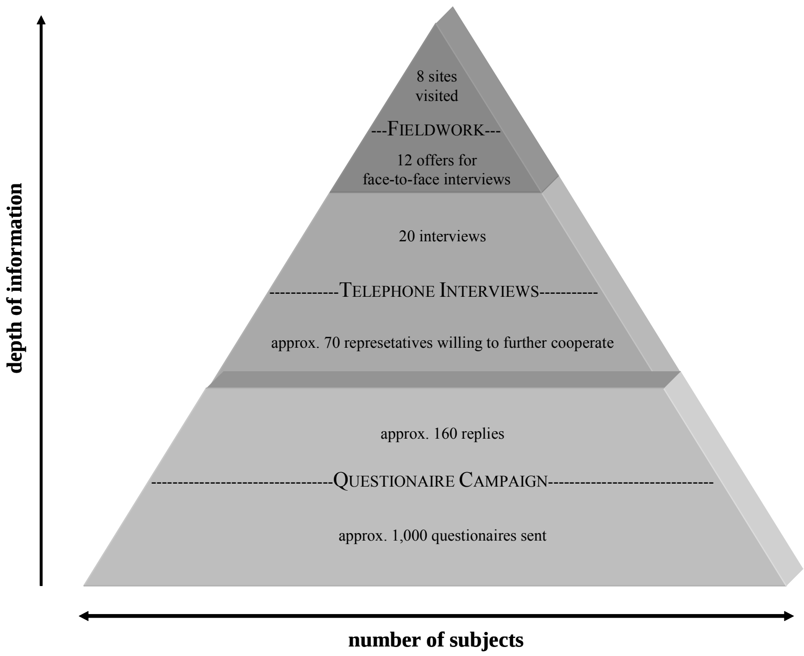

Figure 1.1.6: Acquisition of information as a three-step inquiry process

The data, however, lack information about the reasons for the current technological setting of the site concerning water circulation and potential water-related problems the companies are currently suffering from. Additionally, we face an even stronger information deficit with regard to future prospects and developments of water related issues. Possible future difficulties include in particular those caused by global change and changes in the institutional framework. Furthermore, these data cannot explain

[6] The Data Research Centre (Forschungsdatenzentrum der Statistischen Landesämter) is an institution created by the individual State Offices for Statistics and Data Processing of the Federal States in Germany. It offers different data at the micro-level. Amongst others it provides data concerning industrial water use and industrial waste water. These micro-data are not available for the Austrian part of the catchment area. Here, micro-data is approximated by small-scale regional data provided by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water (2003).

how single companies react to these changes. Taking this lack of information into account, we construct the fundament that is needed to enable our model to forecast industrial water demand. Our aim is to build a bridge between theoretical approaches, representing a schematized reality, and the practical day-to-day business of managers and engineers. Thus, this study enriches the academic discussion, which is all too often separated from the factual conditions.

The necessary information about current and future water-related aspects has been collected in a three-step inquiry process, including a questionnaire campaign, telephone interviews and fieldwork (figure 1.1.6). First, we identified water-intensive industrial producers and power plants in the observed area that were considered for a questionnaire campaign. The “usual suspects” for a water related campaign - such as this - are mining, steel mills, chemical industry, paper manufacturing and, most importantly, thermal power plants, of which only the latter three were identified as relevant branches in the observed catchment area (Federal Statistical Office Germany, 2003; Federal Office for Agriculture, Forestry, Environment and Water Management, 2003). We received 160 replies out of the approximately one thousand questionnaires sent. In a second stage, we selected a subset of twenty company representatives who had indicated their willingness for further cooperation in the questionnaire. With them we conducted extensive telephone interviews. All of these interview partners were either the companies’ environmental representatives or engineers responsible for the production process. In the last stage we visited six representatives personally. In addition to detailed personal interviews, we got a detailed insight into the particular production facilities and processes. The main results of the latter two steps of this process are presented in the following section.[7]

[7] For detailed information on the content and the results of the questionnaire campaign see Egerer and Zimmer (2005).

Results

The telephone interviews included chemical and paper manufacturing as well as thermal power plants. The personal interviews covered four production sites in different sectors of the chemical industry, three paper mills and one cement works. The discussion guidelines used for the telephone and personal interviews can be found in the appendix to the first part of this work. In the chemical industry sector we met representatives of producers of nutrition, care and health chemicals, primary packaging, soap base and cellulosic fiber. The three paper mills are specialized in different kinds of paper and face different problems with respect to their water usage, but were part of a common corporate group. The information about all three production sites was provided by one group representative. The cement producer, as well as all other companies, is among the leaders of its sector.

Water Contingents

In the observed catchment area, the authorities responsible for watershed management allocate extraction contingents to the self-supplying companies. In addition some companies have to pay a fee for each cubic meter water extracted; all companies had to pay a quantity-dependent fee for sewage to the local waste-water treatment plant in case of an indirect discharger and to the local authorities in case of a direct discharger[8]. For the companies we asked, these contingents are usually temporary but commonly allocated for spans of ten to fifteen years or sometimes

[8] A indirect discharger is a facility that discharges the effluents to a public or private waste-water treatment plant whereas direct discharger employ their own treatment facilities and discharge the waste-water directly back into the water cycle (usually into a surface body of water, sporadically by seepage). Typically the large water users will have their own treatment plants or share such facilities with other neighbouring production sites. Direct dischargers only pay an “effluent contribution” (“Abwasserabgabe”) if they exceed certain legal limits. Indirect dischargers pay an “effluent fee” (“Abwassergebühr”) which is determined by cost recovery considerations specific to the treatment plant.

even longer. In some cases the companies still hold historical extraction contingents that were issued for unlimited time spans. The certificates are typically very detailed and can, apart from regulating yearly extraction, also limit monthly, daily or even hourly extraction. In practice the companies mainly monitor their extraction themselves and it is unlikely that any sanctions will be imposed if a limit other than the yearly one is exceeded. Even exceeding the yearly limit usually does not immediately lead to penalisation if the incidence is temporary and the company can justify the causes. Usually the public authorities balance public interests and the well-being of the company, which often lie closely together, e.g. in the case of securing employment.

In addition to the pure extraction amounts, the contingents also prescribe the temperature difference of the extracted surface water and the re-discharged wastewater, as well as its maximum absolute temperature and its contaminant loads. Furthermore, contingents regulate the temperature to which the discharged water may heat the bodies of water[9]. For the examined cases this temperature varies between 18 and 30 degrees Celsius. Additionally, the maximum temperature difference between the inflow and the river water is limited to eight degrees Celsius for two of the production sites.

In general the mixed system of periodical checks and self-control was described as working very well concerning compliance with the regulations, especially since the companies depend on a good relationship with the public authorities. This often leads to precautionary measures and initiatives on the part of the companies to reduce water consumption and pollution. The main motivation for these activities is to

[9] If the temperature of the body of water is too high the production site is simply not allowed to discharge any water. This happed e.g. to a thermal power plant close to Munich in the hot summer of 2003 which had to stop operations when river Isar heated up to over 27°C due to the weather conditions.

ensure that their contingent will be renewed in the future. Thus the reasons are first of all economic rather than altruistic.

The company representatives, interviewed personally or by phone, unanimously thought that contingents and quantity-dependent fees were the best solution to allocate water and rejected the idea of tradable extraction certificates. They emphasised the importance of being experienced under the current system. They pointed out that it is well functioning and that they suspect a system of extraction rights to be more complex. In addition, some representatives highly valued the close connection to the regional authorities that grant the contingents. They were especially worried about the higher anonymity and about a national orientation of regulations associated with alternative solutions like certificates[10].

Water withdrawal and water shortage

All examined sites extract their process and cooling water themselves and receive only a very small quantity from regional water suppliers, which is mainly used for sanitary facilities. For the visited production sites the water contingents varied from 500,000 to 15 million cubic meters annually. In the last five years the contingents were exploited from 60% up to slightly above 100% in one case in the extremely hot summer of 2003.[11] Much lower exploitation rates from 20% to 50%, however, were specified in the questionnaire campaign. Generally, water withdrawal from the producers interviewed has declined slightly in recent years, which holds for the whole industrial sector in Germany and Austria (figure 1.1.7). The current water quantity is not seen as being a problem by the industrial producers. Although - for a few companies - the hot and dry summer of 2003 showed the limits of their

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[10] The repeated response of representatives from medium-sized or small-scaled companies was that they expected the big companies to be the winners of such a system.

[11] An average self-supplied industrial producer extracts about 850,000 m³ water per year, a power plant about 8,000,000 m³ (Federal Statistical Office Germany (2003)).

contingents, this did not result in a change of mind. The representatives expect that there will be enough water for their production processes in the future. Consequently they do not expect their contingents to be reduced by the authorities. However, two examples of quantitative problems detected during our investigations will be specified below.

If a site pumps water from different wells, the selection of the wells used is likely to depend on their actual water temperature. One of the observed sites relies on a flow temperature of exactly 12 degrees Celsius. This is reached by mixing the outflow of the cooling water with the inflow of the fresh groundwater. The groundwater they use has its highest temperature in December, averaging 10.6 degrees Celsius and its lowest temperature in June, averaging 10.2 degrees Celsius.[12] The very wet summer of 2004 caused the groundwater temperature to rise in December 2004 to 11.5 degrees, which consequently almost tripled the demand for cooling water compared to average consumption. A further increase of just 0.2 degrees Celsius would have resulted in a reduction of production output due to the limitations of the water contingent.

Not surprisingly, the outfits most directly affected by water shortages are hydroelectric power plants. More surprisingly, a lack of usable water for power production is rather caused by too much than by too little water[13]. Hydroelectric power plants are built on sites with a reliable supply of water. If there are regular periods of low water supply these are accounted for in the operation of the plant. In contrast to common expectations, in humid regions these tend to be periods in the cold winter months. Obviously, if the air temperature drops below zero the

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[12] It is important to note that the temperature of the extracted water is not necessarily correlated with the current air temperature. This is especially true for mountain streams, which are feed by melting water. The same holds true for aquifers.

[13] In the case of elevated water lines, rivers also tend to carry an increased amount of sediment particles which can damage the power generation turbines. Consequently hydro power generation shows an inverted u-shape with regard to the amount of water in the river.

precipitation falls as snow and thus does not help to raise the water level. Also a hot and dry summer period does not necessary result in a shortage of water since the snowmelt may provide enough resources. The most likely cause for a lack of usable water is extreme rainfall or a flood. These pollute the water with particles and sediments which can cause serious damage to the turbines. Thus the power plant has to be operated at low capacity or even has to stop operating to prevent harm to the facilities.

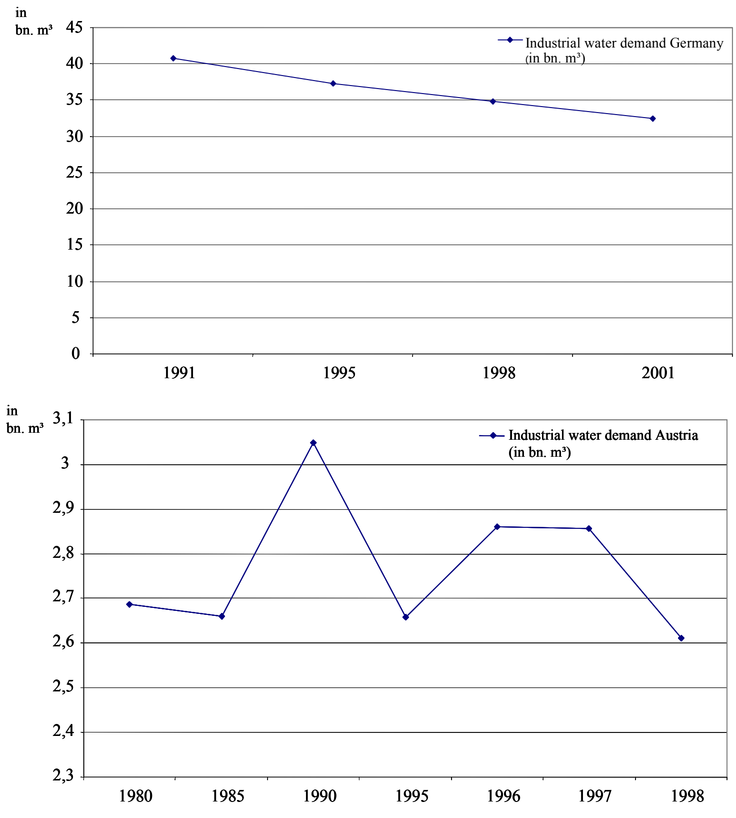

Figure 1.1.7: Development of industrial water use in Germany and Austria (Federal Statistical Office Germany, 2005; Statistik Austria, 2002).

Water quality

Regardless of its origin from surface waters or aquifers, the extracted water typically is of sufficient quality for the companies. Except mechanical filtering, no further treatment is necessary. In some cases for the protection of the tubes in the cooling systems water softener, anti-corrosives and algaecides are used. In closed cycles the water often is demineralized. The most frequent reason for a problematic reduction in water quality is heavy rainfall, which leads to pollution by sediment. In case of flood, pollution caused by contaminants like fuel oil leaking from oil tanks in flooded boiler rooms is also possible. All interview partners stated that they expect constant good water quality in the future.

Investments in water-saving technologies

The main reasons for investments in environment-friendly, water-saving technologies are legal obligations and possible cost savings. These cost savings result especially from lower wastewater charges but also from reduced fresh water charges. Often the short time horizon for the amortization of environmental investments was given as an obstacle for their realization.[14] This is especially true for publicly owned firms where the planning horizon does not exceed two or three years. In contrast, the representative of the cement works stated that average amortization for environmental investments was still about five years when the company was in family ownership and reached 25 years for the modernization of the sewage plant.

[14] The interviewed experts stated that technically a fresh water demand close to zero is possible in most production processes, but the costs would exceed benefits by far. In the paper industry, for example, average water demand has been reduced by 85% over the last 30 years.

However, even in water-intensive industries, the total costs of water, including wastewater, are less than three percent[15]. Most representatives even specified them to be less than one percent. Consequently a substantial increase in water costs would be necessary to have an impact on production. Most companies, however, expect only a slight increase in water costs in the short as well as in the long run.

One of the most water-intensive processes is thermal power production. A substantial increase in water costs will inevitably cause a rise in energy prices. Consequently, for energy-intensive production processes, the indirect effect of the rising energy costs is estimated to be much higher than the direct cost effects. Since many big production sites produce part of their energy themselves, a rise in general energy costs will increase their own energy production and, with this, their water demand.

The company representatives all agreed that positive image effects only play a minor role for the implementation of water-saving investments. The European Water Framework Directive (WFD) did not play any role for these investments. Most of the company representatives didn't even know the contents of the directive or were not aware of it at all. Even for the future, they dis not expected that this Directive will have any influence on water-relevant decisions.

How to Save Water in the Production Process

Obviously, water saving not only involves the financial aspect but eventually, the investment results in a technical implementation. This section elaborates on the options for implementing such water saving. The possibilities to reduce water demand can be categorized into the three basic options: process optimization,

[15] In Baden-Wurttemberg an energy supplier won a lawsuit against the state government because of being exposed to a competitive disadvantage against other European energy suppliers. The controversial subject where the freshwater extraction fees which raised the water related costs of one of the thermal power plants owned by the corporation to an "essential" cost share. The court decided that a contribution of more than 5% of total cost can be considered as essential and thus, results in a reduction of the freshwater fees.

implementation of technologies for the multiple or cycle usage of water, and the substitution of water by another production factor[16].

Process optimization is mostly achieved by improved monitoring or increased awareness and training of the engineering staff. In some of the examined cases, improved monitoring has led to a reduction of up to 70% of the water used. This was achieved by simply reducing the flow in the cooling system in load-dependence to the production process. Previously, the cooling system had always run at full capacity. Another common method to improve the effectiveness of water usage in the existing production process is the installation of more efficient heat exchangers, or the construction of cooling towers.

Typical approaches for multiple or cycle use of water mainly include recovery and cleaning of polluted process water and its re-use in further production steps as well as the use of heated cooling water for the same or other purposes. Possible applications include the re-use in a site's heating system, which lowers the consumption of other combustibles. Recovery methods applied by some of the visited sites include reverse osmosis and condensation of steam.

Due to the water intensity of its production, one of the chemical companies chose its location in a swamp area in the late 1920s. The continuous water extraction lowered the ground-water table so that a large industrial and rural area could develop around the company. In this case the extraction would have to continue even if the site closes production just to prevent the area from becoming swampy again. In the dry summer of 2003 the ground-water table around this production facility dropped over two meters, but regenerated back to the average level in the following two years. In a very dry summer in the 1960s a drop of around four meters occurred. In the 1970s,

[16] Even though our study only covers a small sample of companies for the questionnaire campaign and the in depth interviews a large study about innovations in water saving technologies which is currently conducted by the Fraunhofer Institut für System- und Innovationsforschung so far confirms our findings and is largely congruent to the results in this work. For further details on the current state of the study contact Thomas Hillenbrand at the Fraunhofer ISI Karlsruhe.

the company reacted to a continuous fall in the water table with the introduction of multiple usage and cycle usage of the water. In addition, in the 1980s it started seepage projects in cooperation with the local environmental and forestry authorities. This had become necessary since the vegetation had already started to change dramatically.

As a possible substitute for water as a coolant some experts mentioned compressed air. But in practice, for an existing production site that uses water as coolant, this is merely a theoretical alternative since the installation costs of the new system would be equivalent to those of a complete new production site. Thus, once the decision for a certain cooling medium has been made, a change is very unlikely to occur.

Conclusion

In this chapter we analyzed current and future water-related problems for the industries in the Upper Danube Catchment Area and showed how they cope with them. Do the companies' representatives believe that they can use their water resources in a sustainable way? Do they expect water to deteriorate in quantity or quality, especially due to the effects of global change? And how would they react to that?

To answer these questions we conducted several extensive telephone interviews and visited some sites personally. In particular we aimed to find out whether water scarcity and water saving already is an issue for water-intensive industries. Furthermore we investigated if the company representatives expected a shift in the quantity or quality of usable water. We spotlighted the global change issues, which could have negative effects on their production and how they would react to these. In this regard the results of our investigations are ambivalent: On the one hand the companies of the water-intensive branches we interviewed do not expect to be affected by global change in such a way that water will become scarce as a factor of production. Aside from this, their short planning horizon, caused by high rates of return on investments, leads companies to react to problems instead of undertaking expensive preventive measures that do not amortize in two or three years.

On the other hand it can be observed that even in the humid regions of the Upper Danube increased awareness of possible future climate scenarios is leading to a change in thinking and decision-making of companies, institutions and authorities. Water is used more efficiently in production processes, especially when new or re-investments take place. Existing facilities are optimized in terms of water saving potential. Large potentials in the improvement of the utilization factor are still to be realized, and thus substantial reductions in the fresh-water demand are possible but as yet economically unattractive for the investors. While the direct effects on the useable water quantity are likely to be limited for the companies in the next few decades, the indirect effects through the more extreme weather conditions are already affecting the majority of firms. They are confronted with rising energy prices in hot periods, destruction and pollution through increasingly frequent and severe flooding, and high expenditures for flooding protection. Furthermore water use has become more strictly regulated and immense efforts are being taken to monitor it. This process is steadily continuing and deepening as new technologies and research findings become available.

In contrast to the global average, in the catchment studied the most important water user is not farming, but the electricity suppliers and the industry. Water-intensive producers are typically self-supplied through ground or river-water. Scarcity in water supply therefore has an especially strong feedback on company-internal power generation or external electricity supply prices. Their extraction is regulated by detailed contingents which are generally preferred to alternatives like tariffs or tradable certificates. Cooperation between the private sector and the public supervision authorities functions well and, even though monitoring is mainly based on self-control, regulations are only rarely violated. Water quality, even for river water, is generally sufficient for production processes without any further treatment. Water scarcity in humid regions is usually not characterized by a lack of water supply. It is more likely to be caused by pollution. The most common problems are algae in hot periods or suspended particles and oil spill caused by flooding.

The actual and the expected problems in the observed area are different from those in arid regions. To address them, region-specific research is necessary. Unfortunately, there seems to be no panacea available. Further research on tools to estimate probable scenarios is essential if we want to identify future problems. In this regard it is indispensable to strengthen the link to the stakeholders. The issues and challenges the industries, institutions and authorities face must be included as early as possible in the research agenda, so that the findings meet with broader acceptance and thus generate the impact they all too often lack at present.

Chapter 1.2

GLOWA–Danube

Steps Towards the Global Change

Decision Support System DANUBIA

The environment is everything else except me.

Albert Einstein (1879-1955)

Introduction

The Global Change Decision Support System (GCDSS) DANUBIA is the product of the joint modelling and programming effort of the discipline-specific GLOWA–Danube sub-groups. It represents a new generation of environmental decision support systems, integrating agent-based socio-economic modelling into a natural-scientific simulation of the environment. It is able to simulate scenarios and incorporate the interdependencies between exogenous shocks and the different model components. The objective of this project is to model and simulate the demographic and industrial development.

The Industrial Agent

The industrial agent mimics the decisions of the relevant industrial production sites as close to reality as possible and as abstract as necessary and sensible. The decision process is focused on the questions of the optimal production output and of how to produce this output with minimal costs given regulative and resource constraints. In coherence with the dominant research question in the project we spotlight the use of water resources in the production process. Our special interest lies in the technologies used to increase the efficiency of water usage. These technologies, such as cycle usage or the use of the resource in multiple successive processes determines the utilization factor of water. To put it simply: How often is each litre of water that enters the production process employed in the process before it leaves the facility again? We assume the agent to behave rationally given that her information is limited by her perceptive abilities and her imperfect expectations. Therefore the cognitive process of decision-making is due to a dynamic generation of decision rules as an adaptive response to the perceived changes in the environment.

The conditions influencing the agent's decisions can be categorized into three groups: Factors which the agent perceives as exogenous and thus not influenceable by his actions, factors that he perceives as being influenced by his decisions, and factors which he can directly determine by choice. In our modelling approach examples for exogenous factors are technological progress and the so-called sustainability flags. These flags constitute the means by which the natural scientific models in DANUBIA signal a feedback of the sustainability of the resource usage to the agents. Rather than incorporating this signal directly into the decision process, it is used to determine the amount of regulation imposed on the production site by the local environmental agencies. This approach has been identified as preferential since the industrial producers cannot observe the sustainability of their resource usage. While counterintuitive at first glance, this is the consequence of simple information asymmetry. It is indeed true that in reality the production site cannot observe the consequences of its water consumption and that the monitoring of the environmental effects is done by the local environmental authorities[17]. These also have the means to regulate the water usage by extraction or effluent charges or by limiting the amount of water extraction. Among the factors the industrial agent perceives as influenceable are the water-related expenditures (including eventual charges). These are indirectly determined through factors of his direct choice, namely his investments in technologies that reduce pollution discharge in the effluents or increase the utilisation factor in the production process. Other important factors of direct choice are the labour employed and the production output.

[17] This might not be the case for regions that are less restrictive than Germany and Austria concerning the regulation of environmental pollution. In the observed area production facilities are typically restricted before the environmental effects are obvious to the producer.

Behind the Scenes: The Macroeconomic Model

To evaluate the consequences of industrial production for local natural resources it is necessary to simulate the complex production and decision process within a production site on a microeconomic scale. Still, not all economic processes which are needed to characterize economic development are necessarily or possibly modelled on the level of an individual firm. The simulation of the industrial production in DANUBIA therefore consists of two separate sub-models. A microeconomic agent-based model simulating one representative industrial producer on each industrialized square kilometre, and a macroeconomic model used to endogenously generate the regional economic indicators with regard to the spatial spillovers. These two models do not work separately but form a simultaneous system.

The implementation of the macroeconomic model was the first step in the development of the industrial production module within DANUBIA. This model simulates the supra-regional trends and the important economic interdependencies that are not simulated in the agent-based model. The first basic implementation of this model was based on the work of Langmantel and Wackerbauer (2003) and has been developed further to the current state. The model incorporates the influence of spatial structures like agglomerations on the economic developments. Thus, local economic developments are influenced by spatial spillovers from the surrounding regions and economic developments exhibit multiplier effects through the interregional feedback mechanism. This accelerates agglomeration effects, which are again limited by crowding externalities (e.g. in using common infrastructure as roads) and local resources. As a result factor prices rise. The macroeconomic model follows simple econometrically determined reaction functions.

The elasticities used for this reaction function have been estimated in Langmantel and Wackerbauer (2003) and the equation system has been adjusted to the current agent model:

$$G_i = GDP_{i,t-1}^{0.90} e^{-1.51} \qquad \text{(I)}$$

$$S_i = \bar{\pi}^{0.67} I_i^{0.40} G_i^{0.46} \left(\sum_j w_{ij} GDP_{j,t-1} \right)^{0.42} \left(\sum_j w_{ij} \pi_j \right)^{-0.35} \qquad \text{(II)}$$

$$GDP_i = 16.88 + 1.32 (I_i + S_i) \qquad \text{(III)}$$

$$P_i = (GDP_i / TA_i)^{0.73} (UA_i / TA_i)^{-0.86} \left(\sum_j w_{ij} P_j \right)^{0.66} e^{7.02} \qquad \text{(IV)}$$

$$C_i = GDP_i^{0.75} \left(\sum_j w_{ij} \, GDP_j / TA_j \right)^{0.15} e^{9.34} \qquad \text{(V)}$$

$$\pi_i = d\pi_i \cdot \bar{\pi} \qquad \text{with} \qquad \bar{\pi} = e^{-93.77+0.02t} \qquad \text{(VI)}$$

The government spending of district i is labelled G_i, the gross district product GDP_i , the value added of the services sector S_i and the value added of the industrial sector I_i. While G_i and S_i are determined by the macroeconomic model, the industrial production results from the agent-based model. The local price index for building land P_i depends on agglomeration intensity (measured by GDP per square kilometre), level of urbanisation (calculated as the relation of urban area UA_i to the total district area TA_i) and the spillovers from the land prices in the surrounding districts. The intensity of the spillover effects from district j on district i is determined by the spatial weight w_{ij}. Positive weights indicate neighbouring districts. Districts that are not neighbours receive zero weights and the weights of all neighbours of district i are normalized to sum to unity. To calculate the spillover effects we sum over the spatially weighted characteristics of the neighbouring areas. π_i measures the local labour productivity in the industrial sector and is composed of the average labour productivity $\bar{\pi}$ and the local divergence $d\pi_i$. Economic growth is modelled exogenously within the labour productivity with an annual trend of 2%.

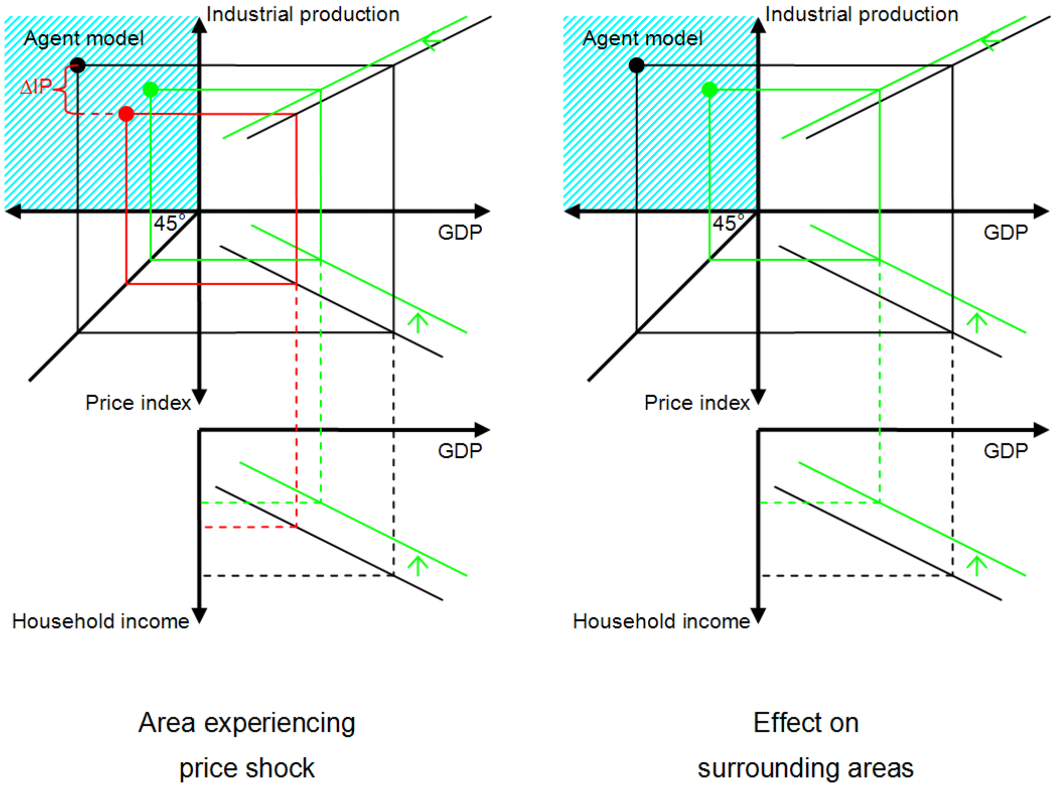

Figure 1.2.1: Schematic illustration of a regional price shock (own illustration).

Figure 1.2.1 illustrates the dynamics of the interaction between the agent-based model and the macro-model. The black dot in the left diagram describes an equilibrium situation in a district. The upper left square is covered by the micro-simulation in the agent-model. An exogenous shock, like more restrictive regulations of natural resource usage, lowers industrial production by ΔIP. Without spatial spillovers the economy would now converge to the new equilibrium described by the red lines. With spatial interdependence the change in the local economic conditions affects the surrounding regions in the right diagram. These in turn affect the district in which the exogenous shock originated. This dynamic process does not equal a move along the curves like a local shock without spillovers. Rather it will shift the curves in both regions until the new global equilibrium described by the green lines is reached. The exact regional effects depend on how severe the local shock is and it is well possible that it might result in a reduction of GDP in one district and an increase in another. An example of the regional effects of a tax on water extraction in the Munich district can be found in Egerer and Zimmer (2006).

Constructing an Industrial Agent

Depending on the available resources there are different approaches to model the industrial agent. Typically, the final implementation is based on anecdotal evidence, theoretical considerations or econometric estimates. To construct the industrial agent we explored all three of these options. In the theoretical approach the production function of the firm is modelled as closely to reality as possible and then the optimal factor demands used in the simulation are derived from this model. To mimic the production process it is necessary to gather as much information about it as possible. To achieve this we conducted a questionnaire campaign, did field- and telephone interviews and visited actual production sites. This participatory process involving the industrial water users was described in depth in chapter 1.1. The final step is to examine the available data that allows conclusions on the production technology to be drawn. A recent cooperation with the Data Research Centre of the German statistics state offices enabled us to empirically estimate actual production functions and price elasticities for the factor demands in the observed area in Germany.

As a result we designed the industrial production sites as profit-maximizing entities in a competitive market environment. It was an essential requirement in the construction to consider the effects of climate change and environmental pollution.

As discussed earlier it is reasonable to model the resulting consequences for the firm as regulatory constraints. The model should not only be able to simulate the effects on water demand and pollution discharge, but should also capture the impact on the job market and local GDP. Due to the integrative nature of DANUBIA these characteristics influence the macroeconomic and the discipline-specific models, which will in turn create a feedback on the industrial agent. The model results are calculated on the scale of a single representative industrial production site on each industrialized square kilometre within the observed catchment area[18]. The characteristics of the agent are determined by the local natural environment, the economic conditions and by the econometric estimates of the production technology.

$$E_n = \sum_i p_{n,i} X_{n,i} + \sum_k p_{n,k} \overline{X}_{n,k}$$

Part of the profit-maximizing behavior of a company is to minimize the production cost for a given production output. With p_n being the prices of the production factors employed the total expenditures E_n of a production site include the aggregated costs for the variable production factors X_n and quasi-fixed factors of production $\overline{X}_n$ [19].

$$Y_n = f\left[X_n, \overline{X}_n, T\right]$$

The output Y_n of the industrial facility is a function of the vectors of variable and quasi-fixed production factors employed and of the technology level at time T. This

[18] For the Upper-Danube Catchment Area this corresponds to a total of 1354 representative agents as identified by analyzing the remote sensing data.

[19] In the analysis of industrial water-use the term of quasi-fixed production factors commonly refers to factors that are exposed to legal regulations and thus the amount employed in the production process cannot be chosen arbitrarily.

black-box, converting multiple inputs in the production output, mirrors the technical production process in a production site.

$$\underset{x_n}{Max}\,\Pi_n = p_{n,Y}Y_n - E_n$$

The utility of the company can be measured by the profit Π_n that it generates with the production output[20]. The managerial effort is aimed at maximizing the difference between revenues $p_{n,Y}Y_n$ and expenditures E_n [21].

Implementation of the Agent-Based Industry Model in the DANUBIA Decision Support System

To implement the industrial agents in the DANUBIA environmental decision support system the economic model had to be constructed according to the requirements of the *DeepActor-Framework*. The *DeepActor-Framework* is the core of all agent-based socio-economic models in DANUBIA. It is itself part of the DANUBIA Framework

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[20] In a competitive market real profits will be very limited, but the effort to maximize them enables the company to stay in the market.

[21] In an interdisciplinary project like GLOWA-Danube it is important to communicate the disciplinary economic logic to the other disciplines within the network. It should therefore explicitly be mentioned that this approach is well in line with the contemporary view of decision processes in other disciplines. We want to highlight this exemplarily for the concept of *satisficing*, which is a popular approach in modelling the decision process of an agent within the psychological discipline. The idea of satisficing was motivated by the economic Nobel laureate Herbert A. Simon. Sidney G. Winter applied the concept of satisficing to the behaviour of the firm (*Satisficing, Selection and the Innovating Remnant.* (Quarterly Journal of Economics, 1971). He showed that the traditional mathematical methodology of profit maximization is a consistent representation of the decision process of a firm that is aiming to satisfy a simple rule of thumb (e.g. at least zero profits as deficits result in bankruptcy in the long run) and that underlies a random evolutionary process that generates new production technologies which the firm is free to employ. Given a competitive market a simple Markov-Chain analysis reveals that in the long run only the companies behaving optimally will survive. Thus the concept of satisficing and profit-maximization are unified to a common result by the existence of a competitive market. Since other individual decision processes are typically not penalized by a market if they are not in accordance to optimal behaviour, this conclusion will not necessarily hold for other disciplines.

that links and coordinates all the discipline-specific sub-models. The following UML-diagram illustrates the coding of the industrial agent. The industrial agent classes (DAI) extend the superordinate abstract classes of the *DeepActor-Framework*. They add to the *Abstract-ActorModel*, *AbstractActor*, *AbstractPlan* and *AbstractAction* the attributes and methods specific to the industry model[22]. The *DAI_Model* class contains the initialization data and stores the updated values in each simulation period.

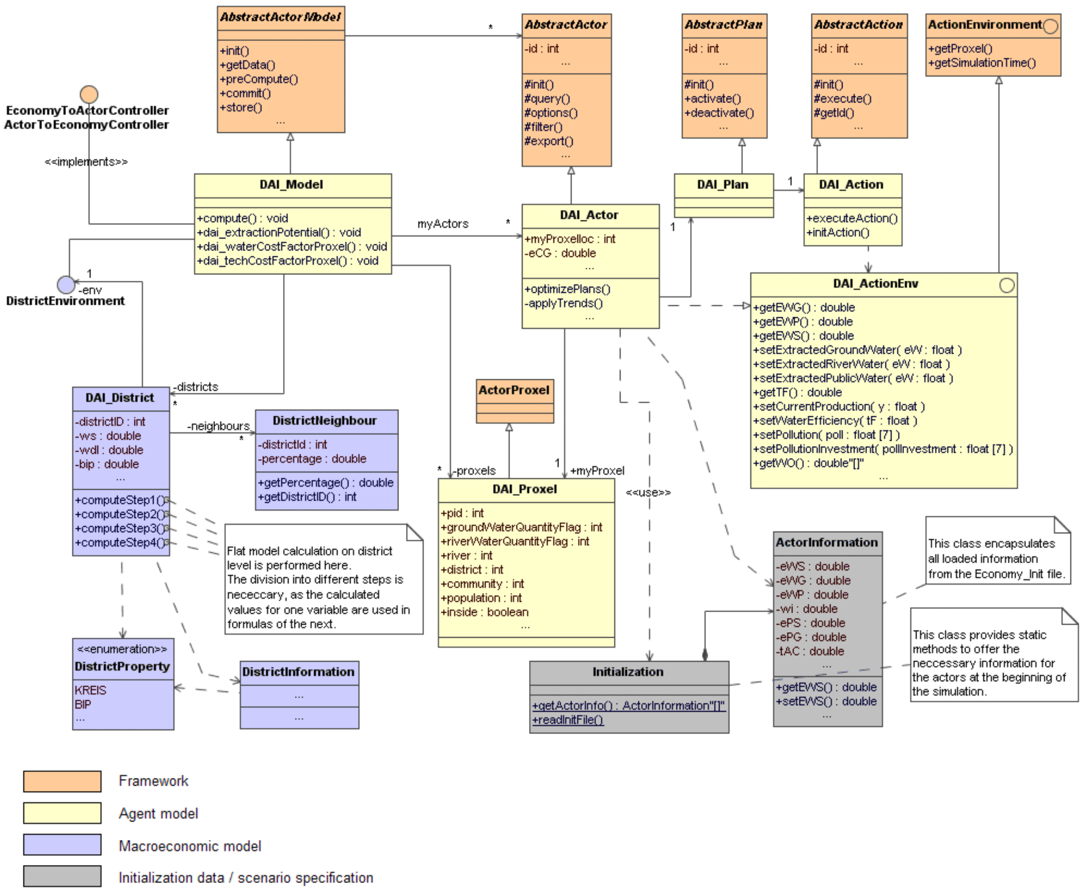

Figure 1.2.2: UML illustration of the industrial agent (own illustration).

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[22] A comment on the nomenclature used here can be found in the paragraph "The Objects Behind the Tool" in chapter 2.1 .

The *DAI_ActionEnv* interface contains the methods the agent (*DAI_Actor*) needs to perceive his environment and communicate his planned factor employments and production to the *DAI_Action* (representing the production facility). The *EconomyToActorController* interface is used to export data to the other discipline-specific sub-models in the framework. Correspondingly, the *ActorControllerToEconomy* allows data import. The macroeconomic model class *DAI_District* is embedded in the industrial agent. To enable a user-friendly adjustment of different scenarios we developed a graphical user interface (GUI) which allows the user the definition of simple scenarios (Figure 1.2.3). In particular, this editor allows the definition of the essential elasticities and trends.

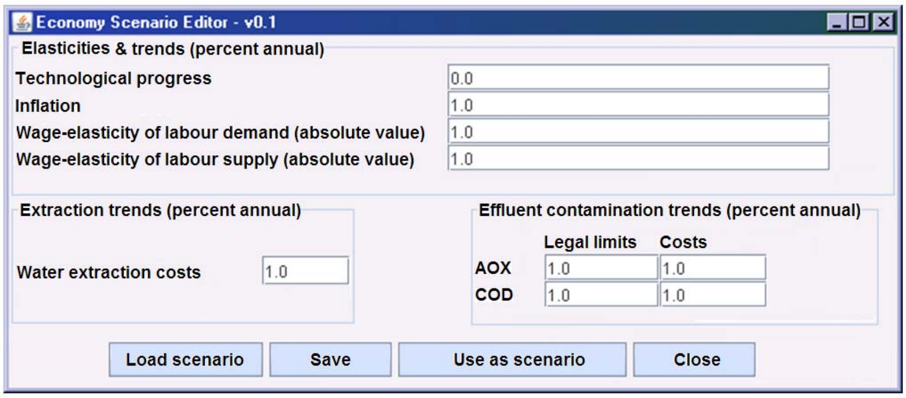

Figure 1.2.3: Scenario editor for the Economy sub-model[23]
(DANUBIA economy model).

[23] Trends are entered in the form of 1.02 for a positive and 0.98 for a negative trend of 2%.

On Stage: How Does the Industrial Agent Perform?

Figure 1.2.4 illustrates the results for the DANUBIA validation scenario runs. These were based the past period of 1995 – 1999 in order to compare the model simulations to measured data.

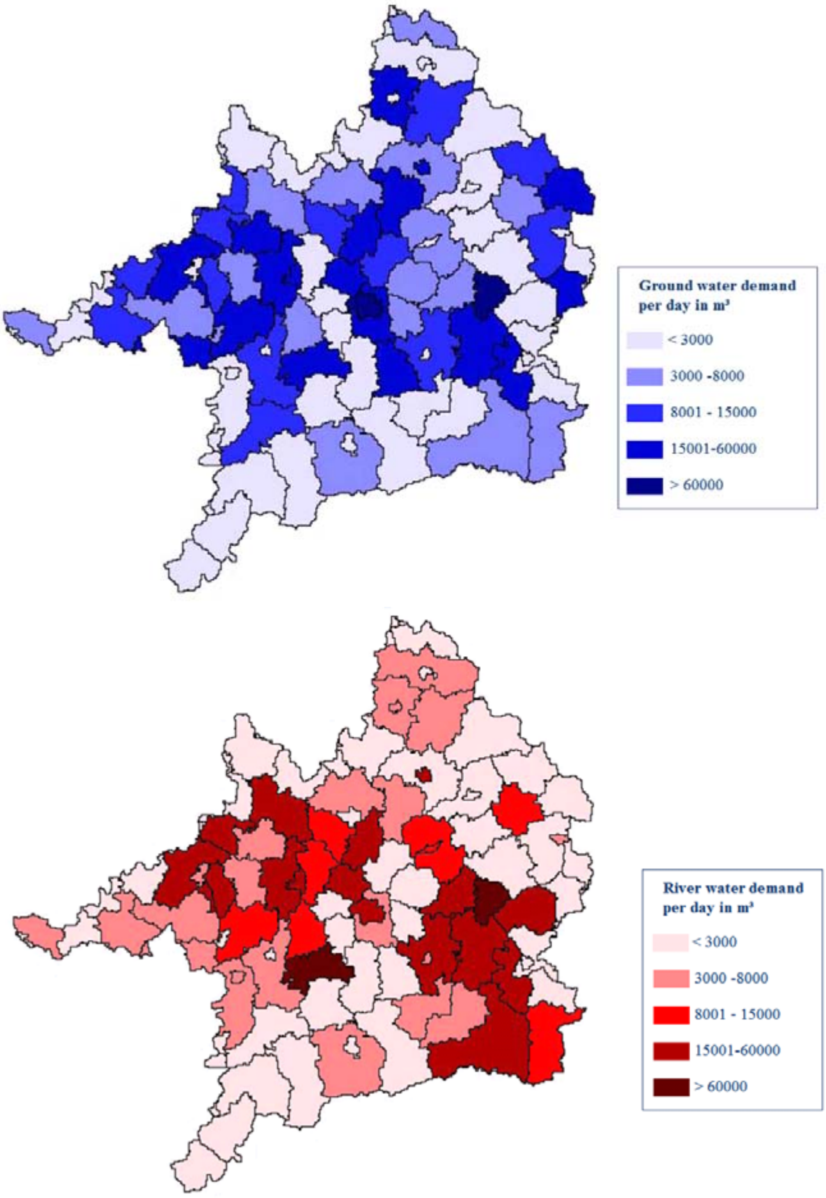

Figure 1.2.4: Water demand in DANUBIA.

A detailed presentation of the results can be found in Egerer (2005) and in Egerer and Zimmer (2006). The model replicates the measured data on a satisfactory level. Industrial groundwater demand in the observed area totals to 12 m^3/sec and river water demand to 22 m^3/sec. The demand is relatively stable and thus, less volatile than the measured demand. This is on the one hand deliberately since in a highly interconnected system like DANUBIA it is important that the feedback mechanisms don't build up to a level that destabilizes the whole simulation. On the other hand the reaction of the firms to changes in the environment is modelled with caution due to the poor quality of the data that is available for econometric estimates. The latter issue will be solved in further development steps of DANUBIA as an intensive collaboration with the Data Research Centre of the Statistical State Offices of Germany has been agreed upon.

Chapter 1.3

For What It's Worth!

The Value of Polluting Water

for Industrial Production

We all live downstream.

David Suzuki (Scientist and Environmental Activist)

Introduction

Industry is one of the main users of water resources. Water is an essential production factor and is used in almost every production process of a manufactured good. The mining industry and the industries that produce paper products, chemicals and metals demand especially large quantities of water. Water is used for cleaning, diluting, transporting a product, cooling, heating, generating steam, sanitation and, of course, as a constituent in the final product. The industries that employ large amounts of water are typically self-supplied. They often circulate the water within the production process or use it multiple times in consecutive processes. While multiple employment might follow from economic considerations, cycle-use is rather a reaction to regulatory constraints[24]. Our main focus in this analysis is the sustainable use of water-resources by industrial producers in the Upper-Danube Catchment Area. The natural and artificial water-cycles have recently experienced a renaissance in political discussion. A prominent example is the European Water Directive. But today the concerns have shifted away from the focus on chemical pollution to climatic change issues like thermal pollution or scarcity. To evaluate environmental regulations concerning the utilization of water, it is indispensable to know the value of this resource for its consumer. Unfortunately, the information currently available on the valuation of water by industry is rare and limited to few locations. In this paper we close part of this knowledge gap by providing estimates for the shadow prices of water and the most common effluent contaminates. Within a translog-framework we analyze sector- and region-specific production functions in Germany.

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[24] This argument is explored in detail in the first chapter. Multiple-use is for example reasonable if water that is used for cooling is later on used for heating. But often water is polluted in the production process and thus not useable for other production purposes without further treatment. Cycle-use is problematic because of salinization and the resulting corrosion, and because of water quality deterioration due to pollution with algae and bacteria. The feedback of the process engineers interviewed revealed that single employment of the extracted water is typically the preferred choice if the production site is not constrained by regulations.

We abstract from restrictive frameworks commonly used. Thus, instead of imposing linear homogeneity or separability a priory, we extend the more flexible framework proposed by Kim (1992). We allow for variable returns to scale and non-homothetic production technologies and generalize the framework by including quasi-fixed factors of production. This extension is essential to estimate the shadow costs of regulations that limit water extraction or pollution. We depart from the common analysis on the scale of a whole sector of the industry and use micro-data to explore the production structure on the firm level. The issue of industrial water use has been largely absent in the journals of the economic profession. Widening the search reveals only a few more contributions to this topic. Noteworthy are two recent research papers by Dupont and Renzetti (2003) and by Dachraoui and Harchaoui (2004). Both analyze the valuation of water for the Canadian industrial sector using a translog-cost framework but do not address the issue of water pollution.

The Water Cycle does Not Care for Administrative Borders

Observing the water cycle it is important to notice that the consequences of using and polluting the water resources usually do not stop at administrative borders. It is therefore only natural for the analysis of industrial water use to not only differentiate between sectors, but also between regions that are delimited by natural borders. Thus, instead of the administrative borders we rather use the watersheds that delimit the river basins. Investigating industrial water usage, this is not only reasonable due to upstream/downstream riparian conflicts, but also due to the fact that environmental characteristics and problems as well as spillover effects concerning the water resources will generally obey the natural borders. Computer-based environmental decision support systems like DANUBIA account for this and typically generate their results to be consistent with the natural borders.

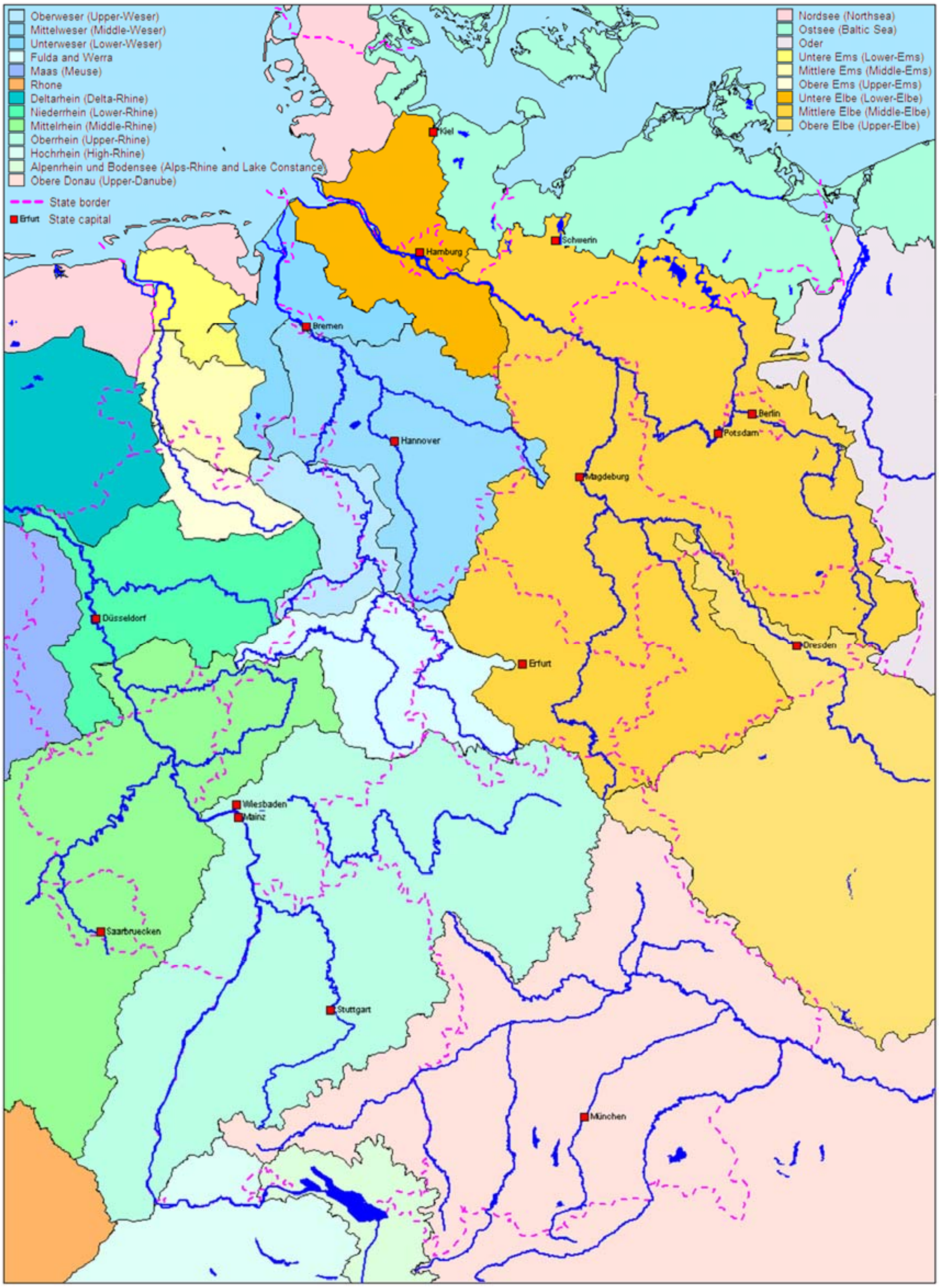

Figure 1.3.1: First-order watersheds in Germany
(based on maps provided by the Federal Office for Hydrology).

Figure 1.3.1 compares the first-order watersheds with the state borders in Germany. The region of main interest for the GLOWA-Danube project is the dusky pink-shaded area in the south-east. Looking at the pink state borders we observe that the major part of the German Upper-Danube Catchment Area lies within Bavaria, which is indicated by its capital Munich (München). In the econometric estimates we display separate results for all of Germany and for the German part of the Upper-Danube Catchment Area.

Pollution Measures and Resource Consumption

The large industrial water users that are responsible for the largest proportion of total water usage in Germany are typically self-supplied. As such they perceive water as an almost free production factor[25]. Nevertheless, the extraction of water is restricted by contingents. These sophisticated extraction permits are enacted by the local environmental authorities[26]. In industrial production processes water is typically not consumed in the traditional sense. It is rather used for production purposes and afterwards returned to the water cycle. The equivalent to "consumption" is rather the reduction of the usable amount of the resource for other natural or artificial utilisations. This might be due to the reduction of water quality below a critical threshold. An upstream/downstream riparian conflict might also be caused by a reason that is closer to the traditional interpretation of consumption, if e.g. the water resources are evaporated in a cooling process[27]. To measure the pollution discharge within industrial effluents we make use of two common measures of effluent contamination, namely the concentration of adsorbable organic halides (AOX) and

[25] Two of the sixteen German states introduced a so-called water-cent. This is a fee of one cent/m^3 for surface water extraction and of about 5 cent/m^3 for the extraction of groundwater. If this fee essentially contributes to the costs of the production process, this fee can be reduced by up to 90%.
[26] A detailed discussion on the structure and the regulatory framework of industrial water usage can be found in the first chapter.
[27] Of course the evaporated water is not really consumed since it returns to the natural water cycle.

chemical oxygen demand (COD). Within effluents, AOX are mostly organic halogens from industrial origin. This index characterizes the amount of organically bounded halogen compounds that are adsorbable by activated carbon and measures the amount of chloride generated in the analytic process of the effluent. COD is the amount of solute oxygen in mg/l necessary for the complete chemical oxidation process of the organic substances in the effluent. It is an index to characterize the absolute contamination with organic pollutants.

Data

The data is provided by the Data Research Centre of the German Statistical State Offices (Forschungsdatenzentrum der Statistischen Landesämter). It consists of two separate data-sets. The Monthly Report of Manufacturing and Mining and the Extraction of Stones and Earths, which contains the economic characteristics of the companies on the level of the individual firm. This statistic is used to extend the characteristics of the production sites contained in the second statistic, the environmental statistic about the industrial water usage. This triennial statistic includes all industrial production sites and mining sites that have an annual water demand of at least 10,000 m^3. Therefore it should be noticed that the conclusions we arrived at are only valid for the sub-group examined. We use the statistics for the years 1998, 2001 and 2004. Unfortunately at the time of this analysis the available data did not include the capital employed and the intermediate products. With the forthcoming environmental statistics for the year 2007 this data will become available and a further research cooperation with the statistical state offices has been arranged to update this analysis accordingly. This will also allow to investigate further research questions.

Extension of the Translog-Production Function Framework

In the following section we want to outline the particular features of our specification of the input inverse demand framework proposed by Kim (1992). While his framework already allows for a non-homothetic production technology and variable returns to scale we additionally focus on the implications of including quasi-fixed production factors. Our special interest lies in determining their marginal shadow values to the producer. The generalized production function has the following form:

$$Y_n = f\left[X_n, \overline{X}_n, T\right] \tag{I}$$

Y_n is the output level of firm n with X_n being the vector of variable production factors, $\overline{X}_n$ the vector of quasi-fixed factors of production and T the time index used to measure technological change. Writing this production function in its translog specification yields the following expression:

$$\begin{aligned} \ln Y_n = {} & \alpha_{n,0} + \sum_i \alpha_{n,i} \ln X_{n,i} + \sum_k \alpha_{n,k} \ln \overline{X}_{n,k} + \frac{1}{2}\sum_i \sum_j \beta_{n,ij} \ln X_{n,i} \ln X_{n,j} \\ & + \frac{1}{2}\sum_i \sum_k \beta_{n,ik} \ln X_{n,i} \ln \overline{X}_{n,k} + \frac{1}{2}\sum_k \sum_l \beta_{n,kl} \ln \overline{X}_{n,k} \ln \overline{X}_{n,l} \\ & + \sum_i \delta_{n,iT} \ln X_{n,i} T + \sum_k \delta_{n,kT} \ln \overline{X}_{n,k} T + \delta_{n,T} T + \frac{1}{2}\delta_{n,TT} \ln T^2 \end{aligned} \tag{II}$$

The indices i and j identify the different variable inputs and k and l the quasi-fixed factors. For the estimation we impose symmetry on $\beta_{n,ij} = \beta_{n,ji}$, $\beta_{n,ik} = \beta_{n,ki}$ and $\beta_{n,kl} = \beta_{n,lk}$. We know that for the general model in (I) the first-order conditions from the output-maximization under a given expenditure-constraint are:

$$\frac{\partial Y_n}{\partial X_{n,i}} = \lambda_n p_{n,i} \qquad \text{note that for competitive firms:} \qquad \frac{\partial E_n}{\partial Y_n} = \frac{\partial C_n}{\partial Y_n} = \frac{1}{\lambda_n} \qquad \text{(III)}$$

Where $p_{n,i}$ is the price of the i^{th} input and the Lagrange multiplier is the reciprocal of the marginal expenditure necessary to increase the output in the short run. With E_n being the total expenditure and C_n being the variable costs within the expenditure it is trivial that the marginal cost increase is equal to the marginal increase in the variable costs. For the maximization problem the expenditure constraint as well reduces to its variable expenditures counterpart:

$$E_n = \sum_i p_{n,i} X_{n,i} + \sum_k p_{n,k} \overline{X}_{n,k} \quad \Rightarrow \quad C_n = \sum_i p_{n,i} X_{n,i} \qquad \text{(IV)}$$

Solving equation (III) for $p_{n,i}$, then substituting it in equation (IV) and finally solving for λ_n yields

$$\lambda_n = \frac{1}{C_n} \sum_i \frac{\partial Y_n}{\partial X_{n,i}} X_{n,i} \qquad \text{(V)}$$

The inverse input demand follows from substituting (V) back into (III) and solving for $p_{n,i}$

$$p_{n,i} = \frac{\frac{\partial Y_n}{\partial X_{n,i}}}{\sum_j \frac{\partial Y_n}{\partial X_{n,j}} X_{n,j}} C_n \qquad \text{(VI)}$$

With $\partial Y_n = Y_n \partial \ln Y_n$ and $\partial X_{n,i} = X_{n,i} \partial \ln X_{n,i}$ the share of variable costs $S_{n,i}$ spent for input i is then

$$S_{n,i} \equiv \frac{X_{n,i} p_{n,i}}{C_n} = \frac{\dfrac{\partial \ln Y_n}{\partial \ln X_{n,i}}}{\sum_j \dfrac{\partial \ln Y_n}{\partial \ln X_{n,j}}} \tag{VII}$$

The derivation of the marginal products from equation (II) is obvious. Substituting these back into the share equation yields the appropriate term for the estimation

$$S_{n,i} = \frac{\alpha_{n,i} + \sum_j \beta_{n,ij} \ln X_{n,j} + \sum_k \beta_{n,ik} \ln \overline{X}_{n,k} + \delta_{n,iT} T}{\sum_j \alpha_{n,j} + \sum_i \sum_j \beta_{n,ij} \ln X_{n,j} + \sum_i \sum_k \beta_{n,ik} \ln \overline{X}_{n,k} + \sum_j \delta_{n,jT} T} \tag{VIII}$$

Compared to the formulation without quasi-fixed productions factors this expression gains the additional terms containing the sums over the logs of the quasi-fixed inputs. For efficient estimates, common practice suggests to simultaneously estimate the nonlinear multivariate equation system composed of (II) and the available cost shares (VIII)[28]. Kim (1992) points out that cost share can only move in the unit interval, which violates the normality assumption for the error terms. Since the cost shares have a logistic-normal distribution it might be preferable to estimate the following equation if more than one cost share is available[29]:

$$\ln\left[\frac{S_{n,i}}{S_{n,h}}\right] = \ln\left[\frac{p_{n,i} X_{n,i}}{p_{n,h} X_{n,h}}\right] = \ln\left[\frac{\alpha_{n,i} + \sum_j \beta_{n,ij} \ln X_{n,j} + \sum_k \beta_{n,ik} \ln \overline{X}_{n,k} + \delta_{n,iT} T}{\alpha_{n,h} + \sum_j \beta_{n,hj} \ln X_{n,j} + \sum_k \beta_{n,hk} \ln \overline{X}_{n,k} + \delta_{n,hT} T}\right]$$

[28] Sample STATA-code for the estimation of the non-linear equation system can be found in the appendix to this chapter.

[29] The full system with all cost shares cannot be estimated because its variance-covariance matrix is singular and non-diagonal. This problem is due to the fact that the variable cost shares sum to unity. It is solved by simultaneously estimating the production function and all but one cost share equations. Christensen and Greene (1976) showed that the estimation results are independent of which cost share is excluded for maximum likelihood estimators.

The estimated system does not loose efficiency since the otherwise excluded cost share equation can now be used as denominator. Compared to (VIII) this equation is essentially reduced in complexity. For specific applications it has the additional advantage that the total variable costs do not need to be known as they cancel down in the equation.

For What It's Worth

The shadow value z_n of being able to vary one of the quasi-fixed factors of production is equal to the marginal reduction in total expenditure resulting from a marginal variation:

$$-z_{n,k} = \frac{\partial E_n}{\partial \bar{X}_{n,k}} \qquad \text{(IX)}$$

Usually this shadow value is derived from the translog cost-function directly. This is not always desirable, since input prices might not be available but factor quantities are known. In our analysis of industrial water-use no market exists for this natural resource and thus this production factor is typically not priced at all. Water is assigned to the industrial producers by the public authorities. Nevertheless, it is a common misinterpretation that because of the assignment process water can be considered a quasi-fixed production factor. Since the water is almost never consumed in the production process, the total amount of water employed in the industrial facility can be increased by employing the same unit of water several times within the production process. Observing production processes on-site and interviewing various production engineers uniformly revealed evidence that this allows them to exceed the limitations of the contingent. The difference being that the cycle- or multiple-utilization is more costly than the one-time usage. To specify our production framework accordingly we define the first variable production factor as the water used in the production process:

$$\ln X_{n,1} \equiv \ln\left(\rho \overline{W}_n + W_n\right) \qquad \text{(X)}$$

In this specification $\overline{W}_n$ is the amount of water that the company is allowed to extract according to its water contingent and $\rho \overline{W}_n$ is the re-use equivalent of this extracted water. This term is included if and only if the contingent is binding[30]. W_n is then either – if the contingent is binding – the additional amount of water employed in the production process or – if the contingent is not binding – the total amount of water that is used in the production process[31]. The conversion of the fixed water contingent into the re-use equivalent $\rho \overline{W}_n$ accounts for the fact that the primary extracted water has different evaluation for the production process than the re-used water. Additional purification techniques have to be applied in order to recycle the once employed water to its original extraction quality. Thus, we would expect the estimate for ρ to be lager than unity[32]. The separation of variable and quasi-fixed production factors is not only necessary to evaluate the shadow value of the water intake but also to assess the value of polluting the effluents. From the firm's perspective the pollutants are a factor of production. If the discharge is free the firm will emit until no additional

---

[30] If the contingent is binding can easily be checked by comparing the known amount of water employed in the production process to the also known amount of water extraction. If the relation is larger than one we define the contingent as binding.

[31] It is obvious that within the production process these two sources of water are perfect substitutes once the already employed water had been purified for further usage. Nevertheless our specification differs from the approaches used to estimate the shadow value of water, as the so far used translog-cost functions do not follow out of duality to our specification.

[32] Regarding the interpretation it might be more intuitive to choose the notation as $\ln X_{n,1} \equiv \ln\left(\overline{W}_n + \rho W_n\right)$. This wouldn't change the results but would require further deviation from the standard notation used for translog-production functions.

pollution results from the production process any longer and would have to be intentionally (and costly) produced. An obvious method to reduce the pollution discharge would be to sanction it by imposing a fee. However, for effluents it is also common to directly regulate the pollution level[33]. Since industrial producers have no incentive to further reduce their pollution discharges[34] and legal limits are low enough to be binding, we can consider effluent pollution as quasi-fixed. Returning to the shadow value of pollution in equation (IX) we need to address the fact that we estimate the production function and not the translog-cost function. By simple manipulation and using the conditions derived in equations (III) and (V) we can express the shadow value as:

$$-z_{n,k} = \frac{\partial E_n}{\partial \overline{X}_{n,k}} = \frac{\frac{\partial Y_n}{\partial \overline{X}_{n,k}}}{\frac{\partial Y_n}{\partial E_n}} = \frac{\partial Y_n / \partial \overline{X}_{n,k}}{\lambda} = \frac{C_n}{\overline{X}_{n,k}} \frac{Y_n \frac{\partial \ln Y_n}{\partial \ln \overline{X}_{n,k}}}{\sum_i \frac{Y_n \partial \ln Y_n}{X_{n,i} \partial \ln X_{n,i}} X_{n,i}} \tag{XI}$$

[33] If the companies discharge their effluents into public sewage treatment systems they have to pay waste-water fees. For direct-discharge (usually into a surface water body), e.g. of cooling water, they are usually within their contingent-restricted pollution discharge. Further details can be found in chapter 1.1 of this work. Typically the local public environmental office will set the individual limits for the company by balancing legal regulations, local economic conditions, demands of other economic entities wanting to pollute the resource or preferring it unpolluted, specific characteristics of the polluted resource and political orientation of local authorities (reflecting the local orientation of the population). Close monitoring hardly allows deviation to higher levels than the absolute pollution discharge intended by the environmental office.

[34] Companies often claim to be environmentally friendly. They validate that by various more or less official labels on their products that proclaim the environment-friendliness. This might lead to the conclusion that pressure through the consumers can result in a reduction of pollution. For the investigations preceding this work we had a special focus on this point. The surprisingly honest message we got from all the company representatives that we interviewed can be concluded in two essential facts:

1st: The causality is the other way around. Since the companies are so strictly regulated they fulfil the requirements of the environmental labels anyway.

2nd: The consumers do not reward environmental friendliness to an extent which would justify further efforts in the reduction of pollution.

Deriving the first-order conditions from the translog-production function in (II) and substituting them in the above equation we can formulate the shadow value of a quasi-fixed production factor as a function of the estimated parameters, the factor inputs and the variable costs:

$$-z_{n,k}=\frac{C_n}{\overline{X}_{n,k}}\frac{\alpha_{n,k}+\sum_i\beta_{n,ik}\ln X_{n,i}+\sum_l\beta_{n,kl}\ln\overline{X}_{n,l}+\delta_{n,kT}T}{\sum_j\alpha_{n,j}+\sum_i\sum_j\beta_{n,ij}\ln X_{n,j}+\sum_i\sum_k\beta_{n,ik}\ln\overline{X}_{n,k}+\sum_j\delta_{n,jT}T}$$

(XII)

To determine the variable costs it is appropriate to assume the pollution discharge to be free-of-charge $\sum_k p_{n,k}\overline{X}_{n,k}=0$. Thus, it follows from equation (IV) that $E_n = C_n$. Likewise the shadow value of being able to increase the water contingent is[35]:

$$-z_{n,\overline{W}_n}=\rho\frac{C_n}{X_{n,1}}\frac{\alpha_{n,1}+\sum_i\beta_{n,1i}\ln X_{n,i}+\sum_l\beta_{n,1k}\ln\overline{X}_{n,k}+\delta_{n,1T}T}{\sum_j\alpha_{n,j}+\sum_i\sum_j\beta_{n,ij}\ln X_{n,j}+\sum_i\sum_k\beta_{n,ik}\ln\overline{X}_{n,k}+\sum_j\delta_{n,jT}T}$$

(XIII)

From equations (VI) and (X) it is obvious that $-z_{n,X_{n,1}}=p_{n,X_{n,1}}$. Hence, the shadow value of increasing the contingent is higher than the water costs if ρ is lager than unity.[36].

[35] This is easy to prove by substituting $\frac{\partial\ln Y_n}{\overline{X}_{n,k}\partial\ln\overline{X}_{n,k}}$ with $\frac{\partial\ln Y_n}{\partial\overline{W}_n}$ in equation (IX).

Results

Table 1.3.1 summarizes the estimation results. The necessary values for the simulation of the industrial production sites within the environmental decision support system are the partial price elasticities $\eta_{i,i}$ and cross-price elasticities $\eta_{i,j}$.

	All production sites	Upper-Danube Catchment	Mining	Chemical industry
R^2	19.8	17.8	24.9	16.7
Observations	29485	4096	2014	2343
$\sigma_{labour,labour}$	-0.086 ***	-0.028 ***	-0.268 ***	0.118 ***
$\sigma_{labour,electricity}$	0.807 **	0.837 *	0.579	0.408
$\sigma_{labour,water}$	0.981	-3.033	1.193	5.469
$\sigma_{electricity,electricity}$	-4.991 ***	-7.822 ***	-3.645 ***	-49.103
$\sigma_{electricity,water}$	-0.094	-2.609	1.290	-10.048
$\sigma_{water,water}$	-29.869 ***	19.845	-23.326 ***	-484.144 **
$\eta_{labour,labour}$	-0.071 ***	-0.024 *	-0.218 ***	0.115 ***
$\eta_{labour,electricity}$	0.099	0.074	0.069	0.005
$\eta_{labour,water}$	0.044	-0.133	0.079	0.051
$\eta_{electricity,labour}$	0.670 ***	0.725 ***	0.470 ***	0.399 ***
$\eta_{electricity,electricity}$	-0.615 ***	-0.698 ***	-0.438 ***	-0.657
$\eta_{electricity,water}$	-0.004	-0.114	0.086	-0.095
$\eta_{water,labour}$	0.815 ***	-2.629 ***	0.969 ***	5.344 ***
$\eta_{water,electricity}$	-0.011	-0.232	0.155	-0.134
$\eta_{water\ water}$	-1.367 ***	0.871	-1.560 ***	-4.590 **
p_{water}	0.075	0.070	0.008	0.019
$-z_{water}$	0.139	0.134	0.011	0.048
$-z_{COD}$	0.142	2.742	0.054	-0.385
$-z_{AOX}$	-0.280	3.232	0.404	1.001

Table 1.3.1: Allen-Uzawa partial elasticities of substitution ($\sigma_{i,j}$), price elasticities ($\eta_{i,j}$)[37], water costs (p_{water}) and shadow values ($-z_k$).

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[36] Note that water contingent is only binding if $\overline{W}_n < X_{n,1}$. Since the water costs for multiple- or cycle-use are likely to be higher, or at least as high as the extraction costs for freshwater, this theoretical result predicts that the production sites that are bound by the contingent constraint have a higher shadow value for a marginal increase in the contingent.

[37] Significance levels of 1% (***), 5% (**), and 10% (*) are given for the elasticities. They are approximated using the delta method.

These are derived from the cost shares and the Allen-Uzawa partial elasticities of substitution $\sigma_{i,j}$ [38]. Negative values in the Allen-Uzawa elasticities indicate substitutes and positive values for complementary production factors. By construction it holds that $\sigma_{i,j} = \sigma_{j,i}$. Labor, electricity and water are ordinary goods as indicated by their negative price elasticities but water tends to be employed in its price-elastic range contrary to the other variable production factors. The estimates for the utilization costs of water range from below one cent up to eight cents per cubic meter of water employed in the production process[39]. The shadow values of increasing the water contingents range slightly higher, between one and fourteen cents per cubic meter of water. Not all of the results for the pollution discharge are consistent with expectations since some of the shadow values are negative[40]. For COD the shadow value measured in euros is the willingness to pay for the legitimization to additionally pollute the effluents such that one additional milligram of oxygen is needed for the oxidation of the organic substances in the effluent. Likewise, for AOX the shadow value is the value for polluting the wastewater such that it generates one additional microgram of chloride in the analytic process[41].

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[38] See e.g. Chang (1994)

[39] This price covers the extraction costs and the costs of multiple- or cycle use. The estimates of Dupont and Renzentti (2003) range between 0.34 cent/m^3 and 6.17 cent/m^3 with an average shadow value of 0.62 cent/m^3 (1991 Canadian \$). The estimates of Dachraoui and Harchaoui for the shadow value of water utilization including recirculation range between −0.37 \$/m^3 and 1.02 \$/m^3 with an average of 0.57 \$/m^3 for the water-intensive industries (Canadian \$).

[40] This could only be the case if the company were willing to pay for being allowed to reduce the fixed amount of pollution discharge.

[41] Usually COD and AOX are measured in relative amounts per litre of effluent. For the production process the absolute values are of interest.

Conclusion

We developed a methodology to investigate the value of water resources and their pollution for the industrial production. The framework incorporates regulated production factors and effluent pollution, but can be applied to other contaminants as well. It solves the conflict of previous theoretical models and combines fixed water contingents with the possibility to use the resource multiple times or in a cycle. Thus the company is free to efficiently choose the amount of water employed while the value of the water contingents can still be determined. The shadow values of water for the observed production facilities range between one and fourteen cent/m^3 and are thus right in the middle of the range of earlier findings for the Canadian industrial production.

Appendix to Part One:

(Ap. I.I) Discussion Guidelines for the Visited Production Sites and the Telephone Interviews:

Subject Area: Production Process

- Which role does water play as a resource in your production processes?
- In which stages of the production process and in which ways do you use water?
- What is the degree of utilization of the water?
- How did this change in the past?

Subject Area: Water Contingent / Water Withdrawal

- How high is your water contingent?
- Is the contingent limited in time? / How did it develop in the past?
- Is it variable?
- How much water do you withdraw per year?
- Are there seasonal variations?
- What kind of water do you withdraw (ground water or surface water)?
- Do you additionally purchase water from a local water supplier?
- Would you prefer alternative solutions concerning the contingents (e.g. tradable contingents, fees on water extraction without limitations)?
- What are your expectations concerning the future development of the natural water supply?
- Do you think there will be enough water for your production processes?

Subject Area: Water Quality

- In what way is the quality of the water relevant?
- Do you purify the pumped water? If yes, how is it purified?
- Is the actual quality of the water satisfactory for the production process?
- What are your expectations concerning the development of the quality of the water?

Subject Area: Costs

- What are your costs for pumping and purifying the water?
- What are your costs for waste water (direct discharge / indirect discharge)?
- Which effects would a rapid increase in these different costs have on your production and on water technology?
- What is the relative importance of the water costs in proportion to the production costs as a whole?

Subject Area: Saving Water

- Is it possible for you to substitute other resources or technologies for water in your production processes or is it possible to save water by changed procedures?
- Have you implemented such measures or do you have them planned?
- What are the effects on the amount of water withdrawn?
- What are your motivations to save water?
- What factors will have an impact on your water usage, e.g.:
    - Climate change: low or high water
    - Laws/regulations: EU-framework directive in the field of water policy
    - PR: image of the company, philosophy of the company, social pressure

Subject Area: Energy

- Energy production is one of the production processes with a very high need for water. How do you estimate the indirect increase of the costs for water caused by increasing costs for energy in proportion to the direct increase of costs caused by increasing costs for water?
- How variable are your costs for the energy supply?

(Ap. I.II) STATA-code for estimation:

```
use "C:\translog\translog", clear
****************************************************************
* log output: y                                                *
* log kapital: x01        (currently not available = 0)        *
* log labor: x02                                               *
* log intermediate: x03   (currently not available = 0)        *
* log electricity: x04                                         *
* log CSB-pollution: x05                                       *
* log AOX-pollution: x06                                       *
* water total/residual: x07                                    *
* water contingent if utilization > 1: x08                     *
* year: x09                                                    *
* labor cost share: s2                                         *
****************************************************************
* Note that water employment is equal to: log(x07+rho*x08)     *
****************************************************************
gen x11 = x01*x01/2
gen x22 = x02*x02/2
gen x33 = x03*x03/2
gen x44 = x04*x04/2
gen x55 = x05*x05/2
gen x66 = x06*x06/2
gen x99 = x09*x09/2
gen x12 = x01*x02
gen x13 = x01*x03
gen x14 = x01*x04
gen x15 = x01*x05
gen x16 = x01*x06
gen x19 = x01*x09
gen x23 = x02*x03
gen x24 = x02*x04
gen x25 = x02*x05
gen x26 = x02*x06
gen x29 = x02*x09
gen x34 = x03*x04
gen x35 = x03*x05
gen x36 = x03*x06
gen x39 = x03*x09
gen x45 = x04*x05
gen x46 = x04*x06
gen x49 = x04*x09
gen x56 = x05*x06
gen x59 = x05*x09
gen x69 = x06*x09
* Estimation of non-linear multivariate equation system for all industries:
nlsur (s2=({b2=0.1}+{b12}*x01+{b22}*x02+{b23}*x03+{b24}*x04+{b25}*x05+{b26}*x06+{b27}
>*ln(x07+{rho}*x08)+{b29}*x09)/({b1=0.1}+{b2}+{b3=0.1}+{b4=0.1}+{b5=0.1}+{b6=0.1}+{b7
>=0.1}+{b9=0.1}+{b11}*(x01)+{b12}*(x01+x02)+{b13}*(x01+x03)+{b14}*(x01+x04)+{b15}*(x0
>1+x05)+{b16}*(x01+x06)+{b17}*(x01+ln(x07+{rho}*x08))+{b19}*(x01+x09)+{b22}*(x02)+{b2
>3}*(x02+x03)+{b24}*(x02+x04)+{b25}*(x02+x05)+{b26}*(x02+x06)+{b27}*(x02+ln(x07+{rho}
>*x08))+{b29}*(x02+x09)+{b33}*(x03)+{b34}*(x03+x04)+{b35}*(x03+x05)+{b36}*(x03+x06)+{
>b37}*(x03+ln(x07+{rho}*x08))+{b39}*(x03+x09)+{b44}*(x04)+{b45}*(x04+x05)+{b46}*(x04+
>x06)+{b47}*(x04+ln(x07+{rho}*x08))+{b49}*(x04+x09)+{b55}*(x05)+{b56}*(x05+x06)+{b57}
>*(x05+ln(x07+{rho}*x08))+{b59}*(x05+x09)+{b66}*(x06)+{b67}*(x06+ln(x07+{rho}*x08))+{
>b69}*(x06+x09)+{b77}*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b79}*(ln(x07+{rho}*x08
>)+x09))) (y={b0}+{b1}*x01+{b2}*x02+{b3}*x03+{b4}*x04+{b5}*x05+{b6}*x06+{b7}*ln(x07+{
>rho}*x08)+{b9}*x09+{b11}*x11+{b22}*x22+{b33}*x33+{b44}*x44+{b55}*x55+{b66}*x66+{b77}
>*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b99}*x99+{b12}*x12+{b13}*x13+{b14}*x14+{b1
>5}*x15+{b16}*x16+{b17}*(x01*ln(x07+{rho}*x08))+{b19}*x19+{b23}*x23+{b24}*x24+{b25}*x
>25+{b26}*x26+{b27}*(x02*ln(x07+{rho}*x08))+{b29}*x29+{b34}*x34+{b35}*x35+{b36}*x36+{
>b37}*(x03*ln(x07+{rho}*x08))+{b39}*x39+{b45}*x45+{b46}*x46+{b47}*(x04*ln(x07+{rho}*x
```

```
>08))+{b48}*x48+{b49}*x49+{b56}*x56+{b57}*(x07*ln(x07+{rho}*x08))+{b59}*x59+{b67}*(x0
>6*ln(x07+{rho}*x08))+{b69}*x69+{b79}*x79), ifgnls
* Estimation of non-linear multivariate equation system by watersheds:
sort weg
by weg: nlsur (s2=({b2=0.1}+{b12}*x01+{b22}*x02+{b23}*x03+{b24}*x04+{b25}*x05+{b26}*x
>06+{b27}>*ln(x07+{rho}*x08)+{b29}*x09)/({b1=0.1}+{b2}+{b3=0.1}+{b4=0.1}+{b5=0.1}+{b6
>=0.1}+{b7=0.1}+{b9=0.1}+{b11}*(x01)+{b12}*(x01+x02)+{b13}*(x01+x03)+{b14}*(x01+x04)+
>{b15}*(x01+x05)+{b16}*(x01+x06)+{b17}*(x01+ln(x07+{rho}*x08))+{b19}*(x01+x09)+{b22}*
>(x02)+{b23}*(x02+x03)+{b24}*(x02+x04)+{b25}*(x02+x05)+{b26}*(x02+x06)+{b27}*(x02+ln(
>x07+{rho}*x08))+{b29}*(x02+x09)+{b33}*(x03)+{b34}*(x03+x04)+{b35}*(x03+x05)+{b36}*(x
>03+x06)+{b37}*(x03+ln(x07+{rho}*x08))+{b39}*(x03+x09)+{b44}*(x04)+{b45}*(x04+x05)+{b
>46}*(x04+x06)+{b47}*(x04+ln(x07+{rho}*x08))+{b49}*(x04+x09)+{b55}*(x05)+{b56}*(x05+x
>06)+{b57}*(x05+ln(x07+{rho}*x08))+{b59}*(x05+x09)+{b66}*(x06)+{b67}*(x06+ln(x07+{rho
>}*x08))+{b69}*(x06+x09)+{b77}*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b79}*(ln(x07+
>{rho}*x08)+x09))) (y={b0}+{b1}*x01+{b2}*x02+{b3}*x03+{b4}*x04+{b5}*x05+{b6}*x06+{b7}
>*ln(x07+{rho}*x08)+{b9}*x09+{b11}*x11+{b22}*x22+{b33}*x33+{b44}*x44+{b55}*x55+{b66}*
>x66+{b77}*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b99}*x99+{b12}*x12+{b13}*x13+{b14
>}*x14+{b15}*x15+{b16}*x16+{b17}*(x01*ln(x07+{rho}*x08))+{b19}*x19+{b23}*x23+{b24}*x2
>4+{b25}*x25+{b26}*x26+{b27}*(x02*ln(x07+{rho}*x08))+{b29}*x29+{b34}*x34+{b35}*x35+{b
>36}*x36+{b37}*(x03*ln(x07+{rho}*x08))+{b39}*x39+{b45}*x45+{b46}*x46+{b47}*(x04*ln(x0
>7+{rho}*x08))+{b48}*x48+{b49}*x49+{b56}*x56+{b57}*(x07*ln(x07+{rho}*x08))+{b59}*x59+
>{b67}*(x06*ln(x07+{rho}*x08))+{b69}*x69+{b79}*x79), ifgnls
* Estimation of non-linear multivariate equation system by industrial sectors:
sort wsz
by wsz: nlsur (s2=({b2=0.1}+{b12}*x01+{b22}*x02+{b23}*x03+{b24}*x04+{b25}*x05+{b26}*x
>06+{b27}>*ln(x07+{rho}*x08)+{b29}*x09)/({b1=0.1}+{b2}+{b3=0.1}+{b4=0.1}+{b5=0.1}+{b6
>=0.1}+{b7=0.1}+{b9=0.1}+{b11}*(x01)+{b12}*(x01+x02)+{b13}*(x01+x03)+{b14}*(x01+x04)+
>{b15}*(x01+x05)+{b16}*(x01+x06)+{b17}*(x01+ln(x07+{rho}*x08))+{b19}*(x01+x09)+{b22}*
>(x02)+{b23}*(x02+x03)+{b24}*(x02+x04)+{b25}*(x02+x05)+{b26}*(x02+x06)+{b27}*(x02+ln(
>x07+{rho}*x08))+{b29}*(x02+x09)+{b33}*(x03)+{b34}*(x03+x04)+{b35}*(x03+x05)+{b36}*(x
>03+x06)+{b37}*(x03+ln(x07+{rho}*x08))+{b39}*(x03+x09)+{b44}*(x04)+{b45}*(x04+x05)+{b
>46}*(x04+x06)+{b47}*(x04+ln(x07+{rho}*x08))+{b49}*(x04+x09)+{b55}*(x05)+{b56}*(x05+x
>06)+{b57}*(x05+ln(x07+{rho}*x08))+{b59}*(x05+x09)+{b66}*(x06)+{b67}*(x06+ln(x07+{rho
>}*x08))+{b69}*(x06+x09)+{b77}*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b79}*(ln(x07+
>{rho}*x08)+x09))) (y={b0}+{b1}*x01+{b2}*x02+{b3}*x03+{b4}*x04+{b5}*x05+{b6}*x06+{b7}
>*ln(x07+{rho}*x08)+{b9}*x09+{b11}*x11+{b22}*x22+{b33}*x33+{b44}*x44+{b55}*x55+{b66}*
>x66+{b77}*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b99}*x99+{b12}*x12+{b13}*x13+{b14
>}*x14+{b15}*x15+{b16}*x16+{b17}*(x01*ln(x07+{rho}*x08))+{b19}*x19+{b23}*x23+{b24}*x2
>4+{b25}*x25+{b26}*x26+{b27}*(x02*ln(x07+{rho}*x08))+{b29}*x29+{b34}*x34+{b35}*x35+{b
>36}*x36+{b37}*(x03*ln(x07+{rho}*x08))+{b39}*x39+{b45}*x45+{b46}*x46+{b47}*(x04*ln(x0
>7+{rho}*x08))+{b48}*x48+{b49}*x49+{b56}*x56+{b57}*(x07*ln(x07+{rho}*x08))+{b59}*x59+
>{b67}*(x06*ln(x07+{rho}*x08))+{b69}*x69+{b79}*x79), ifgnls
* Estimation of non-linear multivariate equ. system by comb. sector and watershed:
sort wgwz
by wgwz: nlsur (s2=({b2=0.1}+{b12}*x01+{b22}*x02+{b23}*x03+{b24}*x04+{b25}*x05+{b26}*
>x06+{b27}>*ln(x07+{rho}*x08)+{b29}*x09)/({b1=0.1}+{b2}+{b3=0.1}+{b4=0.1}+{b5=0.1}+{b
>6=0.1}+{b7=0.1}+{b9=0.1}+{b11}*(x01)+{b12}*(x01+x02)+{b13}*(x01+x03)+{b14}*(x01+x04)
>+{b15}*(x01+x05)+{b16}*(x01+x06)+{b17}*(x01+ln(x07+{rho}*x08))+{b19}*(x01+x09)+{b22}
>*(x02)+{b23}*(x02+x03)+{b24}*(x02+x04)+{b25}*(x02+x05)+{b26}*(x02+x06)+{b27}*(x02+ln
>(x07+{rho}*x08))+{b29}*(x02+x09)+{b33}*(x03)+{b34}*(x03+x04)+{b35}*(x03+x05)+{b36}*(
>x03+x06)+{b37}*(x03+ln(x07+{rho}*x08))+{b39}*(x03+x09)+{b44}*(x04)+{b45}*(x04+x05)+{
>b46}*(x04+x06)+{b47}*(x04+ln(x07+{rho}*x08))+{b49}*(x04+x09)+{b55}*(x05)+{b56}*(x05+
>x06)+{b57}*(x05+ln(x07+{rho}*x08))+{b59}*(x05+x09)+{b66}*(x06)+{b67}*(x06+ln(x07+{rh
>o}*x08))+{b69}*(x06+x09)+{b77}*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b79}*(ln(x07
>+{rho}*x08)+x09))) (y={b0}+{b1}*x01+{b2}*x02+{b3}*x03+{b4}*x04+{b5}*x05+{b6}*x06+{b7
>}*ln(x07+{rho}*x08)+{b9}*x09+{b11}*x11+{b22}*x22+{b33}*x33+{b44}*x44+{b55}*x55+{b66}
>*x66+{b77}*(ln(x07+{rho}*x08)*ln(x07+{rho}*x08)/2)+{b99}*x99+{b12}*x12+{b13}*x13+{b1
>4}*x14+{b15}*x15+{b16}*x16+{b17}*(x01*ln(x07+{rho}*x08))+{b19}*x19+{b23}*x23+{b24}*x
>24+{b25}*x25+{b26}*x26+{b27}*(x02*ln(x07+{rho}*x08))+{b29}*x29+{b34}*x34+{b35}*x35+{
>b36}*x36+{b37}*(x03*ln(x07+{rho}*x08))+{b39}*x39+{b45}*x45+{b46}*x46+{b47}*(x04*ln(x
>07+{rho}*x08))+{b48}*x48+{b49}*x49+{b56}*x56+{b57}*(x07*ln(x07+{rho}*x08))+{b59}*x59
>+{b67}*(x06*ln(x07+{rho}*x08))+{b69}*x69+{b79}*x79), ifgnls
exit
```

Part Two

Domestic Migration

Chapter 2.1

Where are We Going?

Agent-Based Modelling of the Population

It is not the strongest species that survive, nor the most intelligent,

but the ones who are most responsive to change.

Charles Darwin (1809-1882)

Introduction

The primary objective of the demography model is the simulation of the population units of interest. This does not only include demographic trends but also the distribution on each single square kilometre of the examined area. Due to the focus on the water consumption the population units are defined by characteristical determinants of household water demand. Due to the restricted data availability on small regional scales we defined a population unit by three relevant available characteristics: the social milieu the unit is associated with, the household size measured in persons and the number of children in this group of persons. For reasons of uniformity we developed a 4x4x5 matrix as lowest common denominator for the considered regions and countries.

We deliberately separated the demographic development into an exogenous and an endogenous component. As the exogenous component we use the available statistical forecasts for the natural population trends which are determined by the birth- and the mortality rate and the international net immigration. As the endogenous component we model the spatial distribution of this population stock as a decision process in which a household can decide to migrate to a different domestic location. Vital to this decision are not only the differences in the characteristics of originating location in comparison to the ones of destination but also the character of the surrounding districts. This accounts for the fact that a family that chooses to move because of the good job market conditions in Munich might still want to choose its residence location in one of the cheaper rural areas surrounding this metropolitan agglomeration. The migration flows are agglomerations of individuals who expect a net utility gain by the relocation process. They contribute to the relevant measure for the structural changes in the water usage, the net change in the absolute size of the population and its relative decomposition in population units of differing preferences.

The Population in DANUBIA

For most socioeconomic simulations in DANUBIA an accurate population model is a prerequisite for the generation of valid scenario results. To provide this information on the basis of an individual household and in a high geographic resolution is challenging, not least due to the lack of adequate data sets and population projections. Additionally the available projections from the public statistical agencies are based on linear interpolation of the local trends, which are only corrected for global development. These global trends are mostly determined by demographics and immigration. For our approach we need a deeper theory of the domestic migration to mimic a plausible distribution of the population in the observed area. Only then are we able to assess local demand changes in drinking water. Since there have not been comparable attempts to implement population development in such a geographical resolution we had to principally solve the computational difficulties in addition to generating a plausible socioeconomic population model.

The population model simultaneously applies exogenous national vegetative and immigration-induced population changes and models endogenously the spatial distribution of the population. Additionally the population is sub-divided into the units which are relevant for the water consumption. This enables the use of national demographic trends as the driving force for the definition of scenarios by varying the assumptions about fertility, mortality or immigration. Local linear interpolation cannot serve as a basis for DANUBIA scenarios as it cannot account for the feedback of the other natural-scientific and socioeconomic models on the location choice of the households.

Being used as the influencing factor in other discipline specific models, the demographic model has not only to be focused on economic questions, but also on the needs of the other disciplines. In particular the household water demand is, in addition to the obvious size effect, determined by psychological characteristics.

These are covered by the milieu the household belongs to. A more conservative and consume oriented household is probably less likely to implement water saving technologies (like a water saving toilet flush) than an ecological oriented household. The milieu of a household is characterized by the so called Sinus-Milieus. The Sinus-Milieus classify the population through the criteria of social position and social values. The different milieus are shown in figure 2.1.1 . Customarily used by marketing researchers they also serve well for our purposes. An additional important determinant of the household water demand is the number of children in a household.

The Projection of the Population in Population Units

As a first step we needed to generate an initial distribution of the population units which are characterized by household size, the number of children and Sinus-Milieu. Unfortunately this information is only available on differing aggregation levels and in geographic resolutions bigger than the required square kilometre. The statistics about the household size and the number of children can be obtained from the public statistical offices on the scale of a region in Germany and on the scale of a district in Austria. A region is equivalent to a NUTS-2 region in the Eurostat glossary and consists of several NUTS-3 regions which again are equal to a district[42]. A district is typically the next biggest jurisdiction to a municipality. The distribution of the Sinus-Milieus was supplied by Sinus-Sociovision which is specialized in this type of information services. The sub scaling of the five Sinus-Milieus was provided by the Institute for Geography at the University of Regensburg. Since the statistic for Austria is more differentiated than the German one, both are reduced to a common denominator shown in the 4x4x5 matrix in figure 2.1.1.

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[42] NUTS (Nomenclature des unités territoriales statistiques) refers to the regional classification used by the European Union.

Figure 2.1.1: Allocation of the population in a 4x4x5-matrix (own illustration).

In addition to the Sinus-Milieu the matrix can take values of 1, 2, 3 or larger than 3 for the size of the household and 0, 1, 2, or lager than 2 for the number of children. Since by definition there is always at least one child less in a household than there are persons, the matrix is not full and consists only of a total of 50 different types of population units. The process of distributing the population on the scale of a square kilometre can be summarized in the following three steps. First, the construction of the 4x4 matrix of household size and number of children on the smallest common scale available in the public data. The data does not only differ between Austria and Germany but also between the German states in scaling and content. Therefore the distribution procedure had to be adjusted accordingly. Second, the downscaling of the 4x4 matrix on the square kilometre by means of identification of land use types through geographic information systems (GIS)[43]. Thus the relative distribution of the

[43] To find the fraction of a square kilometre that is inhabited we make use of the CORINE landuse data-set. This data is based on remote sensing. More exact data is available from the Federal Office for Geodesy and Cartography but beyond the financial limits of this project.

household types from the first step is identical within one district or region. The population assigned to a square kilometre is equal to the fraction of urban area of this square kilometre compared to the total urban area in that district or region. And as the final step in the construction of the matrix, we expand of the matrix by an additional dimension, the Sinus-milieus. The distribution of the population into the Sinus-milieus on the scale of a square kilometre was already available from our project partners.

To distribute the households into the different milieu-types and due to the lack of available information, we had to develop a simple probabilistic procedure which ensures that after distribution into the household units, the sub-characteristics sum up to their original local values. Assume T to be a matrix containing the relative share of the total population in a specific household type $t_{i,j}$ with $i = \{1, 2, \dots, 10\}$ characterizing the ten possible combinations of household size classes and number of children classes and $j = \{1, 2, \dots, 5\}$ differentiating each of these ten groups into five milieus.

$$T = \begin{pmatrix} t_{1,1} & t_{1,2} & \cdots & t_{1,5} \\ t_{2,1} & t_{2,2} & & \vdots \\ \vdots & & \ddots & \vdots \\ t_{10,1} & \cdots & \cdots & t_{10,5} \end{pmatrix}$$

Now let a_i be the absolute number of persons in a group that is characterized by size and number of children and b_j the absolute number of persons in one of the milieus. Than, $t_{i,j}$ is generated as the product of the two values divided by product of the sums of the groups in the characteristics a_i and b_j :

$$T = \begin{pmatrix} \frac{a_1 b_1}{\sum a_i \sum b_j} & \frac{a_1 b_2}{\sum a_i \sum b_j} & \cdots & \frac{a_1 b_5}{\sum a_i \sum b_j} \\ \frac{a_2 b_1}{\sum a_i \sum b_j} & \frac{a_2 b_2}{\sum a_i \sum b_j} & & \vdots \\ \vdots & & \ddots & \vdots \\ \frac{a_{10} b_1}{\sum a_i \sum b_j} & \cdots & \cdots & \frac{a_{10} b_5}{\sum a_i \sum b_j} \end{pmatrix} \quad \begin{matrix} \sum t_{1,j} = \frac{a_1}{\sum a_i} \\ \sum t_{2,j} = \frac{a_2}{\sum a_i} \\ \vdots \\ \sum t_{10,j} = \frac{a_{10}}{\sum a_i} \end{matrix}$$

$$\sum t_{i,1} = \frac{b_1}{\sum b_j} \quad \sum t_{i,2} = \frac{b_2}{\sum b_j} \quad \cdots \quad \sum t_{i,5} = \frac{b_5}{\sum b_j} \qquad \sum \sum t_{i,j} = 1$$

The sum over the groups of characteristic a_i is equal to the total population which again is equal to the sum over characteristic b_j . Thus, the elements $t_{i,j}$ are equal to the product of the respective shares of a_i and b_j in the total population. Obviously in each row the fractions $t_{i,j}$ sum up to a_i 's share in the total population and in each column they sum up to the share of b_j respectively.

Comparison of the Data of the Official Statistics

At the time of the generation of the initial distribution of the population the most recent data available for the distinction of household size and number of children was that of the year 2001. Table 2.1.1 describes the three data sets used. Even within Germany, differences in the data sets for the states of Bavaria and Baden-Wurttemberg made separate approaches necessary. A problem in the combination of the data sets is the fact that a family is not necessarily equivalent to a household. On the one hand single person households and flat-sharing communities do not show up in the family statistics at all and on the other hand a household can be composed of several families (or several generations of a family who would show up separately in the family statistic).

	Bavaria	**Baden-Wurttemberg**	**Austria**
Base year	2001	2001	2001
Regional scale	Region	Region	District
Definition household	A (privat) household is a community of persons sharing their living space and constituting an economic unit or a single person living alone. A household can include relatives and non-family members. Subtenants form separate households. Community or institutional housing like homeless dormitories, prisons or mental asylums do not count as a household but can include households in their facilities like janitor- or director housing.		
General characteristics	Distribution generated from 1% representative random population sample in 1993 interpolated to the total population in the smallest units of 1,000 persons.	Distribution generated from 1% representative area specific random population sample interpolated to the total population in the smallest units of 1,000 persons.	Population census 2001
Data about household size	Private households with 1 person, 2 persons, 3 persons and 4 or more persons.	Private households with 1 person, 2 persons, 3 persons and 4 or more persons.	Private households with 1 person, 2 persons, 3 persons, 4 persons, 5 persons and 6 or more persons.
Data about children	Private households with 0 children, 1 child, 2 children and 3 or more children.	Private households with 0 children, 1 child, 2 children and 3 or more children.	Families by types (couple, cohabit or single parent) with 0 children, 1 child, 2 children, 3 children and 4 or more children.
Data about family types	Families by types (couple or single parent) with 0 children, 1 child, 2 children, 3 children and 4 or more children.	Families by types (couple or single parent) with 0 children, 1 child, 2 children, 3 children and 4 or more children.	Families by types (couple, cohabit or single parent) with 0 children, 1 child, 2 children, 3 children and 4 or more children.

Table 2.1.1: Data-sets used to generate the 4x4 matrix (own illustration).

Since in the household statistic the number of families in a household is known, it is possible to match most of the family data set through plausibility restrictions and by distributing the remnant by probability. An exact description of the matching procedure with an applied example showing the matching process for the Austrian city of Innsbruck can be found in Egerer and Zimmer (2006).

Implementation of an Agent-Based Demography Model

After generating a plausible initial distribution of the population the next obvious step is plausible simulation of the population dynamics. Among the main requirements was a simple scenario definition through the variation of both demographic components, namely, the vegetative population change and migration. This enables a simple calibration to the different population projections of the public statistical offices.

Since the Public Coordinated Population Projection for Germany is composed of the separate forecasts of the statistical state offices it is recommendable to use these regionalized forecasts. By varying the assumptions about fertility, mortality and immigration the statistical offices provide nine different population projections until 2050. The tables 2.1.2 and 2.1.3 summarize the upper and lower limits and the default assumptions about the key variables. All projections for Germany predict a decline in population due to the low fertility rates. Immigration can reduce the decline but not compensate it, especially since the number of immigrants has been declining in the recent years. The population in Austria will be more stable. Austria profits from a more beneficial demographic structure and recently also from increased immigration from other states of the European Union. A good example illustrating the difference in the situation between the two countries is the flow of migrants from the eastern German states to Austria, due to the superior job market conditions especially in the Austrian tourism and gastronomy sector. In addition to the size the age patterns of the population will also change. The German default scenarios expect the proportion of the young population aged below twenty to drop from one fifth to one sixth in 2050.

	Known base values (2001)	**Assumed lower limit** (2050)	**Assumed default value** (2050)	**Assumed upper limit** (2050)
Fertility	1.4	1.4	1.4	1.4
Life expectancy	74.8 years male / 80.8 years female	78.9 / 85.7 years*	81.1 / 86.6 years*	82.6 / 88.1 years*
Net immigration	+200,000 annual immigrants	+100,000 annual immigrants	+200,000 annual immigrants	+200,000; from 2011 on +300,000 annual immigrants
Population	82,440,300	67,046,200	75,117,300	81,252,500

*Life expectancy of a newborn male/female in the year 2050.

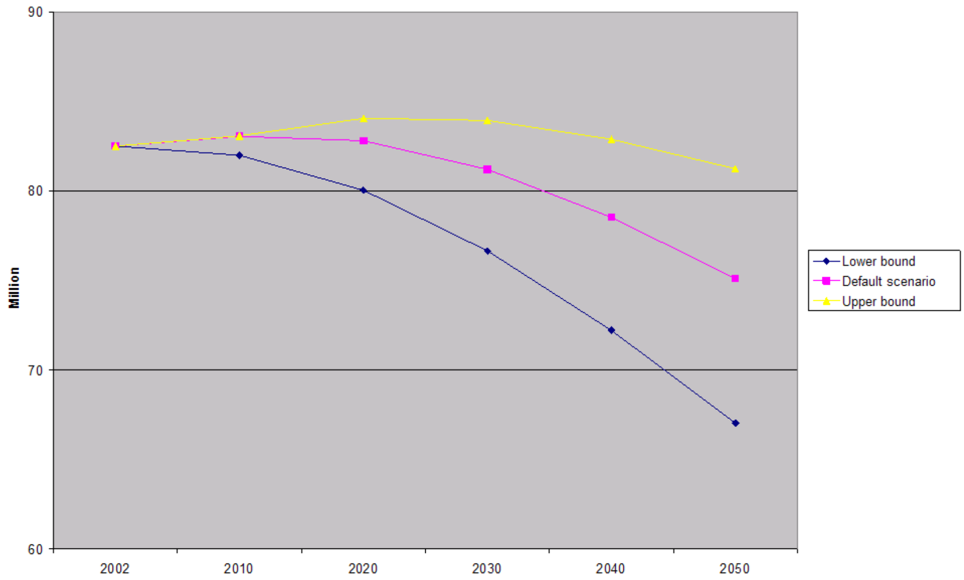

Table 2.1.2: Assumptions and results of the 11th German Coordinated Population Projection (data source: German Statistical Office, 2003).

The fraction of the population aged above 60 will rise from one quarter to one third with the strongest increase in the persons aged above 80. These will triple their share from actual 4% to 12% in 2050. The most eminent issues are the consequences for the social systems arising from this demographic change.

	Known base values (2004)	**Assumed lower limit** (2050)	**Assumed default value** (2050)	**Assumed upper limit** (2050)
Fertility	1.4	1.4; 1.1 from 2030 on	1.4; 1.5 from 2030 on	1.4; 1.9 from 2030 on
Life expectancy	76.4 year male/ 82.1 years female	80.3 / 86.0 years*	84.3 / 89.0 years*	88.3 / 92.0 years*
Net immigration	+50,582 annual immigrants	+5,000–10,000 annual immigrants	+30,000; from 2020 on +20,000 annual immigrants	+30.000 annual immigrants
Population	8.174.733	7.576.597	8.986.033	10.974.237

*Life expectancy of a newborn male/female in the year 2050

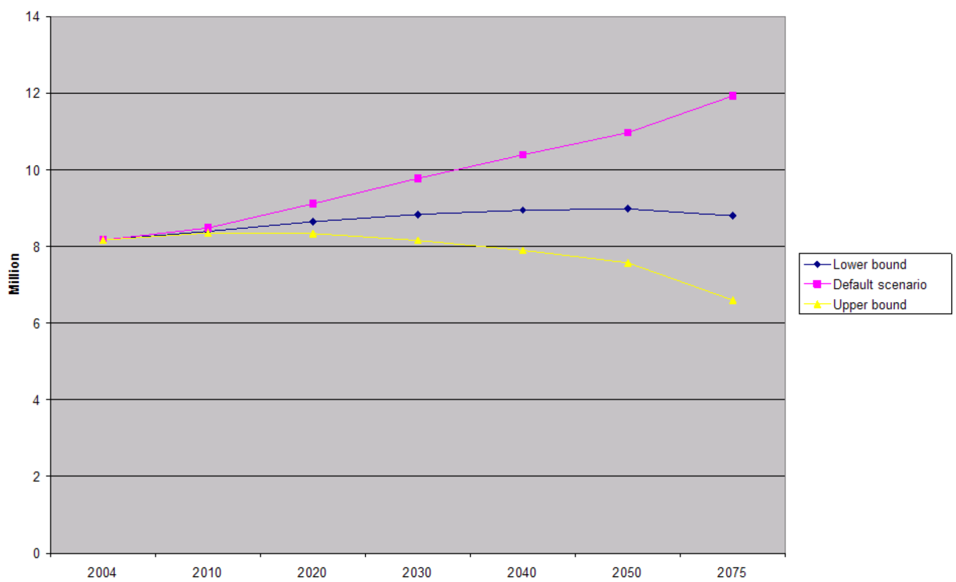

Table 2.1.3: Assumptions and results of the Austrian population projection 2005 (data source: Austrian Statistical Office, 2005).

The almost sole contributor to the system is the working population aged between 20 and 59, while by far the most benefits from the social security systems go to the elderly citizens[44]. This development is in so far problematic as today's relation of 44 / 100 persons of age 60 and above to persons of age 20 to 59 will rise to 78 / 100. From the current political discussion it is yet unclear how that issue is solvable and even more surprising how little attention is devoted to this subject.

By choosing households as units of observation we could avoid the problem of modelling the age structure endogenously[45]. Thus, our main objective remains to endogenously model the regional distribution of the different household types. This is done by modelling the regional net migration as the difference between the monthly migration equilibriums. To determine these equilibriums we model the regional net-migration wish as the difference of migrants having the desire to move in versus those having the desire to leave that location. As this desired amount of migration would be only applicable to a constant number of households, the migration wish is adjusted to the population size. Hence, the equilibrium is reached by scaling this intermediate distribution to the actual total population size determined through the exogenous scenarios of the statistical offices.

The question of which factors to include in order to determine the endogenous migration wish is one of sense as much as of practical issues. Clearly, differences in mortality rates – despite a few exceptions – defy the active decision of the individual.

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[44] In 2005 the total social security budget of the Federal Republic of Germany was about 700 billion Euros which was equal 31% of GDP. Out of this social budget about 34.3% were used on private pension payments, 2.9% on public pensions including supplementary security and 2.6% on nursing insurance. While all of these benefits are obviously directed towards the elderly population it should also be noted that health care spending (which contributes with 19.7% to social security spending) is also mostly spend on citizens above the age of 60. In that respect the prominent position of social welfare in political discussion seems unnecessary (at least for budgetary reasons) as the fraction of the typically discussed benefits (excluding help for handicapped and the like) adds up to 0.1% of the social budget.

[45] In our setting, households live indefinitely. This simplifying assumption is commonly shared by many economic models using the household as unit of observation. A household can only appear or vanish if the regional total number of households of one type changes. The focus of our modelling approach is to endogenously explain these changes. It should also be noticed that our modelling approach is consistent with the general theoretical findings. The fact that migration is a household rather than an individual choice has been recognized since the early days of migration studies, Mincer (1978) just being one example.

Giving birth – despite a lot of exceptions – indeed results from an active decision process. An endogenous motivation in the decision to get pregnant however, demands for sophisticated modelling that - given the objective of the model - is beyond any justification. The remaining issue is the selection of migration determinants. Even though suggested factors by economic theory are manifold our scope of potential candidates is limited to the set available within the environmental decision support system. Another limiting factor is the availability of statistical data on small regional scales, which is necessary to determine the effects of the characteristics. Having identified the potential determinants in the decision processes of the demographic agents, we examine these characteristics not only for the origins and destinations but also in their spatial structure for the surroundings of these regions. It is obvious that the surroundings might influence the migration decision as well. On a small regional scale, the district of residence might differ from that of employment and thus likely commuting areas will influence the choice. The larger the regional disparity of such characteristics is, the more eminent it is to account for their spatial structure. This can be illustrated by examining the population density and the average annual sunshine duration on the district level as shown in figure 2.1.2 . It is eye-catching that the sunshine duration changes only in supra-regional patterns. Thus, including the districts local value and the average of the surrounding ones will not aid any explanatory power, but will just cause problems of multicollinearity for the estimation procedure. On the other hand, the population-density can vary strongly between neighbouring districts and therefore including its spatial structure can capture effects like migrants preferring one rural district over another because of the possibility to benefit from the advantages that a neighbouring city exerts. The region in the south-east encircled by the thick black boarder marks the Upper Danube Catchment area. This area is currently covered through the DANUBIA decision support system. It is mostly within Germany but an essential part lies inside Austria.

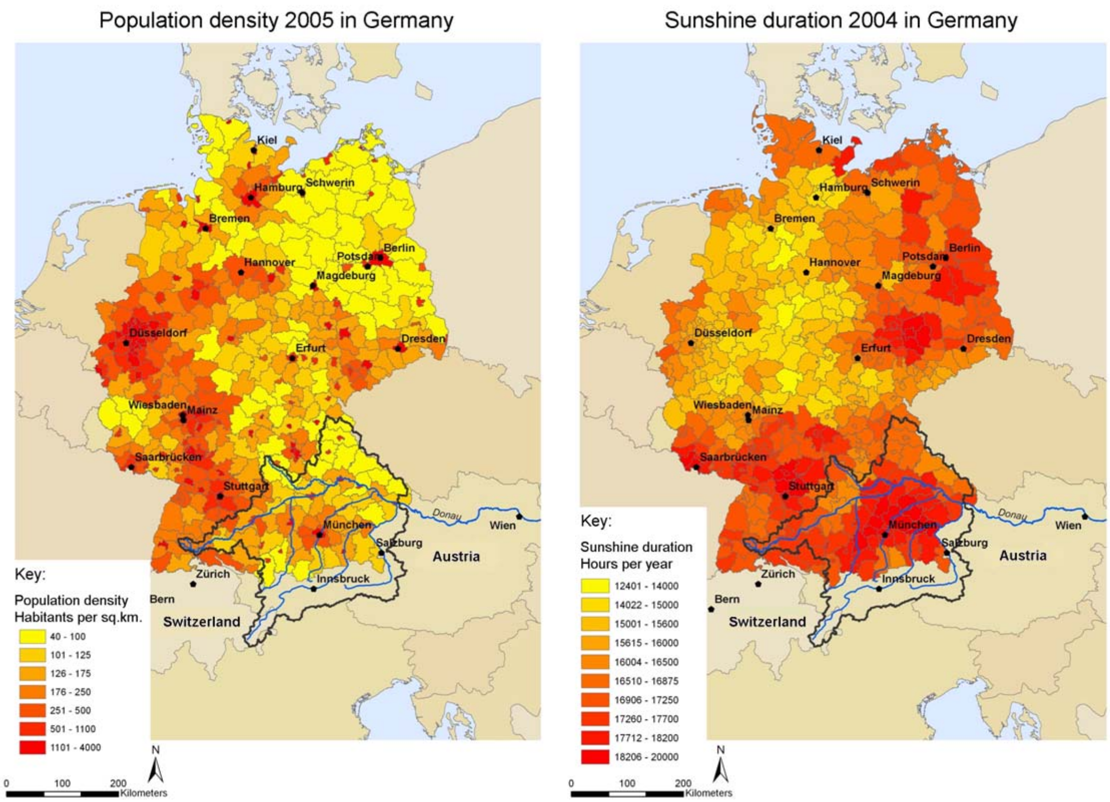

Figure 2.1.2: Regional disparity of population density and sunshine-duration (Data provided by the German statistical states offices and the German Weather Service (Deutscher Wetterdienst)).

While the remaining remnants in Switzerland and in the Czech Republic may be negligible for the simulation, the inhomogeneity of natural and administrative boarders still causes serious problems. Among these are not only the mentioned inconsistencies between the available data sets. But also within a country the issue remains of how to treat the border regions. Since the natural border defined by the Danube watershed cuts through the peripheral administrative districts we needed a procedure to assign the statistical data available on the scale of the whole district to those fractions. We choose a simple and pragmatic approach by allocating the common characteristics (like GDP) proportional to the population. Hence the fraction of the population of a district inside the catchment as approximated by the remote sensing methods also determines the fraction of GDP. In the simulation the cognitive process generating the migration wish is determined by the following expressions:

$$inmove_{type\,i,\,proxel\,j} = \beta^{inmove}_{0,\,type\,i} + \sum_{n=1}^{N}(x_{n,\,proxel\,j}\beta^{inmove}_{n,\,type\,i})$$

$$outmove_{type\,i,\,proxel\,j} = \beta^{outmove}_{0,\,type\,i} + \sum_{n=1}^{N}(x_{n,\,proxel\,j}\beta^{outmove}_{n,\,type\,i})$$

$$net\ migration_{type\,i,\,proxel\,j} = \exp\left(inmove_{type\,i,\,proxel\,j}\right) - \exp\left(outmove_{type\,i,\,proxel\,j}\right)$$

The migration wish is determined separately for each household type on each square kilometre. The functional form originates from the log-linearized gravity model used to estimate migration. An exact description of the theoretical model and the estimation approach can be found in chapter 2.2. In the simulation terminology we call the spatial unit of calculation a process pixel or *proxel* which is, for the demography model, equivalent to a square kilometre. $x_{n,proxel\,j}$ is a matrix containing the characteristics of a *proxel*. The vector of coefficients $\beta_{n,type\ i}$ follows from the type-specific estimates of the household reaction function. The in- and outmoves follow from the specification of the elasticities while the final net-migration is in absolute number of persons.

Objects Behind the Tool

The demography-agent in DANUBIA (*Demography_Actor*) has been developed accordingly to the specific requirements and standards set by the *Deep-Actor-Framework*. The framework is responsible for the intra-simulation communication and translation of the different sub-modules of the natural scientific and socio-economic disciplines in the decision support system. It also initializes the simulation area, organizes the simulation timing and provides general routines common to the separate modules. The following UML-class-diagram illustrates the interaction of the different classes in the demography package[46]. The *Demography* class manages and initializes the module. It offers the interface *DemographyActorEnvironment* to the demography agent which she can use to perceive the district characteristics that are essential to her migration decision. In each of the monthly calculation periods the agent determines her migration behaviour (*Demography_Action* → equilibrium migration) out of the evaluation process of the migration options (*Demography_Plan* → net migration wish in the formal model above). As described above, the difference between the migration-wish and equilibrium is due to the scaling to the

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[46] UML refers to unified modelling language, a concept common to computer science applications. Since the general intuition of the illustration is accessible without deeper knowledge of the terminology we will abstract from a detailed introduction into object-oriented programming. In the nineties, due to the increasing complexity of computer programs, object-oriented programming replaced traditional approaches based on sub-routines. In general it is sufficient to know that in contrast to traditional programming, object-oriented programs simply consist of a collection of objects. Typical types of objects are classes which are represented by the coloured squares. These classes have a name at the top of the square and contain several methods listed at the bottom. They can for example extend (here being a specialisation / arrows with the hollowed triangle as a spike) a more general class provided by the framework or another class specific to the demography module (arrow spiked arrows). They can draw on collections of module specific standard routines (arrow spiked dashed arrows) which for example enable the interchange of data between the discipline specific sub-modules via the framework-interfaces or simply read (and write) in a data-files object (arrow spiked dashed arrows with <<use>>). The idea of object oriented programming gets clear if you imagine you and your boss in your institute. Let's assume there exists the task to produce a printed essay. Then, the institute with everything in it would be the program to solve this task. To do so it can make use of all the more or less helpful objects inside the institute. These objects include you, your boss, a computer, computer programs, a printer, a paper bin and some flowers. Now, the capability of your boss to write an essay is extended to the capability to write a nicely formatted essay in print letters by his usage of the computer and the computer programs (methods) within it. You however extend the capabilities of your boss to also do all this annoying data preparation (standard routines) which then will be included in the essay as part of your boss's achievement. To perform those standard routines your capabilities are as well extended by the usage of the computer and the computer programs and those programs again can use the existing data-files for your data-preparation (read the data-files). While looking at the flower object might distract you from your frustration and thus speed up the process it is preferable if you don't have to use the paper bin object for the final storage of the essay. Rather you just want to use the printer method to store the essay (write it into a data-base file) and thus complete the task of the institute.

macroeconomic trends in the *PopulationScenario* class. The *Actor_Information* class stores the household type specific population numbers. Hence, regarding household size, number of children and Sinus-milieus a total of 50 actor types per inhabited square kilometre is simulated. Finally the *Demography* class collects all the population figures in the module and distributes them back over the framework to the other modules via the *DemographyToActorController* interface and stores the monthly results using the *DemographyResult* interface.

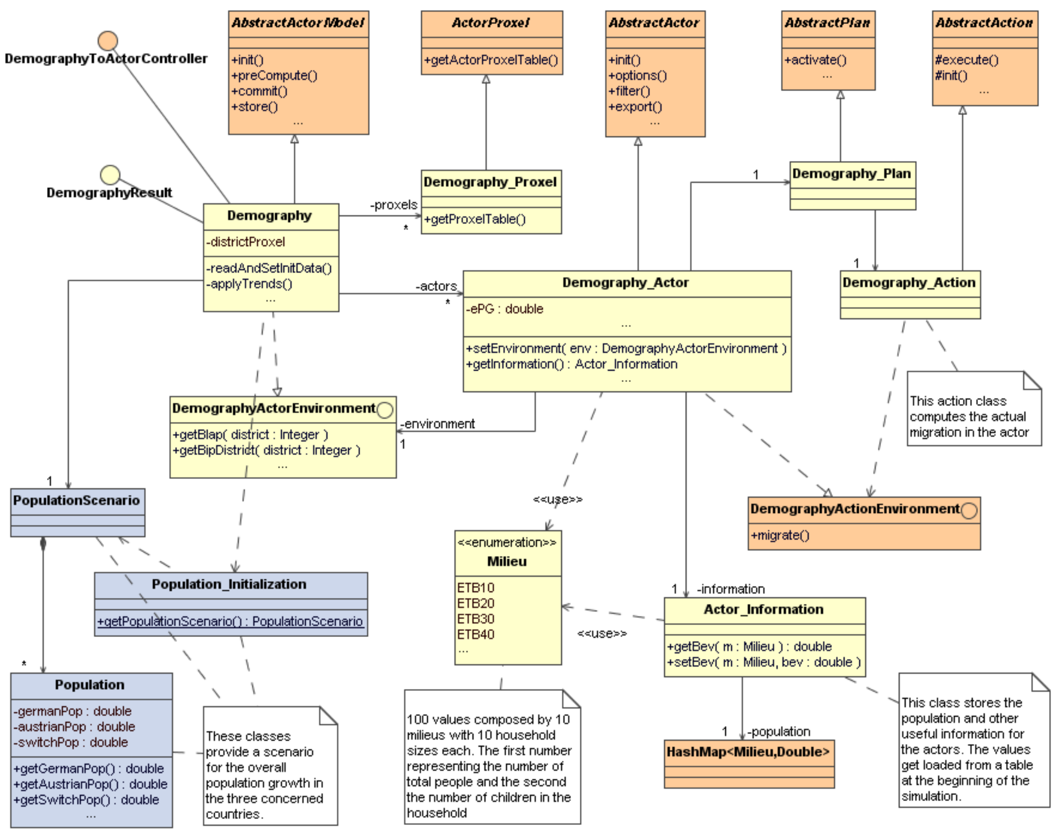

Figure 2.1.3: UML-Diagram of the demography agent in the Deep Demography Module (own illustration).

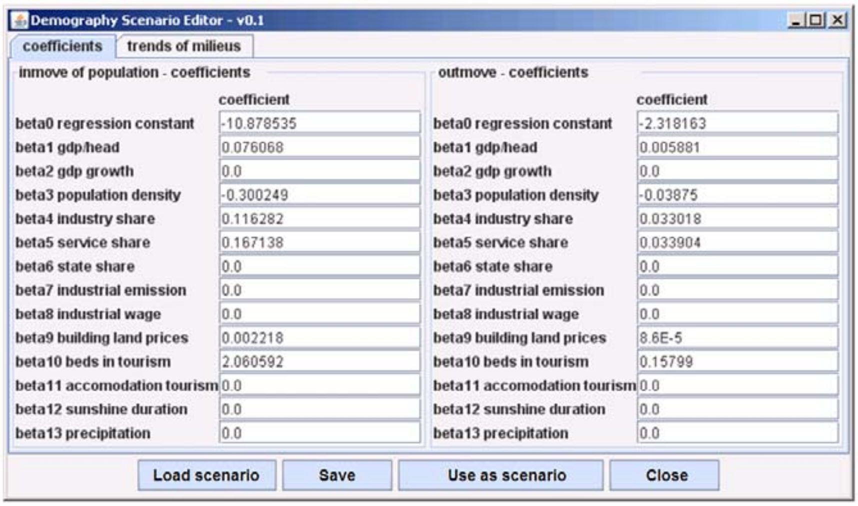

Figure 2.1.4: Model editor for the demography-agents
(DANUBIA demography module).

Figure 2.1.4 shows the model editor used to feed the coefficients into the simulation. For each type of population unit the reaction function to the constantly changing environment can be expressed in elasticities[47]. The elasticities are easily changed or fed into the simulation in the graphical user interface. In this way it is also possible to consider additional effects as new statistical data becomes available. The inclusion of additional natural or socio-economic characteristics will increase the interaction between the different disciplines and thus, allows to stepwise close the gap in simulating the interdependencies of a system as complex as reality. In the current model state we already use tourism to indicate the non-economic attractiveness of a region. The coupling to the natural-scientific modules is also legitimate, as characteristics like the annual sunshine duration are – by common sense – likely to influence migration decisions and are highly significant in econometric estimations. Figure 2.1.5 shows the scenario editor for the *Deep Demography* model. The editor

[47] These are econometrically estimated in chapter 2.2 .

enables an easy definition of different milieu scenarios by allowing to set annual trends for the percentage change.

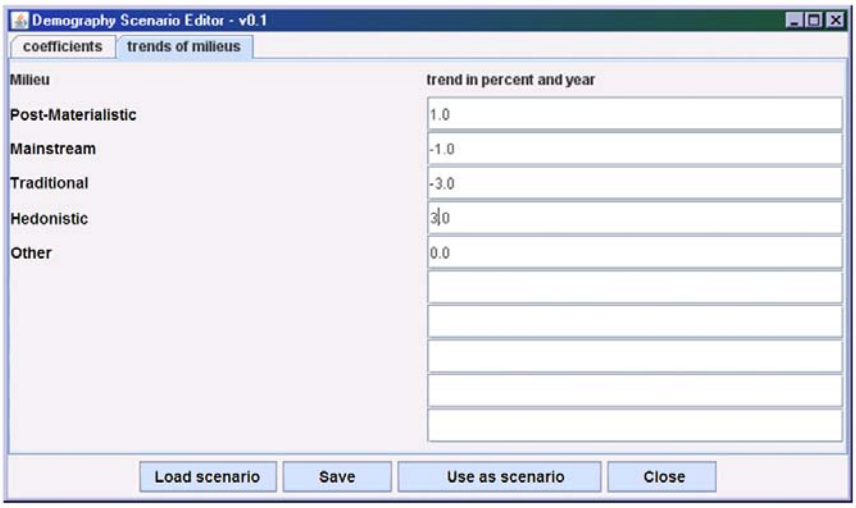

Figure 2.1.5: Scenario-editor for the demography-agent model (DANUBIA demography module).

Results

The results of the scenario runs can be visualized in the DANUBIA Atlas-application. This tool allows an easy access and interpretation of the data. Figure 2.1.6 shows a screen shot of the online-version of the Atlas-application. It displays the distribution of the population around Munich. The menu on the left allows the users to choose which results of the discipline specific module should be presented. To simplify the interpretation additional geographic characteristics can be selected. In the illustration we included, for example, the relief, the main cities and rivers as well as the railroad tracks and motorways. By choosing a point on the map additional information is displayed like the district, the municipality, the watercourses and the catchment area.

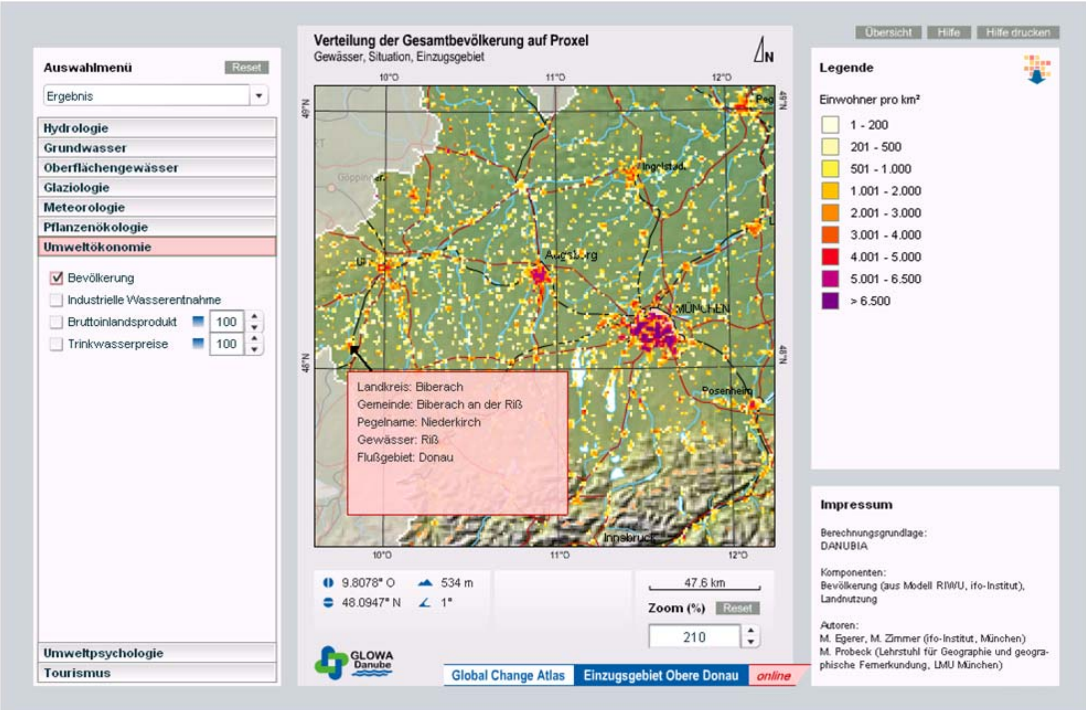

Figure 2.1.6: DANUBIA GUI-Online atlas displaying the demography results for the population distribution around Munich (München).

Figure 2.1.7 displays the relative population change from the year 2000 to the year 2014 in the Upper-Danube Catchment Area for a representative baseline scenario run. In this scenario the population would decline by 2% from 9.7 million to 9.5 million. The regional population change is much more volatile and varied between a decline of 8% and an increase of 3% on a single square kilometre. Especially the greater metropolitan area around Munich and the Austrian areas of the catchment area attracted migrants, while the structurally weak regions in the north of Bavaria showed strong declines in the population.

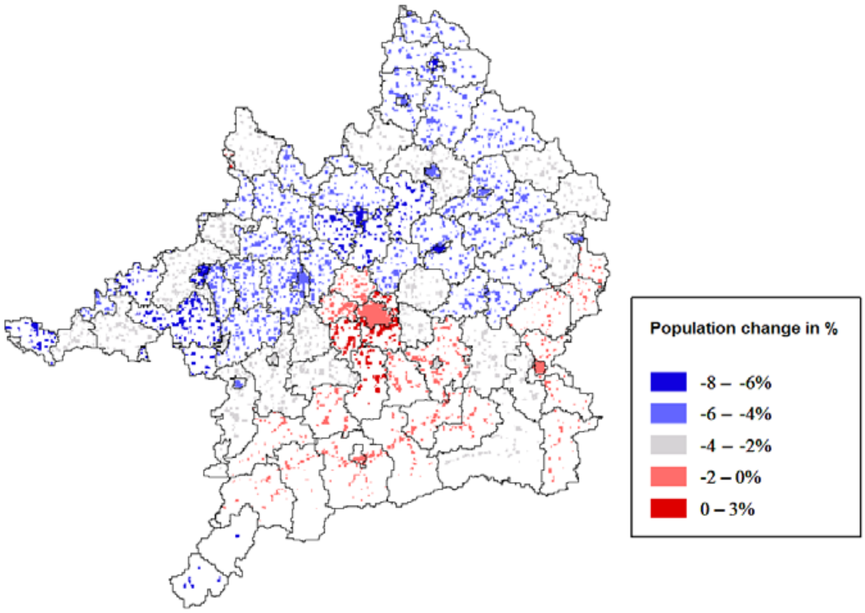

Figure 2.1.7: Relative population change 2000- 2014 (own illustration).

Chapter 2.2

Network Effects on Domestic Migration Flows Across Germany

A Spatial Autoregressive Perspective with Spatially Structured Origin and Destination Effects and Heteroskedastic Innovations

All of life is interrelated. We are all caught in an inescapable network of mutuality, tied to a single garment of destiny. Whatever affects one directly affects all indirectly.

Martin Luther King Jr. (1929-1969)

Introduction

Domestic migration is the main determinant of regional migration flows. While cross-country migration has been intensively investigated in the literature we address the under-researched issue. This is surprising since domestic migration contributes with over 95% to all migration events that cross a German district border. In our model we study the spatial interaction between German districts in order to explain the domestic migration flows. In contrast to the demographic processes of fertility and mortality, domestic migration has a much larger impact on the spatial distribution of the population. While the birth of a new citizen affects only the population of one district, migration has an impact on the origin and the destination as well. Observing a multiregional system as a whole will generate a detailed matrix of migration flows between the origin-destination pairs. Our main objective is to identify the determinants of that migration.

From the perspective of an individual migrant, the decision to relocate depends on the net benefits of migrating, given by the difference between the expected income gains and the economic and psychological costs. Expectations are largely influenced by uncertainty, which decreases the willingness to migrate for risk-averse individuals. Social networks can help to increase expected income and reduce uncertainty. They also lower migration costs through granting access to housing or integration into a familiar social community. As migrants with a common background exert positive network externalities within their community, this gives a rationale for herd behaviour. Consequently, coordinating the timing and location of migration flows increases the efficiency[48]. The means to realize this coordination is the positive signal that migrants exert on each other by their location choice.

It is straightforward to expect that phenomena which include a movement through space are also likely to feature a spatial structure explaining them. It is also plausible to assume that units of observation that are close to each other show interdependencies in their development[49]. In the model presented here we consider several channels of spatial structure. Besides spatially weighted exogenous variables, these structures typically feature endogeneity and therefore demand adequate econometric procedures. Additionally we consider spatial spillovers in the endogenous variable and spatial autoregression in the disturbance term. We allow for heteroskedasticity in the remaining disturbance, which is typically referred to as innovation. Since we consider spatial processes of second order in both autoregressive processes, we refer to this model as SARAR(2,2) model, as suggested by Kelejian and Prucha (2008)[50]. Thus the SARAR(2,2) model contains separate spatial weights matrices for the origin and the destination, which affect the spatial endogenous lag as well as the autoregressive disturbance.

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[48] The term efficiency in this context does refer to a social planer who is not concerned about the economy as a whole but only about the group of migrants. When migrants choose to go to relocate their soul concern is about their own utility gain but not about the positive network externality that they exert on the other migrants. Economic theory would suggest that in the presence of such a positive externality the amount of migration to the same location is inefficiently small if it is based on the decision of the individual migrant. Yet theoretical and empirical work on how much efficiency is increased through signalling and herd behaviour is missing, but would be an interesting field for further research.

[49] These models are also known as Cliff-Ord type spatial models due to the formulation of such models in the works of Cliff and Ord (1973, 1981).

[50] Kelejian and Prucha adopt the original terminology from Anselin (1988) and Anselin and Florax (1995).

Background of the Economic Model

The main motivation to control for spatial structures is the existence of inter-district migrant networks. Therefore, by employing appropriate empirical methods we do not only improve the estimation of the effects of the classical factors influencing the migration flows, but we are also able to determine the size of the network effects. These networks have been widely discussed in the migration literature but have not yet been observed in their spatial structure[51]. Even if this structure could be negligible at the country level it certainly becomes effective as one reduces the size of the observed geographical unit[52]. As we observe migration on a very small scale, the typical migrants to two neighbouring districts will probably only be a few kilometres away from each other or are likely to daily commute to the same district for work. From literature we know that there are two main channels through which these spatial phenomena can affect migration behaviour: The traditional effect of networks of common family, friend, ethnical, social or regional background on the one hand, and the more recent argument of herd behaviour, on the other. The latter is motivated by imperfectly informed migrants, signalling effects and the impact of the own migration behaviour on the location choice of the succeeding migrants.

The previous literature on migrant networks put its main focus on international migration. The autoregressive dynamics of Mexican immigrants in the United States of America are a prominent example. They have been examined in many empirical works, as for example in Munshi (2003)[53]. Other empirical works confirm the

[51] Notable exceptions are LeSage's and Pace's (2007) and Goetz's and Rupasingha's (2004) migration studies who consider a spatial autoregressive structure in a non-network-oriented analysis.

[52] The support of the network members is likely to decrease as the distance increases. Thus, a migrant who moves from Berlin to France will benefit less from the network of migrants that moved from Berlin to Spain (a neighbouring country of France), than a migrant who moves from Berlin to Cologne will benefit from the network of migrants that moved from Berlin to Bonn (a neighbouring city of Cologne).

[53] These works come to the conclusion that the location choice of Mexican migrants is dependent on the stock of earlier migrants in the potential destinations.

existence of migrant networks for domestic migration within the United States (Bartel, 1989, Frey, 1995), for international migration to the United Kingdom, (Nigel and Pain, 2003), to Australia (Chiswick Lee and Miller, 2001) and to Canada (McDonald, 2002) or for regional clustering of Ethnic German immigrants to Germany (Bauer and Zimmermann, 1997)[54].

The channels through which these networks operate are manifold: They can increase the expected income gains by increasing hiring probability (Cocoran, Datcher and Ducan, 1980), reducing the uncertainty about job-market conditions (Massey, 1987) or lowering the search costs for a job (Mortensen and Vishwanath, 1994). They can also reduce moving costs. These costs can be financial or of psychological nature, like the loss of ethnical integration or separation from family or friends (Schwartz, 1973, Mincer, 1978, Church and King, 1993, Chiswick and Miller, 1996)[55]. And finally, due to the uncertainty regarding conditions at a possible destination and because of the increase in the positive network externality with the size of the network it is rational for migrants to show a certain amount of herd behaviour. Under imperfect information the destination choice of other migrants is interpreted as a positive signal regarding the quality of their location choice, which has a positive impact on the own perception of this destination (Epstein and Hillman, 1998). In that respect the signal might not only influence the spatial structure of migration, but also the time dimension (Burda, 1995). Viewing migration from a community perspective, it is sensible to deliberately or unconsciously coordinate the timing and the location of migration flows. As a result, the positive network externalities are

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[54] The term ethnic Germans refers to the German expression “Aussiedler”. These are persons who themselves or whose ancestors had the Second German Reich citizenship as per the borders of 1937 and who lived in territories that after the Second World War felt to the Allied powers. These ethnic Germans could until the year of 1990 freely migrate to the Federal Republic of Germany and apply for citizenship. After 1990 qualification requirements for citizenship were tightened slightly but still grant a preferential status to this group.

[55] For studies reviewing the literature about the effects of networks on migration see Greenwood (1985) and Cohen, Reed, Montgomery and Stren (2003).

increased and the signal through the own migration act gains in value if one's choice to follow the earlier migrants encourages the subsequent ones to act likewise. This results in a regional concentration of ethnic groups very similar to the clustering that follows from pure network effects. However, it provides a justification for the dynamics of migration flows which frequently contradict the expectations from traditional explanations (Epstein and Gang, 2004). Empirical work on the relative importance of network versus herd effects can be found in Bauer, Epstein and Gang (2007). A summary of the functioning of network and herd effects is displayed in table 2.2.1 .

	Network effects	Herd effects
Contribution of the migrants	Circulation of information and provision of ethnic and economic resources	Informal group-dynamics process to internalize the positive externality of migrant networks which results in the coordination of migration flows
Benefit for the migrants	Reduction of economic and psychological migration costs and increase in the expected benefits from migration	Signalling reduces subjective amount of uncertainty and positive externalities of migrant networks increase
Result for the economy	Local clustering of migrants with common background	Efficient amount of migration

Table 2.2.1: Differentiation of network versus herd effects (own illustration)

Commonly the driving forces of migration flows are separated into microeconomic and macroeconomic effects. From a microeconomic perspective of the individual, the probability of migrating is a monotonously increasing function of the net expected utility gain through relocating. The expected utility gains depend on the relative characteristics of the district of origin versus the destination district. Among these, the most commonly used explanatory factor would be the average income gain expressed as the relation of the destination district's GDP per capita relative to the district of origin's GDP per capita[56]. We label these effects as relative size effects. From a macroeconomic perspective, the total number of migrants (driven by their individual utility maximization) also depends on the size of the two districts. This size effect is usually covered by employing a gravity model which predicts the migration flows to vary with the product of the populations of both districts. We refer to this effect as the joint size effect. In a log-linear specification we model the joint size effect of each location as the sum of the logs of the corresponding origin and destination attribute. Likewise the relative size effect will be the difference of the same two values. Accordingly the basic specification of the gravity model is:

$$\ln(mig_{OD}) = (\ln(x_O) - \ln(x_D))'\beta_R + (\ln(x_O) + \ln(x_D))'\beta_J$$

In this specification mig_{OD} is the migration flow from the origin O to the destination D. x_O is the vector of origin and x_D the vector of destination characteristics. β_R is the vector of exponents[57] for the relative size effects and β_J the respective vector for the joint size effects. For convenience we define $\ln(mig_{OD}) = y$ and $\ln(x) = X$ which is also applied to the specification of the econometric model later on.

Data

The data was provided by the Research Data Centre of the Statistical State Offices (Forschungsdatenzentrum der statistischen Landesämter). All variables are defined as

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[56] For uniformity we will define all relative effects the other way around as origin versus destination for our estimation.

[57] These are the exponents in the regular specification of the gravity model before it is log-linearized.

logs of their absolute values[58]. Except for the spatial-autoregressive variables we used the values of the year preceding the observed cross-sectional migration period from 2002 – 2005. We estimate the effects for distance between two districts, the population, GDP (in the sense of Gross District Product), the number of unemployed, and the number of employed differentiated into the production sectors of primary industrial goods, manufacturing, services and residual employment, which covers inter alia agriculture and fishery. Additionally, to characterize the structure of the landscape as well as rurality versus urbanity, we use the area of the district subdivided into agricultural, urban, recreational, forest and bodies of water areas. To cover further effects and amenities we employ the number of students, the tourist overnight stays as a measure of general non-economic attractiveness, the number of holiday homes as a measure of landscape attractiveness[59], and the number of physicians as a measure of health spending[60]. Health care in Germany is practically free for the citizens and the tariffs for treatments and medication that are paid by the public health insurance are largely fixed at a federal level. As such, high health-care spending is an indicator for disease rather than for health[61]. The additional data necessary to construct the distance matrices of the districts was derived from shape files provided by the Federal Office for Cartography and Geodesy. These shape files contain the district borders and are commonly used as interchange format for

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[58] Except for those which might contain zero values. In these cases, e.g. for the number of students in a district, we took the log of the absolute value one.

[59] A closer look at tourist overnight stays and holiday homes reveals that these two measures are not redundant. Still, a relatively high correlation of 0.64 might lead to the conclusion to include only one of the measures due to collinearity. However, the exclusion of either contributes marginally to changes in the coefficients, which is why we left both measures in the regression.

[60] The connection between health risks and migration has also been examined in a recent empirical work by Goetz and Rupasingha (2004). While they use differences in cancer risk due to environmental pollution we use a more direct measure. In Germany the amount of health spending is largely proportional to the number of physicians which is not least due to the fact that health care is mainly publicly financed, with common more or less binding fixed budgets per physician. Further research relating especially to retirement migration with health care can be found in Graves and Knapp (1988) and Gale and Heath (2000).

[61] Concerning its true nature, disease-care spending would be the more appropriate term for these expenditures anyway.

computer-based geographic information systems. Their main purpose is the generation of maps but they serve as well in locating the centroids of the districts.

Spatial Structure of Origin-Destination Flows

The type of spatial interaction used in this paper was originally developed in the context of bilateral international trade flows and has recently been adapted to a spatial econometrics context by LeSage and Pace (2007). A main characteristic of these models is that the number of observations rises quadratically with the number of regions observed. This is due to the fact that each region is a possible origin and destination at the same time. The migration flows span a full matrix instead of a symmetric one because the flows of migration differ depending on the direction. Like LeSage and Pace, we will use distance as a characteristic common to one origin and destination pair in our gravity model. But unlike them, we use – for reasons explained above – the specific characteristics of origin and destination once as differences (in the relative size effects) and a second time as sums (in the respective joint size effects). The implementation of a spatial weights structure in our origin-destination setting might appear challenging at first. But a simple solution is to split the effects. Therefore we will employ separate weights matrices for the origin and the destination. By extending the spatial processes to a higher we are able to stick to the standard spatial autoregressive framework.

As spatial weights matrices we will use row-normalized neighbourhood matrices, where being a neighbour is defined by the distance of the centroids of two districts being below a critical threshold. By varying this threshold we are able to analyse the sensitivity of our results to the assumptions about the spatial structures. If we look at the map of the German districts in figure 2.2.1 this approach seems to be the most reasonable because of the large variances in district size depending on the state.

Figure 2.2.1: District borders in Germany (source: maps provided by the Federal office for Building Regulations and Regional Planning).

A first visual inspection already reveals the districts in the north-east to cover much larger areas than the ones in the south-west. In that respect a more sophisticated weighting scheme based on a function of the distance wouldn't make sense, since it would be biased by district size, whereas our simple row-normalized contiguity definition at least gives us a consistent average characteristic for a fixed circular area around the observed district.

The Econometric Model

We extend both first-order spatial autoregressive processes in the SARAR(1,1) model proposed by Kelejian and Prucha (2008). Thus our SARAR(2,2) model contains separate spatial weights matrices for the origin and the destination. These weights matrices affect the spatial endogenous lag as well as the autoregressive disturbance. For ordinary least squares the spatial dependence leads to inconsistent estimates, while maximum likelihood approaches are, first, computationally challenging for large problems as the one observed here and, second, as mentioned by Kelejian and Prucha, inconsistent under heteroskedasticity for the existing (quasi) maximum likelihood estimators.

$$
\begin{aligned}
y_n = {} & X_{C,n}\beta_C + (X_{O,n} - X_{D,n})\beta_R + (X_{O,n} + X_{D,n})\beta_J \\
& + X_{E,n}\beta_E + \gamma_O W_{O,n} y_n + \gamma_D W_{D,n} y_n + u_n
\end{aligned}
$$

$$u_n = \rho_O M_{O,n} u_n + \rho_D M_{D,n} u_n + \varepsilon_n$$

$$|\gamma_O| + |\gamma_D| < 1 \ , \quad |\rho_O| + |\rho_D| < 1 \qquad \text{(I)}$$

The procedure used by Kelejian and Prucha is based on the nonlinear two-step least-squares method developed by Amemiya (1974). Their spatial regression model is performed in three separate steps, which we apply to our extended model as well. First, the spatial regression model in (I) is estimated using a two-step least-squares method, where the spatially lagged endogenous variable is instrumented[62]. Then, using the residuals from the estimation in the first step the autoregressive parameters ρ_O and ρ_D in the disturbance term are estimated using a generalized method of moments approach. In a third step the Cochrane-Orcutt type transformation of the regression model in (I) is again estimated via the two-step least-squares method, instrumenting for the spatial autoregression in the endogenous variable.

y_n is the n -dimensional vector of observations of migration flows from the l origins to the m destinations[63]. As we only account for domestic migration which crosses at least the district border and the number of originating districts l equals the number of destinations m, the number of observations is equal to $l \bullet m = m^2 = n$ with the intra-district-flows being set to zero. $X_{E,n}$ is a $n \times m$ matrix of dummy variables in which the j^{th} column has once the value one if the j^{th} origin is equal to the destination and otherwise zero (with $j = 1, \ldots, m$)[64]. The remaining exogenous variables split in $X_{O,n}$, the $n \times g$ matrix of origin characteristics and $X_{D,n}$ the respective $n \times g$ matrix of the destination districts characteristics and $X_{C,n}$ the $n \times c$ matrix of common characteristics like distance. With $k = c + g + g + m$ let $X_n = (X_{C,n}, X_{O,n} - X_{D,n}, X_{O,n} + X_{D,n}, X_{E,n})$ denote the $n \times k$ matrix of exogenous regressors. Note that $X_{O,n}$ and $X_{D,n}$ only consist of a total of m different observations, one for each district. $W_{O,n}$, $W_{D,n}$, $M_{O,n}$ and $M_{D,n}$ are the constant $n \times n$ spatial weight matrices assumed to be known. As typically done, we will assume for the later estimation that $W_{O,n} = M_{O,n}$

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[62] A discussion of the limit of the sum of the absolute values of the autoregressive parameters in (I) can be found in Lee and Liu (2006). A summary of the result is included in the appendix.

[63] A detailed description of the construction of the vector y_n, the spatially weighted exogenous variables and of the weights matrices is included in the appendix.

[64] This is necessary since on the one hand including the variation of this migration flows for the origin equalling the destination (which has been set to zero for all such pairs) would bias the estimates. On the other hand we need this vector to be of the same size as the weights matrix in order to be able to multiply both of them.

and $W_{D,n} = M_{D,n}$ but abstract from that simplification for the moment. Among the resulting parameters of interest from the estimation are the k-dimensional parameter vectors β_R for the relative size effects and β_J for the joint size effects. But our special interest is in the scalar parameters γ_O and γ_D which measure the autoregressive effects for spatial autoregressive process and ρ_O and ρ_D which do likewise for the spatial autoregressive disturbance process. Finally u_n is a n-dimensional vector of regression disturbances. We allow for heterogeneity in the n-dimensional vector of residual innovations ε_n . Since the units we observe will differ strongly in their characteristics like area or population such heterogeneous innovations are highly recommendable. The $n \times p$ matrix of instruments used to estimate the first stage in the first step will be denoted by H_n[65].

Given the expansion to the second order spatial processes we will now state the essential changes to the assumptions by Kelejian and Prucha (2008):

Assumption 1: All diagonal elements of the spatial weighting matrices $W_{O,n}$, $W_{D,n}$, $M_{O,n}$ and $M_{D,n}$ are zero. The matrices $(I - \gamma_O W_{O,n} - \gamma_D W_{D,n})$ and $(I - \rho_O M_{O,n} - \rho_D M_{D,n})$ are non-singular with $|\gamma_O| + |\gamma_O| < 1$ and $|\rho_O| + |\rho_O| < 1$.

Assumption 2: The row and column sums of the matrices $W_{O,n}$, $W_{D,n}$, $M_{O,n}$, $M_{D,n}$, $(I - \gamma_O W_{O,n} - \gamma_D W_{D,n})^{-1}$ and $(I - \rho_O M_{O,n} - \rho_D M_{D,n})^{-1}$ are bounded uniformly in absolute value[66].

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[65] As noted in the forthcoming Kelejian and Prucha paper the instruments for the first and the third step of the procedure need not be the same. For notational convenience we will stick to the same notation in the third step nevertheless.

[66] This is the extended representation of *Assumption 3* in Kelejian and Prucha (2008).

It follows that given (2) and assuming that an innovation ε in the vector of innovations has an expected value of zero and a finite variance of σ^2 the variance – covariance matrix is:

$$E[u_n u_n'] = (I_n - \rho_O M_{O,n} - \rho_D M_{D,n})^{-1} diag[\sigma^2_{i,n}](I_n - \rho_O M_{O,n} - \rho_D M_{D,n})^{-1} \qquad \text{(II)}$$

Where $\sigma^2_{i,n}$ is the n x 1 vector of $E(u_{i,n}u_{i,n})$ from which we form the diagonal matrix over the single elements i of this vector.

The GM Estimator for the Autoregressive Disturbance Parameters

Sharing Kelejians and Pruchas (2008) assumptions for the GM-estimator, Badinger and Egger (2008) derive the following moment conditions for the second order heteroskedastic autoregressive disturbance process[67]:

$$n^{-1}E[\bar{\varepsilon}_{O,n}'\bar{\varepsilon}_{O,n} - Tr[M_{O,n} diag[E[\varepsilon_{i,n}\varepsilon_{i,n}]]M_{O,n}']] = 0$$

$$n^{-1}E[\bar{\varepsilon}_{O,n}'\varepsilon] = 0, \quad \text{with } \bar{\varepsilon}_{O,n} = M_{O,n}\varepsilon_n$$

$$n^{-1}E[\bar{\varepsilon}_{D,n}'\bar{\varepsilon}_{D,n} - Tr[M_{D,n} diag[E[\varepsilon_{i,n}\varepsilon_{i,n}]]M_{D,n}']] = 0$$

$$n^{-1}E[\bar{\varepsilon}_{D,n}'\varepsilon] = 0, \quad \text{with } \bar{\varepsilon}_{D,n} = M_{D,n}\varepsilon_n \qquad \text{(III)}$$

Let us additionally define $\bar{\bar{\varepsilon}}_{O,n} = M_{O,n}\bar{\varepsilon}_{D,n}$, $\bar{\bar{\varepsilon}}_{D,n} = M_{D,n}\bar{\varepsilon}_{D,n}$, $\bar{\bar{\varepsilon}}_{OD,n} = M_{O,n}\bar{\varepsilon}_{D,n}$ and $\bar{\bar{\varepsilon}}_{DO,n} = M_{D,n}\bar{\varepsilon}_{O,n}$. Using the expression for the error process u from (I), solving it for

[67] Note that the calculation of the terms in the trace expression due to the size of the weights matrix is computationally challenging. Fortunately, it is possible to use the special properties due to the construction of the matrix to reduce the problem to solvable size. The necessary transformations require only basic matrix algebra and are found in the appendix.

the innovations ε in substituting it in the moment conditions in (III) we get the equation system:

$$\lambda_n - \Gamma_n \alpha_n = 0$$
$$\text{with } \alpha_n = \left(\rho_{O,n}, \rho_{D,n}, \rho_{O,n}\rho_{D,n}, \rho_{O,n}{}^2, \rho_{D,n}{}^2\right)', \quad \lambda_n = \left(\lambda_{1,n}, \lambda_{2,n}, \lambda_{3,n}, \lambda_{4,n}\right)'$$
$$\text{and } \Gamma_n = \left(\lambda_{rs,n}, \lambda_{2,n}, \lambda_{3,n}, \lambda_{4,n}\right)_{r=1,\dots 4, s=1,\dots 5} \qquad \text{(IV)}$$

The single elements of this equation system are:

$$\lambda_1 = n^{-1} E\left[\bar{\varepsilon}_{O,n}'\bar{\varepsilon}_{O,n} - Tr\left[M_{O,n} diag\left[E\left[\varepsilon_{i,n}\varepsilon_{i,n}\right]\right] M_{O,n}'\right]\right]$$

$$\lambda_2 = n^{-1} E\left[\bar{\varepsilon}_{O,n}'\varepsilon_n\right]$$

$$\lambda_3 = n^{-1} E\left[\bar{\varepsilon}_{D,n}'\bar{\varepsilon}_{D,n} - Tr\left[M_{D,n} diag\left[E\left[\varepsilon_{i,n}\varepsilon_{i,n}\right]\right] M_{D,n}'\right]\right]$$

$$\lambda_4 = n^{-1} E\left[\bar{\varepsilon}_{D,n}'\varepsilon_n\right]$$

$$\lambda_{1,1} = 2n^{-1} E\left[\bar{\bar{\varepsilon}}_{O,n}'\bar{\varepsilon}_{O,n} - Tr\left[M_{O,n} diag\left[E\left[\bar{\varepsilon}_{i,O,n}\varepsilon_{i,n}\right]\right] M_{O,n}'\right]\right]$$

$$\lambda_{2,1} = n^{-1} E\left[\bar{\bar{\varepsilon}}_{O,n}'\varepsilon_n + \bar{\varepsilon}_{O,n}'\bar{\varepsilon}_{O,n}\right]$$

$$\lambda_{3,1} = 2n^{-1} E\left[\bar{\bar{\varepsilon}}_{DO,n}'\bar{\varepsilon}_{D,n} - Tr\left[M_{D,n} diag\left[E\left[\bar{\varepsilon}_{i,O,n}\varepsilon_{i,n}\right]\right] M_{D,n}'\right]\right]$$

$$\lambda_{4,1} = n^{-1} E\left[\bar{\bar{\varepsilon}}_{DO,n}'\varepsilon_n + \bar{\varepsilon}_{D,n}'\bar{\varepsilon}_{O,n}\right]$$

$$\lambda_{1,2} = 2n^{-1} E\left[\bar{\bar{\varepsilon}}_{OD,n}'\bar{\varepsilon}_{O,n} - Tr\left[M_{O,n} diag\left[E\left[\bar{\varepsilon}_{i,D,n}\varepsilon_{i,n}\right]\right] M_{O,n}'\right]\right]$$

$$\lambda_{2,2} = n^{-1} E\left[\bar{\varepsilon}_{O,n}'\bar{\varepsilon}_{D,n} + \bar{\bar{\varepsilon}}_{OD,n}'\varepsilon_n\right]$$

$$\lambda_{3,2} = 2n^{-1} E\left[\bar{\bar{\varepsilon}}_{D,n}'\bar{\varepsilon}_{D,n} - Tr\left[M_{D,n} diag\left[E\left[\bar{\varepsilon}_{i,D,n}\varepsilon_{i,n}\right]\right] M_{D,n}'\right]\right]$$

$$\lambda_{4,2} = n^{-1} E\left[\bar{\bar{\varepsilon}}_{D,n}'\varepsilon_n + \bar{\varepsilon}_{D,n}'\bar{\varepsilon}_{D,n}\right]$$

$$\lambda_{1,3} = -2n^{-1}E\left[\overline{\overline{\varepsilon}}_{OD,n}'\overline{\varepsilon}_{O,n} - Tr\left[M_{O,n}diag\left[E\left[\overline{\varepsilon}_{i,D,n}\overline{\varepsilon}_{i,O,n}\right]\right]M_{O,n}'\right]\right]$$

$$\lambda_{2,3} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{OD,n}'\overline{\varepsilon}_{O,n} + \overline{\overline{\varepsilon}}_{O,n}'\overline{\varepsilon}_{D,n}\right]$$

$$\lambda_{3,3} = -2n^{-1}E\left[\overline{\overline{\varepsilon}}_{D,n}'\overline{\overline{\varepsilon}}_{DO,n} - Tr\left[M_{D,n}diag\left[E\left[\overline{\varepsilon}_{i,D,n}\overline{\varepsilon}_{i,O,n}\right]\right]M_{D,n}'\right]\right]$$

$$\lambda_{4,3} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{D,n}'\overline{\varepsilon}_{O,n} + \overline{\overline{\varepsilon}}_{DO,n}'\overline{\varepsilon}_{D,n}\right]$$

$$\lambda_{1,4} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{O,n}'\overline{\overline{\varepsilon}}_{O,n} - Tr\left[M_{O,n}diag\left[E\left[\overline{\varepsilon}_{i,O,n}\overline{\varepsilon}_{i,O,n}\right]\right]M_{O,n}'\right]\right]$$

$$\lambda_{2,4} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{O,n}'\overline{\varepsilon}_{O,n}\right]$$

$$\lambda_{3,4} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{DO,n}'\overline{\overline{\varepsilon}}_{DO,n} - Tr\left[M_{D,n}diag\left[E\left[\overline{\varepsilon}_{i,O,n}\overline{\varepsilon}_{i,O,n}\right]\right]M_{D,n}'\right]\right]$$

$$\lambda_{4,4} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{DO,n}'\overline{\varepsilon}_{O,n}\right]$$

$$\lambda_{1,5} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{OD,n}'\overline{\overline{\varepsilon}}_{OD,n} - Tr\left[M_{O,n}diag\left[E\left[\overline{\varepsilon}_{i,D,n}\overline{\varepsilon}_{i,D,n}\right]\right]M_{O,n}'\right]\right]$$

$$\lambda_{2,5} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{OD,n}'\overline{\varepsilon}_{D,n}\right]$$

$$\lambda_{1,5} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{D,n}'\overline{\overline{\varepsilon}}_{D,n} - Tr\left[M_{D,n}diag\left[E\left[\overline{\varepsilon}_{i,D,n}\overline{\varepsilon}_{i,D,n}\right]\right]M_{D,n}'\right]\right]$$

$$\lambda_{2,5} = -n^{-1}E\left[\overline{\overline{\varepsilon}}_{D,n}'\overline{\varepsilon}_{D,n}\right] \qquad \text{(V)}$$

Let $\widetilde{\lambda}_n$ be the estimate of λ_n and $\widetilde{\Gamma}_n$ be the estimate of Γ_n, then by substituting (V) in (IV) we can estimate $\rho_{O,n}$ and $\rho_{D,n}$ by non-linear optimization:

$$\left(\widetilde{\rho}_{O,n}, \widetilde{\rho}_{D,n}\right) = \underset{\rho_{O,n},\rho_{D,n}}{argmin}\left[\left(\widetilde{\gamma}_n - \widetilde{\Gamma}_n\alpha_n\right)'\left(\widetilde{\gamma}_n - \widetilde{\Gamma}_n\alpha_n\right)\right] \qquad \text{(VI)}$$

Besides deriving the GM-estimator for the second order spatial autoregressive disturbance, Badinger and Egger also provide a Monte Carlo study showing a good performance of the estimator even in small samples.

Choice of Instruments

For the choice of the instruments the changes to Kelejian's and Prucha's approach (Equation 30, Kelejian and Prucha, 2008) are less than one would expect. For our problem the expected values of the lagged endogenous are[68]:

$$E(W_{O,n}y_n) = W_{O,n}(I - \gamma_O W_{O,n} - \gamma_D W_{D,n})^{-1} X_n \beta_n = W_{O,n} \sum_{i=0}^{\infty} (\gamma_O W_{O,n} + \gamma_D W_{D,n})^i X_n \beta_n$$

$$E(W_{D,n}y_n) = W_{D,n}(I - \gamma_O W_{O,n} - \gamma_D W_{D,n})^{-1} X_n \beta_n = W_{D,n} \sum_{i=0}^{\infty} (\gamma_O W_{O,n} + \gamma_D W_{D,n})^i X_n \beta_n \quad \text{(VII)}$$

We will use the instrument matrix H_n to instrument $Z_{O,n} = (X_n , W_{O,n}y_n)$, $Z_{D,n} = (X_n , W_{D,n}y_n)$, $M_{O,n}Z_{O,n} = (M_{O,n}X_n , M_{O,n}W_{O,n}y_n , M_{D,n}W_{D,n}y_n)$, $(M_{O,n} , M_{D,n})Z_{O,n} = ((M_{O,n} , M_{D,n})X_n , (M_{O,n} , M_{D,n})W_{O,n}y)$ and $(M_{O,n} , M_{D,n})Z_{D,n} = ((M_{O,n} , M_{D,n})X_n , (M_{O,n} , M_{D,n})W_{D,n}y_n)$ by estimating their predicted value with a least squares regression of H_n[69]: If we look for example at $Z_{O,n}$ then with $P_H = H_n(H_n' H_n)^{-1} H_n'$ it follows that $\hat{Z}_{O,n} = P_H Z_{O,n}$. The ideal instruments would be $E(Z_{O,n}) = (X_n, W_{O,n}E(y_n) , W_{D,n}E(y_n))$. Accounting for (VII) and following Kelejian and Prucha it seems reasonable to approximate these instruments by using as H_n a subset of the linear independent columns of $(X_n, W_{O,n}X_n, W^2_{O,n}X_n, \ldots, W_{D,n}X_n, W^2_{D,n}X_n, \ldots, M_{D,n}X_n, M^2_{D,n}X_n, \ldots, M_{D,n}W_{D,n}X_n, M^2_{D,n}W_{D,n}X_n, \ldots, M_{D,n}W_{O,n}X_n, M^2_{D,n}W_{O,n}X_n, \ldots, W_{D,n}W_{O,n}X_n, W^2_{D,n}W_{O,n}X_n, \ldots)$. In light of having row-normalized weights matrices and setting $W_{O,n} = M_{O,n}$ and $W_{D,n} = M_{D,n}$ the choice of available instruments is drastically

[68] For the necessary conditions for the expansion see also the explanation of the limiting properties of the autoregressive parameters in the appendix.

[69] The latter terms follow from the Cochrane-Orcutt type transformation of (I) into $y_n = \rho_O M_{O,n}y_n + \rho_D M_{D,n}y_n + (I_n - \rho_O M_{O,n} - \rho_D M_{D,n})X_n\beta_n + (I_n - \rho_O M_{O,n} - \rho_D M_{D,n})W_{O,n}y_n + (I_n - \rho_O M_{O,n} - \rho_D M_{D,n})W_{D,n}y_n$ which is estimated by a two-steps least-squares estimator in the last step of the three stages of our procedure.

reduced due to linear dependence[70]. Therefore we propose – in addition to the exogenous variables – to use the subset of the spatially cross-lagged relative size effects as instruments, since these already include all spatial lags of the district characteristics[71].

Estimation Results

In discussion of the estimation results we will first compare the different empirical specifications on the basis of the total population. Then we will present the differences in migration behaviour between female and male migrants and non-German and German nationals and will find striking results for migrants of non-German nationality. For simplicity all models in the tables will be labelled SARAR(*,**) and the term in bracket describes the order of the lag that is included with * being the order of the spatial autoregressive lag in the endogenous variable and ** being the order of the lag of the spatial autoregressive disturbance[72]. Table 2.2.2 shows the estimation results for the different specifications of the econometric model. The first column displays the results of a simple OLS regression including the spatial endogenous lag but disregarding any steps to correct for spatial autocorrelation. The second column only includes the lags in the endogenous variable whereas the third column only accounts for heteroskedastic autoregressive

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[70] Due to the construction of the dependent variable and the characteristics of the origins only differing for each origin interaction term but not for each origin destination interaction, the interaction terms with the destination weights matrix become linear dependent for row normalized weighting matrices, e.g.: $W_{D,n}X_{R,n} = W_{D,n}(X_{O,n} - X_{D,n}) = W_{D,n}X_{O,n} - W_{D,n}X_{D,n} = X_{O,n} - W_{D,n}X_{D,n}$ since $W_{D,n}X_{O,n} = W^2_{D,n}X_{O,n} = \dots = X_{O,n}$ and $W_{O,n}X_{O,n} = W_{O,n}W_{D,n}X_{O,n} = W_{O,n}W^2_{D,n}X_{O,n} = \dots$. Likewise the argument holds for the destination characteristics. For the interaction of both spatial weights matrices it obviously follows: $W_{O,n}W_{D,n}X_{R,n} = W_{O,n}X_{O,n} - W_{D,n}X_{D,n}$

[71] The cross lag of the relative size effect would be $W_{O,n}W_{D,n}(X_{O,n} - X_{D,n}) = W_{O,n}X_{O,n} - W_{D,n}X_{D,n}$.

[72] Sample STATA-code used for the estimation of the SARAR(2,2) model for the total population and a threshold distance of 100 kilometres can be found in the appendix.

disturbance. The fourth column displays the results for the full model specification and the final column gives information on the instruments used in the estimation[73].

Model	OLS		SARAR(2,0)		SARAR(0,2)		SARAR(2,2)		used as instru-ment
Innovation errors	-		-		Heteroskedastic		Heteroskedastic		
R2	0.7874		0.7877		0.3989		0.4913		
Observations	192721		192721		192721		192721		
Sargan overid			0.3607				0.8228		
Anderson Identification			0.0000				0.0000		
Moran's I Ori.			0.1071 ***		0.2884 ***		0.1071 ***		
Moran's I Des.			0.0992 ***		0.2849 ***		0.0992 ***		
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE	
Ori. rho					0.4527		0.3680		
Des. rho					0.4737		0.4351		
Ori. gamma	0.4632 ***	(0.0037)	0.4399 ***	(0.0142)			0.4313 ***	(0.0375)	
Des. gamma	0.4521 ***	(0.0035)	0.4147 ***	(0.0114)			0.4124 ***	(0.0285)	
Distance	-0.3358 ***	(0.0047)	-0.3998 ***	(0.0252)	-0.2851 ***	(0.0023)	-0.1972 ***	(0.0161)	-
Rel. population	-0.0038	(0.0102)	0.0007	(0.0102)	-0.0219	(0.0196)	-0.0159	(0.0182)	++
Rel. employed rest	-0.0155 ***	(0.0033)	-0.0183 ***	(0.0035)	-0.0411 ***	(0.0064)	-0.0217 ***	(0.0059)	++
Rel. employed prim. Industry	0.0185 ***	(0.0062)	0.0168 ***	(0.0062)	0.0307 **	(0.0119)	0.0182 *	(0.0107)	++
Rel. employed manufacturing	-0.0024	(0.0057)	-0.0134 **	(0.0064)	-0.0388 ***	(0.0122)	-0.0192 *	(0.0112)	++
Rel. employed services	-0.0275	(0.0174)	-0.0624 ***	(0.0201)	-0.1701 ***	(0.0371)	-0.0771 **	(0.0347)	++
Rel. unemployed	0.0556 ***	(0.0199)	0.1240 ***	(0.0288)	0.3216 ***	(0.0503)	0.1389 ***	(0.0498)	++
Rel. GDP (districts)	-0.0477 ***	(0.0099)	-0.0651 ***	(0.0123)	-0.1368 ***	(0.0209)	-0.0597 ***	(0.0203)	+
Rel. medics	0.0149	(0.0095)	0.0145	(0.0099)	0.0221	(0.0176)	0.0272 *	(0.0162)	++
Rel. students	-0.0013 ***	(0.0004)	-0.0011 ***	(0.0004)	-0.0020 ***	(0.0007)	-0.0012 **	(0.0006)	++
Rel. tourist overnight stays	-0.0169 ***	(0.0023)	-0.0153 ***	(0.0024)	-0.0303 ***	(0.0042)	-0.0184 ***	(0.0042)	-
Rel. welfare recipients	0.0018	(0.0032)	0.0025	(0.0033)	0.0056	(0.0068)	-0.0002	(0.0060)	++
Rel. holiday homes	0.0026 *	(0.0014)	0.0009	(0.0015)	0.0017	(0.0027)	0.0032	(0.0024)	++
Rel. recreational area	0.0000	(0.0028)	-0.0001	(0.0028)	0.0092	(0.0061)	0.0026	(0.0052)	-
Rel. agricultural area	0.0051 *	(0.0029)	0.0082 ***	(0.0030)	0.0188 ***	(0.0061)	0.0092 *	(0.0054)	++
Rel. forest area	0.0080 ***	(0.0014)	0.0092 ***	(0.0015)	0.0190 ***	(0.0030)	0.0103 ***	(0.0026)	++
Rel. bodies of water	-0.0028 *	(0.0016)	-0.0030 *	(0.0016)	-0.0061 *	(0.0034)	-0.0026	(0.0029)	++
Rel. urban area	0.0078	(0.0078)	0.0033	(0.0079)	0.0044	(0.0171)	0.0074	(0.0147)	-
Joint population	0.1128 ***	(0.0103)	0.1340 ***	(0.0132)	0.6208 ***	(0.0197)	0.3127 ***	(0.0278)	o
Joint employed rest	-0.0168 ***	(0.0033)	-0.0158 ***	(0.0033)	0.0110 *	(0.0064)	-0.0121 **	(0.0057)	o
Joint employed prim. Industry	-0.0783 ***	(0.0062)	-0.0820 ***	(0.0064)	-0.2052 ***	(0.0119)	-0.1113 ***	(0.0124)	o
Joint employed manufacturing	-0.2719 ***	(0.0056)	-0.2822 ***	(0.0069)	-0.2163 ***	(0.0122)	-0.1897 ***	(0.0127)	o
Joint employed services	-0.4264 ***	(0.0171)	-0.4092 ***	(0.0183)	0.2126 ***	(0.0372)	-0.0727 **	(0.0325)	o
Joint unemployed	0.7481 ***	(0.0191)	0.7392 ***	(0.0194)	0.1299 **	(0.0504)	0.3599 ***	(0.0400)	o
Joint GDP (districts)	0.1056 ***	(0.0099)	0.1227 ***	(0.0120)	0.1683 ***	(0.0209)	0.0628 ***	(0.0203)	o
Joint medics	0.2930 ***	(0.0094)	0.3016 ***	(0.0099)	0.2199 ***	(0.0177)	0.1844 ***	(0.0162)	o
Joint students	0.0079 ***	(0.0004)	0.0081 ***	(0.0004)	0.0099 ***	(0.0007)	0.0057 ***	(0.0007)	o
Joint tourist overnight stays	0.0819 ***	(0.0022)	0.0789 ***	(0.0024)	0.0728 ***	(0.0042)	0.0617 ***	(0.0038)	o
Joint welfare recipients	-0.0733 ***	(0.0032)	-0.0742 ***	(0.0032)	-0.0281 ***	(0.0068)	-0.0326 ***	(0.0058)	o
Joint holiday homes	-0.0126 ***	(0.0014)	-0.0084 ***	(0.0021)	-0.0016	(0.0028)	-0.0039	(0.0026)	o
Joint recreational area	-0.0120 ***	(0.0028)	-0.0106 ***	(0.0029)	0.0180 ***	(0.0061)	0.0033	(0.0052)	o
Joint agricultural area	0.0717 ***	(0.0029)	0.0756 ***	(0.0033)	0.0321 ***	(0.0061)	0.0326 ***	(0.0054)	o
Joint forest area	-0.0125 ***	(0.0014)	-0.0133 ***	(0.0014)	-0.0149 ***	(0.0030)	-0.0159 ***	(0.0027)	o
Joint bodies of water	0.0212 ***	(0.0017)	0.0250 ***	(0.0022)	0.0200 ***	(0.0034)	0.0225 ***	(0.0032)	o
Joint urban area	-0.0982 ***	(0.0079)	-0.1147 ***	(0.0102)	-0.1151 ***	(0.0172)	-0.0697 ***	(0.0162)	o
Constant	5.7145 ***	(0.1741)	6.2472 ***	(0.2696)	2.0957 ***	(0.4727)	1.2424 ***	(0.3868)	

Table 2.2.2: Estimation results for the total population[74].

[73] The selection of the ideal instruments has been discussed in an earlier section. The final column in the table describes the deviation from that selection. All instruments not marked by a circle should be included principally. Nevertheless for all the estimations presented here only the instruments marked by a double positive sign were included. The instruments marked by a negative sign were excluded because they showed high correlations with the error term. The instrument with the single positive sign was excluded because it was identified by testing as being redundant. Alternative estimates including it didn't show any significant differences.

[74] Significance levels are 1% (***), 5% (**), and 10% (*), standard errors in parentheses.

Comparing the Specification-Specific Results

The network effects prove to be important, highly significant and within their theoretical limits regardless of the model specification[75]. The elasticities vary between 0.38 and 0.48 for all observed model specifications. These are partial elasticities which tell us the amount of additional migration induced by an increase in a regional network. For example the regional network at the destination of an origin-destination pair consists of the migrants that move from the origin to the regions surrounding the destination. In a ceteris paribus analysis a γ_D of 0.5 for the destination network predicts that, if the number of migrants in the network rises by one percent, this induces an increase in the migration flow directed to the destination by half a percent. Thus, this value disregards the spatial multiplier effect induced by the spatial spillover and feedback mechanisms and just identifies the first round effect. The In general we find the origin-based network effects to be slightly higher than the destination-based ones. The most influential characteristics besides the network effects are the distance and the joint values for the population, GDP and the prevalence of medical conditions. As indicated above we use the number of physicians to measure health conditions. Comparing these characteristics in the last three columns we can observe how strictly the estimates will be biased if spatial autoregression is neglected. The elasticity of the distance increases by 50% in the SARAR(0,2) model and doubles in the SARAR(2,2) compared to the full SARAR(2,2) specification. Even stronger are the differences in the effect of the population ranging between 0.13 and 0.62 and of the unemployment having a lower bound of 0.13 in the SARAR(0,2) model and an upper level of 0.74 in the SARAR(2,0) specification. Health threats encourage migration in narrower, but yet significantly different limits ranging from 0.18 to 0.30. In general the SARAR(0,2)

[75] It is indeed possible to produce estimation results that are contrary to this statement but for reasonable model specifications the results vary within narrow limits.

model strongly overestimates the elasticities. For example all the employment-related elasticities are more than doubled compared to the full specification. This again is perfectly in line with theory. Since networks increase the employment probability the actual labour market conditions become less important.

Interpreting the remaining results of the SARAR(2,2) model we will examine the effects of relative differences between origins and destination separately from the general impact of the joint size of the characteristics. Note for the interpretation that the relative characteristics are for the origin versus the destination. These differential effects are barely surprising. Migrants choose destinations with relatively higher employment. An exception is the employment in primary industrial production which discourages migration. Unsurprisingly the strongest attraction exhibits a higher employment in the service sector. Other attracting factors are higher local income (measured by the district's GDP), the existence and size of universities (measured by the number of students) and the quantity of amenities (measured by the number of tourists). The main factors discouraging migration are relatively higher unemployment and health threats at the destination. We can also observe a tendency to leave rural regions indicated by the agricultural and forest area. Studying the general effects of the characteristics we can distinguish the supportive joint size effects from those suppressing migration. Obviously combined population of the regions will determine the scale of migration that is possible. As expected this effect is significant and positive. Among the factors that generally encourage migration are income, unemployment levels, health threats, the amount of amenities, the number of students and the rurality. It is not difficult to find plausible explanations for any of these effects. Income is likely to provide resources that increase mobility while unemployment might create the necessity to migrate in order improve the personal job conditions. The existence of regional health risks encourages migration as it would generally decrease the standard of living. The opposing effect holds true for the availability and quantity of amenities. Since we measure the amenities by the number of overnight stays we capture the influence of cultural venues, sights and other factors attracting tourists. Additionally, part of the economic attractiveness is captured because business travel also contributes to the accommodation figures. More students will foster migration since education increases mobility and because finishing a university degree is likely to induce a job-related relocation. Taking the agricultural area as measure for rurality and the urban area as respective measure for urbanity suggests that rural population is in general more mobile than townspeople. But it should be mentioned that these two types of migration are very different. If, for example, one assumes that the equivalent of moving from one quarter to another would be to migrate from one village to the next, then the rural version of this migration is much more likely to cross a district border. Joint size effects repressing migration tendencies include higher employment, which reduces the need to relocate for job improvement, and the number of welfare recipients, as they are less mobile due to budget constraints and the localized welfare payments. The effect of natural amenities is not clear since the bodies of water generally encourage migration while the forest area has a repressive effect. But, as mentioned above, the interpretation of the forest area is not straightforward since it will also capture other effects, given that areas are also likely to be rural or hilly.

The values for the Moran's I statistic are the spatial autocorrelation measures for the given weights matrix. In the presence of beneficial network effects we would expect a positive significant correlation. We do we observe this in the SARAR(0,2) model for the origin as well as for the destination. Employing the endogenous spatial autoregressive process we still observe positive significant values for Moran's I, thus, it is reasonable to further correct for spatial autoregressive disturbances.

Does Gender and Nationality Matter for Migration Behaviour?

The inspection of the different population sub-groups in table 2.2.3 mostly confirms the results for the entire population.

Model	SARAR(2,2)		SARAR(2,2)		SARAR(2,2)		SARAR(2,2)	
Population sub-group	Female		Male		Non-German nationality		German nationality	
Innovation errors	Heteroskedastic		Heteroskedastic		Heteroskedastic		Heteroskedastic	
R2	0.4599		0.4654		0.4309		0.4818	
Observations	192721		192721		192721		192721	
Sargan overid	0.9436		0.8682		0.4560		0.7945	
Anderson Identification	0.0000		0.0000		0.0000		0.0000	
Moran's I Ori.	0.0936 ***		0.0946 ***		0.0534 ***		0.0987 ***	
Moran's I Des.	0.1021 ***		0.1050 ***		0.0794 ***		0.1050 ***	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Ori. rho	0.3618		0.3562		0.2361		0.3740	
Des. rho	0.4374		0.4449		0.4559		0.4281	
Ori. gamma	0.4202 ***	(0.0395)	0.4495 ***	(0.0418)	0.4817 ***	(0.0535)	0.4427 ***	(0.0368)
Des. gamma	0.4003 ***	(0.0294)	0.4223 ***	(0.0337)	0.4243 ***	(0.0347)	0.4150 ***	(0.0295)
Distance	-0.1931 ***	(0.0160)	-0.1790 ***	(0.0175)	3.2860 ***	(0.3454)	-0.1926 ***	(0.0160)
Rel. population	-0.0168	(0.0176)	-0.0207	(0.0175)	-0.1440 ***	(0.0208)	-0.0095	(0.0182)
Rel. employed rest	-0.0202 ***	(0.0058)	-0.0165 ***	(0.0057)	-0.0465 **	(0.0167)	-0.0193 ***	(0.0058)
Rel. employed prim. Industry	0.0138	(0.0104)	0.0159	(0.0103)	-0.0108	(0.0054)	0.0174	(0.0106)
Rel. employed manufacturing	-0.0209 *	(0.0109)	-0.0145	(0.0108)	0.0029	(0.0100)	-0.0185 *	(0.0112)
Rel. employed services	-0.0935 ***	(0.0341)	-0.0422	(0.0326)	-0.0068	(0.0099)	-0.0789 **	(0.0348)
Rel. unemployed	0.1602 ***	(0.0490)	0.0835 *	(0.0465)	0.0032	(0.0300)	0.1292 ***	(0.0497)
Rel. GDP (districts)	-0.0614 ***	(0.0197)	-0.0441 **	(0.0194)	0.0342 ***	(0.0373)	-0.0478 **	(0.0198)
Rel. medics	0.0242	(0.0162)	0.0337 **	(0.0153)	-0.0503 ***	(0.0185)	0.0175	(0.0162)
Rel. students	-0.0010 *	(0.0006)	-0.0009	(0.0006)	0.0807	(0.0150)	-0.0013 **	(0.0006)
Rel. tourist overnight stays	-0.0170 ***	(0.0040)	-0.0170 ***	(0.0040)	0.0006 **	(0.0006)	-0.0173 ***	(0.0041)
Rel. welfare recipients	0.0023	(0.0059)	-0.0030	(0.0057)	-0.0093 ***	(0.0039)	0.0036	(0.0060)
Rel. holiday homes	0.0029	(0.0024)	0.0030	(0.0023)	-0.0204 *	(0.0054)	0.0028	(0.0024)
Rel. recreational area	0.0028	(0.0051)	0.0001	(0.0050)	0.0046	(0.0023)	0.0032	(0.0052)
Rel. agricultural area	0.0069	(0.0052)	0.0070	(0.0052)	-0.0032 **	(0.0048)	0.0055	(0.0053)
Rel. forest area	0.0095 ***	(0.0026)	0.0087 ***	(0.0026)	0.0107	(0.0051)	0.0104 ***	(0.0026)
Rel. bodies of water	-0.0018	(0.0028)	-0.0016	(0.0028)	0.0014	(0.0024)	-0.0033	(0.0029)
Rel. urban area	0.0082	(0.0142)	0.0125	(0.0141)	0.0018	(0.0027)	0.0080	(0.0146)
Joint population	0.2818 ***	(0.0262)	0.2639 ***	(0.0280)	0.0204 ***	(0.0133)	0.3089 ***	(0.0275)
Joint employed rest	0.0021	(0.0057)	-0.0111 **	(0.0055)	0.0765	(0.0225)	-0.0101 *	(0.0057)
Joint employed prim. Industry	-0.1169 ***	(0.0123)	-0.1052 ***	(0.0126)	0.0073 ***	(0.0066)	-0.1146 ***	(0.0125)
Joint employed manufacturing	-0.1794 ***	(0.0123)	-0.1785 ***	(0.0133)	-0.0797 ***	(0.0114)	-0.1840 ***	(0.0130)
Joint employed services	-0.0992 ***	(0.0312)	-0.0847 ***	(0.0311)	-0.1599 ***	(0.0094)	-0.0363	(0.0322)
Joint unemployed	0.3641 ***	(0.0388)	0.3758 ***	(0.0387)	-0.3709 ***	(0.0304)	0.3410 ***	(0.0399)
Joint GDP (districts)	0.0309	(0.0189)	0.0619 ***	(0.0202)	0.5509 ***	(0.0414)	0.0298	(0.0190)
Joint medics	0.2254 ***	(0.0167)	0.1388 ***	(0.0153)	0.0970 ***	(0.0275)	0.1851 ***	(0.0162)
Joint students	0.0046 ***	(0.0006)	0.0045 ***	(0.0006)	0.1745 ***	(0.0156)	0.0047 ***	(0.0006)
Joint tourist overnight stays	0.0563 ***	(0.0037)	0.0511 ***	(0.0036)	0.0043 ***	(0.0006)	0.0623 ***	(0.0038)
Joint welfare recipients	-0.0364 ***	(0.0057)	-0.0253 ***	(0.0056)	0.0333	(0.0036)	-0.0411 ***	(0.0058)
Joint holiday homes	-0.0006	(0.0026)	-0.0023	(0.0026)	-0.0008	(0.0056)	-0.0047 *	(0.0026)
Joint recreational area	0.0041	(0.0051)	0.0062	(0.0051)	-0.0018	(0.0027)	0.0051	(0.0052)
Joint agricultural area	0.0240 ***	(0.0051)	0.0208 ***	(0.0051)	0.0051 ***	(0.0051)	0.0358 ***	(0.0055)
Joint forest area	-0.0201 ***	(0.0027)	-0.0158 ***	(0.0027)	-0.0205 ***	(0.0063)	-0.0131 ***	(0.0026)
Joint bodies of water	0.0184 ***	(0.0031)	0.0167 ***	(0.0031)	-0.0270 ***	(0.0030)	0.0216 ***	(0.0032)
Joint urban area	-0.0536 ***	(0.0154)	-0.0401 ***	(0.0154)	0.0074	(0.0027)	-0.0661 ***	(0.0161)
Constant	1.9439 ***	(0.3778)	1.3087 ***	(0.3762)	0.0120 ***	(0.0134)	1.3162 ***	(0.3967)

Table 2.2.3: Estimation results by gender and nationality[76].

[76] Significance levels are 1% (***), 5% (**), and 10% (*), standard errors in parentheses.

Comparing the gender sub-groups the differences manifest especially in the employment-related elasticities and in the effects of health risks. For the male population the effects of sectoral relative employment differences are close to the total population with the relative employment in the production of primary industrial goods being insignificant. For the female population the differences in employment between the origin and the destination are all insignificant but for the residual employment. Even though this effect indicates that women migrate to destinations with relatively higher employment they are still less affected than their male counterparts. This is also especially true for relative unemployment, with the elasticity for men being more than twice that for women. In general these results display a higher importance of the availability of jobs for the male migrants than for the female ones. Nevertheless the joint effect of income is only significant for women. Thus mobility of male migrants is probably not as dependent on financial resources as the mobility of the more risk-averse female population. Unfortunately we cannot further specify the source of the results that are related to the expected earnings. To do so we would need to distinguish between individual migrants and those relocating as a complete household or into an existing household. We are also unable to control for the employment status of the migrants before and after migrating. Another striking observation is that the migration behaviour of men is in general influenced more strongly by health threats than that of women. But while women prefer locations with relatively lower health risks the male migrants show no significant reaction to those differences. As we observe the migration flows on a small regional scale we face the problem of an increasing proportion of zero migration events between an origin-destination pair if we continuously reduce the size of the observed sub-groups. To avoid this problem we employed the commonly accepted practice of adding one to the total of migrants before taking the logs. For the total population an unproblematic share of less than 7% of the possible one-directional flows between two districts showed no migration. For the gender sub-groups this proportion increased to 12% for the male migrants and 13% for the respective female ones. For the sub-groups of differing nationality that we will observe next this fraction is around 7% for the German-nationals but reaches almost 53% for the migrants of non-German nationality, which should be kept in mind in the interpretation of the results. The migration behaviour of the German sub-group does not differ fundamentally from the total population. The main differences are not in the size but in the significance of the elasticities. As a result the effects are insignificant for the differences in health risk, agricultural area and employment in the production of primary industrial goods. Joint employment in the service sector and joint GDP also no longer show a significant effect but the joint effect of the holiday homes is now significantly negative. This indicates that generally German nationals living in areas with an attractive landscape are less likely to move. The findings for the sub-group of non-German nationals are remarkably different. The insignificance of relative unemployment and employment (except for the redundant sector) might be a sign that for this group networks are more important for finding a job than the job-market differences. Also the negative joint effect of unemployment shows that non-German nationals are unlikely to move as general job perspectives get worse. This is rational if they are dependent on networks and thus would prefer to confront the situation by using their local connections. The importance of networks could also explain the tendency to move to districts with lower relative income. Intense networks give a competitive advantage compared to the German-nationals and allow access to the informal job-market, so that the legal wage levels are less important. The importance of sectoral employment also differs essentially from their counterparts of German nationality. A rise in joint employment in the service sector has a much stronger repressive effect on migration for non-German nationals than for German nationals. It is, besides unemployment and distance, the strongest inhibitory factor of all. Employment in manufacturing has a much lower elasticity and joint employment in the production of primary industrial goods even encourages migration. Some differences might also be attached to sub-groups of certain nationality or social status. The different reaction to the population size and the distance indicate the fundamental differences in migration behaviour. If non-German nationals move they tend to move far. They react highly elastic to distance with a positive (!) value of 3.29. This makes sense if networks are important. The numbers of non-German nationals are relatively low and networks need a certain size to exert a positive externality. Thus the clusters of persons with common nationality will be few, far from each other and probably located within larger agglomerations. Therefore if a migrant wants to profit from these networks, she will have to move far and preferably to a region with a relatively higher population size.

Sensitivity Analysis

In the weights matrix contiguity was defined through a threshold distance. If the distance of the centroids of a district pair was below that limit they were considered neighbours. The specification of the threshold is not based on theory but on reasonable considerations and practical reasons. Considering what is reasonable anecdotal evidence and intuition would tell that the effects of networks will strongly diminish with distance. Commuting 100 kilometres or more is not uncommon and still seems to be a sensible maximum distance to make use of network benefits. Out of practical considerations 75 kilometres is the minimum distance which ensures that every district does have a neighbour at all. Thus we chose a distance of 100 kilometres to ensure that a district has several neighbours. Nevertheless the validity of this assumption should be tested. In table 2.2.4 we explore the effect of varying the assumptions about the spatial structure of the autoregressive processes by varying the threshold distance. We can observe that the estimates for the autoregressive disturbance deplete as we reduce the threshold but the elasticities for the endogenous autoregressive process vary only little.

Model	SARAR(2,2)		SARAR(2,2)		SARAR(2,2)		SARAR(2,2)	
Max. distance neighbours	50 kilometre		75 kilometre		150 kilometre		200 kilometre	
Innovation errors	Heteroskedastic		Heteroskedastic		Heteroskedastic		Heteroskedastic	
R2	0.7025		0.5632		0.4466		0.4386	
Observations	192721		192721		192721		192721	
Sargan overid	0.0000		0.4946		0.4054		0.7588	
Anderson Identification	0.0000		0.0000		0.0000		0.0000	
Moran's I Ori.	0.0472 ***		0.0932 ***		0.0938 ***		0.0825 ***	
Moran's I Des.	0.0621 ***		0.1017 ***		0.0989 ***		0.0865 ***	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Ori. rho	0.1126		0.3035		0.4031		0.4024	
Des. rho	0.1627		0.3536		0.4693		0.4650	
Ori. gamma	0.4590 ***	(0.0171)	0.4363 ***	(0.0263)	0.4307 ***	(0.0539)	0.4570 ***	(0.0512)
Des. gamma	0.4229 ***	(0.0139)	0.4082 ***	(0.0207)	0.3818 ***	(0.0371)	0.3757 ***	(0.0363)
Distance	-0.2360 ***	(0.0247)	-0.2059 ***	(0.0176)	-0.2738 ***	(0.0186)	-0.3889 ***	(0.0196)
Rel. population	-0.0028	(0.0120)	-0.0147	(0.0154)	0.0036	(0.0222)	0.0201	(0.0220)
Rel. employed rest	-0.0093 **	(0.0042)	-0.0184 ***	(0.0052)	-0.0227 ***	(0.0066)	-0.0228 ***	(0.0071)
Rel. employed prim. Industry	0.0042	(0.0071)	0.0150	(0.0093)	0.0150	(0.0127)	0.0150	(0.0130)
Rel. employed manufacturing	-0.0133 *	(0.0076)	-0.0149	(0.0099)	-0.0319 **	(0.0129)	-0.0435 ***	(0.0134)
Rel. employed services	-0.0428 *	(0.0233)	-0.0656 **	(0.0303)	-0.0992 **	(0.0395)	-0.1293 ***	(0.0410)
Rel. unemployed	0.1315 ***	(0.0313)	0.1329 ***	(0.0445)	0.1962 ***	(0.0562)	0.2515 ***	(0.0582)
Rel. GDP (districts)	-0.0692 ***	(0.0131)	-0.0653 ***	(0.0179)	-0.0703 ***	(0.0237)	-0.0809 ***	(0.0252)
Rel. medics	0.0128	(0.0113)	0.0288 **	(0.0142)	0.0184	(0.0188)	0.0275	(0.0200)
Rel. students	-0.0012 ***	(0.0004)	-0.0013 **	(0.0005)	-0.0012	(0.0007)	-0.0009	(0.0008)
Rel. tourist overnight stays	-0.0143 ***	(0.0026)	-0.0171 ***	(0.0035)	-0.0170 ***	(0.0050)	-0.0114 **	(0.0050)
Rel. welfare recipients	-0.0056	(0.0040)	-0.0020	(0.0052)	0.0041	(0.0068)	0.0018	(0.0070)
Rel. holiday homes	0.0022	(0.0017)	0.0021	(0.0021)	0.0028	(0.0028)	0.0017	(0.0030)
Rel. recreational area	-0.0004	(0.0034)	0.0033	(0.0045)	0.0051	(0.0057)	0.0046	(0.0058)
Rel. agricultural area	0.0094 **	(0.0037)	0.0102 **	(0.0047)	0.0152 **	(0.0059)	0.0221 ***	(0.0062)
Rel. forest area	0.0060 ***	(0.0018)	0.0092 ***	(0.0023)	0.0092 ***	(0.0030)	0.0081 **	(0.0031)
Rel. bodies of water	-0.0016	(0.0020)	-0.0037	(0.0025)	0.0002	(0.0033)	0.0005	(0.0034)
Rel. urban area	0.0007	(0.0096)	0.0066	(0.0129)	-0.0131	(0.0158)	-0.0347 **	(0.0162)
Joint population	0.0265	(0.0197)	0.2140 ***	(0.0249)	0.3953 ***	(0.0319)	0.3556 ***	(0.0312)
Joint employed rest	-0.0553 ***	(0.0038)	0.0014	(0.0049)	-0.0036	(0.0064)	0.0008	(0.0067)
Joint employed prim. Industry	-0.0002	(0.0076)	-0.1177 ***	(0.0099)	-0.1365 ***	(0.0147)	-0.0973 ***	(0.0153)
Joint employed manufacturing	-0.2333 ***	(0.0087)	-0.2403 ***	(0.0097)	-0.2263 ***	(0.0156)	-0.2678 ***	(0.0165)
Joint employed services	-0.2616 ***	(0.0217)	-0.2811 ***	(0.0290)	-0.0883 **	(0.0373)	-0.1345 ***	(0.0380)
Joint unemployed	0.4046 ***	(0.0230)	0.6494 ***	(0.0337)	0.3571 ***	(0.0456)	0.4617 ***	(0.0453)
Joint GDP (districts)	0.2149 ***	(0.0152)	0.0459 **	(0.0179)	0.1326 ***	(0.0221)	0.1530 ***	(0.0241)
Joint medics	0.2646 ***	(0.0113)	0.2494 ***	(0.0135)	0.1691 ***	(0.0196)	0.1818 ***	(0.0206)
Joint students	0.0108 ***	(0.0004)	0.0066 ***	(0.0006)	0.0059 ***	(0.0008)	0.0056 ***	(0.0008)
Joint tourist overnight stays	0.0649 ***	(0.0026)	0.0653 ***	(0.0033)	0.0488 ***	(0.0045)	0.0342 ***	(0.0048)
Joint welfare recipients	-0.0622 ***	(0.0038)	-0.0488 ***	(0.0050)	-0.0346 ***	(0.0066)	-0.0433 ***	(0.0069)
Joint holiday homes	0.0152 ***	(0.0019)	-0.0030	(0.0023)	0.0084 ***	(0.0028)	0.0237 ***	(0.0030)
Joint recreational area	0.0023	(0.0035)	0.0177 ***	(0.0045)	0.0040	(0.0058)	0.0033	(0.0060)
Joint agricultural area	0.0555 ***	(0.0044)	0.0376 ***	(0.0050)	0.0401 ***	(0.0059)	0.0636 ***	(0.0063)
Joint forest area	-0.0246 ***	(0.0017)	-0.0161 ***	(0.0023)	-0.0189 ***	(0.0032)	-0.0268 ***	(0.0034)
Joint bodies of water	0.0063 **	(0.0029)	0.0174 ***	(0.0031)	0.0264 ***	(0.0043)	0.0492 ***	(0.0040)
Joint urban area	0.0298 **	(0.0142)	-0.0690 ***	(0.0157)	-0.1229 ***	(0.0172)	-0.1997 ***	(0.0172)
Constant	0.3230	(0.2239)	3.6902 ***	(0.3088)	2.6253 ***	(0.4459)	5.5379 ***	(0.4185)

Table 2.2.4: estimation results for different weights matrices[77].

They lie between 0.43 and 0.46 for the origin and decline slowly from 0.42 to 0.38 for the destination. However, the elasticities for the other effects can vary essentially, as for relative or joint employment in the service sector or joint GDP. Other effects again are influenced less by the choice of the spatial structure as elasticity of relative GDP or joint employment in manufacturing. The partial sensitivity of the results to

[77] Significance levels are 1% (***), 5% (**), and 10% (*), standard errors in parentheses.

the choice of the weights matrix shows that more research towards a better theoretical foundation or econometric determination of the weights matrix is needed. Because of the persistent significance of spatial network effects we have to conclude that neglecting the spatial structure at all would be the worse choice.

Conclusions

In this work we approached the effects of spatially structured migrant networks. We found strong empirical evidence for network effects being a major determinant of domestic migration. The migrants are supported from networks at their origin as well as from those effective at the destination. Migration behaviour differs systematically between population sub-groups which are identified by gender of nationality. We could confirm the expected effects on migration of the traditionally considered regional characteristics as income, unemployment or population size. Additionally we showed that migration flows are directed away from health risk and that migrants are attracted to amenities which we instrument with tourist attractiveness. Our extension of the SARAR model to a second-order autoregressive process in the endogenous as well as in the disturbance term proved to be a highly valuable framework for analyzing spatially structured origin-destination flows.

Appendix to the Second Part:

(Ap. II.I) Construction of the Vector of Migration-Flows:

Let Y be a square matrix of size $l \times m$ with l being the number of origins assigned to the rows and m being the equal number of destinations assigned to the columns. The elements $y_{l,n}$ of the matrix are the logarithmized migration flows from an origin to a destination

$$Y = \begin{matrix} y_{1,1} & \cdots & y_{1,m} \\ \vdots & \ddots & \vdots \\ y_{l,1} & \cdots & y_{l,m} \end{matrix}$$

To use these flows in our model we need to rearrange this matrix into a vector $y_n^{des} = vec[Y']$ which will be of size $n \times 1$ with $n = l \bullet m$. We employ an origin-centric ordering by sorting the flows by the origin as slow index and with the destination being the fast index. Since this origin-centric ordering will be used to calculate the spatially weighted destination characteristics and destination oriented autoregressive effects we refer to this vector as y_n^{des}. For the calculation of the spatial lags it proofs helpful to first employ the whole procedure origin-centric for the destination effects and then to construct the destination-centric vector $y_n^{ori} = vec[Y]$ to calculate the respective origin effects. In this way the spatial structure of the weights matrices can be exploited to employ the simplifications indispensable to make the problem feasible given the computational constraints. Since the procedure is identical we only state it once for the destination effects.

$$
vec[Y'] = y_n^{des} = \begin{array}{ccc} & origin & destination \\ y_{1,1} & 1 & 1 \\ \vdots & \vdots & \vdots \\ y_{1,m} & 1 & m \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ y_{l,1} & l & 1 \\ \vdots & \vdots & \vdots \\ y_{l,m} & l & m \end{array}
$$

Let X be the $m \times g$ matrix of g different district characteristics and *i(m)* a $m \times 1$ vector of ones. Given the vector of migration flows we can easily construct the corresponding destination characteristics by taking the Kronecker-product $X_{D,n} = i(m) \otimes X$, likewise the origin characteristics can be constructed by $X_{O,n} = X \otimes i(m)$ [78].

The following matrix W^{des} is the starting point for the construction of our weights matrices. It is constructed in such way that the diagonal elements are zero, thus preventing a district from being neighbour to itself. The values $w_{l,m}$ are positive and identical within a row if the distance of the respective origin and destination is equal or below the predefined threshold and zero if the distance is above it. The positive row elements will be normalized such that they add up to unity.

[78] See also LeSage and Pace (2007).

$$W^{des} = \begin{matrix} 0 & w_{1,2} & \cdots & \cdots & w_{1,m} \\ w_{2,1} & 0 & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & 0 & w_{l-1,m} \\ w_{l,1} & \cdots & \cdots & w_{l,m-1} & 0 \end{matrix} \qquad \begin{matrix} \sum_{j=1}^{m} w_{1,j} = 1 \\ \sum_{j=1}^{m} w_{2,j} = 1 \\ \vdots \\ \sum_{j=1}^{m} w_{l-1,j} = 1 \\ \sum_{j=1}^{m} w_{l,j} = 1 \end{matrix}$$

Note that for the comparable analysis in the destination-centred ordering this core matrix would have to be transposed, then row-values would be equalized and finally row-normalized. To construct the weights matrix for the destination effects we can employ the following Kronecker product:

$$W_{D,n} = I(m) \otimes W^{des} = \begin{matrix} W^{des} & 0_{1,2} & \cdots & \cdots & 0_{1,m} \\ 0_{2,1} & W^{des} & & & \vdots \\ \vdots & & \ddots & & \vdots \\ \vdots & & & W^{des} & 0_{m-1,m} \\ 0_{m,1} & \cdots & \cdots & 0_{m,m-1} & W^{des} \end{matrix}$$

With *I(m)* being an identity matrix of size $m \times m$ and $0_{m,l}$ being a matrix of zeros of size $m \times m$. The weights matrix therefore will be of size $n \times n$. Without computational constraints the respective origin-effects weights matrix could just be constructed as:

$$W_{O,n} = W^{des} \otimes I(m)$$

(Ap. II.II) Limiting Properties of the Autoregressive Parameters:

Let $S_n = I_n - \lambda_O W_{O,n} - \lambda_D W_{D,n}$ be a term which we want to invert. Then with $\|\bullet\|$ being an arbitrary matrix norm it holds that $\left\|\sum_{j=O,D} \lambda_j W_{j,n}\right\| \leq \sum_{j=O,D} |\lambda_j| \cdot \|W_{j,n}\| \leq \left(\sum_{j=O,D} |\lambda_j|\right) \cdot \max_{j=O,D} \|W_{j,n}\|$. For a row normalized weights matrix the last term of the expression will be equal to one e.g. . As we know that the inverse of S_n is equal to the expansion $S_n^{-1} = \sum_{k=0}^{\infty} \left(\sum_{j=O,D} \lambda_j W_{j,n}\right)^k$ and observing the above statement it is clear that this term will certainly converge if $\sum_{j=O,D} |\lambda_j| < 1$ and thus the added values of the higher order terms in the expansion of S_n^{-1} converge to zero. Hence S_n will be invertible. For a further discussion see also Lee and Liu (2006).

(Ap. II.III) The Trace Calculation:

The calculation of the traces in the moment conditions involves the multiplication of matrices of size n^2. Due to the computational constraints this multiplication is not feasible but it is possible to reduce the size of the matrices due to the special properties following from their construction. As we look at one of the moment conditions in (3)

$$n^{-1} E\left[\bar{\varepsilon}_{D,n}' \bar{\varepsilon}_{D,n} - Tr\left[M_{D,n} diag\left[E\left[\varepsilon_{i,n} \varepsilon_{i,n}\right]\right] M_{D,n}'\right]\right]$$

we can focus our interest on the trace $Tr[M_{D,n} diag[E[\varepsilon_{i,n}\varepsilon_{i,n}]] M_{D,n}']$ and use the condition that the innovations from the first step of the three step procedure are an unbiased estimate for the error term such that $E[\varepsilon_{i,n}\varepsilon_{i,n}] = \hat{\varepsilon}_{i,n}\hat{\varepsilon}_{i,n}$. Additionally remember the construction of the weights matrix as being $M_{D,n} = M^{des} \otimes I(m) = W^{des} \otimes I(m)$, then:

$$Tr\left[M_{D,n} diag\left[E\left[\varepsilon_{i,n}\varepsilon_{i,n}\right]\right]M_{D,n}'\right]$$

$$= Tr\left[\left(I(m) \otimes M^{des}\right) diag\left[\hat{\varepsilon}_{i,n}\hat{\varepsilon}_{i,n}\right]\left(I(m) \otimes M^{des}\right)'\right]$$

$$= Tr\left[diag\left[\hat{\varepsilon}_{i,n}\hat{\varepsilon}_{i,n}\right]\left(\left(I(m)I(m)'\right) \otimes \left(M^{des}M^{des}{}'\right)\right)\right]$$

$$= Tr\left[diag\left[\hat{\varepsilon}_{i,n}\hat{\varepsilon}_{i,n}\right]\left(I(m) \otimes \left(M^{des}{}'M^{des}\right)\right)\right]$$

$$= \sum_{k=0}^{m-1} Tr\left[diag\left[\hat{\varepsilon}_k\hat{\varepsilon}_k\right]\left(M^{des}{}'M^{des}\right)\right]$$

with $\hat{\varepsilon}_k$ being the elements $i = \{m*k+1 , \dots , m*(k+1)\}$ of the vector $\hat{\varepsilon}_{i,n}$. So the whole calculation just involves the multiplication of the sub-matrices which are only of size m x m with $m = n^{1/2}$.

(Ap. II.IV) A Note on the Calculation of the Moran's I Statistics:

We listed the Moran's I statistic as the most common test for spatial autocorrelation. The statistic itself ranges between –1 and 1 and can be interpreted as the spatial correlation of the error terms given the assumed spatial structure (the weights matrix). To keep the calculation computationally feasible we have to take appropriate steps. For our row-normalized weights matrices Moran's I is equal to:

$$I = \frac{\hat{\varepsilon}_{i,n}{}' M_{D,n} \hat{\varepsilon}_{i,n}}{\hat{\varepsilon}_{i,n}{}' \hat{\varepsilon}_{i,n}}$$

Referring to (Ap. II) we notice that the whole problem breaks down to feasible size because:

$$M_{D,n} \hat{\varepsilon}_{i,n} = I(m) \otimes M^{des} \hat{\varepsilon}_{i,n} = \begin{pmatrix} M^{des} \hat{\varepsilon}_{k=1} \\ M^{des} \hat{\varepsilon}_{k=2} \\ \vdots \\ M^{des} \hat{\varepsilon}_{k=m} \end{pmatrix}$$

As the Moran's I statistic doesn't tell us anything as long as we don't know if it is significant, we also observe that:

$$z_I = \frac{\hat{\varepsilon}_{i,n}{}' M_{D,n} \hat{\varepsilon}_{i,n}}{n^{-1} \hat{\varepsilon}_{i,n}{}' \hat{\varepsilon}_{i,n} \left(Tr\left[\left(M_{D,n}{}' + M_{D,n} \right) M_{D,n} \right] \right)^{1/2}}$$

The critical trace term simplifies to:

$$Tr\left[\left(M_{D,n}{}' + M_{D,n} \right) M_{D,n} \right]$$

$$= Tr\left[\left(\left(I(m) \otimes M^{des} \right)' + I(m) \otimes M^{des} \right) \left(I(m) \otimes M^{des} \right) \right]$$

$$= Tr\left[\left(I(m)' I(m) \right) \otimes \left(M^{des}{}' M^{des} \right) \right] + Tr\left[\left(I(m) I(m) \right) \otimes \left(M^{des} M^{des} \right) \right]$$

$$= Tr\left[I(m)' I(m) \right] + Tr\left[I(m) I(m) \right] + Tr\left[M^{des}{}' M^{des} \right] + Tr\left[M^{des} M^{des} \right]$$

$$= 2m + Tr\left[M^{des}{}' M^{des} \right] + Tr\left[M^{des} M^{des} \right]$$

(Ap. II.V) Sample STATA-Code for the Estimation of the SARAR(2,2) Model for the Total Population and a Threshold Distance of 100 Kilometres:

```
use "C:\migration\migration", clear
gen fg   = ln(total_migrants_form_origin_to_destination+1)
gen x0   = 1
gen x1   = ln(distance_in_metre+1)
gen xo1  = ln(origin_population)
gen xo2  = ln(origin_residual_employed)
gen xo3  = ln(origin_employed_production_primary_industrial_goods)
gen xo4  = ln(origin_employed manufacturing)
gen xo5  = ln(origin_employed_services)
gen xo6  = ln(origin_unemployed)
gen xo7  = ln(origin_GDP_district)
gen xo8  = ln(origin_medics)
gen xo9  = ln(origin_students+1)
gen xo10 = ln(origin_overnights)
gen xo11 = ln(origin_welfare_recipients)
gen xo12 = ln(origin_holiday_homes+1)
gen xo13 = ln(origin_recreational_area)
gen xo14 = ln(origin_agricultural_area)
gen xo15 = ln(origin_forest_area)
gen xo16 = ln(origin_water_area)
gen xo17 = ln(origin_urban_area)
gen xd1  = ln(destination_population)
gen xd2  = ln(destination_residual_employed)
gen xd3  = ln(destination_employed_production_primary_industrial_goods)
gen xd4  = ln(destination_employed manufacturing)
gen xd5  = ln(destination_employed_services)
gen xd6  = ln(destination_unemployed)
gen xd7  = ln(destination_GDP_district)
gen xd8  = ln(destination_medics)
gen xd9  = ln(destination_students+1)
gen xd10 = ln(destination_overnights)
gen xd11 = ln(destination_welfare_recipients)
gen xd12 = ln(destination_holiday_homes+1)
gen xd13 = ln(destination_recreational_area)
gen xd14 = ln(destination_agricultural_area)
gen xd15 = ln(destination_forest_area)
gen xd16 = ln(destination_water_area)
gen xd17 = ln(destination_urban_area)
save "C:\migration\080202_mig", replace
use "C:\migration\080202_mig", clear
**********************************************************************************
* Description of the regions:                                                    *
*                                                                                *
* region | Freq.  Percent     Cum.  State                                        *
*--------+--------------------------------------------------------------------- *
*      1 |    15     3.42     3.42  Schleswig Holstein     (former West Germany) *
*      2 |     1     0.23     3.64  Hamburg                (former West Germany) *
*      3 |    46    10.48    14.12  Niedersachsen          (former West Germany) *
*      4 |     2     0.46    14.58  Bremen                 (former West Germany) *
*      5 |    54    12.30    26.88  Nordrhein-Westfalen    (former West Germany) *
*      6 |    26     5.92    32.80  Hessen                 (former West Germany) *
*      7 |    36     8.20    41.00  Rheinland-Pfalz        (former West Germany) *
*      8 |    44    10.02    51.03  Baden-Wuerttemberg     (former West Germany) *
*      9 |    96    21.87    72.89  Bayern                 (former West Germany) *
*     10 |     6     1.37    74.26  Saarland               (former West Germany) *
*     11 |     1     0.23    74.49  Berlin                 (both: West and East) *
*     12 |    18     4.10    78.59  Brandenburg            (former East Germany) *
*     13 |    18     4.10    82.69  Mecklenburg-Vorpommern (former East Germany) *
```

```
*     14 |    29     6.61    89.29  Sachsen                 (former East Germany) *
*     15 |    24     5.47    94.76  Sachsen-Anhalt          (former East Germany) *
*     16 |    23     5.24   100.00  Thueringen              (former East Germany) *
*--------+--------------------------------------------------------------------*
*  Total |   439   100.00                                                     *
*******************************************************************************
* Selection procedure for the states that will be regressed (in this case all
states):
gen oreg = floor(origin/1000)
gen dreg = floor(destin/1000)
*default is Berlin:
gen owest = 0
replace owest = 1 if oreg<11
gen dwest = 0
replace dwest = 1 if dreg<11
gen oeast = 0
replace oeast = 1 if oreg>11
gen deast = 0
replace deast = 1 if dreg>11
capture drop dummy
capture drop dummyo
capture drop dummyd
gen dummyo = 0
replace dummyo = 1 if oreg>0
gen dummyd = 0
replace dummyd = 1 if dreg>0
gen dummy = dummyo*dummyd
drop if dummy==0
drop dummy
* Generate neighbor matrix / define max distance for states to be considered as
neighbors:
capture drop w
gen w = 0
replace w = 1 if distance <= 100000
replace w = 0 if origin==destin
* Define district characteristics used for the estimation:
global nvar = "1/17"
global x = "xo1-xo17 xd1-xd17"
global xr = "xr1-xr17"
global xc = "xc1-xc17"
* Efficiently generate spatial lags of exogenous variables:
egen sum = sum(w), by(origin)
replace sum = 1 if sum == 0
gen wd = w/sum
sort origin destin
gen temp = wd * x1
egen wox1 = sum(temp), by(origin)
forvalues val = $nvar {
       replace temp = wd * xd`val'
       egen woxo`val' = sum(temp), by(origin)
       }
save "C:\migration\temp_weight.dta", replace
set matsize 5000
mata:
YOMAT = st_data(., "fg")
X0MAT = st_data(., "x0")
end
rename origin o
rename destin d
keep distance fg o d wd x0 x1 $x wo*
rename fg y
gen yo = y
sort d o
gen yd = y
mata: YDMAT = st_data(., "yd")
save "C:\migration\yx.dta", replace
* Generation of the spatially laged variables:
```

```
keep o d wd
reshape wide wd , i(o) j(d)
mkmat wd*, mat(MMATD)
use "C:\migration\temp_weight.dta", clear
drop sum
egen sum = sum(w), by(destin)
replace sum = 1 if sum == 0
gen wo = w/sum
replace temp = wo * x1
egen wdx1 = sum(temp), by(destin)
forvalues val = $nvar {
        replace temp = wo * xo`val'
        egen wdxd`val' = sum(temp), by(destin)
        }
replace temp = wd * wdx1
egen wwox1 = sum(temp), by(origin)
forvalues val = $nvar {
        replace temp = wd * wdxd`val'
        egen wwoxo`val' = sum(temp), by(origin)
        }
replace temp = wo * wox1
egen wwdx1 = sum(temp), by(destin)
forvalues val = $nvar {
        replace temp = wo * woxo`val'
        egen wwdxd`val' = sum(temp), by(destin)
        }
forvalues val = $nvar {
        replace temp = wd * wwdxd`val'
        egen wwwoxo`val' = sum(temp), by(origin)
        }
forvalues val = $nvar {
        replace temp = wo * wwoxo`val'
        egen wwwdxd`val' = sum(temp), by(destin)
        }
rename origin o
rename destin d
keep distance fg wo o d wd* wwd* wwo*
sort o d
joinby o d using "C:\migration\yx.dta"
sort o d
save "C:\migration\yx.dta", replace
keep o d wo
reshape wide wo , i(d) j(o)
mkmat wo*, mat(MMATO)
mata:
MMATD = st_matrix("MMATD")
MMATO = st_matrix("MMATO")
WDY = X0MAT
WOY = X0MAT
n = rows(MMATD)
N = rows(MMATD)
for (i=0; i<n; i++){
j = i+1
k = (i*n)+1
l = (i+1)*n
WDY[|k\l|] = MMATD*YOMAT[|k\l|]
}
for (i=0; i<n; i++){
j = i+1
k = (i*n)+1
l = (i+1)*n
WOY[|k\l|] = MMATO*YDMAT[|k\l|]
}
end
use "C:\migration\yx.dta", clear
sort d o
mata:
```

```
st_store(., st_addvar("float", "woy"), WOY)
end
sort o d
mata:
st_store(., st_addvar("float", "wdy"), WDY)
end
sort o d
save "C:\migration\yx.dta", replace
***************************************************************************
* Here a routine to write the weights matrix into STATA:                  *
* mata:                                                                   *
* MMAT1 = MMATD#I(N)                                                      *
* MMAT2 = I(N)#MMATD                                                      *
* n = N*N                                                                 *
* for (i=1; i<=n; i++){                                                   *
* j = "wo"+strofreal(i)                                                   *
* st_store(., st_addvar("float", j), MMAT1[.,i])                          *
* }                                                                       *
* for (i=1; i<=n; i++){                                                   *
* j = "wd"+strofreal(i)                                                   *
* st_store(., st_addvar("float", j), MMAT2[.,i])                          *
* }                                                                       *
* end                                                                     *
***************************************************************************
* Generate the relative and joint variables used for estimation:
gen od = 0
replace od=o if o==d
xi i.od
forvalues val = $nvar {
       gen xr`val' = xo`val' - xd`val'
       }
forvalues val = $nvar {
       gen xc`val' = xo`val' + xd`val'
       }
forvalues val = $nvar {
       gen wxr`val' = woxo`val' - wdxd`val'
       }
forvalues val = $nvar {
       gen wxc`val' = woxo`val' + wdxd`val'
       }
* Estimate 1st step:
* Careful: Add dummies for ORIGIN==DESTINATION in order to avoid biased estimates
>ivreg2 y (woy wdy = wxr1 wxr2 wxr3 wxr4 wxr5 wxr6      wxr8 wxr9 wxr11 wxr12 wxr14
wxr15 wxr16) x1 $xr $xc _Iod*
predict r, resid
gen r2=r^2
egen ss=sum(r2)
scalar S2SLS=ss/(_N-1)
scalar ASLS=_b[_cons]
scalar B12SLS=_b[x1]
scalar list S2SLS ASLS B12SLS
* Used unbiased diesturbance term estimates for GM:
capture program drop nlequ
program define nlequ
if "`1'"== "?" {
global S_1 " rho1 rho2 "
global rho=1
global rho2=1
exit
}
replace `1'=v1*$rho1 + v2*$rho2 + v3*$rho1*$rho2 + v4*$rho1^2 + v5*$rho2^2
end
sort o d
mata: uh = st_data(., "r")
sort o d
mata:
uho = st_data(., "r")
```

```
TEMP1 = uho
TEMP2 = uho
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2[|j\k|] = MMATD*TEMP1[|j\k|]
}
vdh = TEMP2
st_store(., st_addvar("float", "uh"), uho)
st_store(., st_addvar("float", "vdh"), vdh)
MID = uho'vdh/(uho'uho)
* Morans I destination:
MID
TEMP3=(2*n+trace(MMATD'MMATD)+trace(MMATD*MMATD))/(n*n)
MIDZ=MID/TEMP3
* z-value Morans I destination:
MIDZ
end
sort o d
mata:
TEMP1 = vdh
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2[|j\k|] = MMATD*TEMP1[|j\k|]
}
wdh = TEMP2
st_store(., st_addvar("float", "wdh"), wdh)
end
sort d o
mata:
vdh = st_data(., "vdh")
TEMP1 = vdh
TEMP2 = vdh
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2[|j\k|] = MMATO*TEMP1[|j\k|]
}
wodh = TEMP2
st_store(., st_addvar("float", "wodh"), wodh)
end
sort d o
mata:
uhd = st_data(., "r")
TEMP1 = uhd
TEMP2 = uhd
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2[|j\k|] = MMATO*TEMP1[|j\k|]
}
voh = TEMP2
st_store(., st_addvar("float", "voh"), voh)
MIO = uhd'voh/(uhd'uhd)
* Morans I origin
MIO
TEMP3=(2*n+trace(MMATO'MMATO)+trace(MMATO*MMATO))/(n*n)
MIOZ=MIO/TEMP3
* z-value Morans I origin
MIOZ
end
sort d o
mata:
```

```
TEMP1 = voh
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2[|j\k|] = MMATO*TEMP1[|j\k|]
}
woh = TEMP2
st_store(., st_addvar("float", "woh"), woh)
end
sort o d
mata:
voh = st_data(., "voh")
TEMP1 = voh
TEMP2 = voh
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2[|j\k|] = MMATD*TEMP1[|j\k|]
}
wdoh = TEMP2
st_store(., st_addvar("float", "wdoh"), wdoh)
end
* Calculate various moment conditions appearing in the system of equations:
sort o d
mata:
voh = st_data(., "voh")
vdh = st_data(., "vdh")
woh = st_data(., "woh")
wdh = st_data(., "wdh")
wodh = st_data(., "wodh")
wdoh = st_data(., "wdoh")
n_inv = 1/rows(uh)
uhuhhm=uh'*uh*n_inv
vouhhm=voh'*uh*n_inv
vduhhm=vdh'*uh*n_inv
wouhhm=woh'*uh*n_inv
wduhhm=wdh'*uh*n_inv
woduhhm=wodh'*uh*n_inv
wdouhhm=wdoh'*uh*n_inv
vovohm=voh'*voh*n_inv
vovdhm=voh'*vdh*n_inv
vdvohm=vdh'*voh*n_inv
vdvdhm=vdh'*vdh*n_inv
wovohm=woh'*voh*n_inv
wdvohm=wdh'*voh*n_inv
wovdhm=woh'*vdh*n_inv
wdvdhm=wdh'*vdh*n_inv
wodvohm=wodh'*voh*n_inv
wdovohm=wdoh'*voh*n_inv
wodvdhm=wodh'*vdh*n_inv
wdovdhm=wdoh'*vdh*n_inv
wowohm=woh'*woh*n_inv
wdwdhm=wdh'*wdh*n_inv
wodwohm=woh'*woh*n_inv
wdwdohm=wdh'*wdh*n_inv
wodwodhm=woh'*woh*n_inv
wdowdohm=wdh'*wdh*n_inv
end
* Remark: MMAT*(diag(uh_quadratic)) can efficiently be written as:
* MMAT*(vector(uh_quadratic))' (check also MATA-help: mf_trace)
capture drop temp
gen temp=uh*uh
sort d o
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
```

```
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATO'MMATO, 1) + TEMP4
TEMP4 = TEMP3
}
MMM1uhuh1 = TEMP4*n_inv
end
sort o d
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATD'MMATD, 1) + TEMP4
TEMP4 = TEMP3
}
MMM2uhuh2 = TEMP4*n_inv
end
replace temp=voh*uh
sort d o
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATO'MMATO, 1) + TEMP4
TEMP4 = TEMP3
}
MMM1v1uh1 = TEMP4*n_inv
end
sort o d
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATD'MMATD, 1) + TEMP4
TEMP4 = TEMP3
}
MMM2v1uh2 = TEMP4*n_inv
end
replace temp=vdh*uh
sort d o
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATO'MMATO, 1) + TEMP4
TEMP4 = TEMP3
}
MMM1v2uh1 = TEMP4*n_inv
```

```
end
sort o d
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATD'MMATD, 1) + TEMP4
TEMP4 = TEMP3
}
MMM2v2uh2 = TEMP4*n_inv
end
replace temp=vdh*voh
sort d o
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATO'MMATO, 1) + TEMP4
TEMP4 = TEMP3
}
MMM1v2v11 = TEMP4*n_inv
end
sort o d
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATD'MMATD, 1) + TEMP4
TEMP4 = TEMP3
}
MMM2v2v12 = TEMP4*n_inv
end
replace temp=voh*voh
sort d o
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATO'MMATO, 1) + TEMP4
TEMP4 = TEMP3
}
MMM1v1v11 = TEMP4*n_inv
end
sort o d
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
```

```
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATD'MMATD, 1) + TEMP4
TEMP4 = TEMP3
}
MMM2v1v12 = TEMP4*n_inv
end
replace temp=vdh*vdh
sort d o
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATO'MMATO, 1) + TEMP4
TEMP4 = TEMP3
}
MMM1v2v21 = TEMP4*n_inv
end
sort o d
mata:
TEMP1 = st_data(., "temp")
TEMP4 = 0
n = sqrt(length(TEMP1))
for (i=0; i<n; i++){
j = i*n+1
k = (i+1)*n
TEMP2 = diag(TEMP1[|j\k|])
TEMP3 = trace(TEMP2, MMATD'MMATD, 1) + TEMP4
TEMP4 = TEMP3
}
MMM2v2v22 = TEMP4*n_inv
end
mata: mata drop TEMP1 TEMP2 TEMP3
drop temp
mata:
hy1 = vovohm - MMM1uhuh1
hy2 = vouhhm
hy3 = vdvdhm - MMM2uhuh2
hy4 = vduhhm
h11 =  2*wovohm - MMM1v1uh1
h21 =  wouhhm + vovohm
h31 =  2*wdovdhm - MMM2v1uh2
h41 =  wdouhhm + vdvohm
h12 =  2*wodvohm - MMM1v2uh1
h22 =  vovdhm + woduhhm
h32 =  2*wdvdhm - MMM2v2uh2
h42 =  wduhhm + vdvdhm
h13 = -2*wodwohm + MMM1v2v11
h23 = -wodvohm - wovdhm
h33 = -2*wdwdohm + MMM2v2v12
h43 = -wdvohm - wdovdhm
h14 = -wowohm + MMM1v1v11
h24 = -wovohm
h34 = -wdowdohm + MMM2v1v12
h44 = -wdovohm
h15 = -wodwodhm + MMM1v2v21
h25 = -wodvdhm
h35 = -wdwdhm + MMM2v2v22
h45 = -wdvdhm
c1 = (h11\ h21\ h31\ h41)
c2 = (h12\ h22\ h32\ h42)
c3 = (h13\ h23\ h33\ h43)
c4 = (h14\ h24\ h34\ h44)
c5 = (h15\ h25\ h35\ h45)
```

```
cy = (hy1\ hy2\ hy3\ hy4)
end
clear
set obs 4
mata:
st_store(., st_addvar("float", "v1"), c1)
st_store(., st_addvar("float", "v2"), c2)
st_store(., st_addvar("float", "v3"), c3)
st_store(., st_addvar("float", "v4"), c4)
st_store(., st_addvar("float", "v5"), c5)
st_store(., st_addvar("float", "z"), cy)
end
list v1 v2 v3 v4 v5 z
* Estimation of rho by NLS:
nl equ z, init(rho1=0.35, rho2=0.35)
use "C:\migration\yx.dta", clear
sort o d
gen Rho1GM=$rho1
gen Rho2GM=$rho2
* Prepare estimatio of final IV-stage:
gen sy = y - Rho1GM*woy - Rho2GM*wdy
gen sx0 = x0 - Rho1GM*x0 - Rho2GM*x0
gen sx1 = x1 - Rho1GM*wox1 - Rho2GM*wdx1
sort o d
mata:
YOMAT = st_data(., "sy")
WDY = X0MAT
WOY = X0MAT
n = rows(MMATD)
N = rows(MMATD)
for (i=0; i<n; i++){
j = i+1
k = (i*n)+1
l = (i+1)*n
WDY[|k\l|] = MMATD*YOMAT[|k\l|]
}
end
sort d o
mata:
YDMAT = st_data(., "sy")
for (i=0; i<n; i++){
j = i+1
k = (i*n)+1
l = (i+1)*n
WOY[|k\l|] = MMATO*YDMAT[|k\l|]
}
end
sort d o
mata:
st_store(., st_addvar("float", "swoy"), WOY)
end
sort o d
mata:
st_store(., st_addvar("float", "swdy"), WDY)
end
* Note that for row normalized weigths matrix woxd = xd and wdxo = xo:
forvalues val = $nvar {
        gen sxd`val' = xd`val' - Rho1GM*xd`val' - Rho2GM*wdxd`val'
        }
forvalues val = $nvar {
        gen sxo`val' = xo`val' - Rho1GM*woxo`val' - Rho2GM*xo`val'
        }
gen temp = 1
forvalues val = $nvar {
        replace temp = wd * sxd`val'
        egen swoxo`val' = sum(temp), by(o)
        }
```

```
replace temp = wo * sx1
egen swdx1 = sum(temp), by(d)
replace temp = wd * sx1
egen swox1 = sum(temp), by(o)
forvalues val = $nvar {
       replace temp = wo * sxo`val'
       egen swdxd`val' = sum(temp), by(d)
       }
replace temp = wd * swdx1
egen swwox1 = sum(temp), by(o)
forvalues val = $nvar {
       replace temp = wd * swdxd`val'
       egen swwoxo`val' = sum(temp), by(o)
       }
replace temp = wo * swox1
egen swwdx1 = sum(temp), by(d)
forvalues val = $nvar {
       replace temp = wo * swoxo`val'
       egen swwdxd`val' = sum(temp), by(d)
       }
forvalues val = $nvar {
       replace temp = wd * swwdxd`val'
       egen swwwoxo`val' = sum(temp), by(o)
       }
forvalues val = $nvar {
       replace temp = wo * swwoxo`val'
       egen swwwdxd`val' = sum(temp), by(d)
       }
gen od = 0
replace od=o if o==d
xi i.od
forvalues val = $nvar {
       gen sxr`val' = sxo`val' - sxd`val'
       }
forvalues val = $nvar {
       gen sxc`val' = sxo`val' + sxd`val'
       }
forvalues val = $nvar {
       gen swxr`val' = swoxo`val' - swdxd`val'
       }
forvalues val = $nvar {
       gen swxc`val' = swoxo`val' + swdxd`val'
       }
* Final IV-esimate with user supplied constant:
ivreg2 sy (swoy swdy = swxr1 swxr2 swxr3 swxr4 swxr5 swxr6      swxr8 swxr9 swxr11
swxr12 >swxr14 swxr15 swxr16) sx0 sx1 sxr* sxc* _Iod*, noconstant
predict rs, resid
gen res2=rs^2
egen ss2sls=sum(res2)
scalar SH2SLS=ss2sls/(_N-1)
scalar AH2SLS=_b[sx0]
scalar BH2SLS=_b[sx1]
scalar LAMH12SLS=_b[swoy]
scalar LAMH22SLS=_b[swdy]
scalar list AH2SLS BH2SLS LAMH12SLS LAMH22SLS SH2SLS
exit
```

References

Amemiya, T. (1974). *The Nonlinear Two-Stages Least-Squares Estimator*. Journal of Econometrics, Volume 2, pp. 105-110.

Anselin, L. (1988). *Spatial Econometrics: Methods and Models*. Kluwer. Boston. USA.

Anselin, L. and R. Florax (1995). *New Directions in Spatial Econometrics*. Springer. London. UK.

Badinger, H. and P. Egger (2008). *Intra- and Inter-Industry Productivity Spillovers in OECD Manufacturing: A Spatial Econometric Perspective*. CESifo-Working-Paper Series, Number 2181.

Barbian, D. (2000). *Ökonomie und Sustainable Development: Entwicklung eines Ansatzes zur Umsetzung von Nachhaltigkeit*, PhD thesis. Aachen. Germany.

Bartel, A.P. (1989). *Where do New U.S. Immigrants Live?* Journal of Labor Economics. Volume 7, pp. 371-91.

Barth, M., R. Hennicker et al. (2004). *DANUBIA: An Integrative Simulation System for Global Change Research in the Upper Danube Basin*. Cybernetics and Systems Volume 35, pp. 639-666.

Bauer, T., G.S. Epstein and I.N. Gang (2007). *Herd Effects or Migration Networks? The Location Choice of Mexican Immigrants in the U.S.*. Research in Labor Economics, Volume 26, pp.199-229.

Bauer, T. and K.F. Zimmermann (1997). *Network Migration of Ethnic Germans.* International Migration Review, Volume 31, pp.143–149.

Booch, G., J. Rumbaugh and I. Jacobson (1998). *The Unified Modeling Language User Guide.* Addison-Wesley Professional. Boston. USA.

Brakman, S., H. Garretsen et al. (2001). *New Economic Geography in Germany: Testing the Helpman-Hanson Model*. HWWA Discussion Paper 172. Hamburg. Germany.

Brand, K.W. (1997). *Probleme und Potentiale einer Neubestimmung des Projekts der Moderne unter dem Leitbild „Nachhaltige Entwicklung" (Zur Einführung)*. In: Brand, K.W. (Ed.), *Nachhaltige Entwicklung: eine Herausforderung an die Soziologie*, pp. 9-32. Opladen. Germany.

Bundesverband der deutschen Gas- und Wasserwirtschaft (1994). *105. Wasserstatistik Bundesrepublik Deutschland – Berichtsjahr 1993*. Bonn. Germany.

Bundesverband der deutschen Gas- und Wasserwirtschaft (1997). *Wassertarife 1997*. Bonn. Germany.

Bundesverband der deutschen Gas- und Wasserwirtschaft (2001a). *112. BGW-Wasserstatistik Bundesrepublik Deutschland – Berichtsjahr 2000*. Bonn. Germany.

Bundesverband der deutschen Gas- und Wasserwirtschaft (2001b). *Tarife 2001*. Bonn. Germany.

Burda, M.C. (1995). *Migration and the Option Value of Waiting*. The Economic and Social Review, Volume 27, pp.1-19.

Chiswick, B.R., Y.L. Lee and P.W. Miller (2001). *The Determinants of the Geographic Concentration Among Immigrants: Application to Australia.* Australasian Journal of Regional Studies. Volume 7, pp. 125-150.

Chiswick, B.R. and P.W. Miller (1996). *Ethnic Networks and Language Proficiency among Immigrants.* Journal of Population Economics, Volume 9, pp.19–35.

Chung J.W. (1994). *Utility and Production Functions. Theory and Applications.* Blackwell. Cambridge. UK.

Church, J. and I. King (1993). *Bilingualism and Network Externalities.* Canadian Journal of Economics, Volume 26, pp.337–45.

Cliff, A. and J. Ord (1973). *Spatial Autocorrelation*. Pion. London. UK.

Cliff, A. and J. Ord (1981). *Spatial Processes, Models and Applications*. Pion. London. UK.

Corcoran, M., L. Datcher and G. Duncan (1980). *Most Workers Find Jobs through Word of Mouth*. Monthly Labor Review, Volume 103, pp. 33–35.

Cushing, B. (2005). *Specification of Functional Form in Models of Population Migration*. Research Paper, Regional Research Institute, West Virginia University.

Dachraoui, K. and T.M. Harchaoui (2004). *Water Use, Shadow Price and the Canadian Business Sector Productivity Performance.* Economic Analysis Research Paper No. 26/2004. Statistics Canada.

Dupont, D.P. and S. Renzetti (2001). *The Role of Water in Manufacturing*. Environmental and Resource Economics, Volume 18, pp. 411-432.

Dupont, D.P. and S. Renzetti (2003). *The Value of Water in Manufacturing*. CSERGE Working Paper ECM 03-03.

Egerer, Matthias (2005). Global *Change and the Effects on Industrial Water Use in the Catchment Area of the Upper Danube, Conference paper: 7th Nordic Environmental Social Science Research Conference*. Göteborg University.

Egerer, M. and M. Zimmer (2006). *Weiterentwicklung des Regionalmodells RIWU zu einem „tiefen" Akteursmodell.* In: Mauser, W. and U. Stasser (eds). *GLOWA-Danubue - Integrative Techniken, Szenarien und Strategien zur Zukunft des Wassers im Einzugsgebiet der Oberen Donau*. www.glowa-danube.de .

Epstein, G.S. and I.N. Gang (2006). *The Influence of Others on Migration Plans.* Review of Development Economics, Volume 10, pp. 652–665.

Epstein, G.S. and A.L. Hillman (1998). *Herd Effects and Migration.* CEPR Discussion Paper No. 1811.

European Environment Agency (Ed.) (2000). *Sustainable Use of Europes Water? – State, Prospects and Issues*. Copenhagen. Denmark.

Federal Ministry for Agriculture, Forestry, Environment and Water Management (Ed.) (2003). *Umsetzung der Wasserrahmenrichtlinie in Österreich - Wirtschaftliche Analyse der Wassernutzung für den Produktions- und Dienstleistungssektor*. Vienna. Austria.

Federal Statistical Office Germany (Ed.) (2003). *Umwelt – Wasserversorgung und Abwasserbeseitigung in der Industrie*, Fachserie 19, Reihe 2.2, Wiesbaden. Germany.

Federal Statistical Office Germany (Ed.) (2005). *Umweltnutzung und Wirtschaft – Tabellen (Band 1) zu den Umweltökonomischen Gesamtrechnungen 2005*. Wiesbaden. Germany.

Forschungsdatenzentrum der Statistischen Landesämter (Ed.) (2006). *Amtliche Mikrodaten für die wissenschaftliche Forschung: Aktuelles Datenangebot*. Düsseldorf. Germany.

Frey, W.H. (1995). *The New Geography of US Population Shifts: Trends toward Balkanization.* In: Farley, R. (Ed.): *The State of the Union: Social Trends*, pp. 271-336. Russell Sage, New York. USA.

Fujita, M. and P. Krugman (2004). *The New Economic Geography : Past, Present and Future*, Papers in Regional Science Volume 83, pp. 139-164.

Gale, L.R. and W.C. Heath (2000). *Elderly Internal Migration in the United States.* Public Finance Review, Volume 28, pp. 153-170.

Gispert, C. (2004). *The Economic Analysis of Industrial Water Demand: a review*. Environment an Planning C: Government and Policy, Volume 22, pp. 15-30.

Graves, P.E. and T.A. Knapp (1988). *Mobility Behavior of the Elderly*. Journal of Urban Economics, Volume 24, pp.1-8.

Greenwood, M.J. (1969). *An Analysis of the Determinants of Geographic Labor Mobility in the United States.* Review of Economics and Statistics, Volume 51, pp.189–194.

Griffin, R.C. (2006). *Water Resource Economics: The Analysis of Scarcity, Policies and Projects*. The MIT Press: Cambridge. London. UK.

Hanson, G.H. (1998). *Market Potential, Increasing Returns, and Geographic Concentration*, NBER Working Paper Series 6429, Cambridge, Massachusetts. USA.

Kelejian, H. and I.R. Prucha (1999). *A Generalized Moments Estimator for the Autoregressive Parameter in a Spatial Model.* International Economic Review, Volume 40 pp. 509-533.

Kelejian, H. and I.R. Prucha (2008). *Specification and Estimation of Spatial Autoregressive Models with Autoregressive and Heteroskedastic Disturbances.* Forthcoming in Journal of Econometrics.

Knieps, G. (2000). *Der disaggregierte Regulierungsansatz der Netzökonomie.* In: Knieps, G. and G. Brunekreeft (Eds.): *Zwischen Regulierung und Wettbewerb*, pp. 7-22. Heidelberg. Germany.

Krugman, P. (1998). *What's New about the New Economic Geography?* Oxford Review of Economic Policy, Volume 14, pp. 7-17.

Langmantel, E. and J. Wackerbauer (2003). *RIWU - A Model of Regional Economic Development and Industrial Water Use in the Catchment Area of the Upper Danube*. International Journal of River Basin Management, Volume 1, pp. 1-5.

Langmantel, E. (2004). *Regional Industrial Growth and Water Demand : An Empirical Analysis for the Upper Danube Catchment.* Jahrbuch für Regionalwissenschaft, Volume 24, pp. 161-176.

Lee, L.F. (2003). *Best Spatial Two-Stage Least Square Estimators for a Spatial Autoregressive Model with Autoregressive Disturbances.* Econometric Reviews, Volume 22, pp.307-335.

Lee, L. and X. Liu (2006). *Efficient GMM Estimation of High Order Spatial Autoregressive Models.* Ohio State University, Working Paper.

LeSage, J.P. and R.K. Pace (2007). *Spatial Econometric Modeling of Origin-Destination Flows*. SSRN Working Paper.

Loucks, D.P. and J.S. Gladwell (1999). *Sustainability Criteria for Water Resource Systems*. UNESCO International Hydrology Series. Cambridge. UK.

Ludwig, R., W. Mauser et al. (2003). Web-*based Modelling of Energy, Water and Matter Fluxes to Support Decision Making in Mesoscale Catchments : the Integrative Perspective of GLOWA-Danube*. Physics and Chemistry of the Earth Volume 28, pp. 621-634.

Lübbe, E. (2002). *Jahreswasserbericht der Wasserwirtschaft : gemeinsamer Bericht der mit der Wasserwirtschaft befassten Bundesministerien - Haushaltsjahr 2001*. Wasser & Boden, Volume 54, pp. 5-13.

Massey, D.S. (1987). *Do Undocumented Migrants Earn Lower Wages than Legal Immigrants? New Evidence from Mexico.* International Migration Review, Volume 21, pp. 236–274.

Mauser, W., Stolz, R. et al. (2002). *GLOWA-Danube: Integrative Techniques, Scenarios and Strategies Regarding Global Change of the Water Cycle.* In: BMBF (Ed.), *German Programme on Global Change in the Hydrological Cycle (Phase I, 2000 – 2003)*, Status Report, pp. 31-34.

Mauser, W. (2003). *GLOWA-Danube: Integrative hydrologische Modellentwicklung zur Entscheidungsunterstützung beim Einzugsgebietsmanagement*. Petermanns Geographische Mitteilungen, Volume 147, pp. 68-75.

McDonald, J.T. (2002). *The Location Choice of New Immigrants to Canada: The Role of Ethnic Networks*. In: Beach, C., Green, A. and J. Reitz (Eds.): *Canadian Immigration Policy for the 21st Century*, John Deutsch Institute for the Study of Economic Policy, Queen's University. Kingston. Canada.

Mincer, J. (1978). *Family Migration Decisions.* The Journal of Political Economy, Volume 86, pp.749–773.

Mitchell, J. and N. Pain (2003). *The Determinants of International Migration into the UK: A Panel Based Modelling Approach*. NIESR Discussion Paper, Number 216.

Montgomery, M.R., R. Stren, B. Cohen, Reed, H.E., Panel on Urban Population Dynamics, Committee on Population, Division of Behavioural and Social Sciences and Education (Eds.) (2003). *Cities Transformed: Demographic Change and its Implications in the Developing World.* The National Academies Press. Washington, DC. USA.

Mortensen, D.T. and T. Vishwanath (1994*). Personal Contacts and Earnings: It is Who You Know!* Labour Economics, Volume 1, pp. 187–201.

Munshi, K. (2003). *Identification of Network Effects: Mexican Migrants in the U.S. Labor Market.* Quarterly Journal of Economics, Volume 118, pp. 549–599.

Österreichische Vereinigung des Gas- und Wasserfaches (2002). *Daten – Wasser; Betriebsergebnisse der Wasserwerke Österreichs*. Vienna. Austria.

Renzetti, S. and E. Elgar (2002). *The Economics of Industrial Water Use*. Northampton, Massachusetts. USA.

Reynaud, A. (2003). *An Econometric Estimation of Industrial Water Demand in France*. Environmental and Resource Economics, Volume 25, pp. 213-232.

Rothenberger, D. (2003). *Report zur Entwicklung des Versorgungssektors Wasser, Sektorreport Siedlungswasserwirtschaft für das Projekt "Integrierte Mikrosysteme der Versorgung" im Auftrag des Bundesministeriums für Bildung und Forschung.* Centre for Innovation Research in the Utility Sector. Kastanienbaum. Switzerland.

Rupasingha, A. and S.J. Goetz (2004). *County Amenities and Net Migration.* Agricultural and Resource Economics Review, Volume 33, pp. 245-254.

Schnurrer, N. (2001). *Liberalisierung : der Griff nach dem Wasser*. Arbeit & Wirtschaft, Volume 55, pp. 24-28.

Schuh, H. (2001). *Entscheidungsorientierte Umsetzung einer nachhaltigen Entwicklung: empirische Analysen, theoretische Fundierung und Systematisierung am Beispiel der natürlichen Ressource Wasser*. PhD thesis. Published electronically on: Dissertation.de - Verlag im Internet GmbH, Berlin.

Schwartz, A. (1973). *Interpreting the Effect of Distance in Migration.* The Journal of Political Economy, Volume 81, pp.1153–1169.

Statistik Austria (2002). *Regionale Wasser-, Abwasser, und Abfalldaten 1980-1999.* Statistische Nachrichten Volume 5, pp. 374-380.

Statistik Austria (2005a): *Volkszählung 2001 – Haushalte und Familien*. Wien. Austria.

Statistik Austria (2005b). *Zukünftige Bevölkerungsentwicklung Österreichs 2005 – 2050 (2075)*, Statistische Nachrichten 11/2005.

Statistisches Bundesamt (2003). *Bevölkerung Deutschlands bis 2050 - 10. koordinierte Bevölkerungsvorausberechnung*. Wiesbaden. Germany.

Statistisches Bundesamt (2005). *Umweltnutzung und Wirtschaft – Tabellen (Band 1) zu den Umweltökonomischen Gesamtrechnungen 2005*. Wiesbaden. Germany.

Umweltbundesamt (2000). *Daten zur Umwelt – Der Zustand der Umwelt in Deutschland 2000*, CD-Rom. Berlin. Germany.

World Commission on Environment and Development (1987). *Our Common Future*. Oxford. UK.

Youn Kim, H. (1992). *The Translog Production Function and Variable Returns to Scale* The Review of Economics and Statistics, Volume 74, pp. 546-552.

Curriculum Vitae

Markus Zimmer
Astallerstrasse 6
80339 München (Munich)
Germany
Phone: + 49 160 - 97 83 80 13

Experience

Jan. 2003	- Dec. 2007	Junior researcher, assistant lecturer, PhD candidate. Center for Economic Studies at the University of Munich, Schackstr. 4, 80539 München (Munich) and Ifo-Institute for Economic Research, Poschingerstrasse 5, 81679 München (Munich).
Dec. 2001	- Dec. 2002	Student trainee. Controlling, Network-Topologies and IT-Infrastructure Information and Communication Mobile division, Siemens AG, Otto-Hahn Ring 6, 81739 München (Munich).
June 1999	- Dec. 2008	Freelancing broadcast technician television. Plaza Media GmbH, Münchner Str. 101, 85737 Ismaning.
Dec. 1997	- Mar. 1998	Production assistant television. Bayrischer Rundfunk, (public Bavarian TV).
Sep. 1996	- June 1997	Military service. 5./FMAUFKLRGT 940, Heinrich Hertz Barracks, Heinrich Hertz Str., 54550 Daun.

Education

Jan. 2004	- July 2008	PhD. Ifo-Institute for Economic Research.
Nov. 1997	- Dec. 2002	Economics Diplom (MA equivalent).
Aug. 2000	- Dec. 2000	Studies abroad. University of British Columbia, Vancouver.
Mar 1999	- May 1999	Studies abroad. Venice International University, Venice.