Land Use in the Bergen Region

A System Dynamics Analysis of the Jobs-Housing Imbalance

by

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Abstract

The urban development in the Bergen region has been characterized by urban sprawl and undefined expansions of the urban area which gave rise to a geographic imbalance: while the city center of Bergen offers more jobs than housing units, the vast majority of the surrounding urban areas provide more housing units than jobs. As a consequence, the number of commuters has grown, resulting in an unfavorable increase in traffic. The Bergen Land Use Model*, a System Dynamics model, has been designed to analyze the underlying structural causes of the imbalance and to investigate how a better balance regarding the distribution of jobs and housing units could be established. The availability of zoned land is found to play an important role in determining the distribution of jobs and housing units. While the planning authorities have a clear decision rule on how much land to zone for housing, they do not have a clear rule operating when zoning commercial land. Neither is there a rule stipulating which urban area is to be provided with what kind of zoned land. Three policy options have been designed and tested: an arranged relocation policy, a rezoning policy and a zoning decision rule policy. The zoning decision rule policy aims at establishing a connection between the zoning of land for housing and the zoning of land for business, which would serve to help control the future distribution of jobs and housing units. Model simulations indicate that this policy, especially when combined with the rezoning policy, could reduce the imbalance in the region.*

Key Words: System Dynamics, policy design, land use, land use planning, urban development, housing, business, jobs-housing balance, Bergen region, Bergen, Askøy.

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1. Introduction

One of today's major challenges lies in developing more sustainable urban areas. Urban sprawl, traffic congestion, pollution and loss of open space are indications for urban problems caused by unsustainable land use and transportation during the past decades.

Norway's urban development in the post-war period was predominantly characterized by a scattering of functions and the development of suburbs and satellite towns (Lian, Gjerdåker, Hjorthol, Lerstang, & Mydske, 2007). Increasing wealth made possible for many to fulfill their dream of a one-family house and a private car, which led to rising mobility. The omni-presence of cars allowed for land use planning that in turn facilitated an increased use of cars. Despite the national goal to reduce motoring, traffic continues to increase. Since the 1970s there is a political consensus to integrate land use and transport planning in order to reduce the increasing amount of traffic, but motoring keeps rising (Lian et al., 2007).

Bergen is Norway's second biggest city and the capital of Hordaland County. Around 260 000 people live in the city of Bergen, but the total urban area of the Bergen region stretches across several municipalities and forms one big living- and working region. It is home and workplace to more than 350 000 people. The topography is a decisive factor for the urban structure and development compared to other cities. The numerous fjords and mountains are famous trademarks of the region, but they also form distinctive borders between the different urban areas and pose considerable challenges to land use planning.

For the past decades, the Bergen region has been experiencing both a growth in population as well as an increase in available work. Urban development has been characterized by urban sprawl and an increasingly undefined expansion of the urban area. Hordaland county council explicitly states in its latest *Klimaplan for Hordaland*[1] that the lack of coordination regarding the location of workplace, services and residence has created an imbalance (Hordaland fylkeskommune, 2010). While Bergen offers more jobs than housing units, the vast majority of the surrounding municipalities provide more housing units than jobs.

[1] Climate plan for Hordaland (translation by the author)

As a consequence, many people are forced to travel across municipality borders on a daily basis. The number of employees commuting into Bergen municipality has been constantly rising during the past years (Statistisk sentralbyrå, 2009). Road traffic rises accordingly, since the majority of commuters use their private cars for the journey (Meland, 2009). Congestion and pollution are the consequence. The increase of traffic in the region is a major concern for regional and local authorities. Since the need for transportation in an urban area is the result of the geographic distribution of functions (Statens vegvesen, 2011), the goal is to slow down the rise in traffic by pursuing land use planning that reduces the need for transportation (Bergen kommune, 2008a). This is especially important because it is assumed that the Bergen region will grow significantly in the coming years. The number of people living in the region is expected to rise by roughly 160 000 inhabitants by the year 2040. This is an average of 5 000 inhabitants per year. 60-80 000 additional housing units as well as 86 000 new jobs will be needed (Statens vegvesen, 2011). This growth should not be met by increasing the urban area even further since it would lead to a significant rise in demand for transportation and a further loss of open space. Rather the existing urban area needs to be densified: therefore the location of future jobs and housing units plays a central role in the attempt to decrease the need for transportation (Statens vegvesen, 2011). The mismatch between housing units and jobs might be reduced by a careful location of future building structures.

The purpose of this thesis, which includes a System Dynamics model, is to gain a deeper understanding of how land use planning and urban development processes affect the location of jobs and housing units in the region. Several governmental reports state the importance of carefully considering suitable locations for the different functions and strongly suggest the combination of different purposes such as housing, services and workplaces. However, the imbalance between housing units and jobs and its implication on the number of commuters is rarely mentioned specifically. The idea of pursuing effective land use planning which reduces the need for transportation remains vague. Consequently the goal of the thesis and the model is also to provide urban planners and politicians with a useful tool; a tool that helps them understand important feedback processes in the urban system thus enabling them to make long-term decisions regarding land use planning. In addition to analyzing the underlying structural causes of the current jobs-housing imbalance, the thesis investigates whether and how a better balance could be established. Therefore the research questions can be formulated as follows:

1. What are the causes for the imbalance between jobs and housing units?

2. What can be done to reduce the current imbalance?

The *Bergen Land Use Model* is designed to investigate the research questions. To find the answer to the first question, past decisions made in the land use sector are analyzed. Here the central task is to identify all stakeholders involved, to understand their interactions and to reveal important feedback processes in the system. An explanatory model is designed for this purpose. Studying and understanding the underlying structural relationships is important and necessary preparation when trying to find suitable policies. In a further step, the explanatory model is extended to a policy model so as to find an answer to the second research question. The policy model will be used to test different policy options and to analyze their impact and feasibility.

The *Bergen Land Use Model* is part of a bigger modeling project which consists of two additional models: one model describes the intra urban migration processes (Li, 2013); the other model explains the transportation dynamics in the region (Brandsar, 2013). The three models are designed in a way that allows linking them together to form a more comprehensive model. This opens up many possibilities. Various important interactions between land use, transportation and population can be described. Connecting the models makes it possible to analyze how land use planning affects people's behavior and need for transportation. Therefore a central point is to identify the role the jobs-housing imbalance plays in regard to the problem of traffic increase and to establish whether a better balance regarding jobs and housing units could reduce the traffic pressure on the city of Bergen.

2. Research Method

Urban systems include the complex and dynamic interaction between land use, transportation, population and regional economy. These sectors interact on different spatial and temporal levels. As mentioned before, the need for transportation in an urban area is the consequence of the location of residences, businesses and other services. Their location determines the distance and the number of trips the inhabitants need to travel in order to meet their daily obligations. While urban sprawl generally conditions motoring, dense urban areas can encourage biking and walking. At the same time the settlement pattern is influenced by the transportation sector: the area's accessibility affects the land use. Furthermore, there are various interactions between different stakeholders at different spatial and temporal levels within the land use sector. Land use planning decisions made by national, regional and local authorities have implications on the construction of business and housing structures which in turn affect the area's attractiveness for enterprises and residents.

With the numerous protagonists and their inherent complex interactions, designing sustainable policies is a difficult task. Moreover, changes in land use are slow processes and the location of buildings, roads and other physical infrastructure is an irreversible intervention which leads to long lasting consequences for future generations. A long term perspective is therefore essential in land use planning. These circumstances require tools that allow for a holistic analysis of the underlying structures and processes. Systems Dynamics modeling is an appropriate tool for this kind of analysis and management.

System Dynamics is a methodology for analyzing and managing complex and dynamic systems. It was founded by Jay W. Forrester at the Massachusetts Institute of Technology (M.I.T.) in the 1960s. Important milestones in the early development of the discipline were Industrial Dynamics, Urban Dynamics, and Limits to Growth. Computer simulations are used to explore a system's behavior and help understand the effect of time delays and nonlinearities (Ford, 2010). The purpose of a System Dynamics model is to gain a deep understanding of the dynamic interrelations in a system. They can reveal the impact of different policies by uncovering both short-term and long-term consequences. Compared to agent-based modeling, where the individuals in populations such as firms and social groups are represented explicitly (Sterman, 2000), the level of aggregation in the System Dynamics model is high. The members of a population such as the construction firms, the businesses located in the region, and the inhabitants living in the region, are modeled as an aggregated entity. This is done so as to concentrate on the interactions and highlight important feedbacks among the different actors involved in the urban land use system.

The construction of a System Dynamics model requires a wide range of data sources. Existing numerical data normally only covers a very small fraction, thus a wide range of qualitative data is needed in addition. This is especially important when gathering information on decision rules. The sources for qualitative and quantitative information for the Bergen Land Use Model include an extensive literature review, a systematic data collection from the databases drawn up by Statistics Norway (SSB) and Hordaland County Council (statistikk.ivest.no), as well as several semi-structured interviews with experts in different fields relevant to urban land use.

Two urban planners working at the planning department of the Bergen municipality (Etat for plan og geodata) were interviewed to gain deeper insight and knowledge about Bergen municipality's planning goals, its area of authority and the procedures that are involved in every urban planning process. An additional interview with the head of the planning department of Askøy municipality (Plan og utvikling) improved the understanding of the planning activities in Askøy. Questions regarding the supply of building plots and the decision-making processes involved were clarified by interviewing the CEO of the Bergen tomteselskap, a land developer in the Bergen region owned by the Bergen municipality. Bergen tomteselskap has played an important role in the construction activity in the region by providing the market with suitable and prepared building plots. Questions concerning the perspective and concerns of the business sector were answered by the administrative contact of the resource group "Urban Development" of the Bergen Chamber of Commerce (Bergen Næringsråd) as well as the Director of Communication of the Business Region Bergen. Business Region Bergen works to strengthen and develop the trade and industry in the Bergen region. Lastly, the CEO of the real-estate company Stadsporten AS explained the perspective and the motives of developing structures for firms and residences.

3. Literature review

In the following chapter I will be presenting literature relevant to the topic – both literature specifically concerning System Dynamics modeling efforts and, secondly, research literature covering a variety of other fields.

3.1 System Dynamics literature

The most important work in System Dynamics which addresses urban planning is Jay W. Forrester's *Urban Dynamics*, published in 1969. Forrester perceives an urban area as "*a system of interacting industries, housing, and people*" (1969, p. 1) and introduces a simulation model of an urban area which is divided into three subsystems: business, population, and housing. It raised attention worldwide by opening new perspectives of analyzing urban problems. Forrester examines the life cycle of an urban area over 250 years: its growth, stagnation and decay as the urban area goes from mostly vacant to fully occupied land. As the urban area stagnates and declines, an imbalance arises between jobs and people because obsolete housing units are increasingly filled by more low-income and underemployed people while at the same time obsolete business structures offer fewer jobs. It shows the importance of a balance between the local labor force and locally available jobs. Forrester uses the model to explore the impacts of different urban-management programs. He reveals how many common strategies to solve problems of urban decay do not work as intended and – quite the contrary – might even worsen the situation. This is caused by complex systems often being counterintuitive. Based on his urban dynamics model, Forrester recommends other approaches which are "*addressed to the underlying causes of urban decay rather than to symptoms*" (Forrester, 1969, p. 2). Alfeld and Graham (1976, p. 296) summarize: "*The simulation and analysis of the Urban Dynamics model behavior led to the three basic elements of urban dynamics theory: land use as a limit to growth, the attractiveness principle, and aging and obsolescence as the long-term determinants of the character of an urban area's business and housing structures*".

The System Dynamics Group at M.I.T. engaged in further research on urban behavior and published *Readings in Urban Dynamics: Volume 1* (Mass, 1974). It presents the first results of this research and contains twenty papers on the concerns, discussions and problems regarding the Urban Dynamics model. Its objective is to clarify assumptions the Urban Dynamics model is based on, to eliminate misunderstandings, and to point to potential future modeling efforts in the field. It also includes a paper describing the effort to apply the Urban Dynamics model to a real world city: Lowell, Massachusetts. *Readings in Urban Dynamics: Volume 2* (Schroeder III, Sweeney, & Alfeld, 1975) was published one year later. The different papers in the book examine criticisms to the Urban Dynamics model and introduce three extensions of the original model including land zoning, city-suburb interactions and housing abandonment.

The original *Urban Dynamics* model does not include land prices and land availability explicitly. However, zoning of land has a direct influence on the supply of land, the availability of land and - consequently - land prices. Also the population mix, the future housing market and employment conditions are determined by zoning decisions. Therefore Miller (1975) extended the *Urban Dynamics* model by a land-rezoning model called *Rezone2* designed to test land-rezoning policies on the *Urban Dynamics* model. While the *Urban Dynamics* model neither distinguishes between land zoned for business and land zoned for housing nor differentiates between land used for business and land used for housing, the *Rezone2* model makes a difference between residential land and business land. "*The Rezone2 model can thereby* *represent forces that determine the proportions of residential and business land in the city*" (Miller, 1975, p. 136).

One of the more recent System Dynamics publications on land use planning is written by Pfaffenbichler (2003). He developed a dynamic Land Use and Transportation Interaction (LUTI) model by constructing a "*strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Activity Relocation Simulator)*" (Pfaffenbichler, 2003, p. 1). In accordance with typical LUTI models, Pfaffenbichler divided the model into two main sub-models: the *transport sub-model* and the *land use sub-model*. The land use sub-model is again divided into the *land use residential location sub-model* and the *land use workplace location sub-model*. The spatial distribution of workplaces and residences is an input into the transport sub-model while the accessibility generated by the transport sub-model is an input to the land use sub-model. The land use residential location sub-model and the land use workplace location sub-model are competing for available land thus influencing the land price. The model is explicitly designed to help stakeholders in their decision making process by evaluating different policy options and the impacts of policy combinations (Pfaffenbichler, 2011). The model runs over 30 years and, compared to other LUTI models, it is a highly aggregated model. The model was originally calibrated with data from Vienna, Austria but has now been applied to numerous other cities (Pfaffenbichler, Emberger, & Shepherd, 2008, 2010).

The System Dynamics models presented above were used as a starting point for the *Bergen Land Use Model*. They provided a general idea of how a System Dynamics model could be applied to explain urban dynamics and illustrated its main concepts. The *Bergen Land Use Model* can be seen as a further demonstration of how System Dynamics can be applied in this context. In contrast to Pfaffenbichler's approach, who did not construct the model based on a specific dynamic problem, the *Bergen Land Use Model* is set up in order to explain internal structural causes of a specific problem. When comparing it to Forrester's Urban Dynamics model - which is a general theory or a methodology for analyzing urban dynamics – the *Bergen Land Use Model* examines a more specific urban area. The time frame and -perspective as well as the problem definition are different. Rather than looking at a time span of 250 years - following the life cycle of an urban area in its entity and examining the causes of urban decay – the *Bergen Land Use Model* concentrates on how the imbalance between jobs and housing units develops over a 50 year-period. In this case, the cause of imbalance is not urban decay, but the growth of the urban area. The role of land use planning is analyzed. Similar to the *Rezone2* model, the *Bergen Land Use Model* distinguishes between land zoned for housing and business and investigates the decision rules governing the zoning process. One of the criticisms of Forrester's Urban Dynamics model is that it does not include the interrelationship between a city and its suburbs and the role of suburbs in urban problems (Schroeder III, 1975). The *Bergen Land Use Model* explicitly explains the relationships between the core city and its surrounding urban areas.

3.2 Non-System Dynamics literature

The Non-System Dynamics literature reviewed can be divided into three main categories. The first category consists of articles about an agent-based approach in land use modeling. The second category covers articles dealing with the concept of the jobs-housing balance. They are published in the field of Urban Planning. The third category is literature on the specific situation in Norway and Bergen, respectively: literature concerning the housing market, business location theories with special focus on the specific situation in Bergen, and transportation and land use issues in the Bergen region.

Loibl and Toetzer (2002) apply a spatial agent model to simulate the polycentric development of the suburban growth observed in the Greater Vienna Region outside the core city. The model comprises six agent classes represented by enterprises and households with different socio-economic characteristics. In three modeling steps, their migration behavior is simulated as a result of regional and local attractiveness/repellent factors. Matthews, Gilbert, Roach, Polhill, and Gotts (2007) give an extensive review of agent-based land-use models (ABLUMs). The characteristics of ABLUMs are that individual decision making processes and individual interactions of each agent are modeled. Together, the individual reactions of the modeled agents in turn form the aggregated overall system behavior. This is very different to System Dynamics and other approaches, where the average behavior of an aggregated entity itself is modeled. ABLUMs are useful, therefore, when the behavior of the agents is particularly heterogenic and characteristic to the modeled system. Matthews et al. (2007, p. 1447) conclude that "*agent-based land-use models are probably more useful as research tools to develop an underlying knowledge base which can then be developed together with end-users into simple rules-of thumb, rather than as operational decision support tools*".

The concept of jobs-housing balance originates from the United States. Robert Cervero is the leading scholar on the concept and published numerous articles covering jobs-housing balance (Cervero, 1989, 1996; Cervero & Duncan, 2006). He believes that the ongoing increase in commute distance is partly due to a rising jobs-housing imbalance in many metropolitan areas in the US. A ratio of jobs to housing units is used to express a balance or imbalance, respectively. Cervero (1989, p. 137) is convinced that "*many of the nation's most pressing and persistent metropolitan concerns – congestion, energy depletion, air pollution sprawl, and class segregation – would be relieved by balancing jobs and housing growth*". He highlights however that the ratio of jobs to housing units does not reflect "*the share of jobs in a community actually filled by residents, and conversely the share of worker finding a place to live in that community*" (Cervero, 1989, p. 137). A jobs-housing balance should therefore be aimed at providing residents with the opportunity to reside close to their workplace if they wish to do so. In addition to a possible quantitative match between jobs and housing units, there should be a qualitative match between "*the skill levels of local residents and the local job opportunities as well as between the earnings of workers and the cost of local housing*" (Cervero, 1989, p. 137). Levine (1998) provides a summary of how controversially the concept of jobs-housing balance is discussed. He points out the importance of the geographic scale when talking about a jobs-housing balance: "*measuring the degree of balance or imbalance poses a significant quandary; regions as a whole are by definition "balanced" in their jobs and housing, while blocks or neighborhoods almost never are*". In addition to the fact that "*there is no nonarbitrary geographic scale within which to assess the match or mismatch*" he explains that "*the jobs-housing approach has been criticized for implicitly assuming a particular process of residential choice in which the selection is made with reference to long-term workplace of a single employed member of the household*" (Levine, 1998, p. 134). Levine (1998) concludes that the main benefit of balancing jobs and housing is to increase the household's choice of their residential locations. Weitz (2003) counters the skeptics' view on jobs-housing balance by arguing that people become more and more frustrated with their long commutes and that the distance to work therefore becomes increasingly important when deciding where to reside. He states "*that many individuals and households want the choice of living closer to work; for a community to use public policy to provide that choice, therefore, is a smart political decision*" (Weitz, 2003, p. 13). Cervero and Duncan (2006) investigate whether jobs-housing balance or retail-housing mixing reduces vehicle travel more. The area of their study is the San Francisco Bay Area. They use regression models for the analysis and conclude that jobs-housing balance reduces travel more. Their results together with a national study “*suggest that achieving jobs-housing balance is one of the most important ways land-use planning can contribute to reducing motorized travel*” (Cervero & Duncan, 2006, p. 488). Cervero and Duncan (2006, p. 488) highlight however that “*jobs-housing balance and mixed-use development (…) are complementary, not substitute, land-use strategies*”.

Barlindhaug (2005) examines the housing market in Norway. The book comprises eight articles by different authors on people’s preferences concerning their places of residences and types of dwelling. Barlindhaug and Nordahl (2005) look at the risk and profitability in housing-construction projects. They explain that the deregulation of the housing and credit market in the early 80ies has led to an increase in marked-steered housing construction which is supported by Orderud (2005). Barlindhaug and Nordahl (2005) stress the long time delays caused by the fact that all development requires the approval of the planning authorities. Orderud (2005) highlights that even though the public planning authorities are no longer an active actor in development, they do represent an important factor in the overall picture none the less: they conduct high-level planning and set out general guidelines as to what can be constructed where and give out construction permits and detailed ordinances regarding the construction.

Asplan Viak (2009) by order of the Business Region Bergen investigated the space required by the businesses in the Bergen region and their location preferences. The aim was to draw a connection between the supply of zoned land for business and the demand for it. Land use plans and detailed zoning plans were the point of departure for mapping out existing and future business land. To investigate the demand for business land, a survey was conducted including 626 businesses in addition to in-depth interviews with five regional businesses which either had moved or were considering to do so. Asplan Viak (2009) reveal that the vast majority of businesses demand locations no further away than 30-minutes’ drive from the city center. However, the region lacks suitable business land especially in these areas. Furthermore the report argues that the labor market in the Bergen region is divided into market segments, with the Bergen center forming an obstacle. Opus Bergen (2012) followed up the report from Asplan Viak (2009) and elaborated mandatory strategies for the sustainable development of new business land with a 20-year perspective. A project was established to improve the relationship between supply and demand for business land in the Bergen region. The study suggests the strengthening and further development of already existing urban junctions as the best way to achieve local self-sufficiency and the efficient coordination of housing and jobs. This – it is argued – would be best achieved by strategic business location. Job-intensive businesses should be located close to the central city of Bergen and other regional centers, while land-extensive businesses should be located close to these said junctions as well as to main transport corridors. Opus Bergen (2012) highlight the importance of a good inter-municipal collaboration regarding land use planning to solve problems across municipality borders.

Jakobsen (2000) applies a business perspective and investigates important location factors, the stability of the location patterns, and advantages and disadvantages of locations in selected business districts in Bergen municipality. He also analyzes the municipal authorities' role regarding the companies' location choice. The analysis is based on a survey of 463 businesses located in the municipality on the one hand and in-depth interviews with representatives of selected firms and municipal authorities on the other. Good road connections are identified as the most important location factor. Other important location factors are access to general services (such as banks and post offices), closeness to qualified workers, and expenditures for land, buildings or office rental. These insights are similar to the findings of Asplan Viak (2009) who investigate the location preferences for businesses in the Bergen region. Reasons to relocate include low prospects of expansion as well as the price of the current office/real-estate. Closeness to the main road, the area's reputation/profile and good prospects of expansion are central location factors. Jakobsen (2000) states that three out of four businesses in the Bergen municipality are extremely or very satisfied with their location and only less than 5 % are extremely unsatisfied. This corresponds with the findings of Asplan Viak (2009) who write that roughly 77 % of businesses are very satisfied with their current location, while ca. 8 % are dissatisfied. Furthermore, 60 % of the businesses have moved to their current location during the past ten years, while 10 % have concrete plans to relocate. Jakobsen (2000) states that one out of three businesses has remained in the same location for more than ten years. When asked about the most interesting urban district to relocate to, Bergenhus is named first - followed by Ytrebygda, Årdtad, and Fana, while the district of Arna is considered the least attractive. Asplan Viak (2009) reveals that just over 50 % of businesses prefer to stay in their current municipality, while 40 % wish to remain in the Bergen region.

Roald and Nielsen (2010) give an extensive insight into Bergen's urban development. They explain the individual urban development processes in Bergen and map out the role the individual players and the planning authorities play. The amalgamation of Arna, Fana, Laksevåg, Åsane and Bergen municipality, their research reveals, was the starting point for the development of several new urban centers such as Loddefjord, Olsvik, Midtbygda in Åsane in addition to that of Bergen. Realizing that the new residential areas would lead to people now living in one area and working in another, the planning authorities aimed to create a balance between jobs and housing units as well as between public and private services in the new urban districts (Roald & Nielsen, 2010).

The Norwegian Public Road Administration's (Statens vegvesen, 2011) paper *Konseptvalgutredning (KVU) for transportsystemet i Bergensområdet*[2] currently is the most extensive paper on transportation issues and policies in Bergen, and it includes the topic of land use planning policies. Its aim is to suggest long-term land use- and transportation strategies and it specifies the type and timing of measures required. The task was to see how different measures work together in a long-term perspective. The objective is to create a more balanced region with less pressure on Bergen city center which allows a larger part of the transportation need to be satisfied locally. The impact of a "*multicenter urban development*" – which in this case describes self-sufficient regional centers such as Straume, Knarvik, Arna, Kleppestø lying around the main city center - on transport was tested. Statens vegvesen (2011) found that the concentration of housing, services and workplaces in regional centers so as to handle the expected growth of the region would relieve the city of Bergen and have a favorable effect on overall motoring in the Bergen region.

This literature review illustrates how sustainable land use planning in order to reduce the need for transportation plays an important role in numerous reports on urban development in the Bergen region. However, all reports remain vague when it comes to the question of how this could be achieved. In my study, the concept of jobs-housing balance serves as a theoretical foundation for land use planning aimed at reducing the need for transportation. The *Bergen Land Use Model* investigates the drivers affecting the location of jobs and housing units, identifies interactions between the urban areas (in this specific case those between the core city of Bergen center and the neighboring urban areas), and reveals connections between the housing market and the business sector – these having been analyzed separately in the reviewed literature. In contrast to agent-based modeling attempts on land use, this System Dynamics modeling approach aims to cast light on the structural relationships between the vari-

[2] "Concept study for the transportation system in the Bergen region" (translation by the author)

ous sectors and stakeholders involved on different spatial and temporal levels. Exploring existing relationships as well as the role of delays and nonlinearities in the system is an important step towards making the *Bergen Land Use Model* a useful and powerful decision making tool for policy makers.

4. Problem Statement

In this chapter the problematic dynamic behavior the model is designed to explain will be described in more detail. I will go into why it is considered a problem, describe the impacts of the problem and present existing policies. I will end by identifying future challenges.

4.1 The area of interest: the Bergen region

The Norwegian public roads administration (*Statens vegvesen*), includes twelve municipalities in what they call the "functional Bergen region"[3]: Bergen, Fjell, Sund, Øygarden, Askøy, Meland, Lindås, Radøy, Osterøy, Vaksdal, Samnanger and Os municipality (see Figure 1). Altogether 370 000 inhabitants live in these municipalities which together form one common working, living and service region. These municipalities have less than one hour's travel time to Bergen's city center. Over 20 % of the employed population living in these municipalities work in Bergen municipality (Statens vegvesen, 2011). In this thesis, the term Bergen region refers to these twelve municipalities and the term Bergen center refers to the city center of Bergen, which is located in the Bergen municipality.

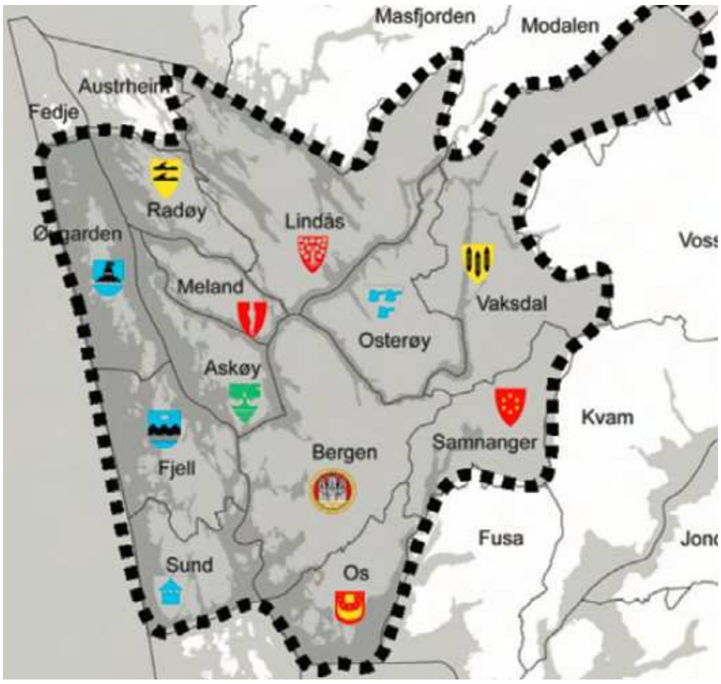

Figure 1. The Bergen region consisting of 12 municipalities (Statens vegvesen, 2011, p. 10).

[3] "det funksjonelle Bergensområdet" (Statens vegvesen, 2011, p. 10).

For the analysis of the problematic dynamic behavior in the Bergen municipality, the municipality is separated into five defined urban districts: The urban districts Bergenhus and Årstad together form the so called *Bergen Center*. Laksevåg and Fyllingsdalen are defined as *Bergen West*, Ytrebygda and Fana together make up *Bergen South*, Arna constitutes *Bergen East* and Åsane is *Bergen North* (see Figure 2 for a map of the urban districts). This division is based on similarities regarding various characteristics such as land use densities and closeness to both city center and airport. The main reasons for analyzing the Bergen municipality on a more detailed scale are its population size and considerable imbalances in jobs and housing occurrence in the individual urban districts.

Figure 2. The urban districts of Bergen municipality (Bergen kommune, 2013).

Problematic dynamic behavior observed in the neighboring municipalities is analyzed on the municipal level. Since a model including all 12 municipalities of the defined Bergen region would go beyond the scope of this paper, I chose Askøy municipality as an example neighboring municipality to Bergen – for several, carefully considered reasons.

Askøy is a direct neighbor municipality to Bergen northwest of Bergen city center. It is surrounded by fjords and connected to the mainland by both a bridge and a ferry which runs from Askøy's municipality center Kleppestø to Bergen center. Its closeness to Bergen makes Askøy attractive for businesses that wish to relocate outside Bergen municipality (Asplan Viak, 2009). In addition, the Askøy planning authorities stress their desire to reduce Askøy's current out-commutes and to increase the number of businesses located on the island (Askøy kommune, 2010). Askøy municipality has existing business areas less than 30 minutes' drive away from Bergen city center. There are plans for their extension so as to meet the future need for business areas (Askøy kommune, 2010).

Askøy has the highest population growth rate in Hordaland County and one of the highest in Norway. Between 2000 and 2009, the population in Askøy grew by 2.7 % per year. It is expected that by the year 2020, the population will have increased to 30 000 inhabitants (Askøy kommune, 2010). This poses big challenges to land use planning. Askøy municipality plans to concentrate the future population in the southern part of the island (Askøy kommune, 2010). This area already is the most densely populated area in the municipality, but there still are considerable possibilities to increase the density and to develop a strong urban center (Askøy kommune, 2010).

It needs to be emphasized that municipalities are political artifacts that do not capture the actual spatial configuration in an urban area. They are, however, the entities that are entitled to regulate land use. Municipalities are the planning authorities and they are responsible for settlement patterns and commercial areas. Consequently, it is they, who influence how the urban area grows.

4.3 The problematic dynamic behavior

The concern is the mismatch between the number of housing units and the number of jobs in the municipalities of the Bergen region and in the urban districts within the Bergen municipality. Bergen center offers far more jobs than housing units, while most of the surrounding urban districts within the Bergen municipality and the remaining municipalities in the Bergen region hold substantially more housing units than jobs.

Figure 3 illustrates the development of the number of jobs and the number of housing units in Bergen center. Bergen center is clearly dominating the region regarding the number of jobs. For the past 12 years, there have been considerably fewer housing units than jobs. In 2000 there were 68 499 jobs in Bergenhus and Årstad and 45 714 housing units. The number of housing units has been slowly increasing to 49 004 housing units in 2011. The number of jobs, however, increased slowly until around 2004, when suddenly, between 2004 and 2008, it grew significantly and reached just below 80 000 jobs. This figure has remained more or less constant since[4]. Bergen South (Ytrebygda and Fana) shows a similar development with the number of jobs outnumbering the number of housing units, though not as pronouncedly as in the case of Bergen center.

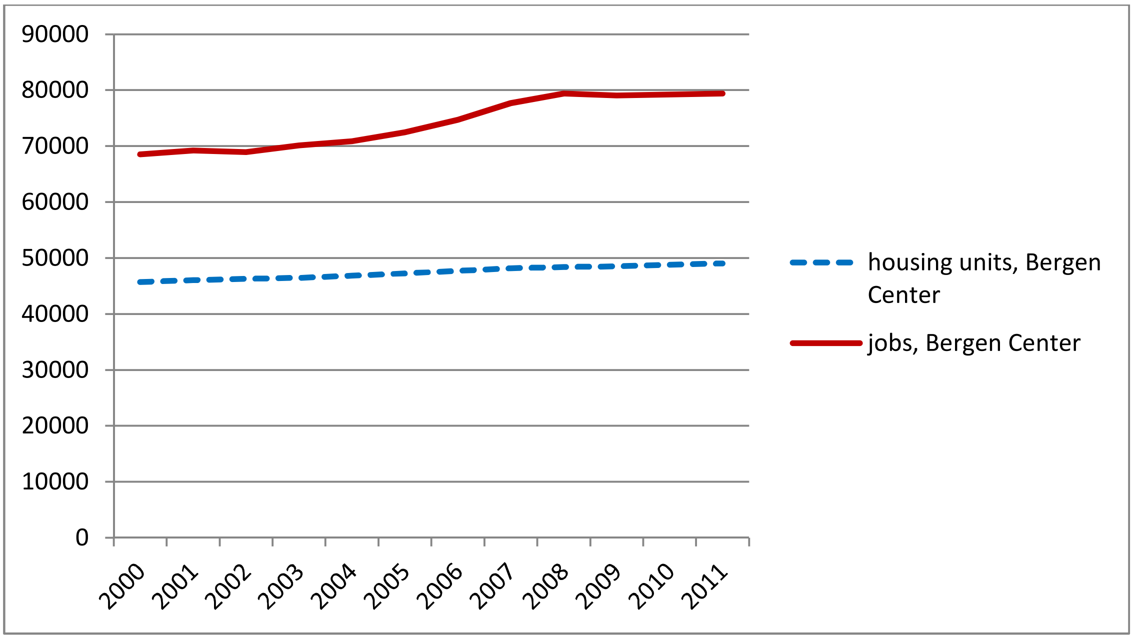

Figure 3. The number of jobs and housing units in Bergen Center (Bergenhus and Årstad) between 2000 and 2011 (own calculation based on data received from Etat for plan og geodata, Bergen kommune).

Figure 4 illustrates the development of the number of housing units and jobs in Askøy from 2000 to 2011. In the year 2000, there were 7 681 housing units and roughly 5 150 jobs. This mismatch remained more or less constant until 2008 with the number of housing units and jobs increasing approximately at the same speed. Since 2008, however, the discrepancy

[4] Numbers obtained by calculations based on data received from Etat for plan og geodata, Bergen kommune.

seems to have increased slightly with the rise in the number of jobs slowing down somewhat in comparison to the increase in the number of housing units. In the year 2011, there were 10 114 housing units and 7 158 jobs in Askøy (Hordaland fylkeskommune, n.d.; Statistisk sentralbyrå, n.d.-a, n.d.-b).

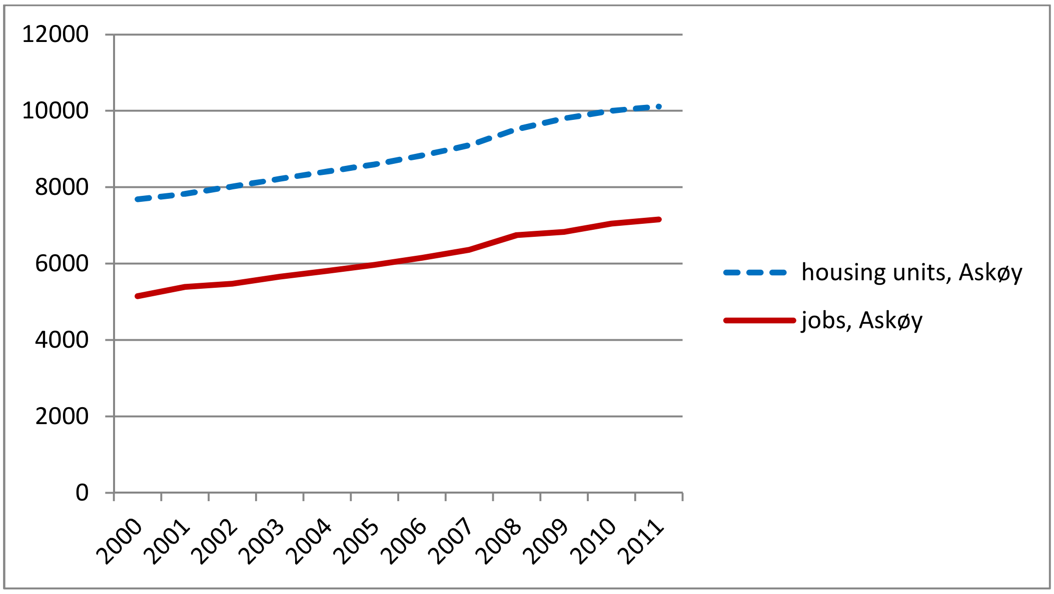

Figure 4. The development of the number of jobs and housing units in Askøy municipality between 2000 and 2011 (Hordaland fylkeskommune, n.d.; Statistisk sentralbyrå, n.d.-a, n.d.-b).

A very similar development can be observed in the other urban districts in the Bergen municipality with the number of housing units significantly outnumbering the number of jobs. This mismatch is especially severe in Bergen North (Åsane) and Bergen West (Fyllingsdalen and Laksevåg).

However, comparing the number of housing units to jobs does not reveal the imbalance fully, since the number of people per housing unit varies strongly between areas and the number of employed people per housing unit differs accordingly. Therefore, it is common practice to express a balance (or imbalance, respectively) in an area with the ratio of jobs to housing units, the so called jobs-housing ratio. As Weitz (2003, p. 4) puts it: "*Generally and simply stated, the jobs-housing ratio is a ratio between a measure of employment and a measure of housing in a given area of analysis*". Balance is achieved, when the number of workers equals the number of jobs in the area of interest. Theoretically, a balance between the number of jobs and the number of housing units is favorable in regard to the overall transport volume (Statens vegvesen, 2011). To obtain the jobs-housing ratio which indicates balance, it is important to adjust it to the average number of workers per housing unit. In practice, a jobs-housing ratio is balanced when it is equal to the number of workers per housing unit. "*Any jobs/housing ratio above (…) suggest that there is an insufficient supply of available housing to meet the needs of the local work force, resulting in a predominant pattern of in-commuting of workers in the morning and out-commuting in the evening*" (Cervero, 1989, p. 137).

The jobs-housing imbalance in Bergen center is especially striking when looking at the jobs-housing ratio. In Bergen center, a ratio of approximately 0.7 implies balance. As Figure 5 illustrates, the observed jobs-housing ratio in Bergen center was around 1.5 in 2000, increasing to over 1.6 in 2004 and 2008 - where it stayed more or less constant. In 2000, 32 695 workers lived in Bergen center while 68 499 people had their place of work in Bergen center. In 2011, the number of workers living in Bergen center had risen to 38 371 while the number of jobs in Bergen center increased to 79 390. So, to express this mismatch in absolute numbers: there were 47 110 housing units lacking in 2000 and 53 972 housing units lacking in 2011.

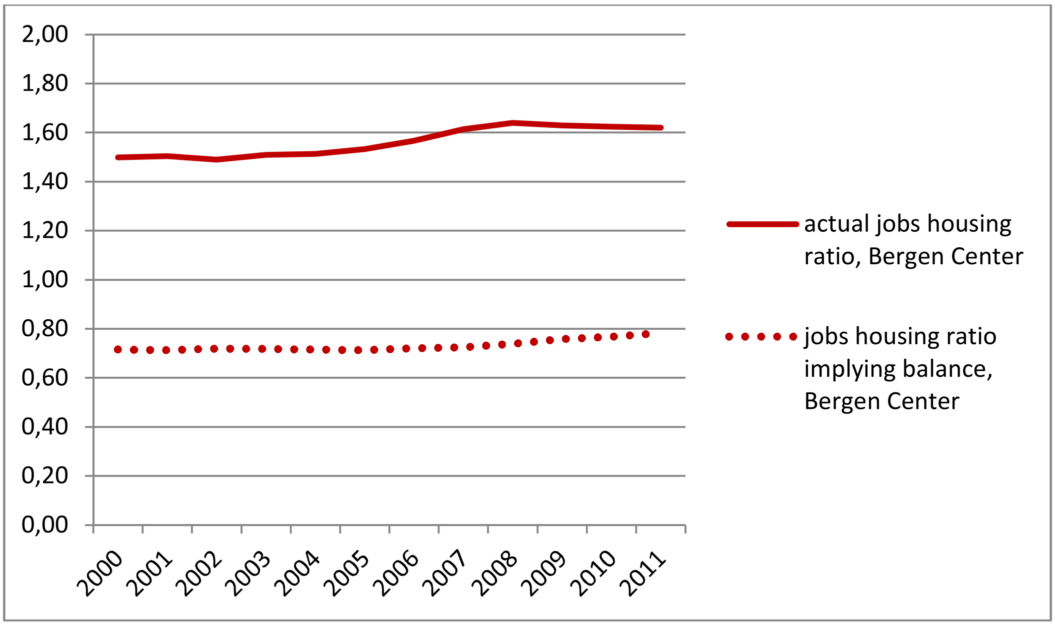

Figure 5. The actual jobs-housing ratio compared to the jobs-housing ratio implying balance in Bergen Center (Bergenhus and Årstad bydel) (own calculation based on data received from Etat for plan og geodata, Bergen kommune).

Looking at the jobs to housing ratio for Askøy in Figure 6, we see that the actual ratio is stable at around 0.9 while the ratio implying balance lies at about 1.3. In absolute numbers, the mismatch constitutes a shortage of about 5 000 jobs in 2000 and of about 6 000 jobs in 2011.

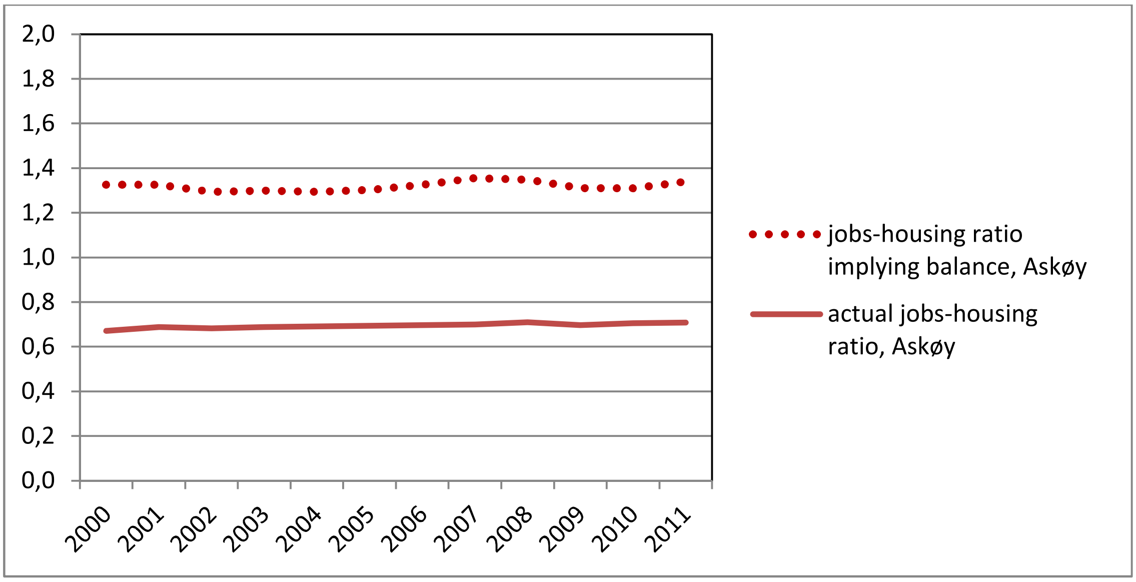

Figure 6. The jobs to housing ratio implying balance compared to the actual ratio in Askøy. (Own calculation based on data from (Hordaland fylkeskommune, n.d.; Statistisk sentralbyrå, n.d.-a, n.d.-b)).

4.4 The impacts of the problem

When the place of living and the place of work are not in the same area, people are forced to commute to work. Studies conducted in the Unites States revealed that "*Land-use patterns – which have increased travel distances because of the separation of homes, jobs, and other destinations – can be blamed for approximately one-third of the increase in driving*" (Weitz, 2003, p. 1). Figure 7 illustrates the fact that there is a lot of commuting in the Bergen region. As can be seen in the figure, Bergen municipality is the only municipality that has a positive net commute of roughly 15 300 workers (in 2008); in comparison, all other municipalities have only out-commutes. Askøy has the highest net out-commute with 5 300 commuters. More than 5 800 employees working in Bergen live in Askøy (Statens vegvesen, 2011). If the imbalance between jobs and residences remains or even increases, it is highly likely that the number of commuters will rise accordingly.

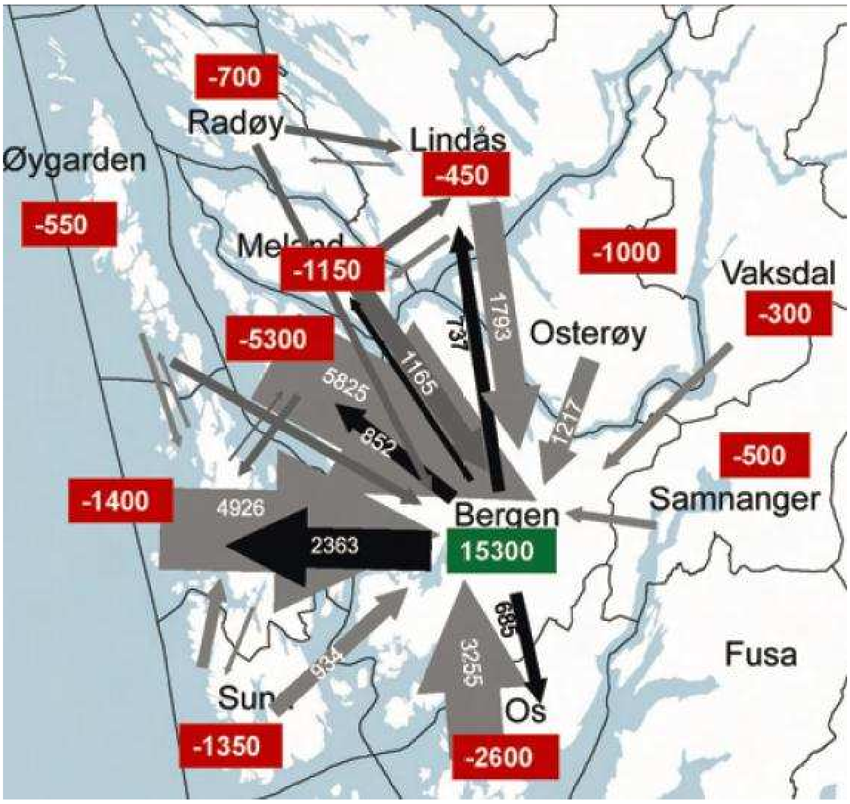

Figure 7. Commute inside the twelve municipalities, 4. quarter 2008. Arrows with numbers show the biggest commutes. The numbers in the boxes stand for the municipality's net in commute (Statens vegvesen, 2011, p. 16).

When looking at the urban district level in Bergen municipality, a lot of travel activity can be observed. The Figure 8 illustrates the total number of trips made (grey allows) and shows how many of those were made using public transport (black arrows). There are two sets of numbers: those describing trips made within Bergen municipality, and those made between Bergen municipality and the neighboring areas in the North, South, East and West. The trips include not only commutes to work but also shopping trips, leisure time trips amongst others. It can be observed that the main travel activity is concentrated to Bergen center (Bergenhus and Årstad) and to a minor extent between the bordering urban areas.

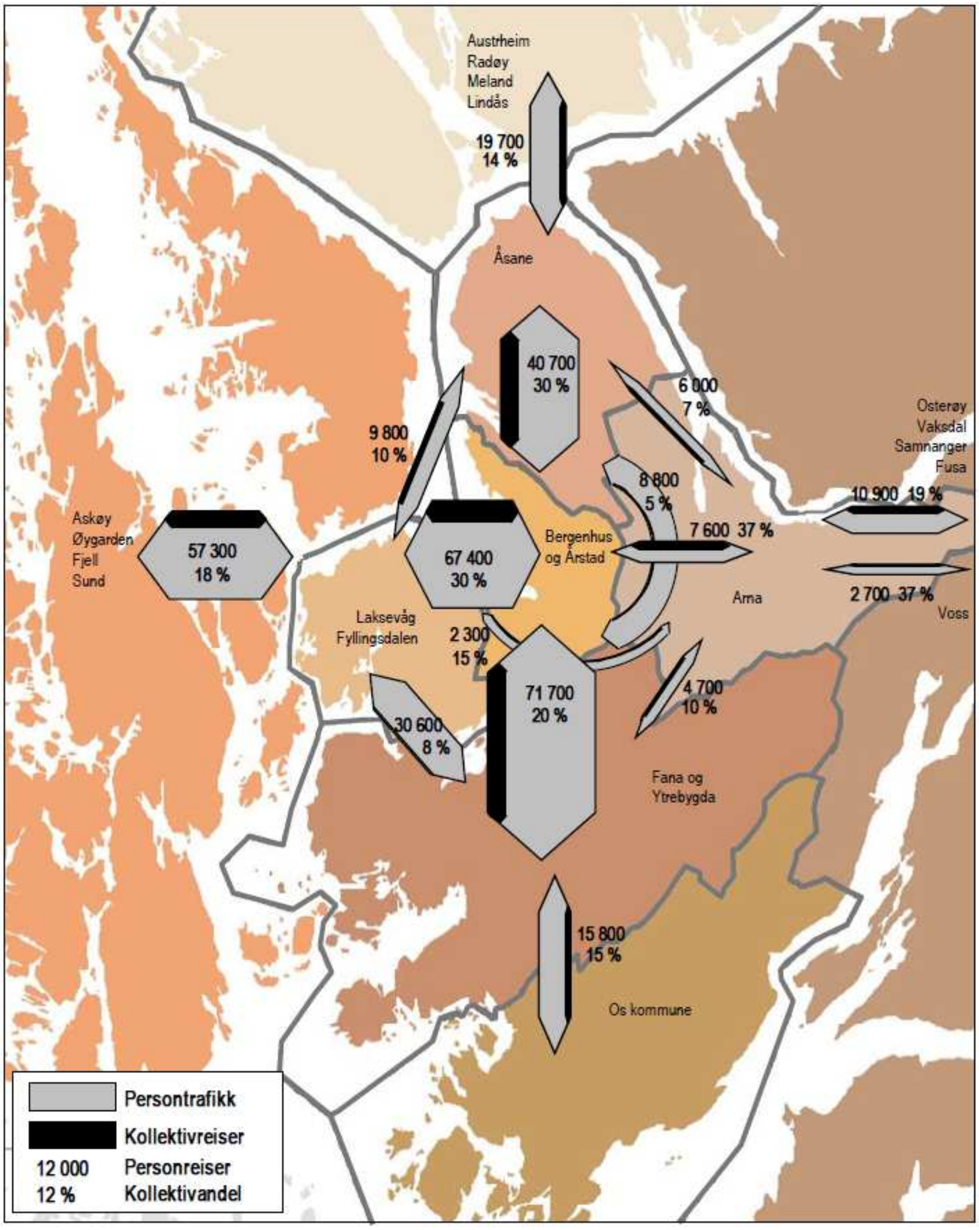

Figure 8. Movement of travelers inside Bergen municipality on urban district level (Meland, 2009, p. 22). The grey arrows indicate the total number of trips (in numbers), the black arrows represent the proportion of the public transportation (in %).

In the Bergen region only around 11 % of the working population uses public transportation to get to work, with the majority using a private car to commute (Meland, 2009). This growing number of commuters causes the road traffic to increase significantly. Overall motor traffic has been constantly rising in the Bergen region. The traffic using the toll ring in towards Nygårdstangen/city center has risen from around 60 000 vehicles per day in 1990 to about 90 000 vehicles per day in 2010 (Statens vegvesen, 2011, p. 20). Nygårdstangen is the navel in the street system since Bergen does not have a ring road around its city center. Therefore, in many cases even traffic between the outskirts of town needs to drive through it. In the future, Statens vegvesen (2011) is expecting a further increase in traffic volume, due to an equally expected rise in population.

In addition to the problem of traffic congestion, the road traffic causes environmental problems along the main roads and in the central parts of Bergen. If no appropriate measures are taken, increasing traffic will cause further environmental problems. Road traffic is the biggest single source of local air pollution. It is responsible for 70 % of the NO_X emissions and around 20 % of suspended dust in Bergen (Statens vegvesen, Bergen kommune, & Hordaland fylkeskommune, n.d.). Also, for the past five to six years, the yearly average level of NO_2 has exceeded the critical value of 40 microgram NO_2 per m^3. The continued exposure to high values of NO_X, NO_2 and suspended dust can cause negative health effects (Strand, Aas, Christiansen, Nenseth, & Fearnley, 2010).

It is the global, national and regional goal to reduce emissions of greenhouse gases. In Hordaland the goal is to reduce the emission of greenhouse gases by 30 % by 2030 according to the *Klimaplan for Hordaland* (Hordaland fylkeskommune, 2012). Road traffic accounts for nearly 70 % of emissions – which makes it the main focus of attention (Bergen kommune, 2001). There are several ways of reducing emissions from transportation, for example by new technology. But one very important and central strategy is to reduce the need for transport itself, which to a large extent is conditioned by land use patterns.

4.5 Existing Policies

In Norway there are several laws and guidelines at different levels on land use planning. At a top level, there is the national law (*Plan- og byningsloven*). At the county level (*fylkeskommune*), there are the land use guidelines which are defined in the *fylkesdelplan*. At a municipality level, we find the *Kommuneplan* and *Kommunedelplan*.

Norway got a new planning- and construction law (*Plan- og Bygningslov*) in 2009. § 1-1 states the law's objective: to encourage sustainable development by emphasizing long-term solutions. § 11-1 decrees that municipalities need to have a municipality plan (*kommuneplan)* which describes the municipality's goals and how to achieve them (*handlingsdel*) and contains a map showing the zoned areas for different purposes (*arealdel*). The *kommuneplan*'s objective is to enforce municipal, regional and national goals. It needs to include all important aims and tasks in the municipality during a planning period (Miljøverndepartementet, 2012).

During the past years, awareness for the close interrelationship between land use- and transportation planning has developed. Governmental authorities have their focus on environmental friendly urban development which encourages environmental transportation while limiting motoring. Accordingly, the Ministry of Environment, (*Miljøverndepartmentet*), which is in charge of planning, published *retningslinjer for samordnet areal- og transportplanlegging*[5]. These guidelines determine that a sustainable perspective has to underlie all planning activity, and that land use and transportation planning is necessary and important, in order to limit the need for transportation (Miljøverndepartementet, 1993).

Hordaland county council is concerned about an increasing need for transportation being generated by the current urban development pattern. One of the objectives for land use and environment stated in the *Fylkesplan for Hordaland* is to take into consideration the effective use of land when locating businesses, housing and services and to thereby generate the lowest possible need for transportation (Hordaland fylkeskommune, 2005). Similar to the suggestions by Statens vegvesen (2011), Asplan Viak (2009) and Opus Bergen (2012), Hordaland county council has developed five main strategies for more effective land use planning (Hordaland fylkeskommune, 2010, p. 57):

- A decentralized center structure (strong municipality centers and regional centers with a good offer of services, jobs, etc.)
- Densification of existing urban areas instead of further expansion
- Suitable locations for businesses and services (job-intensive and visitor-intensive businesses need to be located centrally while land-extensive businesses dependent on heavy transport should be located outside the center)
- Coordinated land use planning across the municipality borders
- Good coordination between land use- and transportation planning

It is also the municipal goal to reduce the need for transportation. In 2002, the so called *Bergensprogrammet*[6] for transport, urban development and environment was launched. It is

[5] Guidelines for coordinated land use- and transportation planning (translation by the author)

[6] The Bergen program (translation by the author).

based on nine principal objectives. The first two principal objectives involve land use planning measures: 1.) reduce traffic increase, 2.) pursue urban development that reduces the need for transportation (Bergen kommune, Hordaland fylkeskommune, & Statens vegvesen, n.d.). The second objective is explained as *"one of the most complicated objectives in the Bergen program. An urban development which reduces the need for transportation requires a destinct connection between land use- and transportation planning. An urban development where short distances, good public transport facilities, a good network of roads for walking and biking and the development of junctions and district centers is emphasized so that the inhabitants can perform their daily duties with as many short travelling times as possible"*[7] (Bergen kommune et al., n.d., p. 8). In the land use-part of its municipality plan from 1996, Bergen municipality stressed the importance of slowing down the then-prevailing development of continuously losing open space. In its land use plan from 2000, Bergen put a curb on further expanding the urban area. The 2007 land use plan also considers sustainable land use- and transportation planning important: 60 % of the housing construction is to take place inside existing urban areas (i.e. increase density) while only 40 % of the housing construction is allowed to be field development (Bergen kommune, 2008b). Bergen municipality points out that land use and transportation planning is decisive in reaching the goal of reducing local air pollution and the emission of climate gasses. The city government wishes to actively collaborate in the Bergen region, i.e. to work on land use- and transportation planning together with the neighboring municipalities. In addition, Bergen has a special focus on so called transformation areas - areas - currently dominated by land-extensive businesses - which are to be turned into areas with mainly job-intensive businesses mixed with housing units. Prioritized transformation areas and areas where the density can be increased are identified around urban district centers and local centers; around the city rail stops and the commercial areas at Midtun, Laksevåg (Puddefjordsbroen-Laksevågneset) and the so called “business corridor”- a corridor stretching from Solheimsviken to Fjøsanger. The objectives are to have a dense mixed use in and around urban district centers, to increase the share of housing units, as well as to create office workplaces (Bergen kommune, 2008b).

Askøy municipality also wants to reduce the need for transportation. The planning objective of Askøy’s latest municipality plan is to contribute to well-being and balanced growth in the municipality through different measures. One of the specified measures is to provide suffi-

[7] Translation by the author.

cient areas for business development in the next 15 years. That way jobs can be established in Askøy and the need for commuting can be reduced (Askøy kommune, 2010).

4.6 Future challenges

As mentioned before, it is expected that the Bergen region will grow significantly in the coming years. Population forecasts expect the number of people living in the Bergen region to increase by around 160 000 inhabitants by 2040 (Statens vegvesen, 2011). This will lead to a demand for about 60-80 000 additional housing units and roughly 86 000 new jobs will be created (Statens vegvesen, 2011). The challenge is to find suitable locations for the future workplaces and residential areas. Opus Bergen (2012, p. 18) expect that 70 % of the new businesses will be job-intensive businesses while around 30 % will be land-extensive businesses. They recommend co-locating housing with as many business activities and public operations as possible. This would make for sustainable and mixed land use and avoid having "lopsided" business areas on the one and housing areas on the other hand. Opus Bergen (2012) believe that the majority of jobs in the private and public service sector could be easily integrated into residential areas without causing conflicts.

The planning authorities agreed on extensive plans for the transformation and densification of central urban areas. Mindemyren is a typical example for an area where land-extensive businesses are to be replaced by job-intensive businesses. Today, there are around 7 000 jobs. By the year 2030, there will be an expected 27 000 jobs and 400 000 m² of new business space for job-intensive businesses (Opus Bergen, 2012). Asplan Viak (2009) point out that many land-extensive businesses currently located in central areas wish to relocate. Formerly having been located outside the city core area, they now are surrounded by the growing city center. Land value and purchase prices have risen accordingly and now expansion at the current location is not viable. However, the lack of suitable land plots for relocation is delaying the transformation process the authorities are aiming for (Asplan Viak, 2009).

5. Dynamic Hypothesis

In the following chapter a dynamic hypothesis is developed offering one possible explanation for the historical trend of jobs-housing imbalance in the Bergen region. The description of the dynamic hypothesis begins with a general discussion and a first, very simple structure of the model. This will be followed by a presentation and explanation of the main feedback loops. Finally, the stock and flow structure of the model will be presented.

5.1 Discussion

The overall model consists of six modules. Each module contains a land use sub-model for a distinct area. One module represents the land use in Askøy municipality. The remaining five modules are land use sub-models for Bergen municipality with each representing a different geographic part of Bergen. One central task was to identify important feedbacks between the different areas. Figure 9 illustrates the interactions between the geographic areas represented by the modules. They are based on several interaction grounds which will be described in more detail later on. When looking at the arrows indicating the interactions, it becomes apparent that not all land use sub-modules interact with each other. Even though this might not be in perfect accordance with reality, it represents the geographic division of the urban area which Asplan Viak (2009) defined. Their findings indicate that the Bergen region can be divided into three different spatial job markets. Bergen center acts as a border between them which, for example, makes Bergen West not very attractive for businesses located in Bergen East.

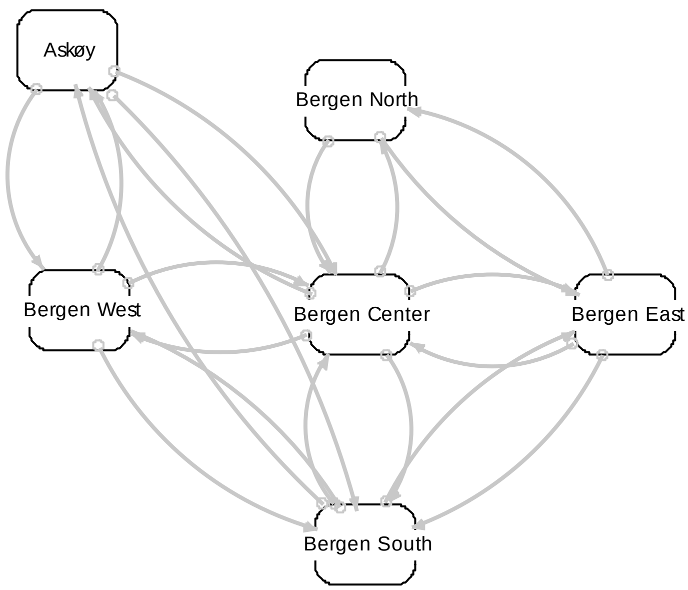

Figure 9. The six land use sub-modules and their interactions.

Each land use sub-model consists of several sectors. Figure 10 summarizes the general structure of these models. Each model is divided into two main parts: the *housing sector* and the *business sector*. These two sectors are equally overlapped by the *land use planning sub-*

sector. Even though there is no direct interaction between the *housing* and *business sector* in the *land use planning sub-sector*, they compete for a limited resource: land area available for building construction. The municipal authorities come to a decision as to how much-, and what kind of land will be zoned for what purpose. "***Zoning*** *is simply the establishment of districts that permit only specified types of land use*" (Kaplan, Hodler, Wheeler, & Holloway, 2004, p. 342). Once the land is occupied it becomes unavailable for others.

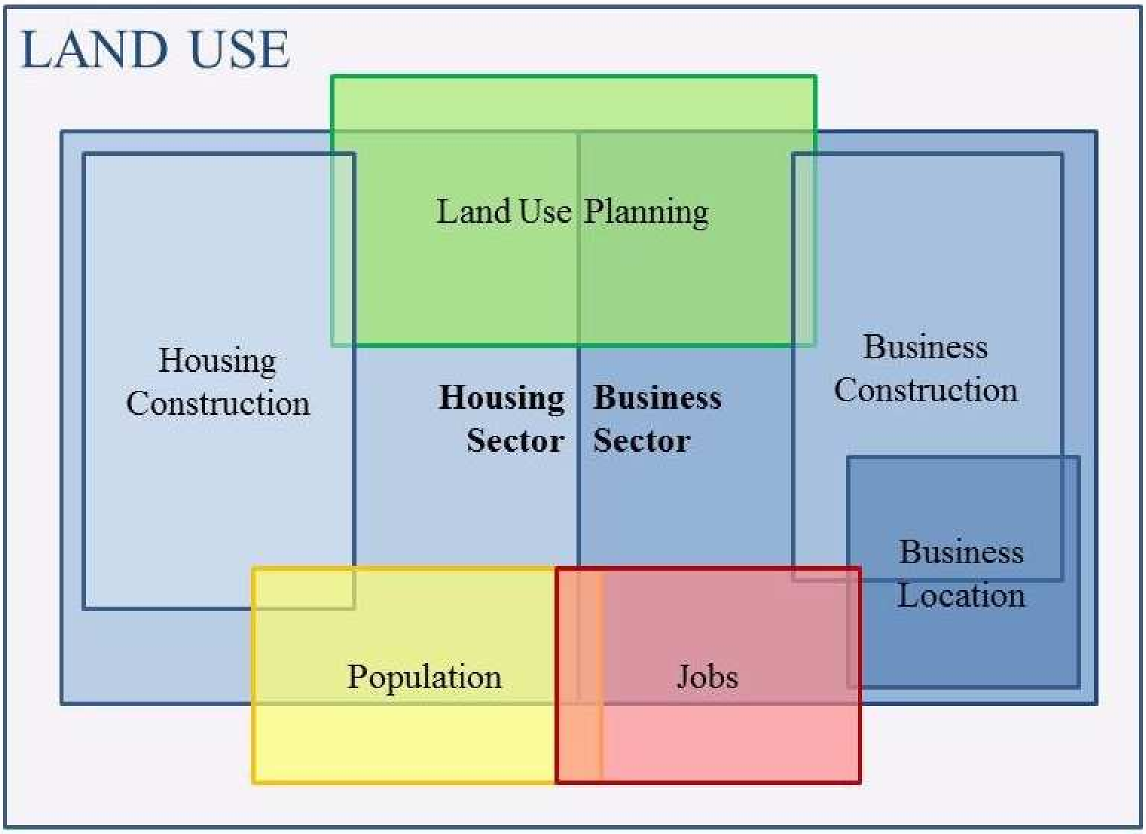

Figure 10. The different sectors and sub-sectors included in the land use sub-models. The overlap illustrates that interactions take place.

The *housing sector* can be divided further into the *housing construction sub-sector* and the *population sub-sector*. Housing construction can only occur when there is enough vacant land zoned for housing. Once housing units have been constructed, people can move in, thus increasing the population. The *business sector* consists of three sub-sectors: the *business construction sub-sector*, the *business location sub-sector* and the *job sub-sector*. Business structures can be constructed when there is enough vacant land zoned for business. Businesses can decide to locate in the given area once there are vacant business structures. The *business location sub-sector* incorporates the most important factors businesses take into consideration when deciding where to locate. The location of businesses influences the number of jobs in the area. Important interaction between the *housing* and *business sector* happens in the *job* and *population sub-sector*. The number of jobs depends to some extent on the size of the population because it increases the demand for services, both public and private. These can entail, for example, additional teachers and eventually new schools, kindergartens, doctors' surgeries, grocery stores, shopping malls, etc. At the same time the migration of people depends on the number of jobs available.

Several stakeholders are involved in the *Bergen Land Use Model*. The green *land use planning sub-sector* represents the municipal planning authorities who set up zoning plans and give out building permits. They are free in their decisions to a certain extent but have to follow several rules and laws from the regional and governmental planning authorities. The blue *housing* and *business sectors* are mostly private construction and real-estate companies who decide to develop a land plot after the municipal authorities have zoned it. The construction plans need to be in accordance with the zoning plans from the municipality. Only a small part is developed by the public sector. This includes the construction of student housing, hospitals, schools, buildings for authorities, etc. The yellow *population sub-sector* constitutes the individual who can decide freely where to live and work. The *population sub-sector* is quite simplified in my model; it is modeled in more detail by Li (2013) in his intra urban migration model. The dark blue *business location sub-sector* represents the individual firms that decide where to locate. The red *job sub-sector* depicts the consequences of the population's decisions (since the number of service related jobs depends on the number of inhabitants) as well as the results of decisions made by private businesses on where to locate and how many people to employ.

5.2 Causal Loop Diagram

In the following chapter the main feedback loops are presented. They illustrate the dynamic interactions within the *Askøy land use sub-model* and its interactions with the *Bergen center land use sub-model*. The same feedback loops are also present in the other land use submodels. First we will explore the loops in the *job* and *business construction sub-sector*. Then important loops in the *business location sub-sector* will be presented. Finally, the loops inherent in the *housing sector* will be described.

Feedback loops in the *Business Construction Sub-Sector*

We will first explore how the number of jobs comes about. The loops in Figure 11 describe the balancing effect the business space availability has on the number of jobs. Business space stands for the utility space in the existing business structures. Loops C1 and C2 express the fact that businesses can only relocate when there is vacant business space. Loop C1 describes the immediate short term effect when businesses from Bergen center relocate to Askøy: As more business space becomes vacant, more businesses can relocate to Askøy. Since businesses normally take their employees with them when they relocate within the same region (Asplan Viak, 2009), the number of jobs increases instantly. By occupying business space, the amount of vacant space is reduced. Loop C2 illustrates the long-term effect when businesses relocate to Askøy. When businesses relocate, they add to the total number of positions in the specific urban area they are moving to. When these businesses grow, more positions are created and more positions are perceived to be needed by the firms' bosses. Consequently more vacancies are advertised; then – with a slight delay - more workers are hired, and - thereby – increase the number of jobs. By occupying business space, the amount of vacant business space is reduced and fewer businesses can relocate than would have done otherwise. Also a growing population in Askøy and a positive GDP development increase the perceived need for positions.

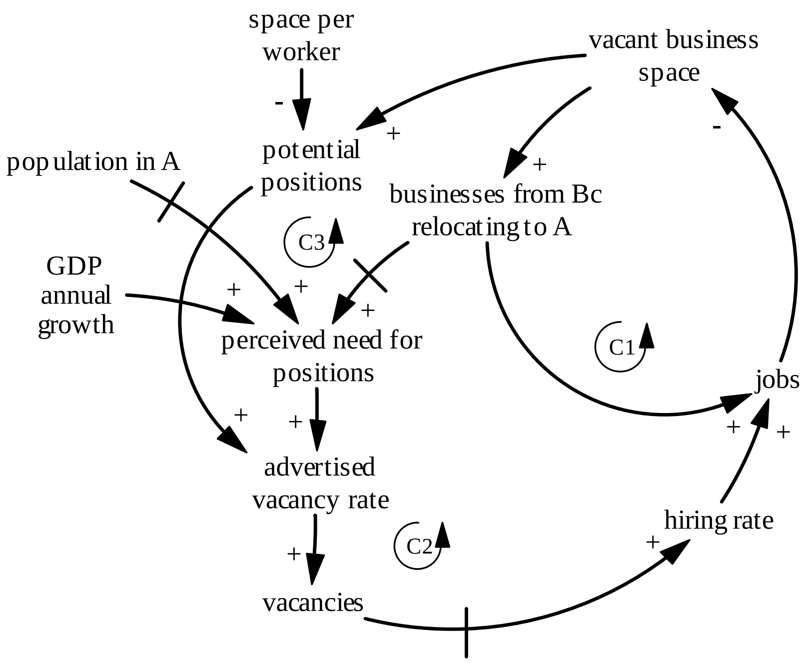

Figure 11. Job creation loops in the *Askøy land use sub-model*. The crossing line in the links denote significant delays.

In situations where there is plenty of business space available, the advertised vacancy rate equals the perceived need for positions: the firms hire as many workers as they perceive they need. Loop C3 illustrates the situation when vacant business space is a constraint. The potential positions indicate the maximum number of positions which is possible due to the available business space and the business space which is required per worker. When the vacant business space decreases, the number of potential positions is reduced. At the point when the potential positions are less than the perceived need for positions, the advertised vacancy rate is determined by the potential positions. This slows the hiring rate and the addition to jobs is lower than it otherwise would have been. This in turn leads to a lower reduction in vacant business space.

The main finding of the three counteracting loops in Figure 11, is that the amount of vacant business space regulates the number of jobs and vice versa. In theory, any vacant business space should be filled with jobs until there is no more vacant space. In reality, there will always be vacant business space due to relocating businesses, the economic development and construction of business structures.

The amount of vacant business space is not only a result of the number of businesses relocating in Askøy and of the number of jobs. As the loops in Figure 12 show, business construction is also a decisive factor that influences the amount of vacant business space. Loop C4 shows that any increase in business construction - with the delay this involves - leads to an increase in vacant business space – which in turn constitutes the supply side. An increase in supply, all else being equal, results in a drop in requested land for business – real-estate companies reduce their construction activity, since the perceived overcapacity of business space lowers their profit expectations. Loop C5 and R1 represent the demand side for business space. Loop C5 describes the short-term effect. Vacant business space allows businesses from other parts of the region, in this case Bergen center, to relocate to Askøy. Once these businesses have relocated to Askøy, the total number of businesses seeking to relocate to Askøy is reduced and – everything else kept equal - the demand for business space is lowered. A decrease in demand slows down business construction, i.e. less of the vacant business space is built on than would have been otherwise. Loop R1 depicts the long-term effect: as more businesses relocate to Askøy, more positions are created. In a situation of economic growth, this leads to a greater perceived need for positions. As a consequence, the perceived need for business space and the demand for it rise also. The rising demand increases business construction, which results in more vacant business space and subsequently to more businesses being able to relocate to Askøy.

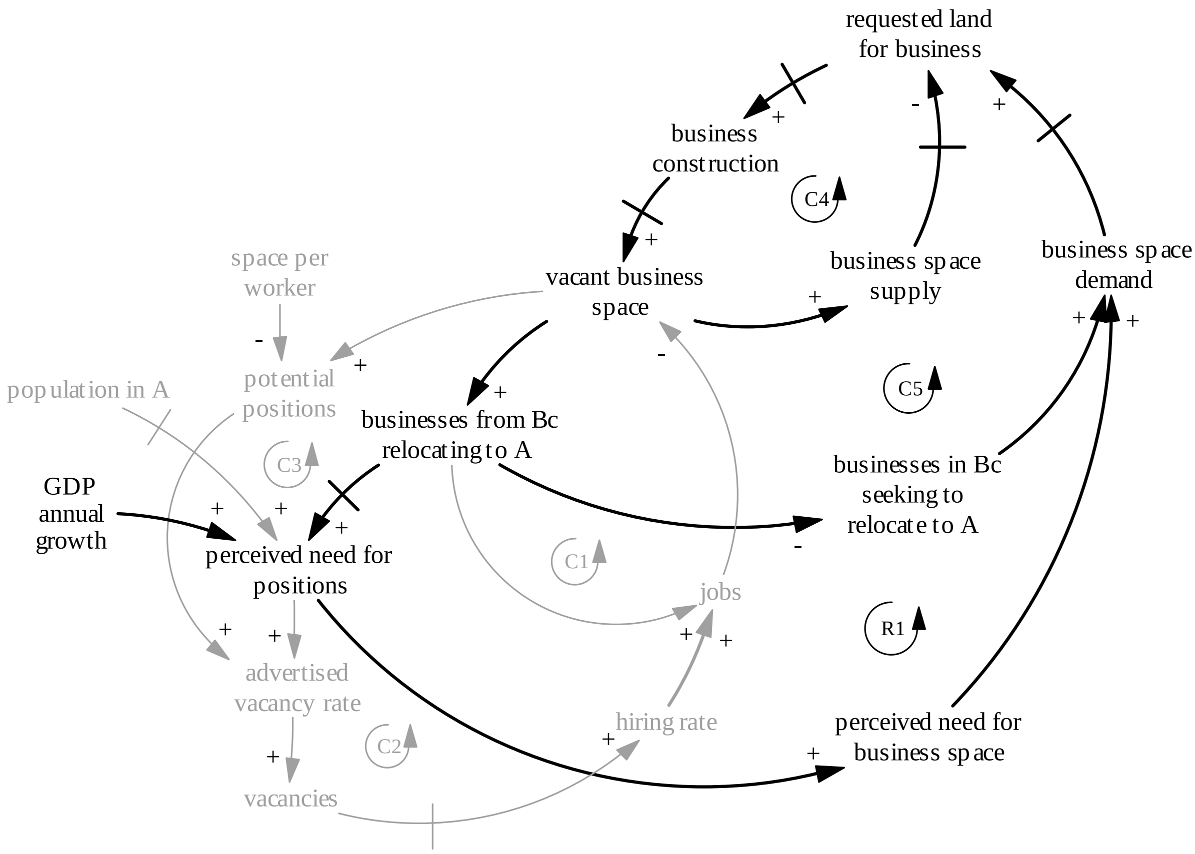

Figure 12. Business space construction loops.

The main finding of the loops illustrated in Figure 12 is the importance of supply and demand for business space construction. We have vacant business space on the supply side, while on the demand side we have businesses not yet located in Askøy but seeking to do so and businesses already located in Askøy.

The following two feedback loops in Figure 13 illustrate what influences the amount of vacant land zoned for business and the effect it has in the construction activity. Loop C6 depicts how the amount of vacant land zoned for business is reduced when the demand for it increases. The availability of zoned land in turn influences how much land is requested for business construction: when the amount of vacant land zoned for businesses decreases, the demand for business land slows down. The reaction is to leave more land vacant than one would have done otherwise. This is because the amount of vacant land is a physical constraint if it falls below the amount of requested land: only what is vacant and zoned can be used for construction. Furthermore, Alfeld and Graham (1976) suppose that the amount of vacant land can be a constraint even before it falls under the desired level because the probability of the remaining vacant land matching the demanded requirements in size and character diminishes. In addition, zoning restrictions, inaccessibility or problems with the plot may make the remaining land unsuited for construction. Lastly, high land prices or high construction prices due to the qualities of the plot may discourage business construction (Alfeld & Graham, 1976). The expert interviews confirmed that this assumption is true for the Bergen region and revealed that the available vacant land has constrained construction in the past. Some zoned land is situated in areas with insufficient road access or bears too high risk regarding construction permits due to conflicting interests in the neighborhood.

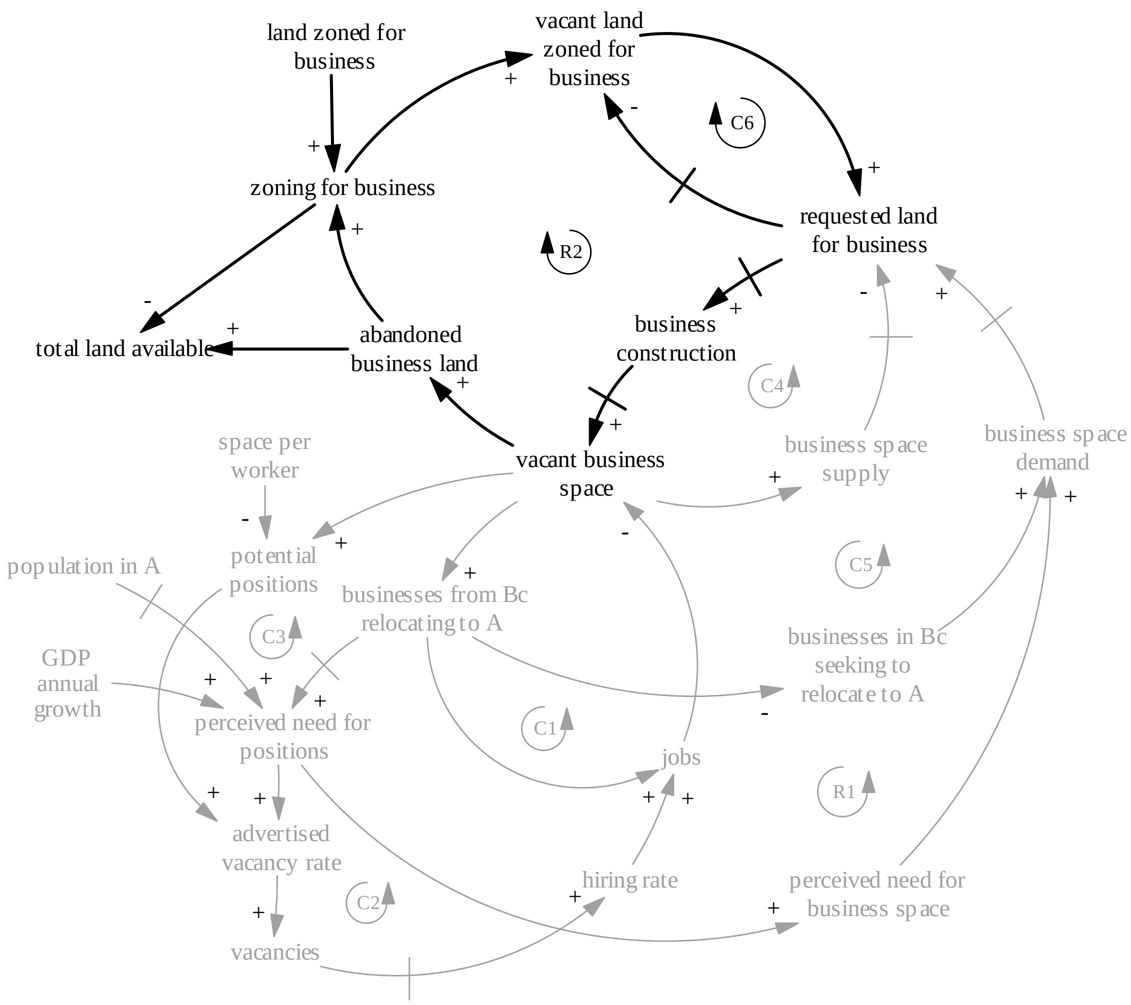

Figure 13. Business land loops.

Loop R2 describes how a certain amount of vacant business space is demolished which creates abandoned business land. As business structures age, they become less suitable for modern requirements. Consequently, they are demolished and replaced by newer structures. Mostly, abandoned business land remains land zoned for business purposes which increases the amount of vacant land zoned for business. This in turn reduces the land availability constraint and more business construction can take place than would have done otherwise. Since parts of the abandoned land can be rezoned for other purposes, for example housing, the total land area available for construction is increased when land is abandoned.

The loops in Figure 13 show that the amount of vacant land zoned for business depends on two factors: the amount of abandoned business land and an exogenous variable called *land zoned for business*. This variable represents the zoning activity by the planning authorities. There is no clear decision rule concerning the amount of land zoned for business. Zoning does not seem to depend on the total of available land. However, as new land is zoned for business the total of available land is reduced. Land is a limited resource and once it is occupied it becomes unavailable for other purposes. The more land is zoned, the fewer areas are available. The total amount of available land is depleted.

<u>Feedback loops in the *Business Location Sub-Sector*</u>

The feedback loops described in this section illustrate the factors influencing the choice of location for businesses in the Bergen region. Five out of several location factors specified in two papers by Asplan Viak (2009) and Jakobsen (2000) are included in the model. Two location factors are exogenous to the model and are described in the next chapter. The remaining three factors included in the model are part of feedback loops: the clustering effect, the rental price and the expansion possibility. These location factors influence both residing businesses in the specific area (in this case Askøy) and businesses located in other areas of the Bergen region (in this case Bergen Center).

Figure 14 illustrates the well-known phenomenon in business location theory: the so-called clustering effect, which describes how businesses find it attractive to locate close to each other. Business clusters can be horizontally integrated (an accumulation of businesses in the same commercial sector) and vertically integrated (businesses connected through a common supply chain). Business clusters develop because businesses have location advantages by being located close to each other. The two greatest of them are shared knowledge and shared infrastructure. Clusters can also be made up of businesses from different commercial sectors or with different supply chains which profit from the urban economy and the allocation of public goods (Asplan Viak, 2009). Even though Asplan Viak (2009) could not identify a strong clustering effect in the traditional sense within the Bergen region, they found that businesses did consider the area's reputation when relocating. If an area is reported as being a good business location, this can have a kind of clustering effect.

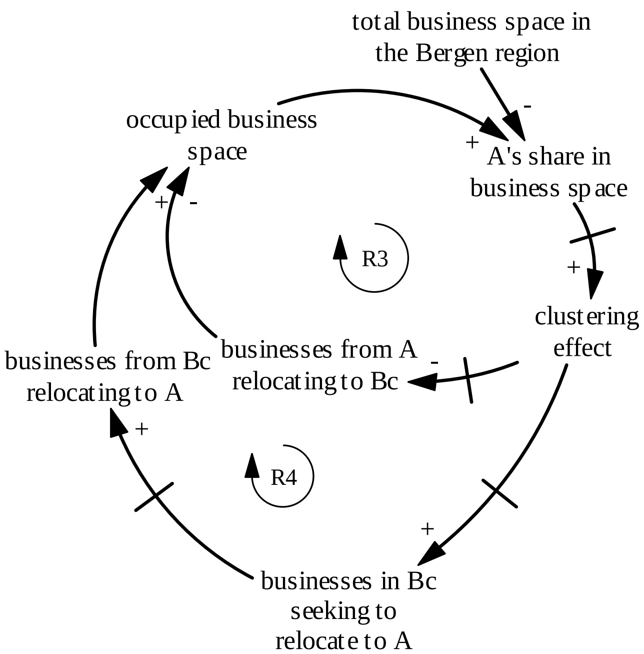

Figure 14. Clustering effect loops.

Loop R3 in Figure 14 describes how an increase in occupied business space in Askøy equals an increase in its share of total business space occupied in the Bergen region. This intensifies the clustering effect, since it acts as an indication to businesses in the region for it being an established and attractive business location. Fewer businesses leave Askøy to relocate in Bergen center, less occupied businesses space is vacated, and the share in business space remains high – preserving and strengthening the clustering effect. Loop R4 reveals how a stronger clustering effect leads to more businesses located in Bergen center wanting to locate in Askøy, thus increasing the number of relocating businesses. By occupying business space they increase Askøy's share in business space and subsequently the clustering effect gains in strength.

The loops in Figure 14 show the causal effect of businesses located in an urban area encouraging the perception of this particular area being a well-established and attractive business location. More businesses will move there as a consequence. Currently Bergen center holds the highest share in business space and attracts the most businesses.

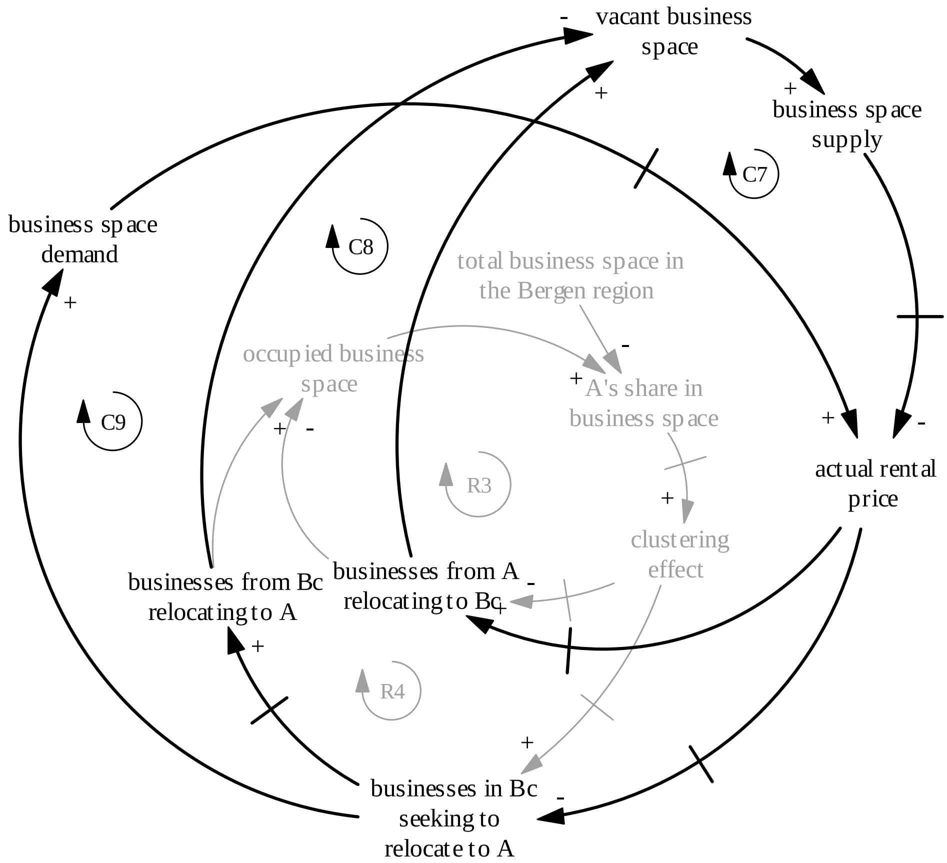

Figure 15. Rental price loops.

Figure 15 illustrates another important (re)location factor; namely rental prices for business space. These are very much subjected to supply and demand: a rising demand – with everything else kept equal – will cause the rental price to increase while a rising supply will result in lower rental prices. Loop C7 demonstrates how lower rental prices lead to fewer businesses leaving Askøy and relocating other places. Askøy maintains occupied business space and its supply is lower than what it otherwise would have been. With a delay, the rental price adjusts upwardly. Loop C8 illustrates how rising rental prices mean that fewer businesses wish to locate in Askøy, which obviously means that fewer businesses actually do so. Business space remains vacant, more than otherwise would have been the case. The higher supply causes the price to adjust downwards with a delay. Loop C9 illustrates the effect demand for business space has on rental prices. Rising rental prices decrease the number of businesses seeking to relocate to Askøy which reduces the demand for business space. Everything else kept equal, this leads to lower rental prices than before.

The loops in Figure 15 illustrate that rental prices are a decisive factor for businesses to locate. However, the decisions businesses take will have an effect on prices over time. They will always adjust according to the supply and demand and consequently will balance the businesses' choice of location.

Another central factor influencing the choice of location for businesses incorporated in the model is the possibility of expanding capacity in the given area. In Figure 16 we can see, what happens when there is less vacant zoned land: the less land is vacant, the smaller the chances for a business to expand at the current location. Loop C10 describes that the fewer businesses leave Askøy, the less business space becomes vacant and the more business construction occurs. This in turn increases the requested land for business. The amount of vacant land is reduced, and the possibility for further expansion is curbed. Loop C11 shows how as the possibility to expand increases, more businesses from outside seek to move to Askøy and finally more actually do locate in Askøy. This reduces vacant business space, causes the supply of business space to decrease and the requested land for business to increase. Subsequently diminish the possibilities for expansion.

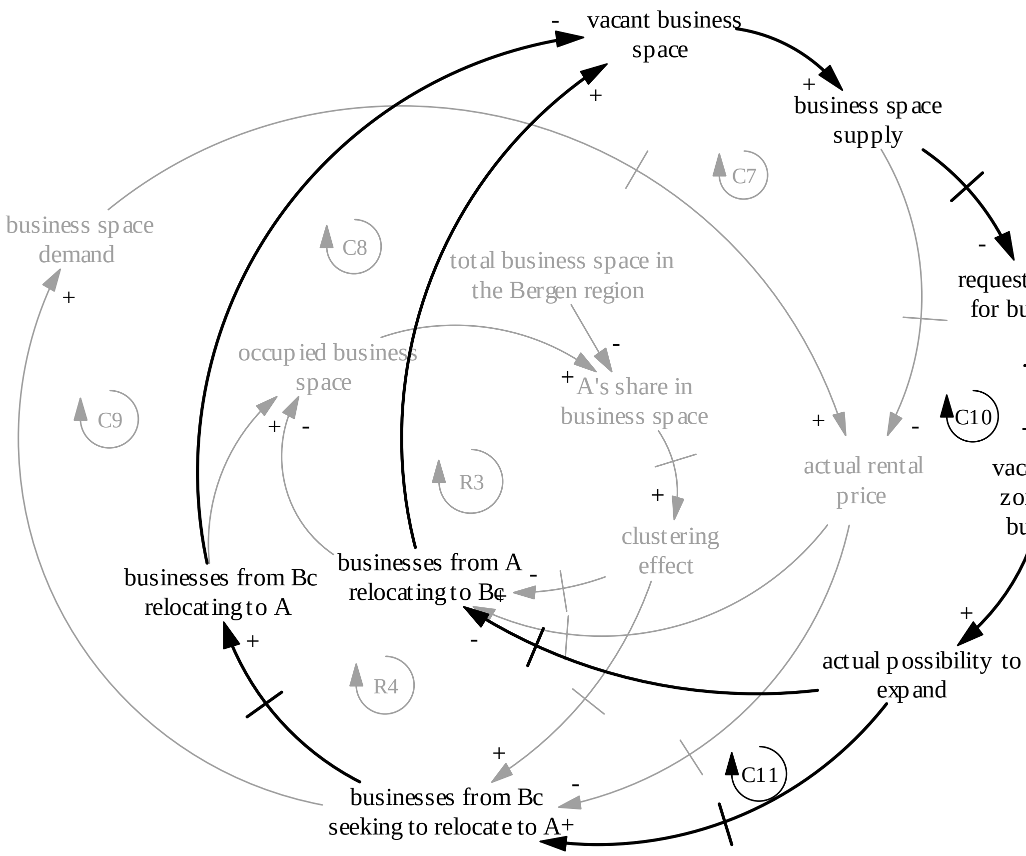

Figure 16. Expansion possibility loops.

The loops in Figure 16 make clear that the prospects of expansion depend on the amount of vacant land zoned for businesses. Location decisions of businesses as well as the consequent land-occupying construction activity affect this process.

Feedback loops in the *Housing Sector*

The following feedback loops illustrate the dynamics occurring in the model's *housing sector* and explain the interacting factors influencing the number of housing units in the specific areas. The first loops shown in Figure 17 clarify the effect of the existing housing space on the future housing space construction. Loop C12 shows that a diminishing amount of vacant housing space increases construction companies' eagerness to build more housing units. If there is little vacant housing area, this implies a high turnover rate and is likely to mean that housing prices are high. So the real-estate companies have reason to entertain high profit expectations. Consequently, they request more land for housing so as to build accommodation. With a delay, the amount of vacant housing space will rise to a higher level than it would have done otherwise. Loop R5 shows vacant housing space giving people the possibility to move to Askøy thus increasing the population. More housing space is occupied and real-estate companies try to build more housing so as to profit from the high demand. The vacant housing space is further increased. The loops in Figure 17 highlight the important role of supply and demand for housing which is represented by the amount of vacant and occupied housing space.

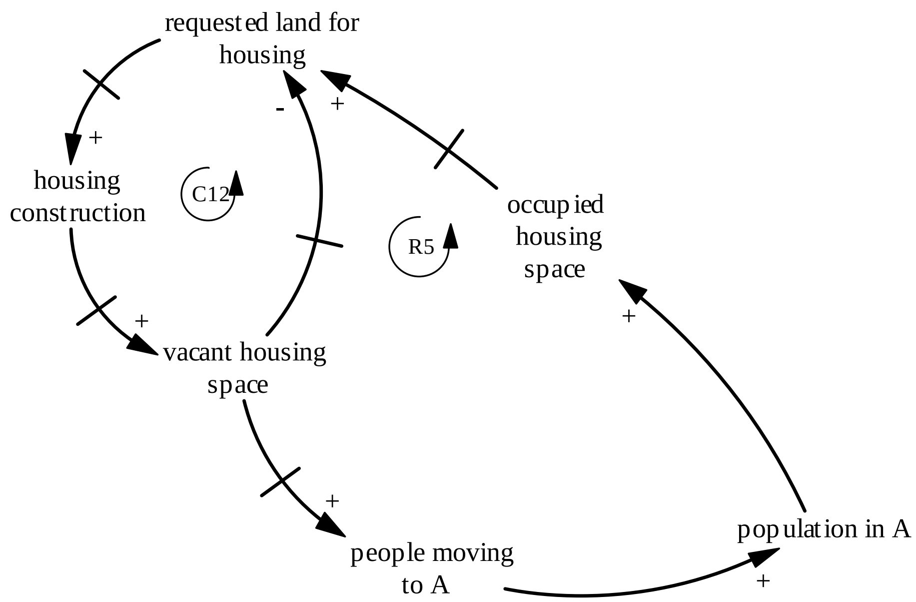

Figure 17. Housing space construction loops.

The loops in Figure 18 explain what causes the population in Askøy to change. Loop C13 shows how vacant housing space in Askøy encourages people to move there. A rising number of people moving to Askøy causes the residential population to increase. This reduces the remaining vacant housing space. As a direct consequence, fewer people can move to Askøy. C14 depicts the effect of housing vacancies on the number of people seeking to move to Askøy. It is based on the assumption that few vacancies leads to fewer people wanting to move there – they might worry about finding a nice and suitable house and fear the high house prices caused by the high demand. This then means, that fewer people move to Askøy than would have done otherwise, that the population increases more slowly and more housing space remains vacant than otherwise. Loop R6 shows how attractive job vacancies are to a potential population. These vacancies do not have to be in Askøy directly; all job vacancies in the Bergen region come into play. An increase in population creates new jobs in the local service industry; the new residents of Askøy require schoolteachers, kindergarten-nannies, doctors, receptionists and sales assistants. With a long delay, this will lead to more job vacancies which in turn will make Askøy an attractive place to move to. More people will move and the population will increase further.

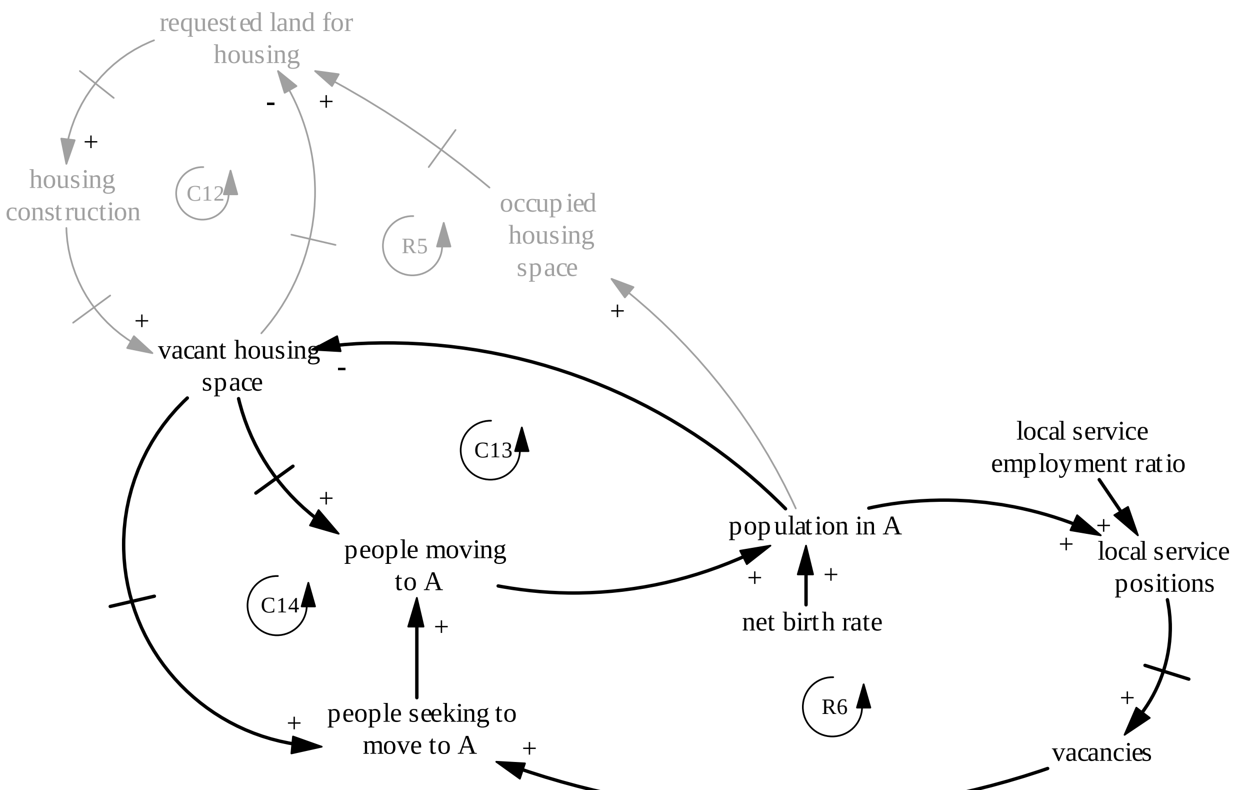

Figure 18. Population loops.

Figure 19 illustrates two more feedback loops operating in the housing sector. Loop C15 shows the same effect of vacant zoned land we saw in the business sector applying to the housing sector: the demand for land area allotted to housing construction is not only influenced by the supply and demand of houses but also by the supply of vacant land zoned for housing. The less the vacant land, the lower the chances of the remaining vacant land areas to match the developers' preferences. If the remaining areas do not satisfy their demand, they will require less land for construction and construct less. The amount of vacant land zoned for housing will remain higher than it would have done otherwise.

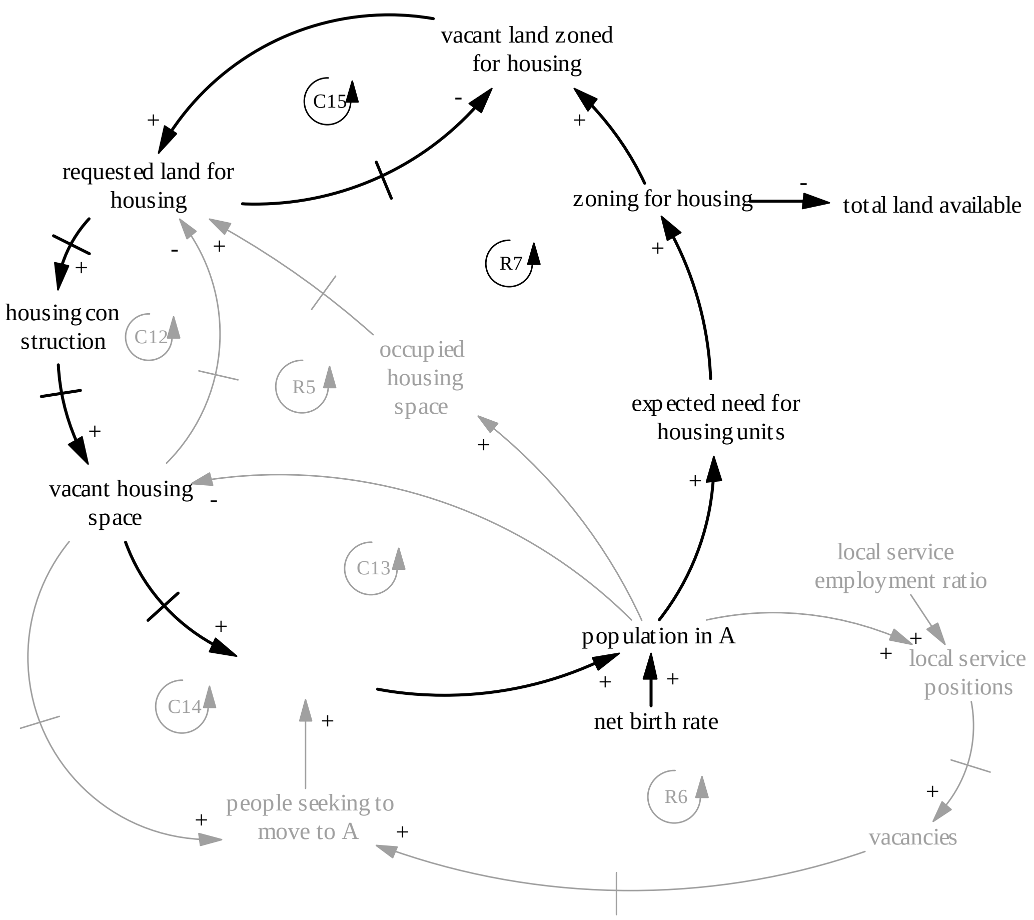

Figure 19. Housing land loops.

Loop R7 describes the decision rule governing the amount of land zoned for housing purposes. The planning authorities use population forecasts based on the extrapolation of the past population growth to estimate the expected need for housing units and the consequential need for zoned land. In loop R7 we can see this decision rule creating a reinforcing feedback loop. The more land is zoned for housing the more land zoned for housing will remain vacant. The constraining effect of the land availability will be reduced and more housing construction can take place. Eventually, more vacant housing space will be the result. More people will move to Askøy and the population will grow. The expected need for future housing will increase - which in turn will lead to more land zoned for housing.

This chapter revealed numerous important feedback loops governing the land use in the Bergen region. The vast dynamic interactions illustrate the complexity of the different factors involved. Major insights can be gained: first, the zoning activities do not seem to be influenced by the total land available for construction and there is no feedback link between zoning for business and zoning for housing. Second, the only link between the *housing sector* and the *business sector* is the population: The availability of vacant housing space governs the population size. The population size affects the number of local service positions and subsequently the number of jobs. The number of jobs influences the growth in population. Third, the availability of business space influences the number of businesses locating and consequently the number of jobs, while the availability of housing space influences the population size. Fourth, supply and demand for housing and business space affect the construction activity of real-estate firms, as does the availability of zoned land, which can have a potentially constraining effect.

5.3 Stock and Flow Diagram

In this chapter the stock and flow structure will be described by subdividing the model into main sectors as presented in Figure 10. Each of the sectors will be explained separately. However, due lack of space not all equations and assumptions will be discussed. For more detailed information on the model structure see the full model in iThink which accompanies the thesis. In addition, model equations can be found in the Appendix.

Figure 20 illustrates the simplest model of the jobs-housing ratio namely the number of jobs divided by the number of housing units. A one dimensional array is used to distinguish between high-density and low-density. For land use planning, this distinction is of major interest. It impacts on the need for land and the appropriate location of the different functions. High-density businesses are defined to be job-intensive businesses such as headquarters and banks. Low-density businesses include industrial businesses and storage rooms. They are characterized by having relatively few employees but a lot of land. High-density jobs are jobs in high-density businesses and low-density jobs are jobs in low-density business structures. On the housing side, flats in apartment blocks represent high-density housing units because they accommodate many inhabitants relative to the land they occupy. Low-density housing units include one family houses and other houses which occupy a lot of land compared to the number of people living in them.

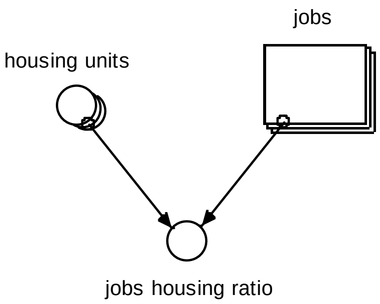

Figure 20. The simplest model of the jobs-housing ratio.

In the business register (*bedriftsregister*), businesses are categorized by their financial activity and the industry sector they belong to. Urban planners, however, are not so much interested in the line of business, as they are in the actual on-site business activity (Asplan Viak, 2009). It is therefore important to separate between the line of business and the business activity on-site. Looking at a business, it is not possible to directly deduct from its line of business what its land needs might be. It is therefore most interesting to look at the development of business space within the different types of business structures, instead of the number of businesses in the different lines of businesses. The type of buildings and the utility space connected to them was obtained by the planning department of Bergen municipality, but had to be estimated for Askøy since no data was available.

The Job Sub-Sector

Figure 21 illustrates the stock and flow diagram (SFD) of the *job sub-sector*. The number of jobs equals the number of people who have their workplace in Askøy. This means that one job equals "one chair" equals one person. *Jobs* are modeled on an aggregated level to include all employment related to production and services. As can be seen in Figure 21, the number of *jobs* is represented by a stock and determined by four different flows. It is increased when people are hired (*hiring rate*) and when *businesses relocating to Askøy* take their employees with them. The number of *jobs* is decreased when employees quit their jobs or are laid off, and when businesses leave Askøy because they relocate to another area. Whether employees are hired or fired depends on the *positions gap*: when there are more *required positions* than filled (=*jobs*), the gap is positive and the required positions are advertised. The *vacancies* accumulate and eventually are filled. It takes time to hire and fire people. This is represented by the *hiring time* and the *time to fire*. When less people are required than are employed, the redundant is laid off. The number of *required positions* is a function expressing both the firm's *perceived need for positions* as well as the actual *potential positions*:

Required positions = MIN (perceived need for positions, potential positions) (1)

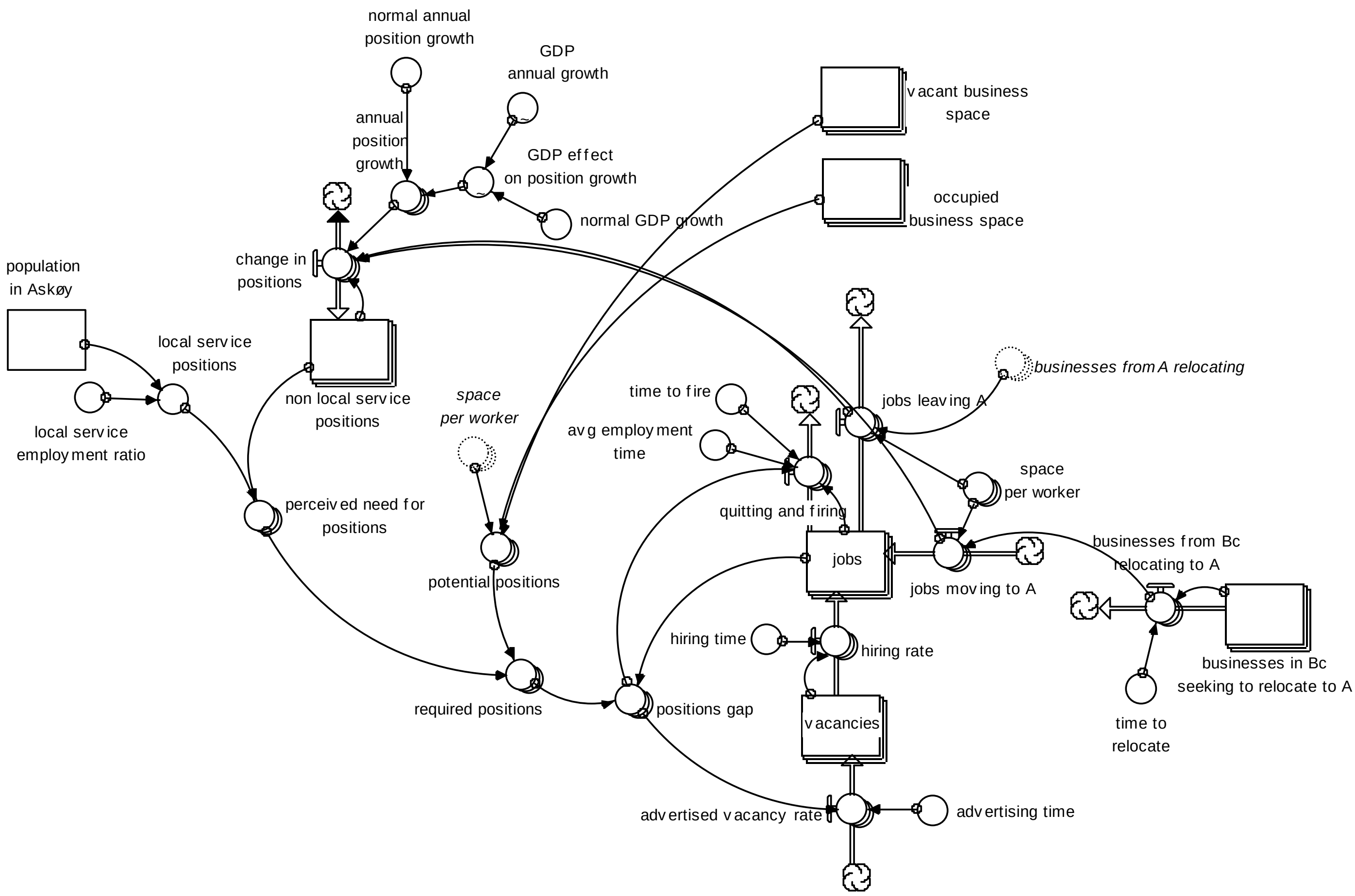

Figure 21. The job sub-sector.

Equation 1 shows that the *required positions* consist of the minimum value of each of the two. There are never more positions required than are possible to accommodate and no more are positions required than are perceived to be needed. *Potential positions* are constrained by the existing *business space* and the average space required by each worker. Currently, *space per worker* is a parameter but in future modeling efforts this may be turned into a variable as businesses will try to reduce the required space per worker. Business space stands for the utility space in business structures used by the diverse sectors in accordance with the highly aggregated definition of jobs. The reason for using utility space as a parameter instead of the number of businesses or the number of business structures, is that the latter do not give any indication as to their size, the size of their premises, or their number of employees. This kind of information – which is central for land use planning - can easily be gained from the information on utility space.

The *perceived need for positions* is a delayed function of the total number of positions which is composed of two main categories: 1) *local service positions* and 2) *non-local service positions*. Non-local service positions include positions in companies located in Askøy not offering services to the local market but serving a bigger region. As mentioned before, local service positions include positions both in the public and the private sector that offer different kinds of services to the local population. The number of people living in Askøy is represented by the stock of *population in Askøy*. The size of the population influences the number of *local service positions*. More of these positions will develop as the population rises. This is represented in the model by multiplying the population in Askøy with a *local service employment ratio*. The number of *non-local service positions* is represented as a stock determined by its flow *change in positions*:

Change in positions = non-local service positions*annual positions growth + jobs moving to Askøy – jobs leaving Askøy (2)

Annual position growth stands for the annual fraction of non-local service positions which increase or decrease according to the economic development. In prospering economic conditions, the demand for products and services generally rises and firms need more workers for it to be met. This results in new businesses being founded. In economic downturns, however, there will be fewer jobs: companies have to save money and need to lay off employees. Some businesses might even go bankrupt. These developments are represented by the *GDP effect on position growth*. GDP is exogenous in the model, since the overall economic trend is not modeled. The GDP effect increases the *annual position growth* in cases when the *GDP growth* exceeds the *normal GDP growth* (the latter being defined as the average GDP growth between 2000 and 2011). The shape of the table function is discussed in the Model Analysis chapter.

The Business Construction Sub-Sector

Figure 22 gives an overview of the stock and flow structure of the *business construction sub-sector*. It explains the interrelating factors influencing how much business space is constructed. Figure 22 illustrates business land being divided into the stocks *vacant land zoned for business* and *occupied land zoned for business*. The business space itself is also divided into stocks: namely *business space under construction*, *vacant business space* and *occupied business space*. *Occupied business space* describes firms already located in Askøy. The *occupied business space*-stock is determined by two flows: it decreases when businesses leave Askøy or when they move to a smaller office (the flow *reducing and leaving)*, and increases when businesses move to Askøy or when the office is extended (the flow *extending and moving to A*). Whether businesses in Askøy reduce or extend, depends on their *recent need for business space*. This is determined by the number of workers they employ – assuming that every worker needs a certain-size work space. While low-density businesses need approximately 200 m² per worker, high-density businesses only require roughly 50 m² per worker[8].

Whenever there is *vacant business space*, businesses have the possibility to relocate and move into the vacant structures. The minimum-function in equation 3 ensures that no more businesses relocate than there is vacant business space for:

Businesses from Bc relocating to A = MIN (vacant business space/time to relocate, businesses in Bc seeking to relocate to A/time to relocate) (3)

[8] This numbers are based on own calculations with data on existing business space and the number of people working in high- and low-density businesses. There is, however, some uncertainty since the jobs are classed according to lines of business rather than actual activity on-site.

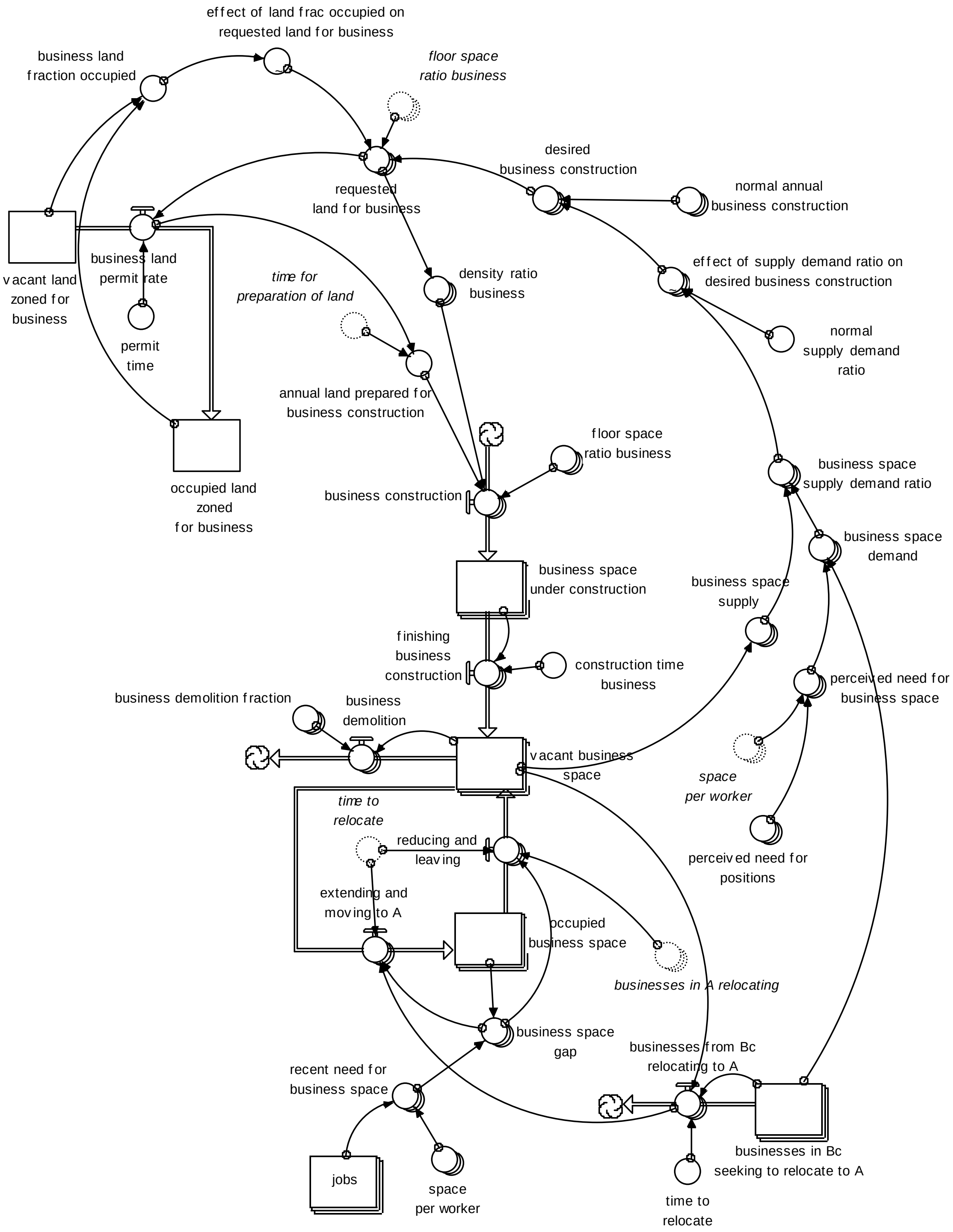

Figure 22. The business construction sub-sector.

Business space is vacated when businesses move out and when the construction work on new business premises is completed. Larger business structures, in particular, are planned and constructed by real-estate companies on direct order of the firms that wish to rent it afterwards[9]. Construction takes approximately two years[10] (*construction time business*). The *business construction* each year depends on the *annual land prepared for business construction* and the *floor space ratio business*. This ratio describes the amount of business utility space per land area. The parameter expresses how effectively the land area is used. In Bergen, low-density structures often have a ratio of approximately 0.1 (10 m² occupied land gives 1 m² utility space) while high-density business structures normally have a ratio between 1 and 2[11].

Before any construction work can start, basic infrastructure such as streets, water, and electricity has to be in place, first. This *time for preparation of land* can be long – especially when the area is far from existing business- or housing areas. In such cases, it takes approximately five to eight years from the time the land was zoned for the construction work to start (Asplan Viak, 2009). This significant delay is accounted for in the model by making the variable *annual land prepared for business construction* a delayed function of the *business land permit rate*. Business construction can only take place on land which is zoned for businesses. Detailed zoning plans with information on how the area will be developed need the construction permission from the authorities. It is for this reason, that the flow *business land permit rate* is a delayed function of the *requested land for business*. Getting a detailed zoning plan approved often takes a long time, especially when the areas that are to be developed are large (Asplan Viak, 2009, 2013). The assumption is that all plans will be approved at a certain point in time. If there are conflicts, the procedure will take longer and involve meetings with the municipality and other stakeholders until an agreement is made. Once a detailed zoning plan has been approved, formerly vacant land is occupied.

The demand for business land depends on the availability of zoned land and the *desired business construction* by the companies. The fact that the amount of *vacant land zoned for business* can be a constraint is represented by the *effect of land fraction occupied on requested land for business*. The shape of the table function can be seen on Figure 71 in the Appendix.

The amount of business space the construction companies desire to construct is affected by the supply (=*vacant business space*) and demand for business space (=*perceived need for*

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[9] Expert interview with Stein Olaf Onarheim at Stadsporten.

[10] Expert interview with Frode C. Hoff at Bergen tomteselskap.

[11] Based on estimations done by Svein Heggelund at the planning department in Bergen municipality (*Etat for plan og geodata).*

business space and *businesses seeking to relocate to Askøy*). This is represented by the *effect of the supply demand ratio on desired business construction*. As soon as any current supply demand ratio is above the normal (defined to be “one”), the effect will be negative. This means there is not as much demand for business construction, since the supply is perceived to be higher than the demand. In order to take into account the time it takes to perceive changes to the supply and demand chain, the *business space supply demand ratio* is delayed with a third order smooth-function of half a year. The *normal annual business construction* is defined to be the average annual business space construction between 2000 and 2011 in the specific urban area.

The Business Location Sub-Sector

The following sector shown in Figure 23 illustrates the choice of location for businesses in the Bergen region. Firms vacate business structures for several reasons. Jakobsen (2000) discovered that there is a high correlation between dissatisfaction and plans to relocate. Of course it is likewise possible for dissatisfied businesses not to consider resettlement. Or for satisfied businesses to discuss resettlement anyway (Jakobsen, 2000). In the model, only dissatisfied businesses not serving the local market, can consider relocation. This is modeled by multiplying the *occupied business space* of businesses not serving the local market with the fraction that is not satisfied. It is assumed to take about two years (*perception time*) for a business to become dissatisfied enough to consider relocation. Whether businesses are satisfied or not depends on several factors. The *fraction satisfied at their current location* and for the unsatisfied businesses the *fraction leaning to Askøy* as a new location are influenced by the same five factors. When firms are not satisfied with their location they will often search for alternatives. They will assess the advantages and disadvantages of resettlement and check out the supply of land sites and business offices. It is assumed that it takes considerable time decide where to relocate to. Therefore the *time to make decision* is set to two years.

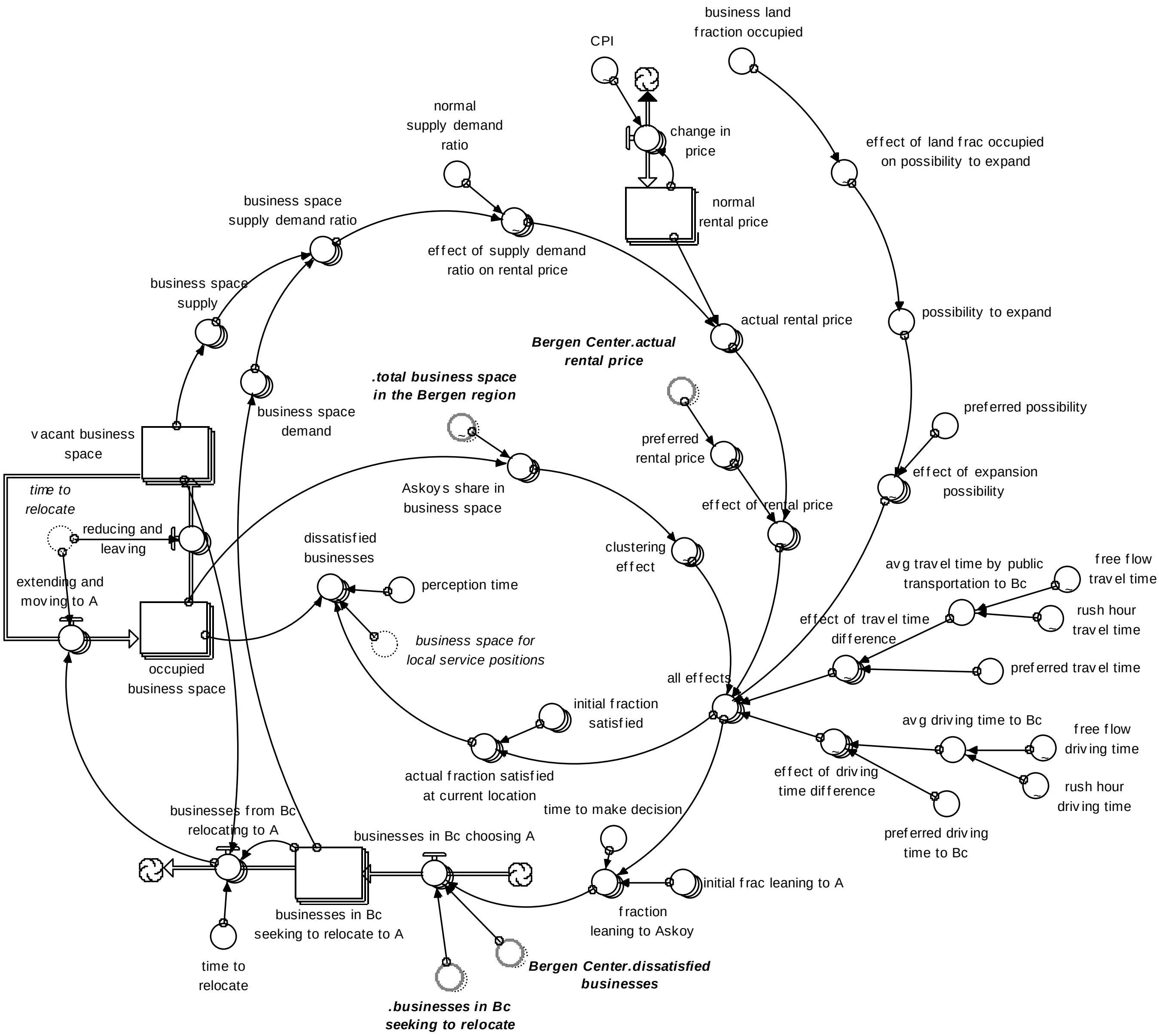

Figure 23. The business location sub-sector.

All location factors included in the model are taken from Asplan Viak (2009) and Jakobsen (2000). Good road accessibility ranks as most important for businesses of all sectors. Especially industrial businesses and wholesalers emphasize the importance of good road connections (Jakobsen, 2000). This location factor is represented by the *average driving time to Bergen center*. For businesses in the Bergen region it is important to be located close to the city center. Their *preferred driving time* to the city center is not more than 30 minutes (Asplan Viak, 2009). When the average driving time is shorter than the preferred 30 minutes, this has a positive effect on the *fraction leaning to Askøy* and on the *actual fraction satisfied at their current location* in Askøy. However, if the driving time exceeds the preferred time span, this reduces the number of businesses considering Askøy as a potential location as well as the number of satisfied Askøy-based businesses. The same applies to *travel time by public transportation to Bergen center*. Especially high-density businesses wish for good accessibility by public transportation and travel time difference has a greater impact on location choice for high-density businesses than it does for low-density businesses. It is assumed that free flow travel and driving time is the most important consideration for relocation. In order to account for the fact that traffic congestion influences the perceived travel time, the average travel time is calculated with 90 % *free flow travel time* and 10 % travel time during peak-hour (*rush hour travel time*). These travel times are exogenous inputs to the model. They are outputs from the transportation model by Brandsar (2013).

As has been discussed before, businesses in the Bergen region consider an area's reputation for being a good business location a deciding factor when making relocation choices. *Askøy's share in business space* out of the *total business space in the Bergen region* is taken as an indicator for this clustering effect. The higher the share, the higher the *clustering effect* and vice versa. The shape of the *clustering effect* is discussed in more detail in the Appendix.

Also the rental price for business structures is an important factor. The vast majority of businesses rent their space as opposed to owning it[12]. The *actual rental price* changes according to the *business space supply demand ratio*. The rental price increases when the demand exceeds the supply, while the price decreases when the supply is bigger than the demand. The *normal rental price*-stock, representing the basis for the *actual rental price*, changes – just as it would for any other product. This change in price is modeled by allowing the price to be affected by the Consumer Price Index (*CPI*), which is exogenous in the model. The *actual rental price* is compared to a *preferred rental price*. It is assumed that the *preferred price* is always slightly lower than rental prices in Bergen center. When the *actual rental price* is lower than the *preferred rental price*, it has a positive effect on the satisfaction-level, while a higher price reduces it. Rental prices are more important to low-density businesses than to high-density businesses (Jakobsen, 2000). This is accounted for in the table function.

As mentioned before, one of the most important reasons for a business to relocate is the lacking possibility to expand at their current location (Asplan Viak, 2009). The table function in the *effect of land fraction occupied on expansion possibility* determines the actual *possibility*

[12] Expert interview with Frode C. Hoff at Bergen tomteselskap

to expand. The higher the amount of occupied business land is, the smaller the *possibility to expand* becomes. The *preferred possibility* is set to 0.7, which means that 70 % of the businesses wish to be able to expand, which is based on findings by Asplan Viak (2009). Then, the *actual possibility* is compared to the *preferred possibility*. If the *actual possibility* is lower than the *preferred possibility*, the fraction considering Askøy and the fraction satisfied in Askøy diminishes and vice versa. Since the possibility to expand is more important for low-density businesses, the effect is stronger for low-density businesses than high-density businesses. See the first graph in Figure 79 in the Appendix for the shape of the table function.

The Population Sub-Sector

Figure 24 gives an overview over the stock and flow structure of the *population sub-sector*. The number of *all housing units* is calculated by dividing the *occupied housing space* and the *vacant housing space* by the average *housing space per housing unit*. For low-density housing units this equals an average of 140 m² while high-density housing units usually equal about 100 m², though there are considerable differences between the individual urban areas[13]. Whether *vacant housing space* is taken into use or whether *occupied housing space* is abandoned and turned into *vacant housing space* depends on the effective *need for housing space* at the time. This in turn depends on the *population in Askøy* and on the number of *people per housing unit*, which also varies between the different urban areas. The *housing preference* represents the fraction of people preferring low- or high-density housing units.

The stock of *population* is determined by *annual net births* and by *people moving to Askøy*. The number of *people moving to Askøy* depends on the number of *people seeking to move to Askøy* and the area's *capacity for new inhabitants*. The *capacity for new inhabitants* is calculated by the number of *vacant housing units* multiplied with the average number *of people per housing unit*. In a no-nonsense way this calculation gives credit to the fact that not more people can move to Askøy than there is actually room for. The number of *people seeking to move to Askøy* depends on two factors: First, on the housing situation in the area. This is represented in the model by the *housing vacancy fraction* having an effect on the migration. The

[13] Values are obtained by dividing the low-density housing utility space by the number of low-density housing units in every urban district. The same is done for high-density housing units. Data on housing space and housing units are obtained from the planning department of Bergen municipality *(Etat for plan og geodata)*. The number of housing units in Askøy is obtained from SSB, with the housing space having been estimated because no data was available.

assumption is, that people need considerable time to perceive and react on changes in the housing sector. To account for that delay, a smooth-function is used to describe the *effect of housing vacancy on people seeking to move to Askøy*. Second, the number of people wanting to move to Askøy depends on the number of job vacancies. Job vacancies include all vacancies in the region, not only in Askøy. Here, too, the effective *job vacancy fraction* at the time is compared to the *normal job vacancy fraction*. When more jobs are vacant than usually, more people will seek to move to Askøy and vice versa. Therefore, the same perception delay is used as in the effect of vacant housing. These two effects are then multiplied with the *normal migration*. The *normal migration* is defined to be the average of the net migration to Askøy between 2000 and 2011. See Figure 76 in the Appendix to see the shape of the table function and the assumptions based on it.

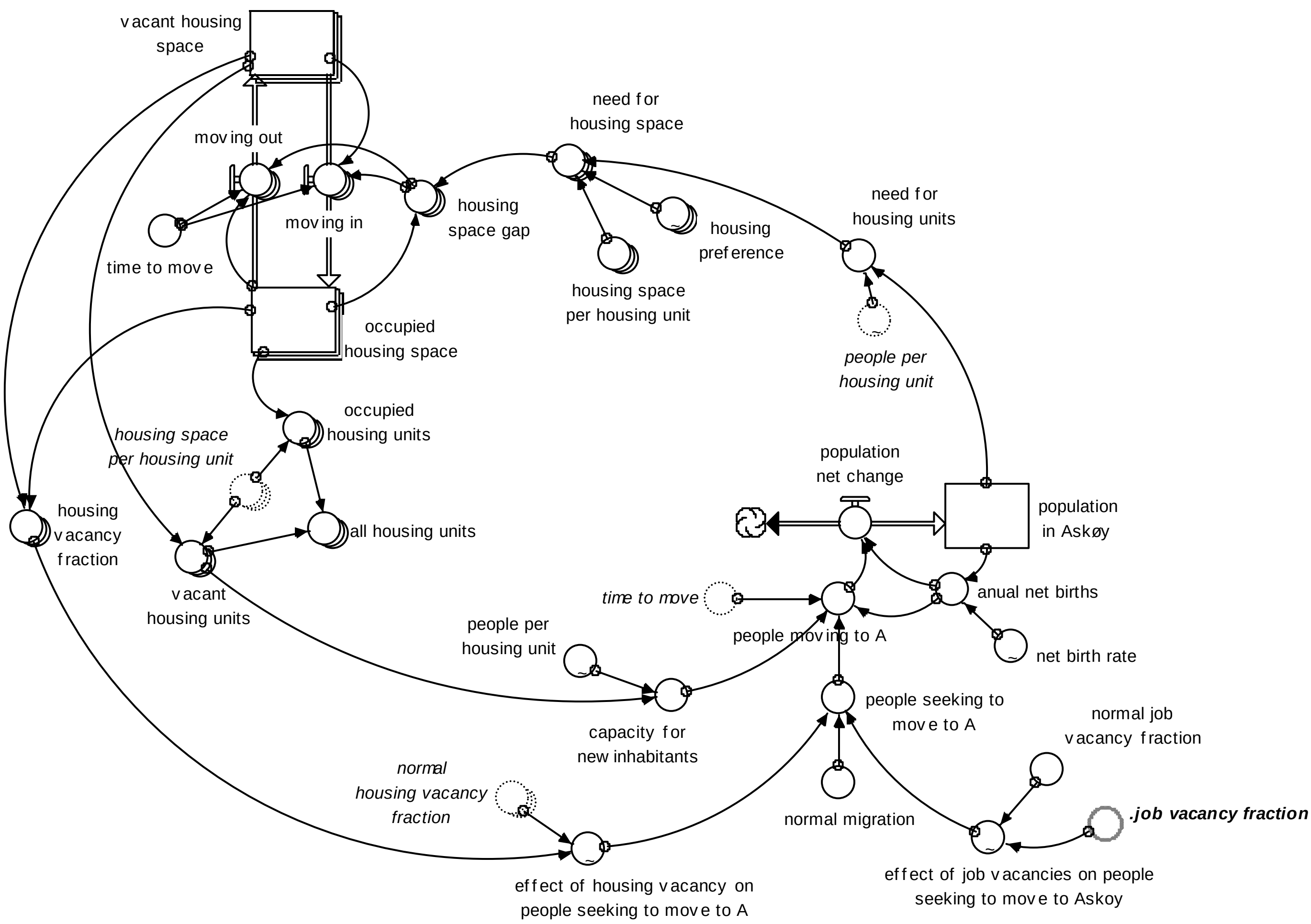

Figure 24. The Population sub-sector.

The Housing Construction Sub-Sector

The SFD of the *housing construction sub-sector* is shown in Figure 25. This sector is very similar to the *business construction sub-sector*. Here, too, the housing land is divided into the stock of *vacant land zoned for housing* and the stock of *occupied land zoned for housing*. The housing space is divided into three stocks: *housing space under construction*, *vacant housing space* and *occupied housing space*. *Vacant housing space* increases when more housing space is constructed (constructed meaning finished and ready to move in) than demolished. The amount of housing construction projects that are started depends both on the *annual land prepared for housing construction* as well as the average housing space per land area. This figure is expressed by the *floor space ratio housing*. Just as with business construction, *housing construction* can only take place where the main infrastructure such as streets, water and electricity is in place. Also, *housing construction* is restricted to land with a detailed zoning plan which has been approved by the authorities. The *density ratio housing* determines how much of the land area prepared for construction will be used for low-density- and how much for high-density housing.

According to Orderud (2005) and Barlindhaug and Nordahl (2005) housing construction is market steered and economic yield is a central objective. In the model this is represented by the effect of the *housing vacancy fraction* on *desired housing construction*. Whether the *desired housing construction* is higher or lower than the *normal annual housing construction* (which is defined as the average annual housing construction between 2000 and 2010) depends on how much of the existing housing space is vacant. When the *housing vacancy fraction* is higher than normal, the demand for housing construction will equally be higher than normal.

Just as with the *business sector*, the *requested land for housing* depends not only on the expected profit but also on land availability, a fact represented in the chart by *the effect of land fraction occupied on requested lad for housing*. The fraction of occupied housing land is calculated by dividing the occupied land by the total land zoned for housing.

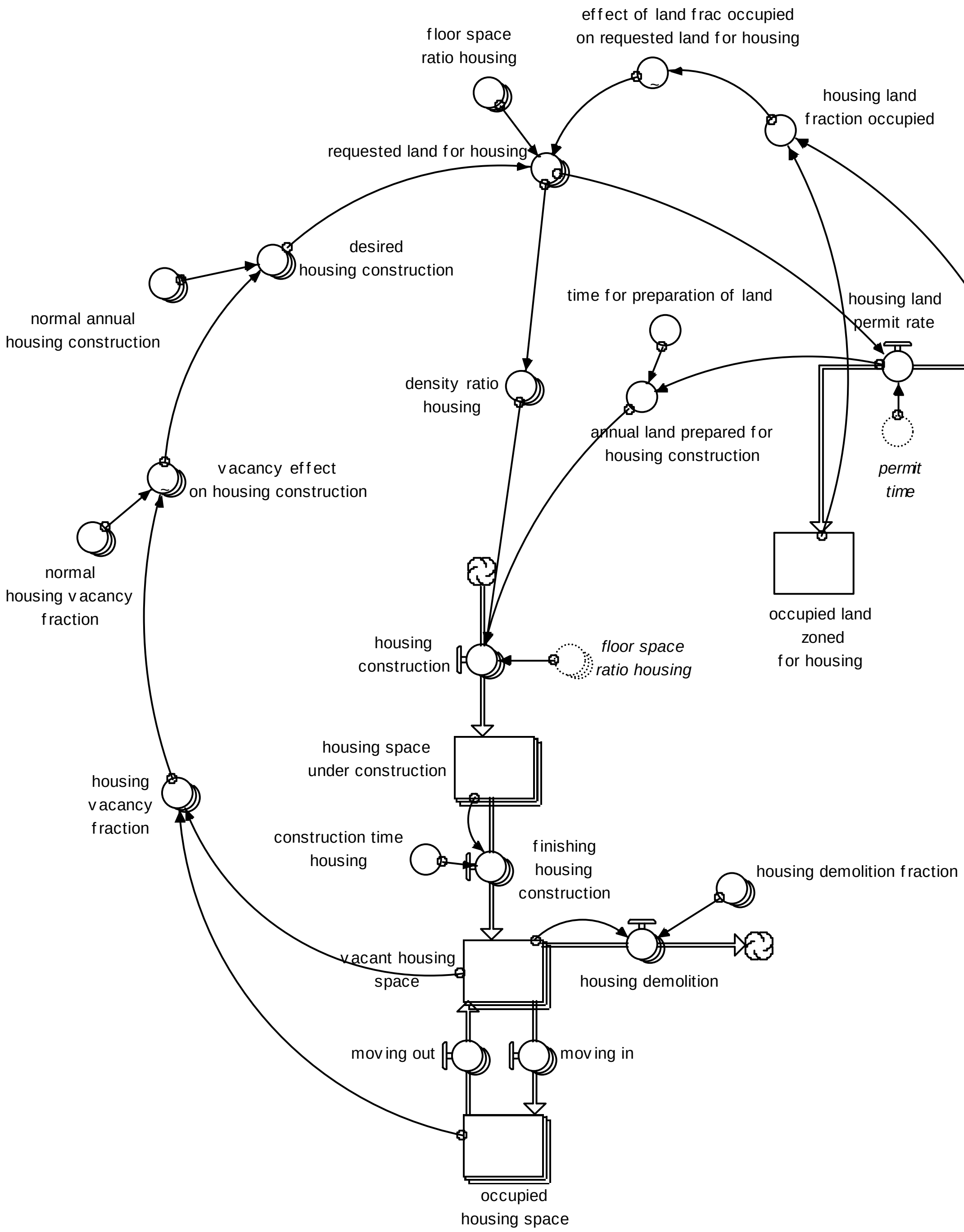

Figure 25. The housing construction sub-sector.

The Land Use Planning Sub-Sector

The last sector presented depicts the *land use planning sub-sector* shown in Figure 26. It illustrates the decision processes regarding the zoning activities of the municipal planning authorities. Municipal authorities increase the stocks of *vacant land area zoned for business* and *housing* by zoning more of the *total available land* area. This zoning process is conducted in four year intervals by the municipality (*zoning interval*). Every four years, a new city government is elected and they have to set up a new plan for the municipality's future development. This municipality plan includes a land use plan where different areas are zoned for different purposes. How much land is newly zoned for housing depends on the *needed and for housing* which in turn depends on the *expected need for housing units*, the *floor space ratio housing* and the average *housing space per housing unit*. The authorities estimate this expected need for housing units by using population forecasts based on an extrapolation of the past years' annual population growth. In the model, this is captured with the TREND-function:

Expected annual population growth = TREND (population in Askøy,1,0.02) (4)

The authorities in Askøy municipality add an additional 50 % *reserve* to the calculated number of housing and another 1% to the expected annual population growth units to be on the safe side (*add factor*). This is not the practice in Bergen municipality. The *population forecast interval* is 10 years in Askøy (Askøy kommune, 2007, 2010) and 12 years in Bergen (Bergen kommune, 2001, 2008b). Surprisingly, there is no clear decision rule for the *zoning for business* purposes. An expert interview with planners working at the planning department of Bergen municipality confirmed that there is no systematic decision rule operating. Therefore it is kept exogenous in the model.

It is assumed that business premises and housing units have a certain lifetime expectancy like any other physical infrastructure. As they age, they become less suitable for modern requirements and consequently are demolished and replaced by newer structures. This *housing/business demolition* flow is defined by multiplying the *vacant business space* with the *demolition fraction*. The planning authorities in Bergen assume that approximately 0.09 % to 0.36 % of the total existing housing units is demolished per year (Bergen kommune, 2001, 2008b). No parameter was obtained for the business sector, so it is assumed that the *business demolition fraction* is the same as the *housing demolition fraction*. Only the *business demolition fraction* of low-density business structures in Bergen center is assumed to be higher due to high land value and zoning permissions that allow for more efficient utilization. It is assumed that 10 % of vacant low-density business space is demolished per year in Bergen center. Once structures are demolished, the land they occupied becomes available again and can be rezoned differently. However, only a fraction of the *abandoned business/housing land* is rezoned for other purposes. It is assumed that 75 % of the abandoned land area stays zoned for either housing or business purposes (*fraction still zoned for business/housing*).

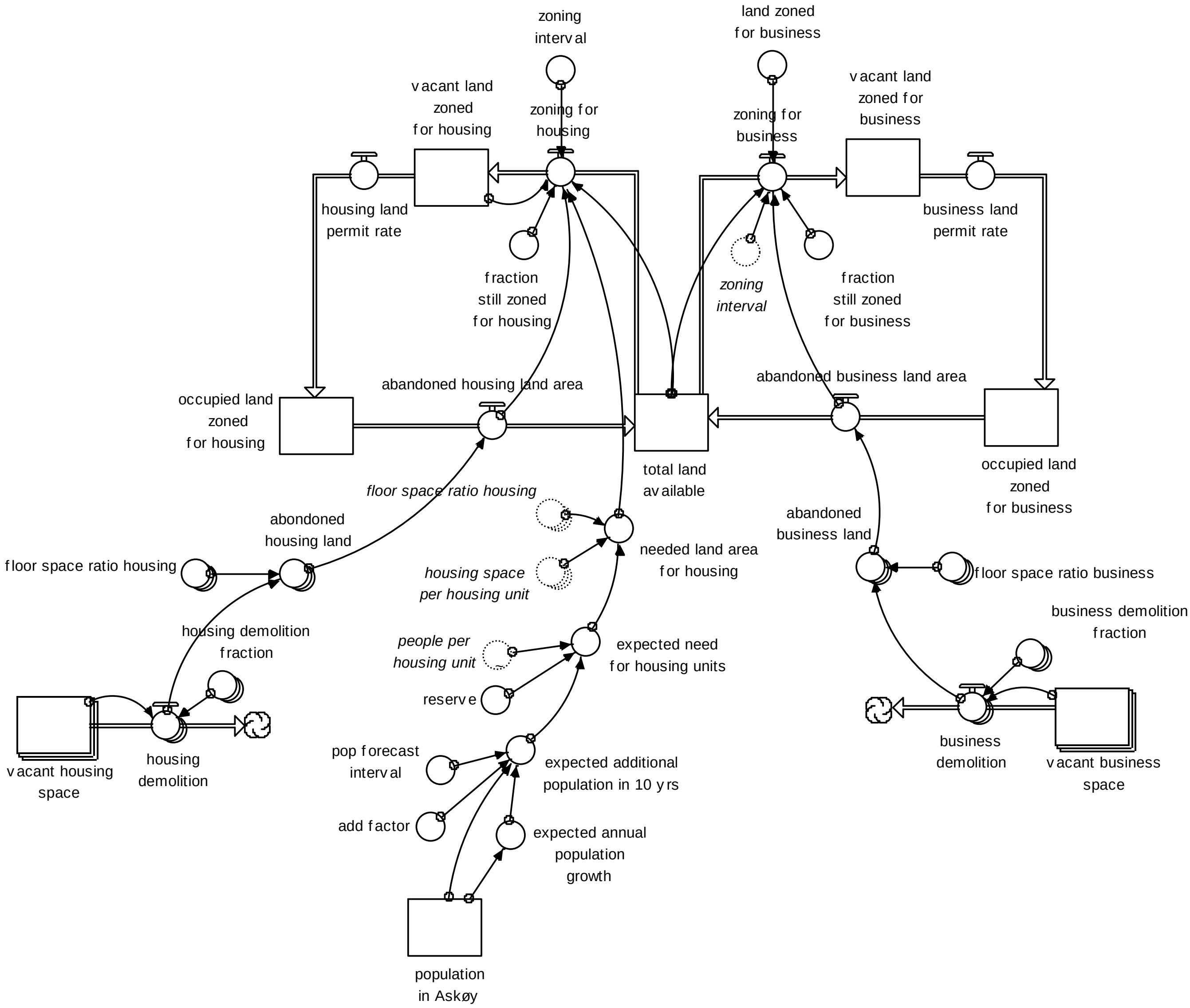

Figure 26. The land use planning sub-sector.

The presented stock and flow structure of the land use sub-models in the *Bergen Land Use Model* contains numerous significant delays in the urban system: it takes several years for land that is zoned to finally be built upon due to the required detailed zoning plans, construction permits and the need for infrastructure. The construction work itself takes approximately two years before the structure is available. Firms and private people need time to react on changes in the supply of business space and housing space. The planning authorities in turn have to react on these decisions. They work with a planning interval of 10 to 12 years.

6. Model Analysis

A model is a theory and as "*any other theory that refers to the world (it) relies on imperfectly measured data, abstractions, aggregations, and simplifications*" (Sterman, 2000, p. 847). To be able to gain confidence in a model and to understand its usefulness it is important to test and analyze it. The purpose of testing and analysis is to find formal and mental flaws in the model structure and to reveal the limitations of the model. Finding limitations is the prerequisite to improving the model and using it correctly. The model's boundary, time horizon, level of aggregation, and its behavior in extreme conditions must be examined and challenged in relation to its purpose.

A series of iterative tests has been conducted to validate the model structure while proceeding in extending the model. The first step after a new structure has been added to the model was to check the unit consistency. Also a "*face validity test*" was conducted throughout the modeling process. This test is a "*common sense test*" (Ford, 2010, p. 166) which means that the model is evaluated in terms of reasonableness. The objective is to assess whether the model, its structure and its parameter values, make sense, to assure that all equations are logically correctly formulated, and to safeguard that all relationships represent reality correctly. The review of literature provided the basis for the dynamic hypothesis presented in the last chapter. Each sector in the model is established on literature or on information gathered from expert interviews. Model parameters are – whenever possible – based on data from local, regional and national databases. Parameter values not to be found in databases were acquired by reading valid literature and conducting expert interviews. In some cases values had to be chosen arbitrarily by myself, because of a lack of alternatives.

This chapter gives a summary of the conducted tests and highlights the conclusions which can be drawn from the testing results. All tests are presented in more detail in the Appendix.

Reference Mode Replication Test

To test whether the model replicates the historically observed behavior, the model was initialized with historic data and parameter values. Whenever there was no data available, estimates of historic values were used. This model has numerous reference modes: the number of jobs and housing units for all six urban areas. In this chapter only the reference modes for Askøy and Bergen are presented and discussed[14].

Figure 27 and Figure 28 show the historic development of jobs in Askøy and Bergen center compared to the modeled behavior. The replicated behavior for Askøy fits the data very well and the modeled behavior for Bergen center is also relatively accurate. The simulated number of jobs increases somewhat faster in the first years, while it stays slightly below the historic behavior in the last six years of simulation. For Bergen center there is a lack of roughly 2 500 jobs (76 858 jobs compared to 79 390 jobs) in 2011. In the model, a further increase of jobs is constrained by the lack of business space - which in turn is caused by insufficient land zoned for business. The small oscillations in the beginning are caused by the initial stock values for vacant business space and job vacancies.

Figure 27. Historic (1) and modeled (2) jobs in Askøy.

[14] The enclosed version of the model in iThink includes a page on the Interactive Learning Environment where all replicated reference modes can be studied.

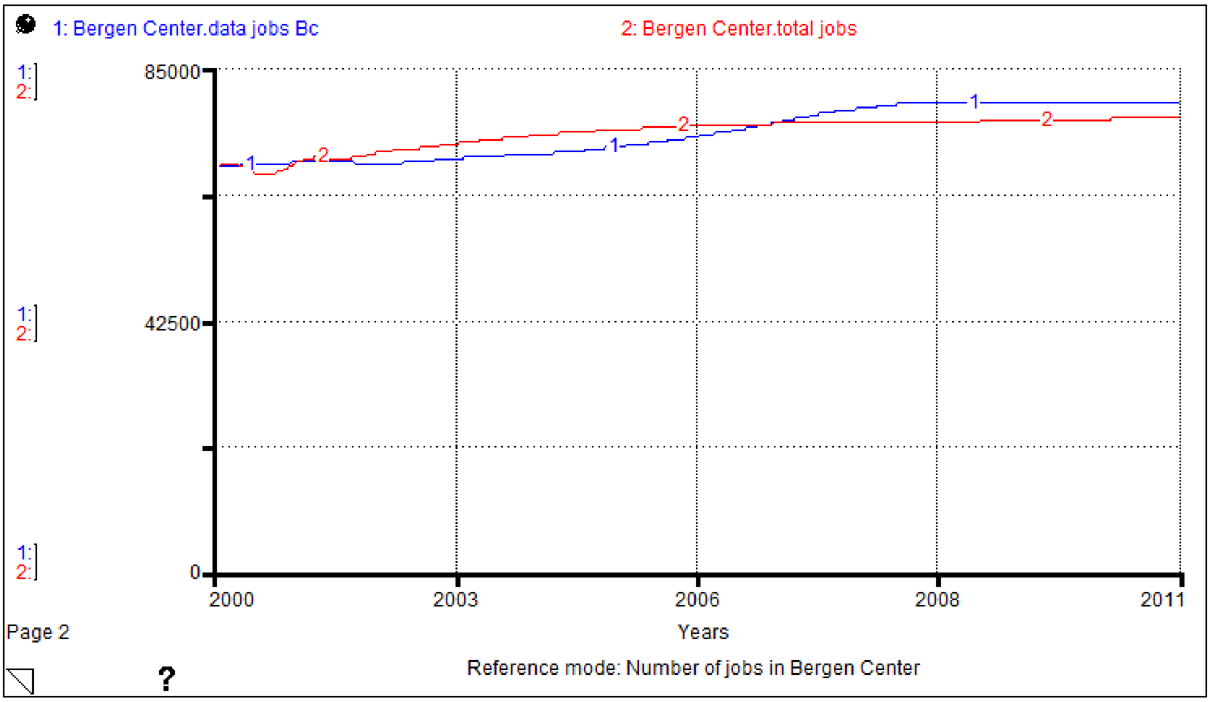

Figure 28. Historic (1) and modeled (2) jobs in Bergen center.

Figure 29 and Figure 30 illustrate the modeled behavior compared to the historic behavior of the development of housing units in Askøy and Bergen center. Here the replicated behavior for Bergen center has a close to perfect fit, while there is a small difference in the modeled behavior for Askøy. The main reason for this is that the model underestimates the construction of high-density housing units. Likely this is because the model is not well suited to replicate the demand for low and high-density housing units. Such information goes beyond the model's scope.

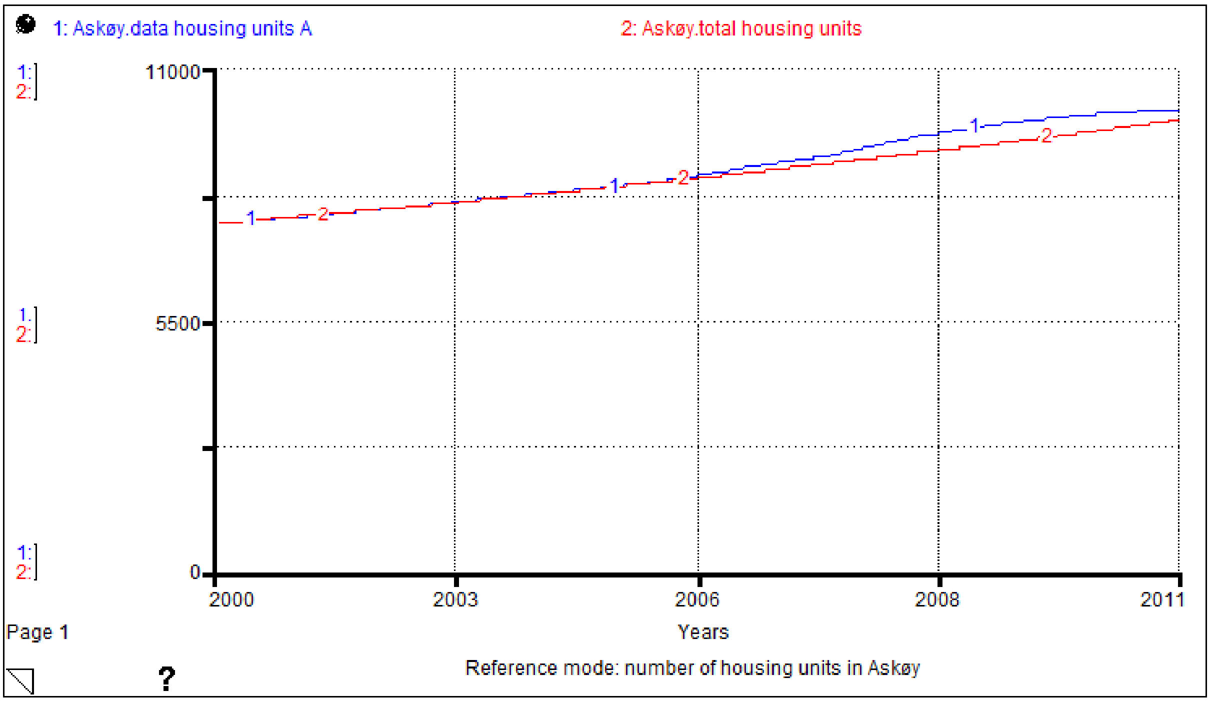

Figure 29. Historic (1) and modeled (2) housing units in Askøy.

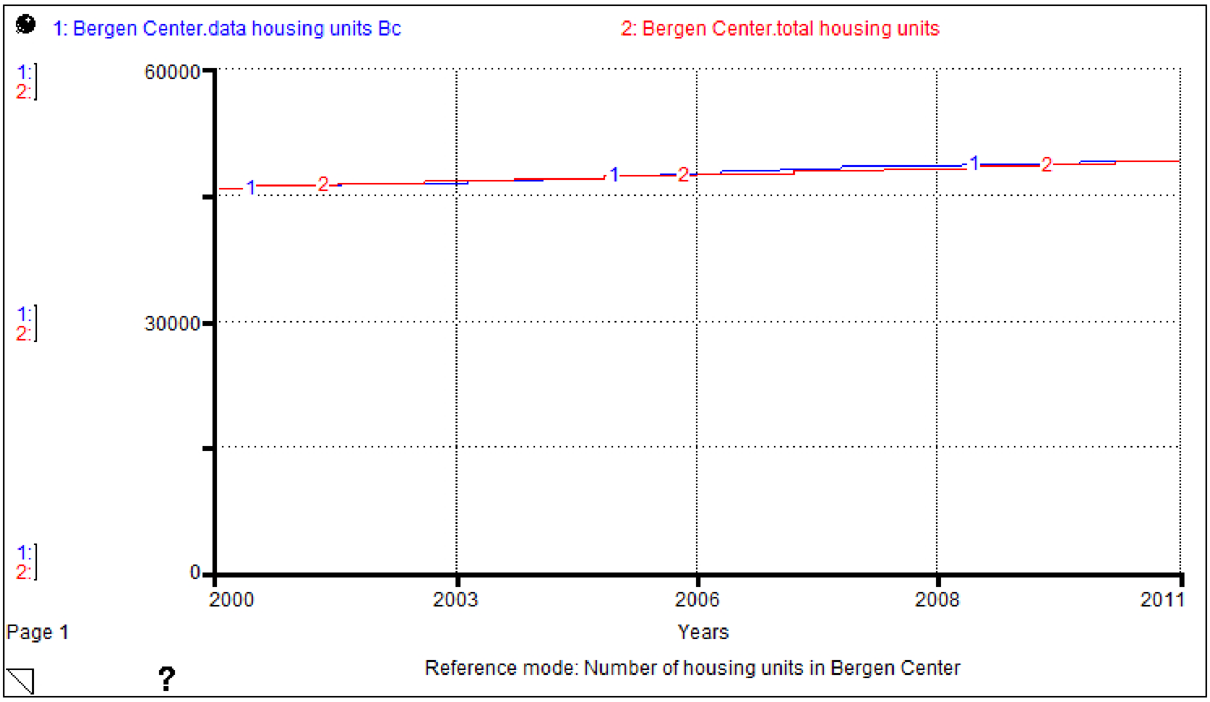

Figure 30. Historic (1) and modeled (2) housing units in Bergen center.

Cutting the Loops

The structure-behavior test called "Cutting the loops" is conducted to compare the model's behavior with and without certain feedback: feedback loops are cut one by one and the model's behavior is assessed both with and without the loops. The purpose is to locate the source of the endogenous dynamics and to use the insights gained in order to design policy options.

Graphs showing the model's behavior with and without the cut loops and more details about the test can be found in the Appendix. The test reveals that the demand for business space by businesses seeking to relocate plays an important role in the construction of business structures and - as a consequence - plays a part in explaining the development of jobs. Similarly, supply and demand for housing units plays a central role in explaining housing construction activity and consequently the development of housing units. The demolition of low-density business structures in Bergen center helps generate a growth in jobs in the future. This, however, is of little importance for the recent generations of jobs up until 2011. The test further reveals that the limited availability of suitable zoned land for housing and business accounts for the speed in which jobs and housing units develop. Without loop C6 (in the *business sector*) and loop C15 (in the *housing sector*), the number jobs and housing units would grow more. In accordance with this finding, cutting the loop R7 - which describes the authorities' decision rule for the zoning of land for housing - revealed its central role in explaining the growing number of housing units.

Essentially, two main insights can be gained from the structure-behavior test. First, the demand for housing units and business structures plays an important part in explaining the growth in housing units and jobs, respectively. Second, the limited availability of zoned land for both housing and business is responsible for the pace of growth of both housing units and jobs. The zoning decision rule for housing facilitates the increase in housing units. This proves that policies successful in influencing the availability of land and the demand for business and housing structures could counteract the jobs-housing imbalance.

Parameter Sensitivity Test

In parameter sensitivity analysis, changes to parameter values within the realms of reality are applied to assess the model's sensitivity to it. The test helps to assess the robustness of the model. For a model to be robust, the behaviors obtained as a result of simulations with different values should follow the "*same general pattern*" (Ford 2010, p. 158). The test is undertaken in order to identify effects of uncertainty and to set priorities for further data research. Sterman (2000) mentions three types of sensitivity: We talk about a numerical sensitivity when changes in parameter values lead to changes in the numerical value of the simulation. When parameter changes result in changed behavior pattern generated by the model, this is called behavior mode sensitivity. Policy sensitivity describes what happens when changes in parameter assumptions reverse the policy results and influence the desirability of the proposed policy options.

The test was conducted by identifying parameters in important feedback loops. The model was then run with two alternative parameter values and the simulation results were compared. The extensive parameter sensitivity tests revealed significant numerical sensitivity to some parameter changes. No changes to the behavior pattern were observed. Graphs showing the model behavior can be seen in the Appendix. The model's numerical sensitivity to changes in the table function *effect of expansion possibility* (see Figure 79 and Figure 80) suggests investigating the bearing land availability has on a company's possibility to expand the plant. It is also recommended to examine real-estate-companies' reactions to changes in supply and demand for housing and business structures, since the model is numerically sensitive to changes in the table functions *effect of supply demand ratio on business construction* and *effect of housing vacancy on housing construction*. In accordance with this, it is recommendable to investigate the level of satisfaction businesses feel towards their current location and whether they have concrete plans to relocate. The model is also numerically sensitive to changes in the *space per worker*. It would be useful, therefore, to collect data on the average utility space required per worker for low-density and for high-density business structures. This prepares the way for good estimates of the future need for business space.

Particularly changes to the amount of vacant land zoned for housing and business, will change the numerical value of jobs and housing units substantially. Changes to the floor space ratio for high- and low-density housing and business structures result in notable numerical differences in the values. This confirms the central role of land availability on the overall model behavior. It is highly recommended to dedicate more research effort on the gathering of better data. It is necessary to know more about land zoned for different purposes: how much of it is vacant, how much is occupied? And what are the floor space ratios?

Extreme Condition Test

"*Models should be robust in extreme conditions. Robustness under extreme conditions means the model should behave in a realistic fashion no matter how extreme the inputs or policies imposed on it may be*" (Sterman, 2000, p. 869).

Extreme condition tests are based on major changes in the values of the parameters in the model to observe the model's response. Knowing that the model behaves appropriately under extreme conditions increases the confidence that the model will run appropriately under normal circumstances as well. Several extreme condition tests were conducted whilst the model was constructed. Many times, they provided important insights and helped further improve the model structure and equation. It was possible to react realistically when faced with extreme conditions such as no vacant zoned land, zero or thousands inhabitants or zero or several thousands of jobs.

Equilibrium Shock Test

The purpose of the equilibrium shock test is to identify and correct incomplete and false equations and to improve the understanding of the source of dynamics. The model was shocked in equilibrium condition with three different inputs. In the first test, the shock input consisted of a sudden increase of 10 000 extra inhabitants to the population in each land use model - thus also activating the net birth rate and the migration. This test was conducted so as to understand the role of the population on the overall model behavior. The model reacted as expected with a rise in housing construction, an increase in the number of local service jobs and a consequent increase in business construction. We learn that population is an important factor in the dynamics at work. The second shock test challenged the system with a sudden relocation of businesses in each land use sub-model. The expected result to this test was a rising number of jobs, which was observed in the model's response to the test. In the third test the model was "shocked" by activating exogenous inputs such as the development in GDP and CPI to reveal how much of the observed behavior is created exogenously. The number of jobs increased as expected. The exogenous input recreated much of the development of jobs in Bergen Center while it hardly generated the behavior in Askøy. The reason for this is that Norway experienced a strong growth in GDP between 2004 and 2007, which led to good employment conditions. Bergen center holds most jobs and was therefore affected more by the economic upturn than Askøy which holds mainly local service jobs are not so much affected by economic development. The model's responses to the different equilibrium shock tests can be seen in Figure 88, Figure 89 and Figure 90 of the Appendix.

Boundary Adequacy and Level of Aggregation

The model's boundary defines which variables should be endogenous, which should be exogenous and which to exclude. All important variables and feedback loops essential for the purpose of the model should be endogenous because keeping a variable exogenous means we have no explanation for its behavior. The purpose of this test is to find out whether the boundary of the model is appropriate for the model's purpose (Sterman, 2000). The model's boundary can be described by drawing a table which depicts all variables in the model and provides information on whether they are endogenous, exogenous or excluded (see Table 1).

Table 1. The model's boundary.

Endogenous	Exogenous	Excluded
• Zoning for housing • Zoned land for housing / business • Housing / Business space construction • population migration • Expansion prospects for businesses • Rental price for business structures • Clustering effect • Job creation / destruction	• Zoning for business • Economic development / annual position growth (GDP) • Price inflation (CPI) • Population net births • Area's accessibility	• Land price • Housing price • Business structure characteristics • Other location factors

The variables included in the model are those considered vital for understanding the location of jobs and housing units in the area of interest. The purpose of the model is to investigate the causes of the imbalance between jobs and housing units. Therefore, the major forces governing the imbalance must lie within the model's boundary. The zoning activity (which governs the availability of land for housing), the factors influencing the construction activities (supply and demand as well as land availability) and factors determining the location of businesses are endogenously included in the model. The fact that zoning for business is exogenous is an interesting finding by itself because the activity is not exogenous on purpose but rather no decision rule governing this activity could be identified. Research reveals that the vast majority of businesses rent their location[15] which makes modeling land prices unnecessary and including the rental price for business structures more important. Modeling housing prices was not felt to be insightful enough to justify the increase in the model's complexity (caused by including housing prices in the model).

The level of aggregation is relatively high. Apart from distinguishing between high- and low-density (land-intensive and land-extensive), other differences – regarding the characteristics of jobs, housing units, business structures or type of firms for example – are not included in the model. This was felt to be beyond the scope of this work and not necessary for the purposes of the model. Including these features would have rendered the model more complex than useful. The model captures three important business location factors endogenously (expansion prospects, rental price, clustering effect) and two exogenously (the area's accessibility indicated by the travel time by car and public transportation). Of course, there are many more factors businesses take into consideration when deciding where to relocate to. However, it is felt that the factors included can explain the business location choice quite well and including more factors would be beyond the scope of this work and would not necessarily add additional insight.

Time Horizon

The historical time horizon for the explanatory model is 12 years (2000-2011). Ideally it should span a longer time period. Land use planning, construction work and changes in the market are time consuming processes and include numerous significant delays. Therefore, it takes many years before significant changes in the system can be seen. The reason for starting simulation in 2000 is mainly owed to data availability. For the policy model, the simulation runs until 2040 so as to account for the long delays in the system.

[15] Expert interviews with Frode C. Hoff and Stein Olaf Onarheim.

7. Policy Design

In the previous chapters a dynamic hypothesis has been established which gives one possible explanation of the causes for the imbalance between jobs and housing units in the Bergen region. Extensive tests have been conducted to reveal flaws in the designed model, to gain extra insights into the source of dynamics, and to identify important leverage points in the system. This chapter concentrates on the second research question: What can be done to reduce the current imbalance? As Ford (2010, p. 167) puts it: "*The final test of model usefulness is whether the modeling process leads to better understanding of policies to improve system behavior*". The main findings suggest that land availability and the demand for it are the most important leverage points in the explanatory model and are therefore the most suitable means to control land use. Since it is not possible to change or control the demand for land, the suggested policies aim to change the supply of land. Three different policy options have been developed and tested to investigate whether and how the imbalance could be improved.

7.1 Arranged Relocation Policy

One suggestion on how to create geographic balance is put forward by Jakobsen (2000). Planning authorities are to zone and develop land sites according to the requirements of specific land-extensive businesses, thereby controlling their location. Bigger firms in the industrial sector – for example shipyards – need specific qualities for their plot, which can be difficult to obtain. Due to a lack of alternatives, they will likely (re)locate where the authorities has planned for them. Jakobsen (2000) further assumes that bigger firms settling in a certain place can convince smaller firms to do the same – so an arranged relocation and the subsequent establishment of other firms close by, might help achieve a better balance. Askøy municipality tries to attract more businesses by facilitating the relocation processes of bigger firms with short processing times and a good dialog[16]. The relocation of Frank Mohn AS and Framo Engineering from Bergen to Askøy are two examples for this (Gaasemyr & Glatved-Prahl, 2009; Øyehaug, 2012).

To test the effectiveness of this policy, a small structure was added to the *land use planning sub-sector* and to the *business construction sub-sector*. The added structure in the *land use*

[16] Expert interview Eva Herdlevær at the planning department in Askøy municipality.

planning sub-sector in Figure 31 represents actions required by the local authorities. The variable *desired arranged relocation* stands for a business currently located in Bergen center about to relocate to Askøy. The size business is measured by the utility floor space it occupies and with the help of the *floor space ratio business*, the *policy specific land area* needed for the business is calculated. Surveys reveal that most businesses are dissatisfied with the long waiting time between the zoning of an area and the beginning of construction work (Asplan Viak, 2013) so shorter permit- and processing times might be instrumental in attracting the so-dissatisfied firms to relocate. The reason this cannot be implemented is that there might always be external objections to the planned projects. Therefore the *policy permit time*, which represents the time needed to approve detailed zoning plans and to give a construction permit, can be chosen freely when simulating the policy in the enclosed model version in iThink.

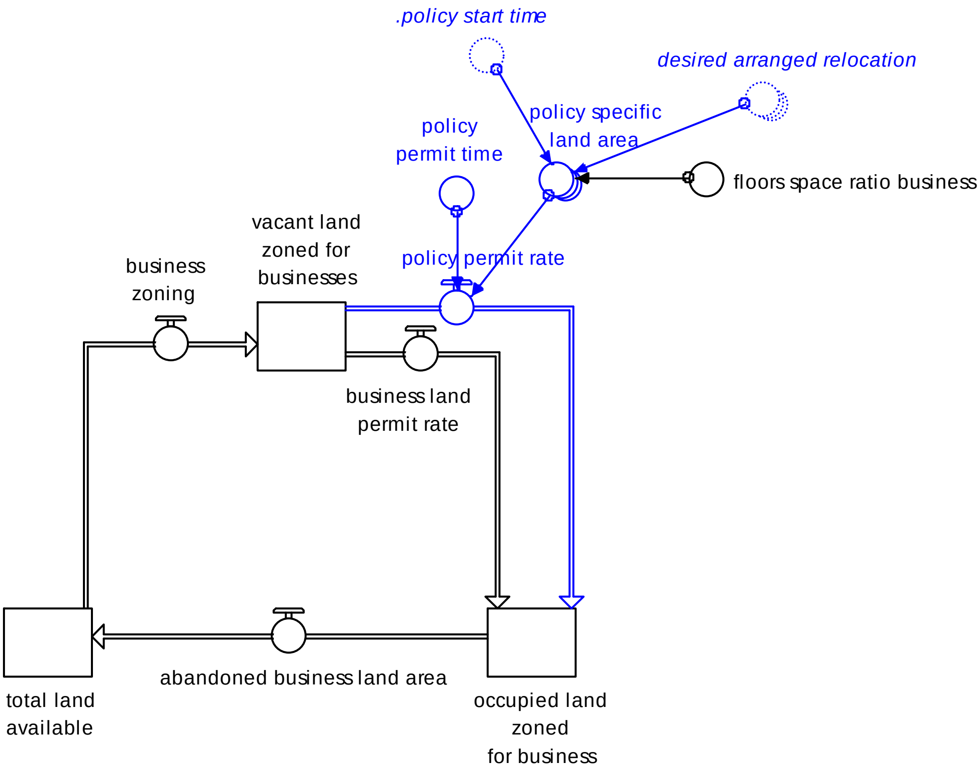

Figure 31. SFD for the *Arranged Relocation Policy* in the land use planning sub-sector.

The added structure in the *business construction sub-sector* in Figure 32 illustrates the actions required by construction firms and the businesses themselves. Once the permit is granted, the land site is prepared for construction (this takes approximately two years) and after that the construction work starts. As soon as a relocation agreement is made, the business – at this point still located in Bergen center – waits for its relocation. After the specific business structure has been constructed and is vacant, the business can relocate. By relocating, it occupies business space in Askøy and leaves space vacant in Bergen Center. The number of jobs in Askøy is increased by the relocation.

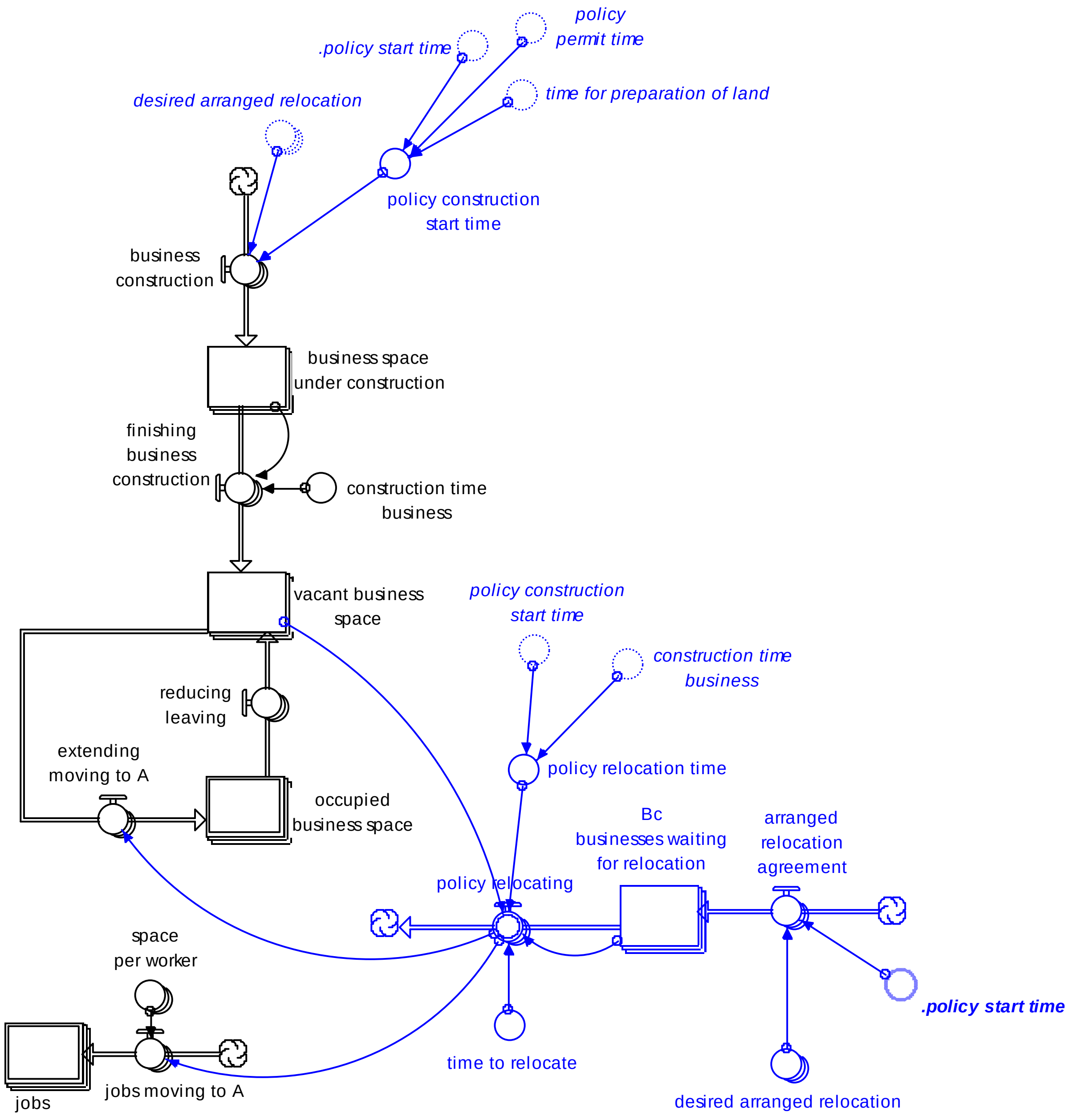

Figure 32. SFD for the *Arranged Relocation Policy* in the business construction sub-sector.

The policy is tested by arranging the relocation of a firm consisting of 30 000 m² low-density structure and 30 000 m² high-density structure in the year 2014. This corresponds to a large industrial plant combined with the firm's headquarters or office building. A real world example for this is Framo Engineering which is about to relocate in Askøy and will bring around 800-1000 new jobs to the municipality (Øyehaug, 2012).

Figure 33 shows the simulation result for the number of jobs in Askøy without the policy - (blue line, 1) and with the policy implemented in 2014 (red line, 2). As can be seen, the number of jobs increases roughly five years after the policy's implementation. The overall effect on the total number of jobs, however, is not immense. In addition, the relocation does not seem to attract many other firms. This suggests that even a firm of this size and jobs-volume cannot alter the clustering effect enough for many other firms to be attracted. To see whether this is due to the chosen shape of the clustering effect, different curves are tried. Even a substantial increase to the clustering effect did not have any significant impact on the policy. Simulation results with different clustering effects can be seen in the Appendix.

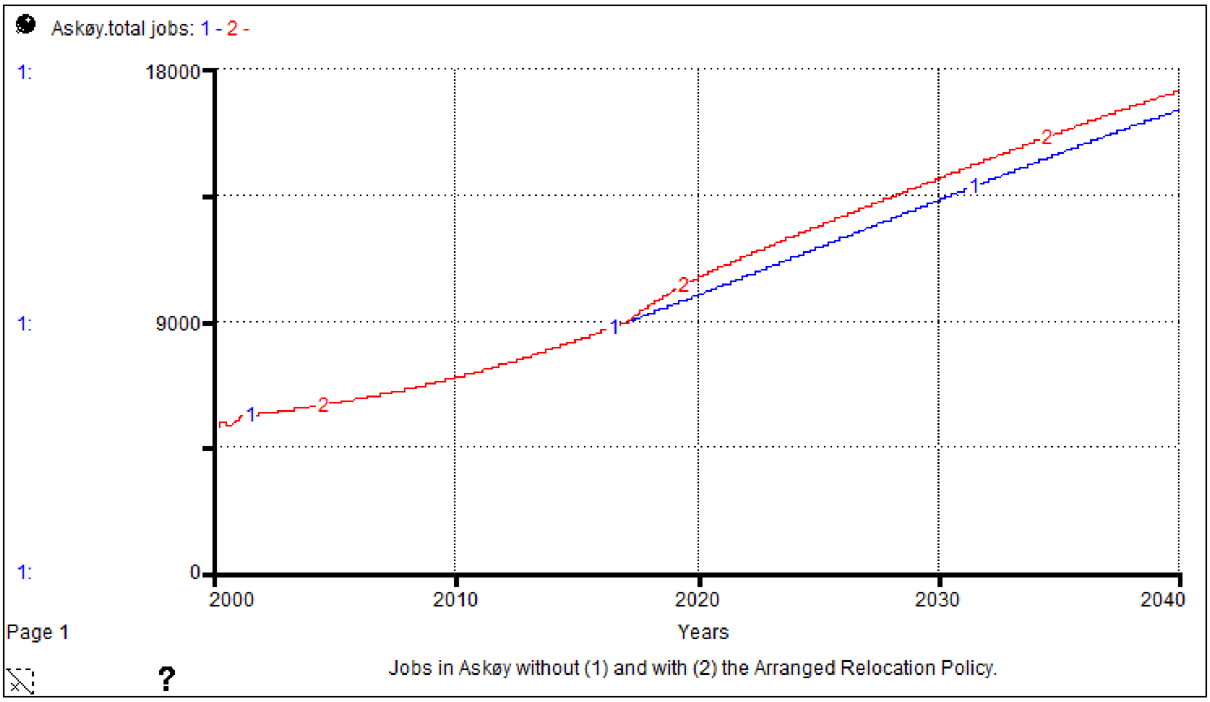

Figure 33. Jobs in Askøy without (1) and with (2) the *Arranged Relocation Policy*.

The effect of the suggested policy seems to be rather small. Of course 1000 new jobs in a municipality with a very limited job market are by far better than none but, none the less, taken by itself it does not make a significant improvement to the imbalance. In addition, it must be considered that a firm of this kind might provoke intense protests by the inhabitants, who might not be happy about a big industrial plant and office buildings in their neighborhood and fear the traffic, noise and pollution it might cause.

7.2 Rezoning Policy

One central policy already implemented by the Bergen municipality, is the rezoning policy. It plans to transform central parts of Bergen where currently there are still many low-density industrial firms. The planning authorities have adopted several zoning plans for these areas (for example Mindemyren and Solheimsviken) which allow for the increase of the floor space ratio and the construction of office buildings, schools and apartment blocks replacing the old industrial structures. The objective of this rezoning policy is to increase the densities of valuable central urban areas, and to mix apartments, services, and workplaces. A specific aim is to increase the share of private residence in these central areas (Bergen kommune, 2008b). Miller (1975, p. 135) states that "*by influencing the price and availability of land for urban, industrial, and residential development, rezoning policies offer an important leverage point for attaining an improved balance of population, housing, and business*".

To test whether this policy can improve the balance, a small structure was added to the *Bergen center land use sub-model* (see blue variables in Figure 34). The policy is run through the model by increasing the *demolition fraction* of low-density businesses in Bergen center. Doing so is justified by the assumption that new zoning planes encourage a more effective land-utilization. When new zoning plans allow for a higher floor space ratio and opens for mixing areas for different uses, this causes the land value to rise, which in turn is undesirable for low-density businesses. Their rental agreements might not be extended by the property owners who might want to invest in more modern structures and take advantage of the new zoning plans. Once the old low-density structures are vacated, they will be demolished. Parts of the abandoned land can be rezoned for housing. When testing the policy, the fraction of *land rezoned for housing* can be chosen freely. Once this land is rezoned for housing and/or businesses, and permits have been obtained, new structures can be built. However, with the higher floor space ratio and the majority of the structure being high-density, office buildings will be constructed rather than industrial firms and storage halls, and apartment blocks rather than family houses. The fraction of high-density structures, too, can be freely determined when running the policy.

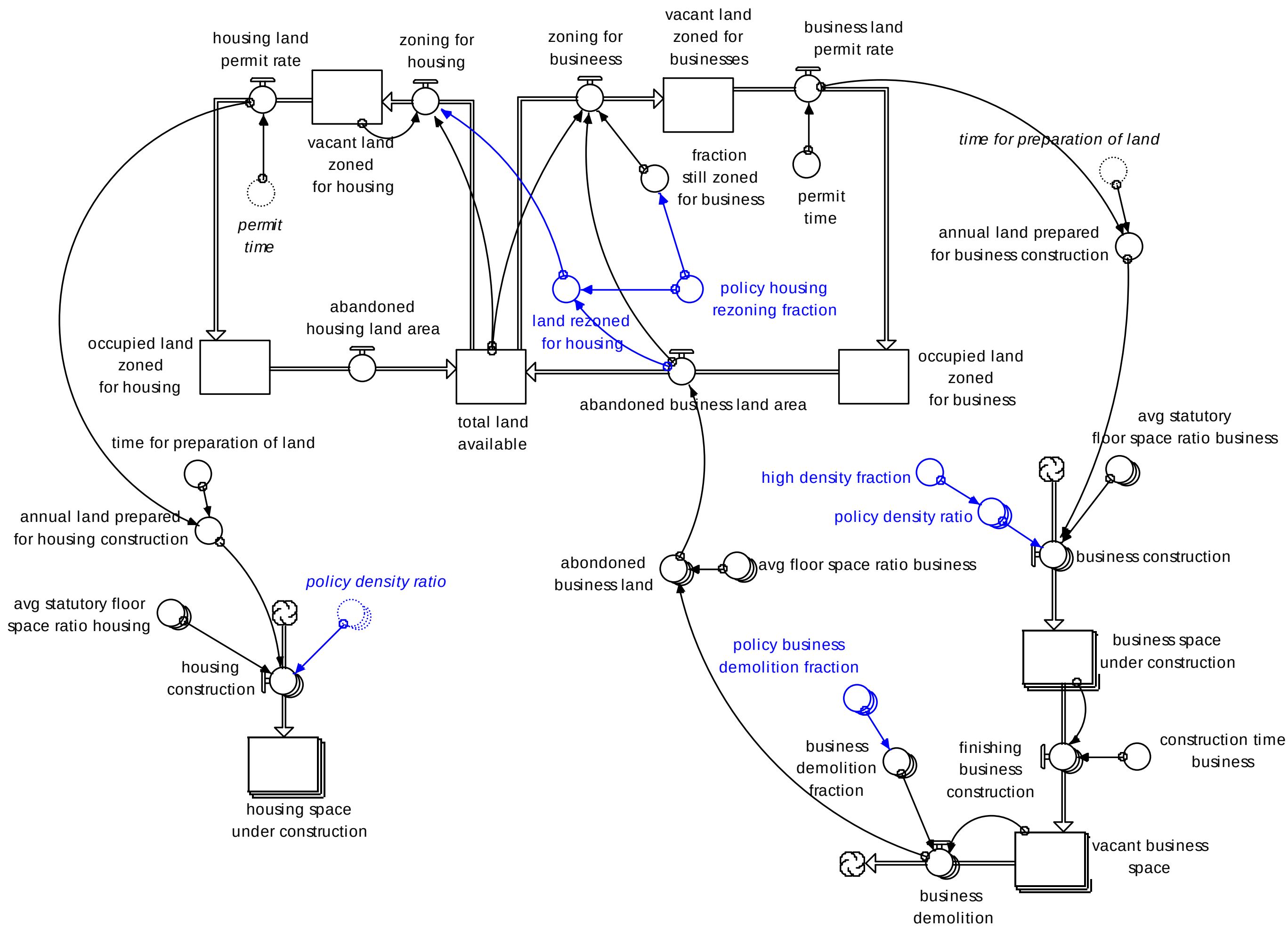

Figure 34. SFD for the *Rezoning Policy*.

Figure 35 and Figure 36 show the simulation results for this policy. The policy is run with a business demolition fraction of 0.5 for vacant low-density business structures. 50 % of the abandoned land is chosen to be rezoned for housing and 90 % of the newly raised structures are high density. As can be seen, both the number of jobs and the number of housing units rise after implementing the policy. The rise in number of housing units was to be expected since 50 % of abandoned land was zoned for housing. But why does the number of jobs increase so significantly? With high-density business structures replacing low-density structures, far more workers can be accommodated than before.

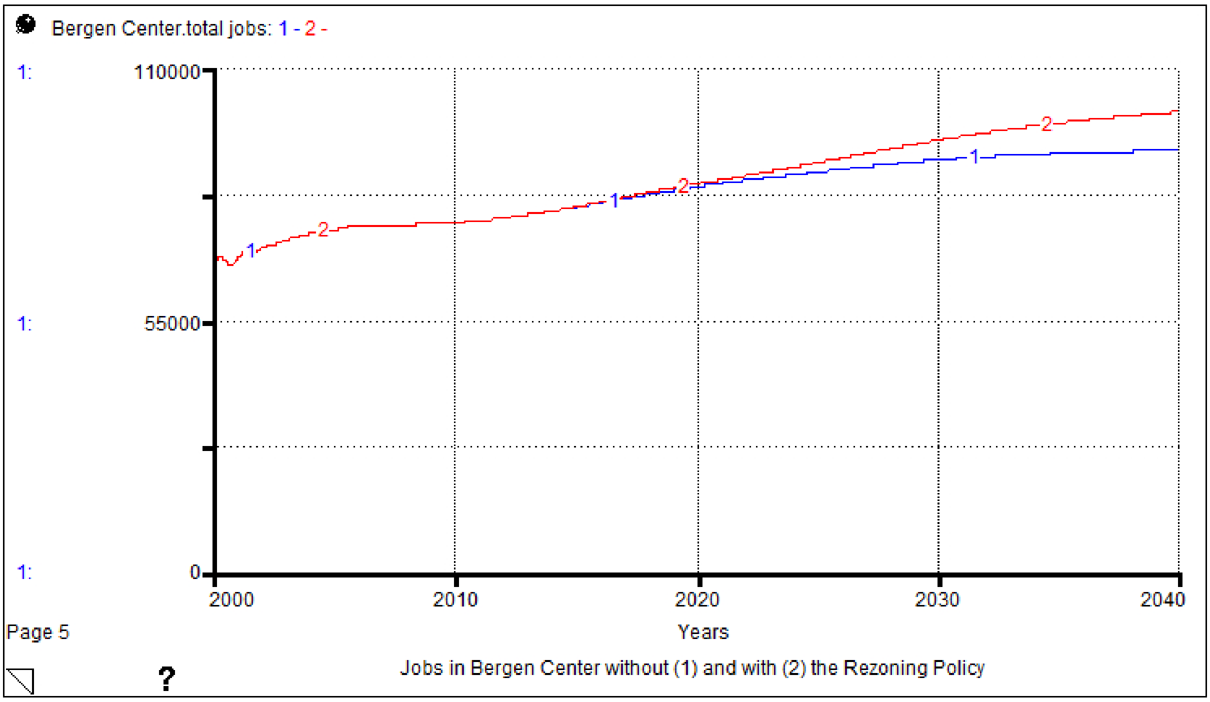

Figure 35. Jobs in Bergen Center without (1) and with (2) the *Rezoning Policy*.

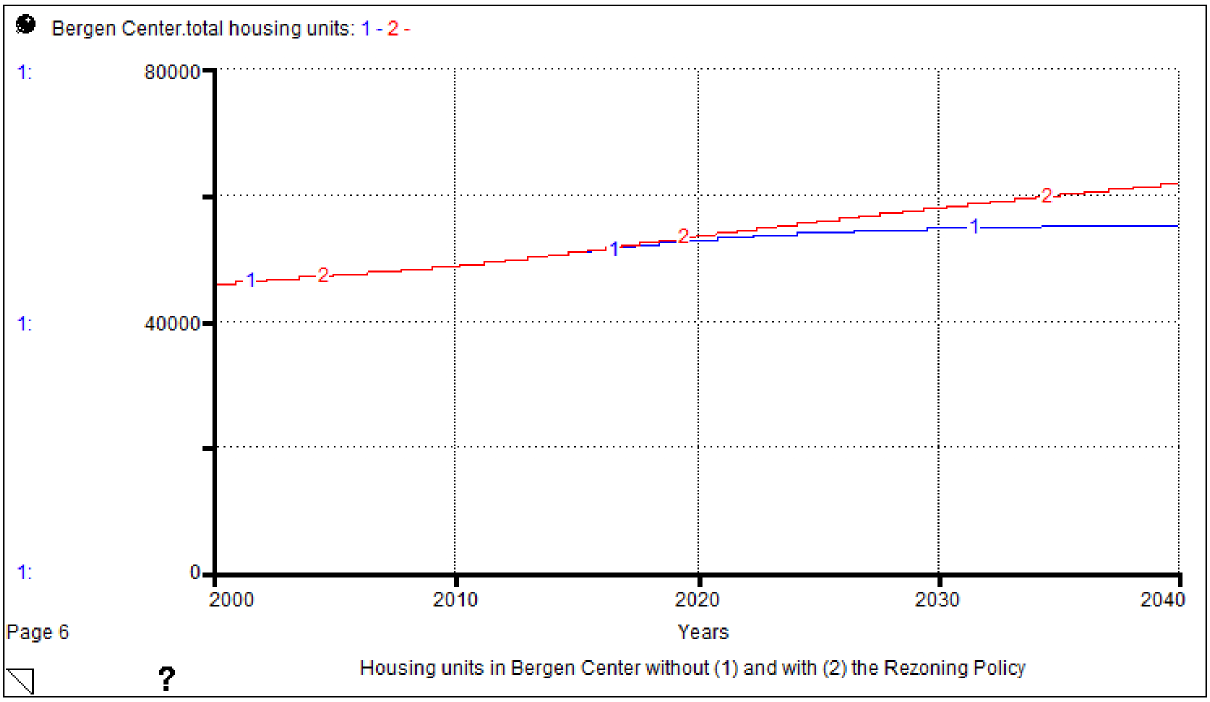

Figure 36. Housing units in Bergen Center without (1) and with (2) the *Rezoning Policy*.

To test whether the policy is more effective with a higher *policy business demolition fraction* and *policy housing rezoning fraction*, the policy was run with a high demolition fraction for vacant low-density structure, with a 100 % rezoning for housing and with 100 % of the re-built structures as high-density structures. Even then, however, the effect of the policy on improving the balance is unimpressive - even though it seems to increase the density of the urban area very effectively. The reason for this outcome is as follows: Even though the demolition fraction is very high, not much can be demolished because there is not much vacant. Since low-density businesses lack suitable areas to relocate to, they are forced to stay where they are: even though they might wish to relocate because of the rising rental prices.

7.3 Zoning Decision Rule Policy

One striking finding of the explanatory model is that the planning authorities do not have a specific decision rule governing the zoning of land for business purposes. This finding is supported by Asplan Viak (2009) who states that the municipalities' planning authorities are normally very qualified in estimating the need for housing units and public services, but are generally less competent in estimating the need for businesses land. However, business development is an important domain for the municipalities and controlling the supply of new land areas by the means of formal land use plans is one of their the most important politico-economic instrument (Asplan Viak, 2009). Therefore, the policy suggests a decision rule for the zoning of land for businesses. In addition, the policy includes a new decision rule for the zoning for housing. If these two decision rules are combined, the imbalance between jobs and housing units can be reduced. For the Bergen municipality these decision rules can act as a help in zoning the right amount of land for business- and housing purposes on an urban district level. So far, the distribution of newly zoned land on an urban district level does not seem to follow a specific rule.

Figure 37 shows the Causal Loop Diagram for the policy. The zoning for housing depends on the number of people working in Bergen center while the zoning for businesses depends on the number of people living in Bergen center. This should in theory (with unlimited land supply) lead to a zoning distribution that allows a balance between jobs and housing units. Three reinforcing loops R8, R9 and R10 and four counteracting loops C16, C17, C18 and C19 are added.

Loop R8 illustrates the decision rule acting for the zoning of land for business purposes. Based on the growth in population, the expected number of workers living in Bergen Center is calculated. As the population increases, the expected number of workers living in Bergen center rises, too. Based on this expectation, the expected need for business space increases. Additional business space is required to supply the future workers living in Bergen center with sufficient space. More land is zoned for business which increases the vacant land zoned for business. This results in more business construction and subsequently more vacancies attracting people to move to the area. With a significant delay, the population increases. Loop C16 shows how the more vacant land zoned for business there is, the less needs to be zoned. Loop C17 illustrates that the additional need for business space is reduced as more business structures are constructed.

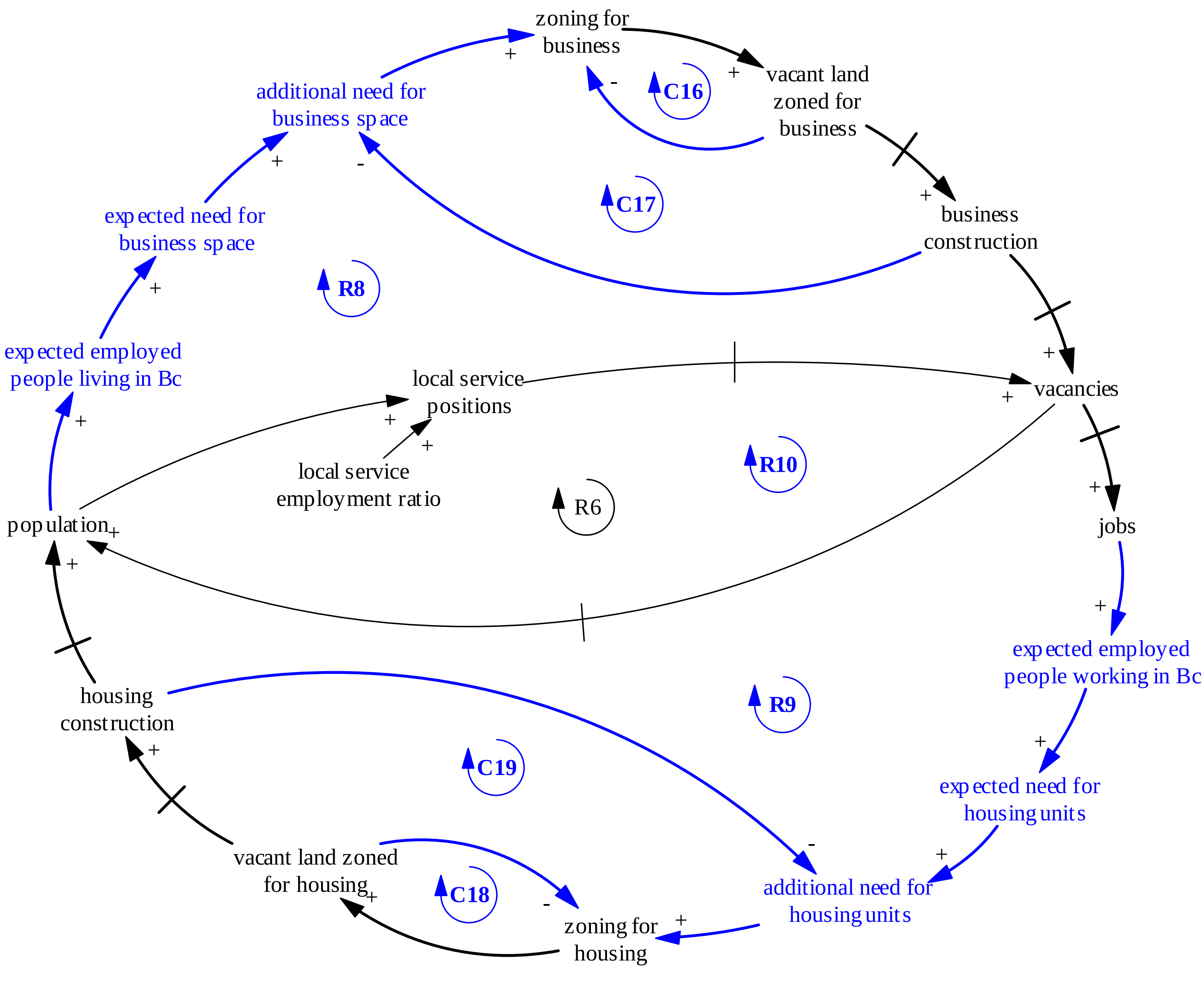

Figure 37. CLD for the Zoning Decision Rule Policy. The blue variables and links denote the added structure by the policy.

Loop R9 describes the decision rule designed for the zoning of land for housing. The expected need for housing units is based on the expected growth in jobs: as the number of jobs increases in Bergen center, the expected number of employed people working in Bergen center goes up. Having the goal of supplying future workers with housing units, means that the expected need for housing units will rise. The need for additional housing units increases, additional land is zoned for housing and - consequently – the amount of vacant land zoned for housing has risen. With considerable delays, housing construction increases which allows the population to rise. This leads to a higher number of local service positions which after some time causes the number of jobs to grow. The small C18 illustrates how the more zoned land for housing is vacant, the less additional land will be zoned. Loop C19 depicts how increasing construction of residences reduces the additional need for housing units.

Loop R10 comprises the links between the two decision rules for the zoning for housing and business. It illustrates that a rise in jobs leads to more zoning for housing which in turn leads to a rise in population. More land is zoned for business, business construction increases and, consequently, more jobs are created.

If the population and the jobs are not expected to increase, but - quite the contrary – might even decrease, the decision rules will ensure no more zoning thereby hindering business and housing construction and maybe cause a decrease in population and jobs. It is important for planning authorities to realize that the decision rules will theoretically cause exponential growth (or exponential decay). In reality, the growth is limited by the availability of land. However, these loops highlight that the decision rules require being reflective when zoning land. Land is a limited resource and it is difficult to renew once it is occupied.

Figure 38 illustrates the designed SFD for the zoning decision rules in the *Bergen center land use sub-model*. The *needed land for business* is estimated by extrapolating the population growth for the next 12 years, which corresponds to the planning interval common for Bergen municipality. This extrapolation is conducted with a TREND-function. By estimating the population size 12 years from now, the e*xpected number of employed people living in Bergen center* can be calculated. Roughly 50 % of the population is employed. Based on the assumption that every employed person living in Bergen center should have a corresponding space to work, the *expected need for business space* can be calculated. Depending on how much business space already exists, the *additional need for business space* is estimated. If the *existing business space* already satisfies the expected need, no more land needs to be zoned. However, if less exists then more land will need to be zoned in the future. With the help of the *statutory floor space ratio business*, the required land is estimated. This is the method used by Opus Bergen (2012) to estimate the future demand for business space.

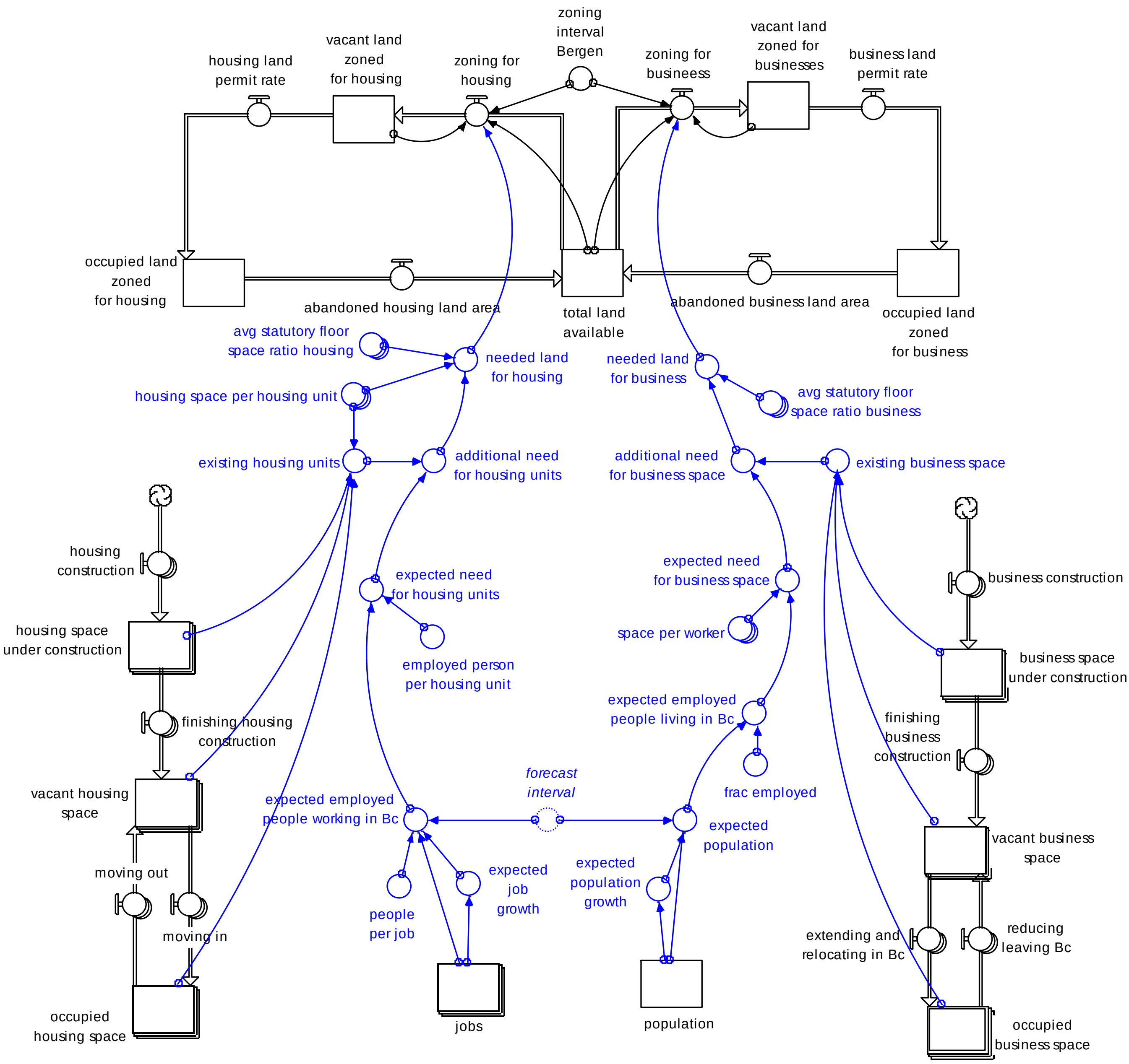

Figure 38. SFD for the Zoning Decision Rule Policy.

The *needed land for housing* on the contrary, is estimated by extrapolating the growth in *jobs* and estimating the future number of jobs in Bergen center. Assuming that every job is filled by one person, it gives us the future number of *employed people working in Bergen Center*. By dividing the latter with the average number of *employed people per housing unit*, the *expected need for housing units* is calculated. Based on the number of housing units that already exist, an *additional need for housing units* can be estimated. Given the average *housing space per housing unit* and the *statutory floor space ratio*, the *needed land for housing* is obtained.

The policy has to be seen as an attempt to establish a connection between the housing and business sector. Workers need houses to live and people need places to work. The growth of a population depends on the growth in jobs and vice versa. In theory, the policy should lead to land being zoned in such a way, that relatively equal amounts of zoned land for housing and business are the result. Even though there is probably not quite enough suitable land to implement the decision rule completely, the rule is still a useful tool for working out how much land is needed for housing or business, respectively, in order for the imbalance to be reduced.

Figure 39, Figure 40 and Figure 41 show the simulation results for Bergen North, where the policy worked most effectively. Figure 39 shows that the number of housing units is unchanged while Figure 40 illustrates that the number of jobs increases significantly compared to the development without the policy in place. When looking at the actual jobs-housing ratio with the implemented policy – and comparing it to the ratio implying balance, it becomes apparent that a numerical balance has almost been achieved (Figure 41).

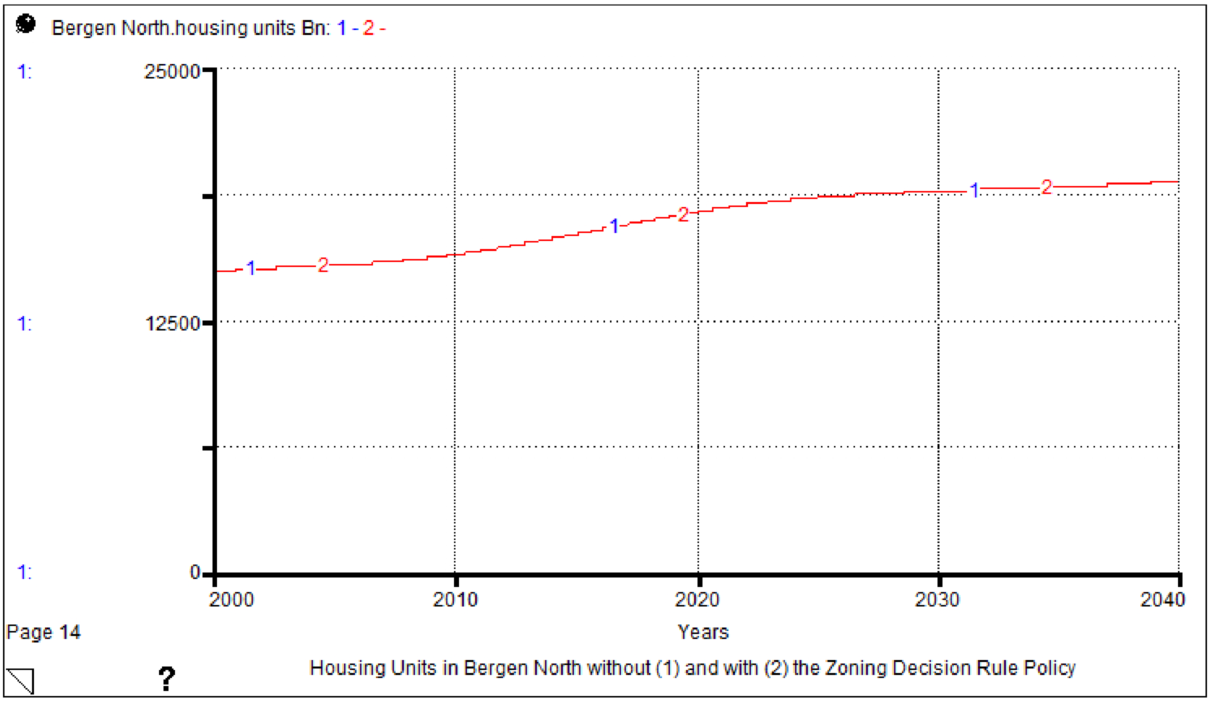

Figure 39. Housing units in Bergen North without (1) and with (2) the *Zoning Decision Rule Policy*.

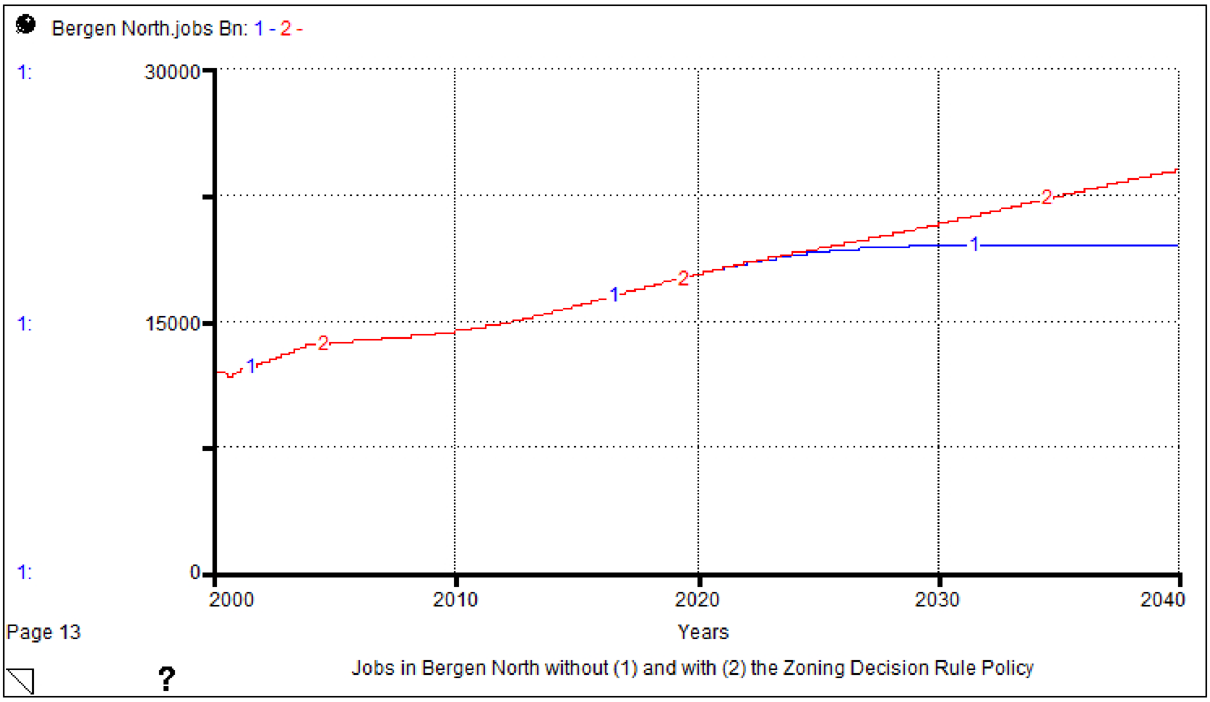

Figure 40. Jobs in Bergen North without (1) and with (2) the *Zoning Decision Rule Policy*.

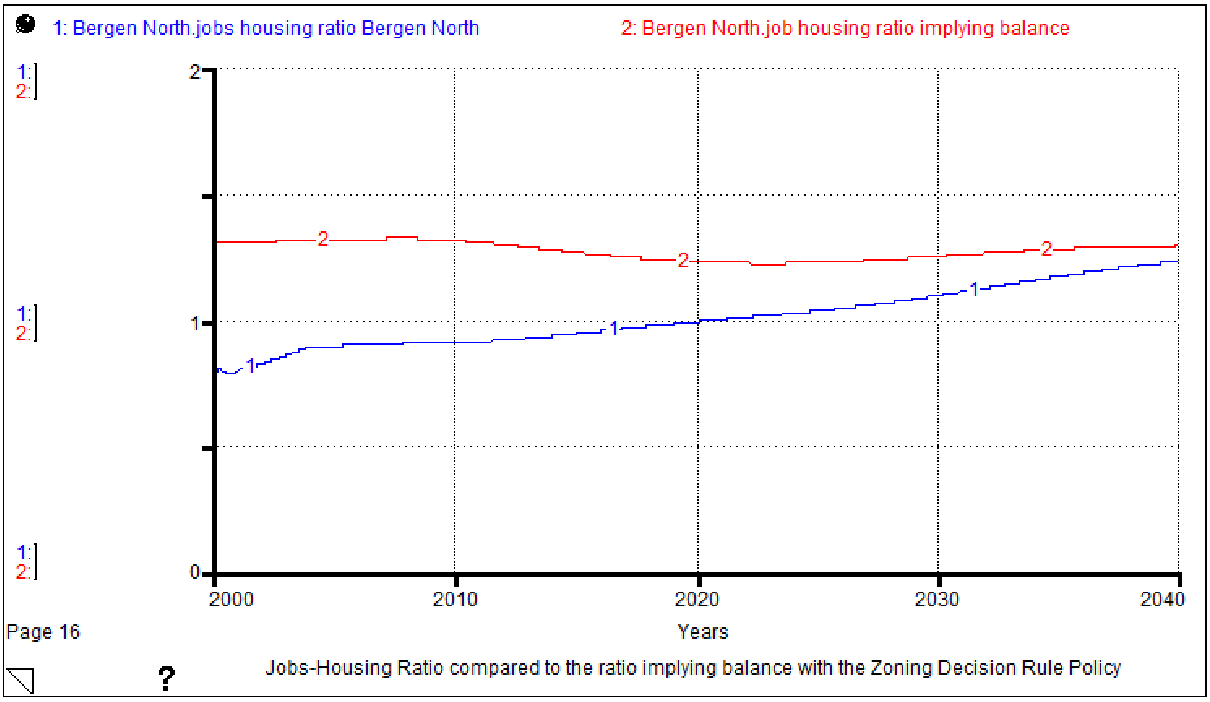

Figure 41. Jobs-housing ratio compared to the Jobs-housing ratio implying balance for Bergen North with the *Zoning Decision Rule Policy*.

The policy has, however, less of an effect in Askøy and the other urban districts in Bergen. Figure 42, Figure 43 and Figure 44 show the simulation result for Askøy. Despite the jobs-housing ratio drawing closer to a balanced jobs-housing ratio, balance itself is not achieved. The total number of jobs is only marginally increased by the policy, while the future development of housing units actually decreases. Askøy already has sufficient business zoned land, so the reason for businesses not to locate there cannot just be the lack of zoned areas, but must be other location factors.

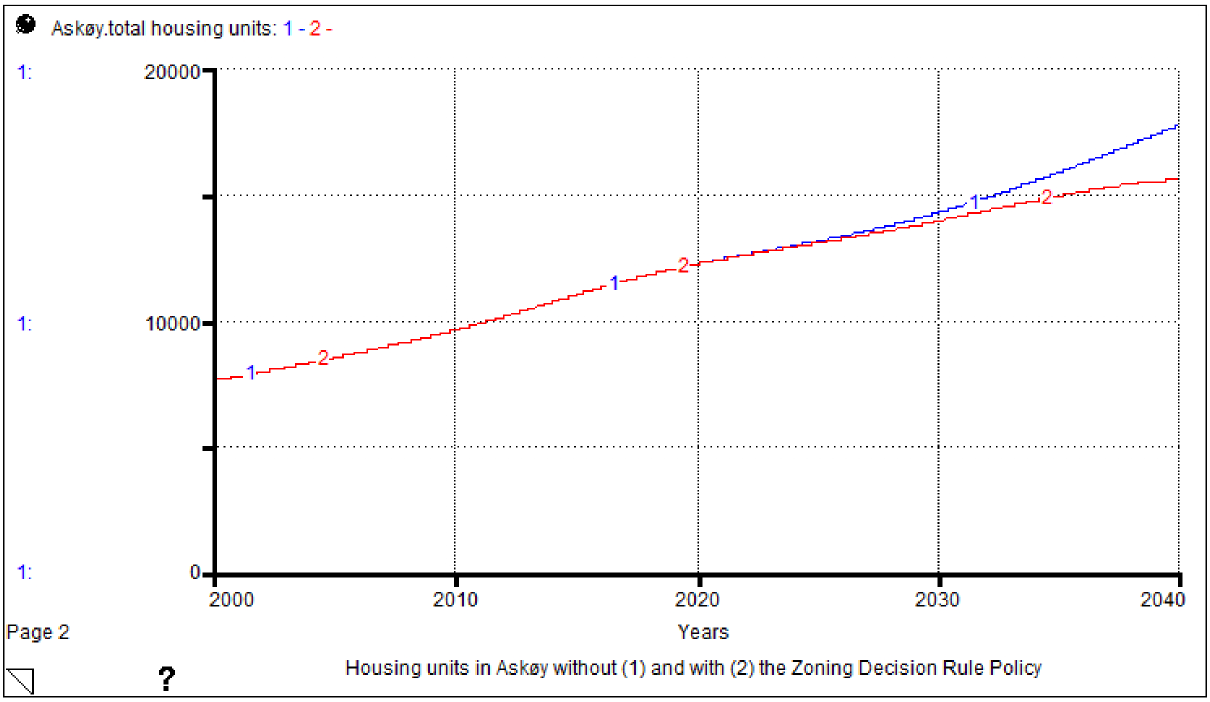

Figure 42. Housing units in Askøy without (1) and with (2) the *Zoning Decision Rule Policy*.

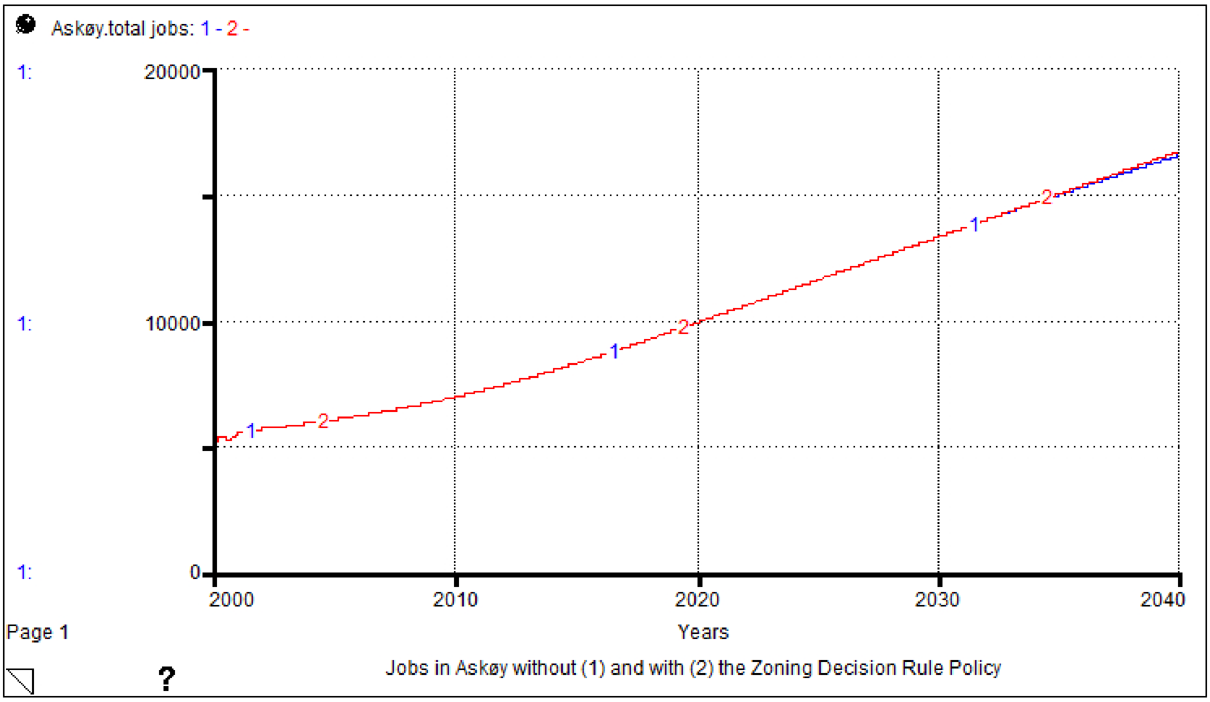

Figure 43. Jobs in Askøy without (1) and with (2) the *Zoning Decision Rule Policy*.

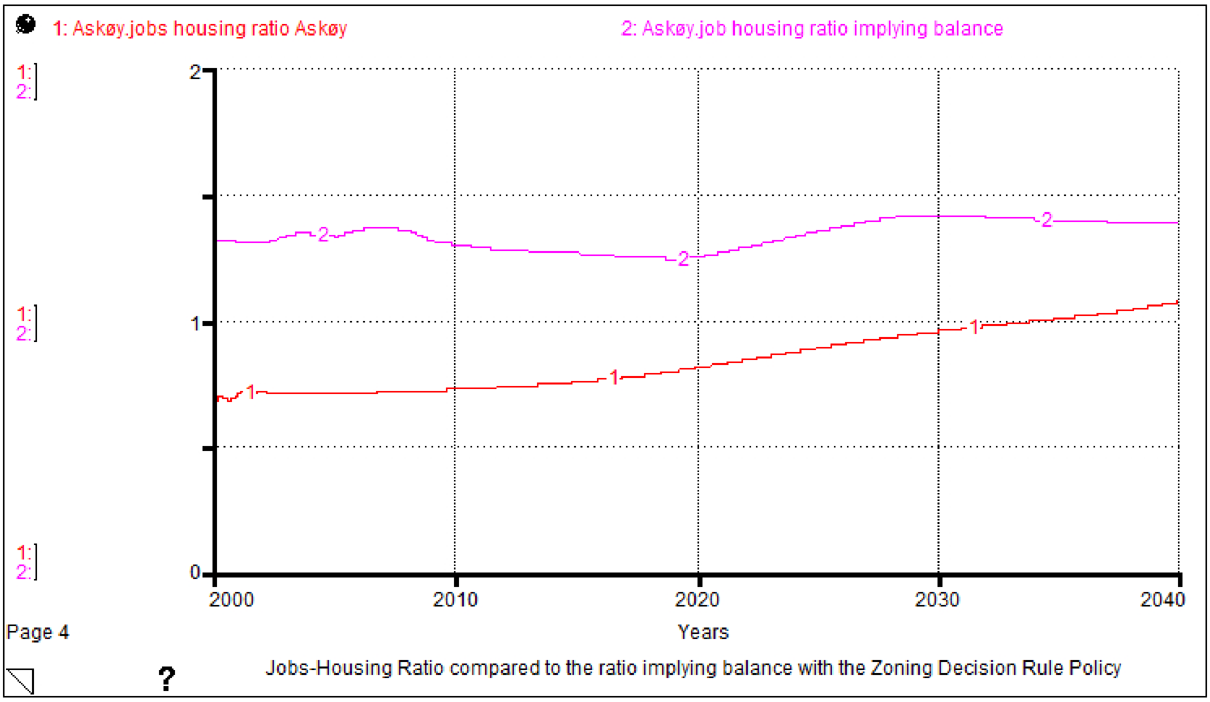

Figure 44. Jobs-housing ratio compared to the Jobs-housing ratio implying balance for Askøy with the *Zoning Decision Rule Policy*.

Figure 45, Figure 46 and Figure 47 show the simulation results for Bergen center. The first simulation with the blue line shows the behavior without the policy in place, while the second red line indicates the behavior with the *Zoning Decision Rule Policy* activated. As Figure 45 illustrates, the housing units actually increase as a result of the policy. However Figure 46 reveals that the number of jobs slightly decreases before it increases significantly. This behavior is unintuitive upon first sight. It proves, however, what has been stated before. As more land is zoned for business in the other urban districts of Bergen, more businesses finally have the possibility to relocate (for example to Bergen North). This vacates business space in Bergen Center which is demolished and replaced by high-density structures. This increases the number of jobs. It is for this reason, that the jobs-housing ratio in Bergen center remains unchanged even with the policy in place rather than leaning towards a ratio implying numerical balance (see Figure 47).

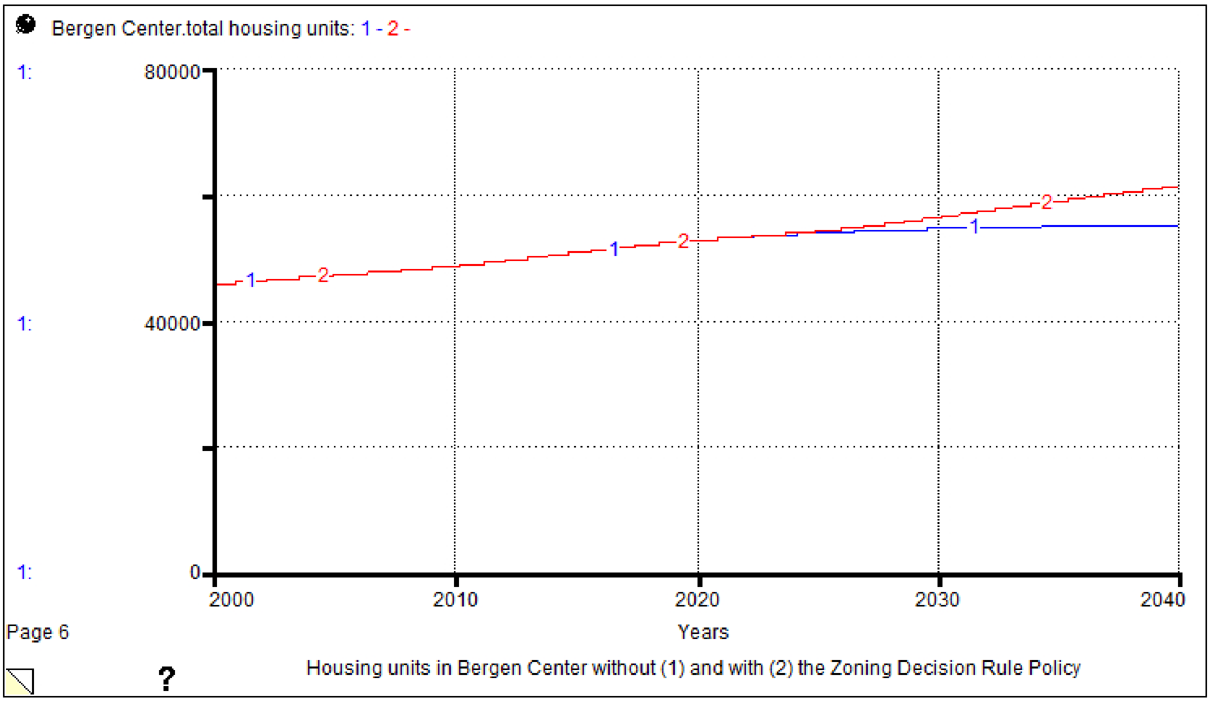

Figure 45. Housing units in Bergen Center without (1) and with (2) the *Zoning Decision Rule Policy*.

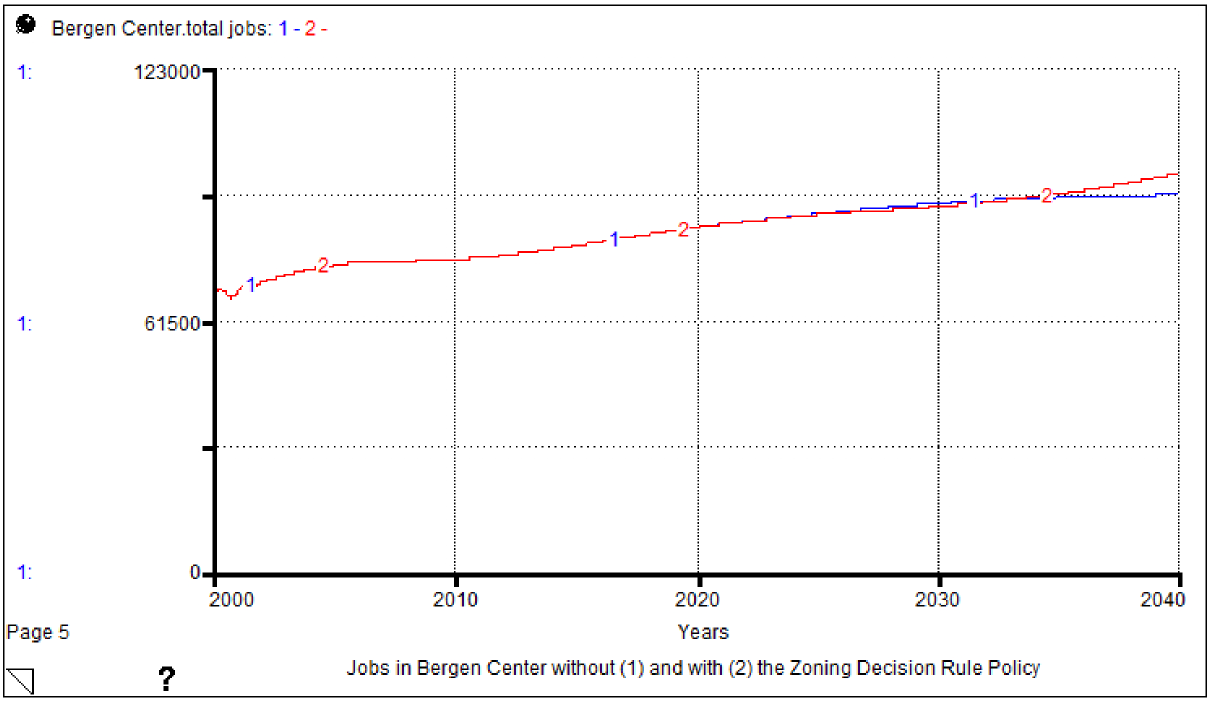

Figure 46. Jobs in Bergen Center without (1) and with (2) the *Zoning Decision Rule Policy*.

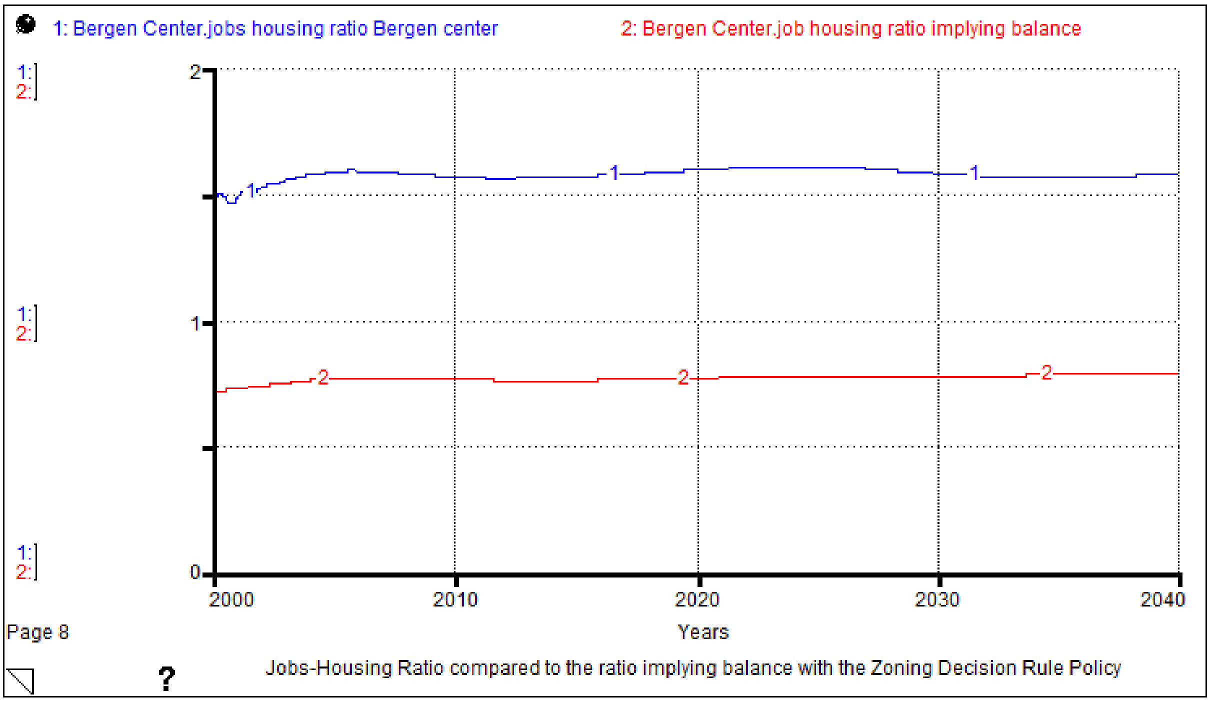

Figure 47. Jobs-housing ratio compared to the Jobs-housing ratio implying balance for Bergen Center with the *Zoning Decision Rule Policy*.

The simulation results of the policy encourage testing a combination of the *Zoning Decision Rule Policy* and the previously-discussed *Rezoning Policy*. Combining the two might result in the jobs increase in Bergen center behaving differently than recently observed. Figure 48, Figure 49 and Figure 50 show the simulation result for Bergen center without any policy (blue line, 1), with the *Zoning Decision Rule Policy* (red line, 1) and with a combination of the *Zoning Decision Rule* and *Rezoning Policy* (pink line, 3). For the *Rezoning Policy* a low-density business demolition fraction of 0.5 was chosen along with 90 % for housing rezoning and a high-density fraction of 90 %. Figure 48 shows that this actually reduces the growth in jobs in Bergen center. Figure 49 illustrates how this could lead to a significant increase in housing units and consequently the imbalance could be slightly reduced (Figure 50).

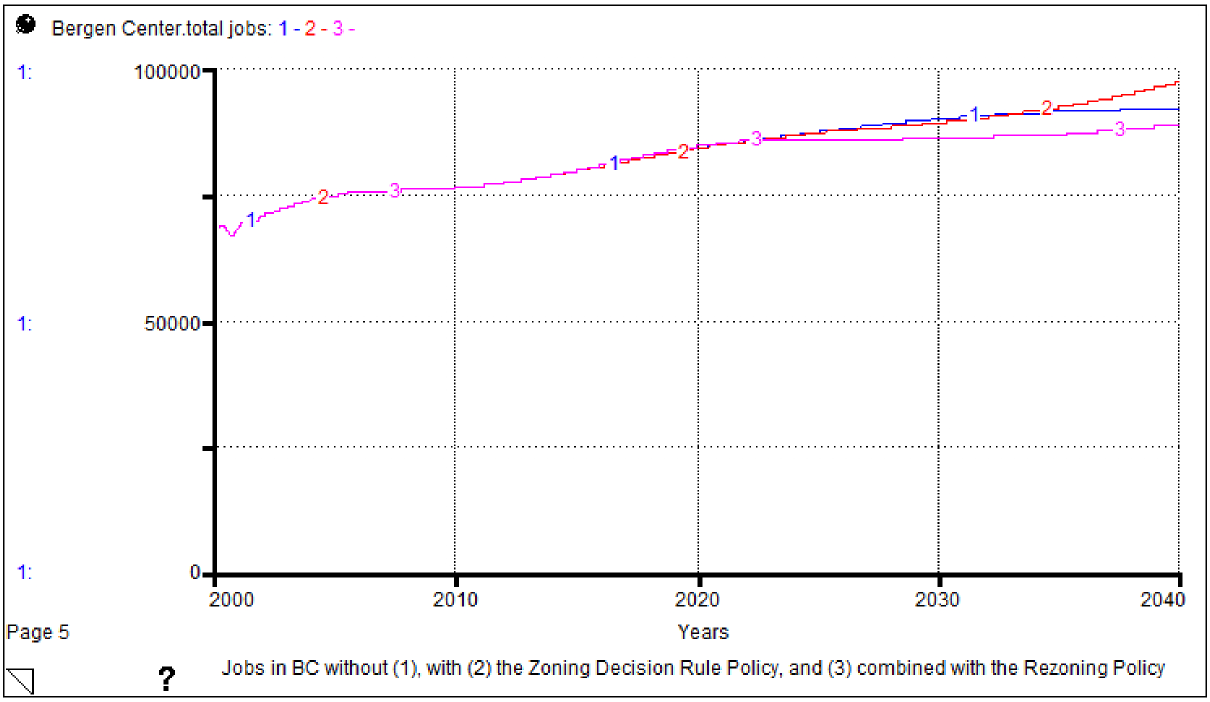

Figure 48. Jobs in Bergen Center without (1) and with (2) the *Zoning Decision Rule Policy* and (3) combined with the *Rezoning Policy*.

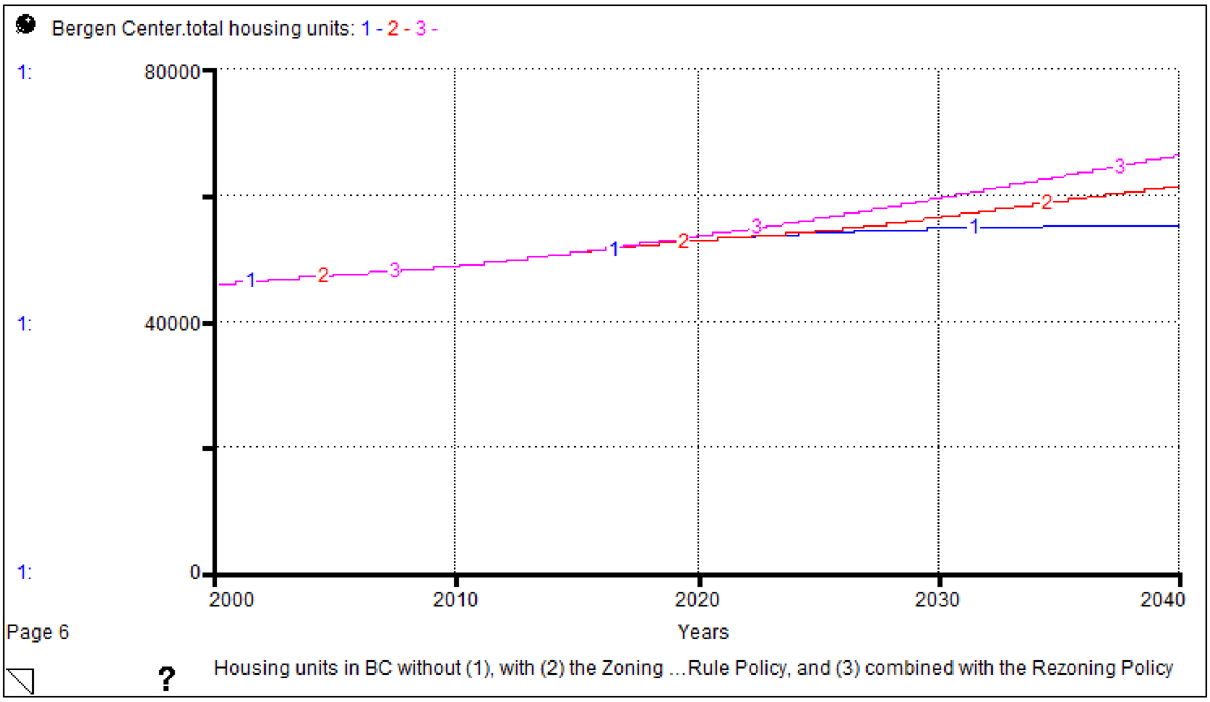

Figure 49. Housing units in Bergen Center without (1) and with (2) the *Zoning Decision Rule Policy* and (3) combined with the *Rezoning Policy*.

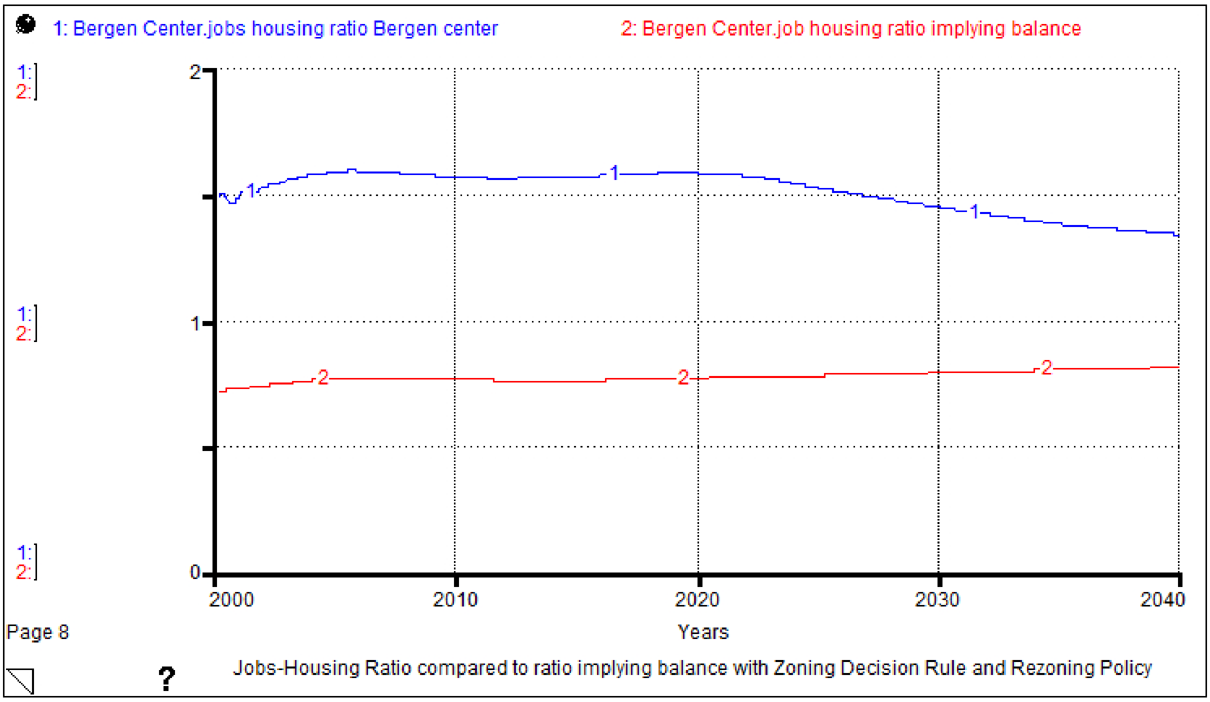

Figure 50. Jobs-housing ratio compared to the ratio implying balance in Bergen with the *Zoning Decision Rule Policy* combined with the *Rezoning Policy*.

7.4 Conclusions from the Policy Options

Three different policy options were identified and tested. None of the tested policies were able to improve the imbalance between jobs and housing units on their own. Rather, the simulation results with the different policies appear to advise a combination of the *Zoning Decision Rule Policy* and the *Rezoning Policy*. With this combination, the imbalance can be reduced in the urban areas surrounding Bergen Center. Bergen Center itself will at least be able to keep its imbalance stable and might even slightly improve it. Anyway, for Bergen Center it is not realistic to reach numerical balance. A balance would not be desirable because by definition any city center will and needs to offer an abundant number of jobs and services and attract businesses to locate. So the effort should rather lie in limiting a further increase in the imbalance by constituting a zoning policy that allows workers living in Bergen center and jobs to grow at the same pace. For the remaining urban areas in Bergen, the most realistic way of reducing the imbalance seems to be zoning more land for businesses. The designed *Zoning Decision Rule Policy* helps estimate the future demand for business space and consequently seems to result in a more satisfactory situation than would be achieved without the policy in place.

The advantage of the *Zoning Decision Rule Policy* is that its implementation does not require a lot of work or resources since it is only a rather simple decision rule for the estimation of the future need for land. However, implementing the policy completely might not be feasible, neither politically nor socially. One obstacle might be the availability of land and its qualities. The qualities of the remaining land might not match the zoning requirements according to the zoning decision rule. Another obstacle might be the fact that the policy suggests for areas with a significantly higher number of housing units than jobs, to have many years of zoning land for business purposes only. In Bergen Center, by comparison, the policy dictates for land to be zoned for housing, only. However, the high demand for housing units will create political pressure to zone more land for housing in the urban districts surrounding Bergen center. And the businesses will demand more land in the center. Bergen municipality wants the region to be a highly attractive area for businesses, while at the same time it wishes to pursue an environmentally friendly development with a location pattern that reduces the need for transportation. Jakobsen (2000) claims that this can result in an inherent tension in the municipal industrial land use policy: while the aim is to develop balanced districts, one is trying to give businesses as much freedom as possible in order to attract more new ones. Without doubt, it is a balancing act to stimulate job- and business creations on the one hand and to trying to control their location and the land use on the other hand.

The Limits to Growth archetype by Braun (2002) hypothesizes that nothing can grow forever but that there will always be something that eventually limits further growth. This means that every reinforcing process will meet a balancing process at some point in time. The central insight from this archetype is that it is important to identify the growth engines and to map out the potential limits to growth. As could be seen in the previous chapter, the zoning decision rule forms a reinforcing loop. One growth engine in this reinforcing loop is the zoning of land and one important limiting factor is the available land. More zoned land gives the industry and the population the possibility to grow and expand. However, land is a natural resource that will be depleted at some point in time. For now, the limiting factor is the availability of zoned land. But eventually the limiting factor will be the total available land. This limiting factor can be delayed by increasing the density of the existing urban area and by developing land that formerly was not considered suitable. But at some point in time the limit will be met. And it should not be forgotten that there are two other important growth engines in the reinforcing loop which can become limiting factors at any time: the growth in population and jobs. The zoning of land results in more construction because there is a high demand from the population and the growing economy. But this growth cannot continue forever and there are certain factors that can result in sudden changes. An urban area that grows too fast can become unattractive for inhabitants and businesses and lead to emigration. It is therefore important to be reflective about growth. This requires the authorities and city government to be aware of the growth engines and to consider the limiting factors. It is wise to specify how much growth is desired and how it can be controlled.

8. BergenSim – An Integrated Land Use, Transportation and Urban Migration Model

BergenSim is the name of the comprehensive model combining the *Bergen Land Use Model*, the transportation model by Brandsar (2013) and the urban migration model by Li (2013). Figure 51 depicts the connections between the three models. The output of the land use sub-model consists of the construction of new housing units and the net job creation in the six urban areas[17]. This is used as an input into the urban migration sub-model, which models people's decisions where to live and where to work. The population forms an input to the land use sub-model, while the number of commuters (those living in one urban area and working in another) is put into the transportation sub-model. The transportation sub-model calculates the traffic on the roads and the according travel time between the different urban areas. The travel time constitutes an input to the urban migration sub-model and the land use sub-model. People's decisions on where to live to some extent depend on the accessibility of their accommodation (which the travel time is an indicator for) just as firms consider different business locations according to their accessibility.

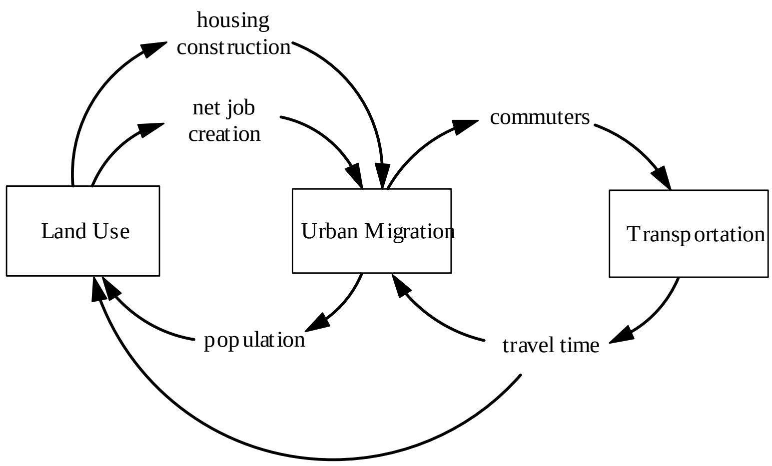

Figure 51. Links between the Transportation Sub-Model, Urban Migration Sub-Model and Land Use Sub-Model in *BergenSim*.

[17] Bergen Center, Bergen West, Bergen South, Bergen East, Bergen North and Askøy.

The transportation model by Brandsar (2013) confirms the assumption that the increase in traffic is due to population growth and the current land use pattern with a rising number of people living in the outskirts while working in Bergen center. Without the rising number of commuters, the traffic at peak-hour would stabilize rather than increase. This indicates that increased car ownership or significant road construction during the past years are not valid explanations.

The feedback from the transportation model in form of travel time by car and public transportation has less effect on the Land Use Model than expected. This is due to travel times not changing considerably during the course of simulation. The transportation model does not include any transport policies aimed at constructing new road networks, such as the possible road tunnel connecting Bergen center with Arna. It is assumed that these kinds of policies would have a stronger effect on the land use model.

The three suggested land use policies discussed in the previous chapter were tested on the *BergenSim* model to analyze their effect on the number of commuters. The *Arranged Relocation Policy* does not change the total number of commuters at all; however, it results in a small increase in people commuting into Askøy. The *Rezoning Policy* only affects the total of commuters marginally. As previously discussed, this policy leads to an increase in jobs and housing units in Bergen center, which gives more people the possibility to live in the center, while working in other urban areas. This causes the out-commute from Bergen center to rise and the in-commute to decrease by roughly 5 000. The in-commute into all other urban areas increases accordingly. The *Zoning Decision Rule Policy* also leads to an increasing number of commuters out of Bergen Center, with a fewer amount of commuters out of all other urban areas. Only a slight decrease can be observed in the total number of commuters. The suggested combination of the *Rezoning Policy* and the *Zoning Decision Rule Policy* manages to reduce the in-commutes to Bergen Center by roughly 6 000, however raises the number of out-commutes from Bergen center by approximately 5 000. The total number of commuters is slightly reduced.

To summarize, the combined zoning policies do have an effect: more housing units in Bergen center can decrease the total number of commuters. However, an increase of 4 000 housing units in Bergen Center by 2030 would only decrease the total number of commuters by roughly 1 500. To test whether the land use policies are more effective when people are encouraged to live closer to their workplaces, the *Zoning Decision Rule Policy* was combined with a commuter tax policy. A charge is raised for commuting across urban areas which makes it more attractive to live close to work. This results in approximately 6 000 fewer commuters by 2030 (ca. 135 000 commuters instead of 141 000 commuters).

It needs to be stated, however, that these findings are of preliminary character. Before secured policy conclusions can be drawn from the combined model, it is strongly advised to test and analyze the *BergenSim* model in more detail to reveal possible flaws in the combined model. Basically, the findings indicate that it is very hard to reduce commuting. Even a more balanced land use would not result in significant changes to the total number of commuters. It would, none the less, reduce the pressure on Bergen Center.

9. Limitations

In this chapter the limitations and weaknesses of the *Bergen Land Use Model* are discussed before suggestions for further research are put forward.

There is a great uncertainty about many parameter values in the model. Many values were chosen arbitrarily because, surprisingly, a lot of data was unavailable – despite these data sets being considered essential to land use planning. For example, no data could be obtained on the actual land occupied by residences and businesses. Nor could Askøy municipality provide data on the housing- and business space. Extensive and time-consuming estimates had to be made instead, which – by nature – hold a high level of uncertainty, despite the greatest possible accuracy having been applied. Equally, no data could be obtained on the floor space ratio – either in Askøy or in Bergen. Since the values of these parameters have a significant impact on the availability of land and consequently the model's behavior, the high uncertainty and data limitation is a weakness of the model. In addition to data unavailability, there were some issues with data inconsistency: The number of jobs in each urban district of Bergen would not add up to the total number of jobs in Bergen.

Moreover, numerous assumptions have been made in the model which might reduce the model's reliability. For example, only businesses inside the Bergen region are considered in the model. This means that no businesses from outside of the Bergen region can move into the region and no businesses located in the Bergen region can relocate outside of it. Since no data on these relocation activities exists, it could not be made exogenous in the model. Maybe this does not matter so much, since the fraction of businesses located in the Bergen region wanting to relocate outside the region is assumed to be small. This assumption is supported by the survey from Asplan Viak (2009). They found that around 50 % of the businesses considering relocation wish to relocate inside their current municipality and around 40 % wish to relocate within the Bergen region. Only less than 10 % would consider to relocate outside of the Bergen region.

In addition, the model assumes that businesses only consider relocation within in the job markets they are part of. As mentioned earlier, Asplan Viak (2009) stated that the Bergen region could be divided into job markets - with Bergen center forming a border. Therefore, a business located in Bergen West will only consider relocating to Askøy, Bergen South or Bergen Center but not to Bergen North and Bergen East.

Another assumption made is that vacancies are always filled; there can be no lack of workers. Neither does construction work depend on any other resource but land – obviously in reality it also depends on workers and building materials. The fact that land availability had been the only major factor reducing business construction in the past decades is confirmed by Frode C. Hoff in Bergen tomteselskap.

Each land use model consists of 16 table functions. Even though the shape of each table function was thoroughly tested, they do constitute an uncertainty. The most uncertain is the table function covering the business location factor “possibility to expand”. This factor is one of the most important relocation factors, however no assured data or detailed research exists that could help model the shape of the table function.

The model simulation of the explanatory model starts in year 2000 and ends in 2011. For urban development, 12 years is not a long time perspective due to the many long delays incorporated in the urban development process. The reason for taking 2000 as a point of departure is data availability. A lot of data was only available from 2000 onwards. Therefore, the model cannot explain how the imbalance between jobs and housing units arose but rather looks at the forces keeping the imbalance stable and maintains which internal forces influence the location of housing units and jobs.

Even though the model offers anything but the complete picture of the land use dynamics in the Bergen region, it still generates very useful insights; such as the decisive role of the supply of zoned land on the construction activity, the current decision rule used for the zoning of residential land while the zoning of commercial land does not follow any specific rule, and the importance of the demand for business and housing structures on the construction activity. Also, actually, the finding that a lot of essential data is unavailable is an important insight in itself. It is strongly recommended to establish a database on the land area zoned for different purposes and the land area occupied by different functions. It is also recommended to collect the floor space ratios and data on the number and quality of business and housing structures. Not to forget the number of jobs on urban district level. Furthermore, as mentioned before, it is not the line of industry that is important for land use planning but the activity on site. Another recommendation is to dedicate research effort on business relocation processes. Important findings have been made by Asplan Viak (2009), Opus Bergen (2012) and Jakobsen (2000). However, there is still a lack of information concerning the number of businesses that already have relocated: why, when and where did they relocate from and to?

10. Conclusion

The stated objective of the *Bergen Land Use Model* was to analyze the causes for the imbalance between jobs and housing units in the Bergen region and to investigate whether and how a better balance could be established. Important insights were gained from the research, the modeling process, the model analysis and the designed policy options. The demand for housing units by an increasing population, and the demand for business structures by a rising number of businesses both are central forces generating a growth in jobs and housing units in the Bergen region. Land use planning was found to play a central role in affecting the location of jobs and housing units. The amount of zoned land available determines the construction of housing units and business structures. By providing zoned land in specific areas, the location and distribution of jobs and housing units can also be influenced to some extent.

The detailed reading of literature as well as interviews with experts indicated a lack of zoned land for businesses. This was supported by the model, which in addition revealed the lack of a clear decision rule for the zoning of land for business purposes. The recent rezoning efforts in Bergen center seeking to transform former low-density industrial areas into high-density business areas mixed with some apartments will most likely lead to a rising imbalance between jobs and housing units in Bergen center. However, the lack of zoned land for businesses in the region will slow down the desired transformation process anyway: the old industrial low-density businesses expected to relocate currently have too few alternative sites to relocate to. Literature and the *Bergen Land Use Model* also revealed that there is in fact sufficient land zoned for housing in the region. The planning authorities have a clear idea of how much land needs to be zoned to meet the expected future demand for housing units.

Consequently, the generous zoning for housing in the areas surrounding Bergen center and the less consistent zoning for business can act as an explanation for the prevailing imbalance. The fact that there is no connection between the zoning of land for business and housing might have led to a more amplified imbalance than intended. Currently, the housing sector and the business sector are two separate sectors which have no common interacting grounds other than the population which is part of both sectors.

Three policy options have been designed to address the problem of the jobs-housing imbalance. The policies aim at altering the supply of land and using this to control the future distribution of jobs and housing units. The so-called *Zoning Decision Rule Policy* tries to establish a new connection between the housing and the business sector by using the expected population growth to estimate the future need for business space, and by using the expected increase in the jobs market to estimate the future need for housing units. Model simulations suggest that a combination of the *Zoning Decision Rule Policy* and a *Rezoning Policy,* where rezoning for housing is prioritized in Bergen center, could reduce the imbalance in the region. However, it would take many decades to achieve a better balance. There are numerous significant delays involved in the land use which lead to slow changes in the system. Simulation runs with the integrated land use, transportation and urban migration model, *BergenSim*, indicate that the suggested land use policies will not be able to reduce the number of commuters significantly. However, they will manage to reduce the pressure on Bergen center to some extent and to decrease the total number of commuters by a few thousand.

Especially high-density businesses want a central location. However, there is also an increasing number of the population wishing to live centrally rather than living in the suburbs where they are dependent on their cars and subjected to the rising traffic congestion. This suggests a balance between jobs and housing units as a fair approach to accommodate the two interested parties. If the suggested *Zoning Decision Rule Policy* were implemented, though, land for business would mainly be zoned in the urban areas surrounding Bergen center and land for housing would mainly be zoned in the center for the next years. It is highly likely that this would lead to objections and would be difficult to implement completely, therefore. For this reason, a combination of the newly designed decision rule with the current decision rule sounds a good idea.

Lack of central data is a limitation of the model. Therefore further research should concentrate on gathering important data on land availability. It is also suggested to establish a database which captures the (re)location processes of businesses in the region. This would provide understanding for the businesses' needs and their need for mobility. Knowing this is a must for implementing a good zoning decision rule.

11. Appendix

11.1 Explanatory Model Testing

Cutting the loops

Loop C5 “The business relocation demand loop”

According to loop C5, the demand for business space by businesses seeking to relocate plays an important role in determining the construction of business structures. To test this hypothesis, C5 was cut by creating a long delay to perceive this demand. Figure 52 illustrates that business construction (both low-density and high-density) is considerable lower without the loop. Only after around 20 years, does business construction reach the same value. The reason for this is that loop R1 (with the perceived need for business space deducted from the amount of positions currently located in Askøy) creates an additional demand for business space.

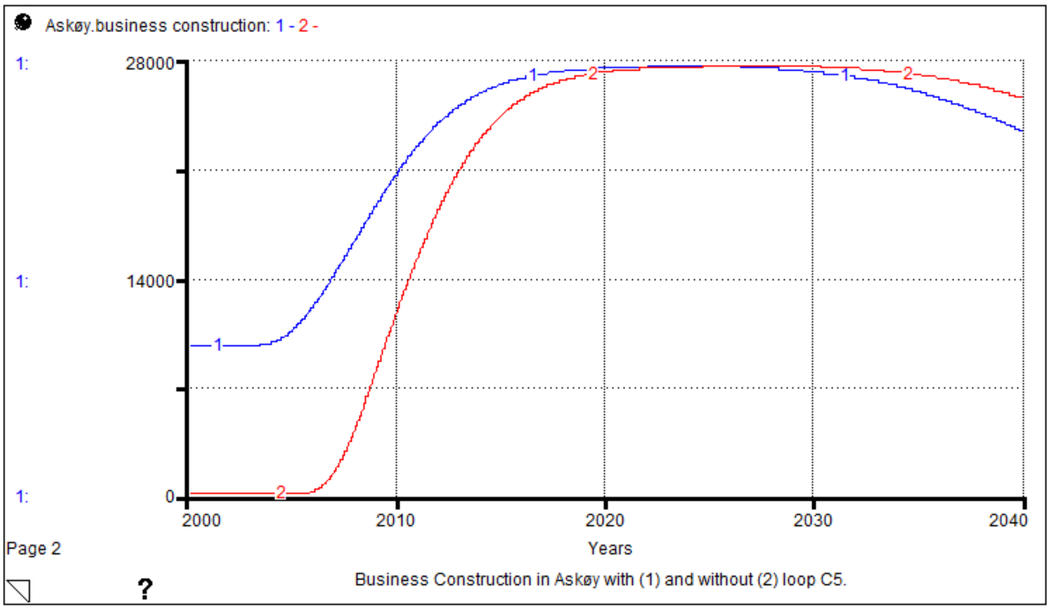

Figure 52. Comparison of business construction in Askøy with (1) and without (2) loop C5.

Figure 53 shows the development of jobs with and without the loop. We can see that due to the low business construction in the first twenty years, the total number of jobs stays below what it otherwise would have been.

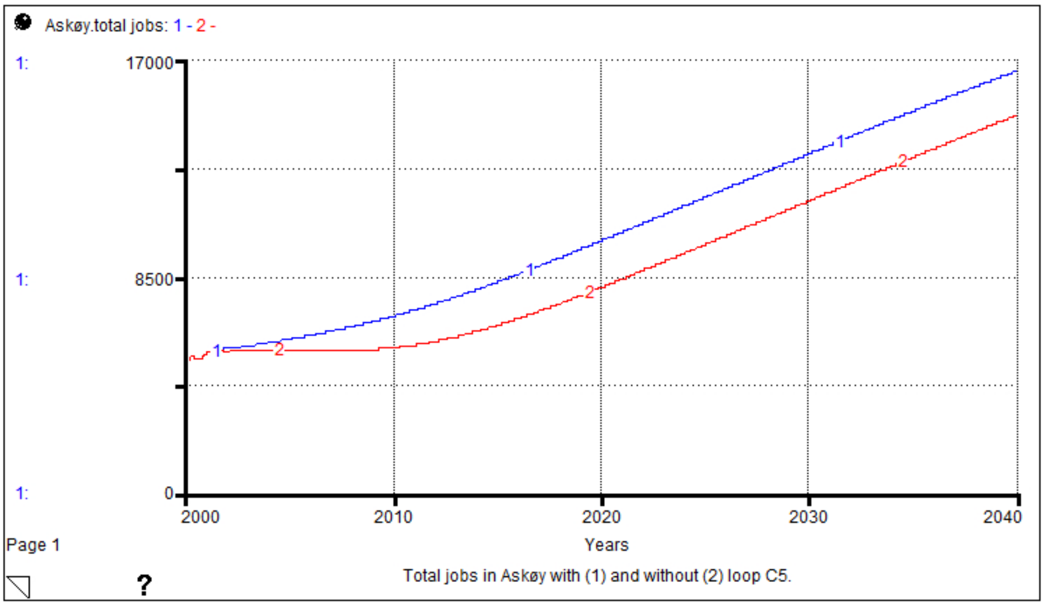

Figure 53. Comparison of total jobs in Askøy with (1) and without (2) loop C5.

<u>Loop R2 "The business demolition loop"</u>

The loop R2 suggests that the demolition of vacant business space increases the vacant land zoned for business which influences the construction of business structures. This was tested by cutting loop R2 in the Bergen center model by setting the business demolition fraction down to zero. As can be seen in Figure 54, business construction is significantly lower without the loop. After 2020, no more construction takes place. The reason for this is that there is no more land available in Bergen center and without demolition no more construction can take place. Figure 55 illustrates that this also affects the total number of jobs in Bergen center. It reflects the importance of business demolition in central areas, especially the demolition of older low-density structures to give way to newer, more land effective structures.

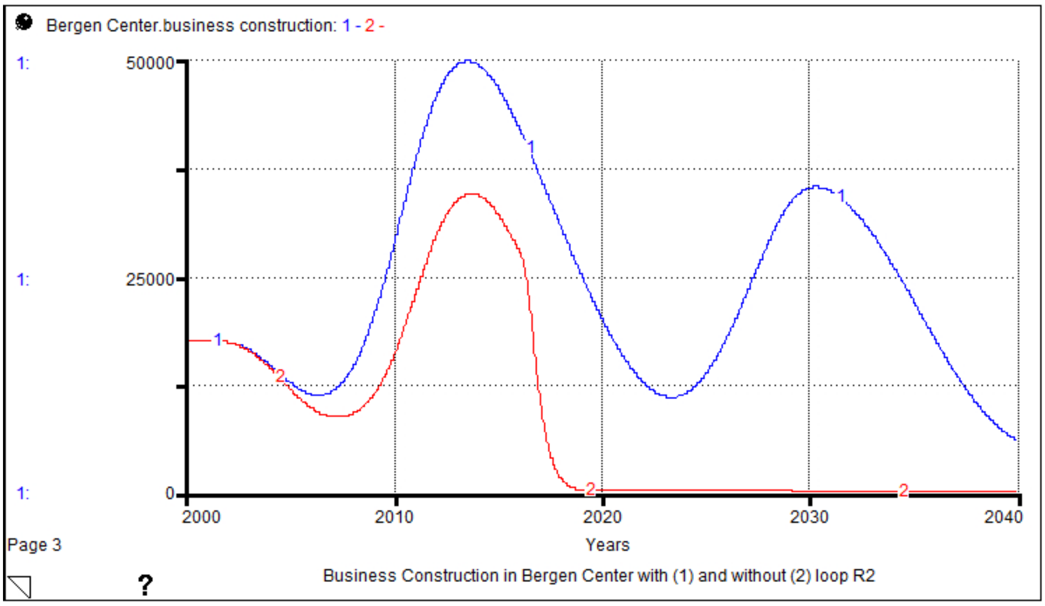

Figure 54. Comparison of the business construction in Bergen Center with (1) and without (2) loop R2.

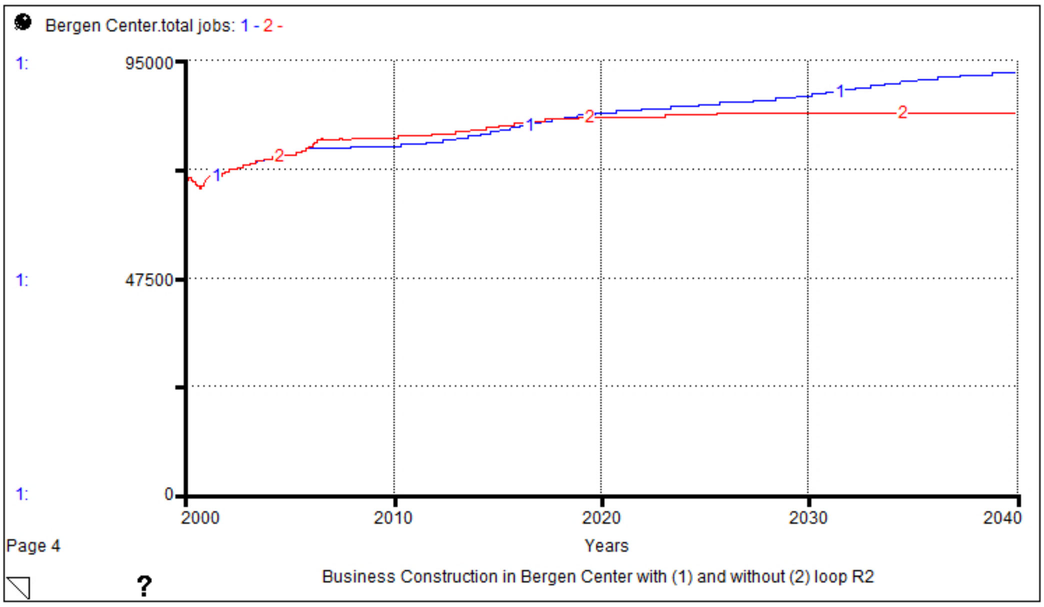

Figure 55. Comparison of the jobs in Bergen center with (1) and without (2) loop R2.

<u>Loop C11 “The expansion loop”</u>

According to loop C11, the possibility to expand is an important relocation factor influencing the number of businesses seeking to relocate and consequently the number of businesses actually relocating. To test this hypothesis, the *effect of the expansion possibility* is set to one, which means it does not influence the choice of location and the desire to relocate. Figure 56 confirms that the possibility to expand influences businesses seeking to relocate: there are significantly fewer businesses seeking to locate (measured in the utility space they occupy) in

Askøy without loop C11. This proves that the possibility to expand is an important factor influencing the location choice of Askøy.

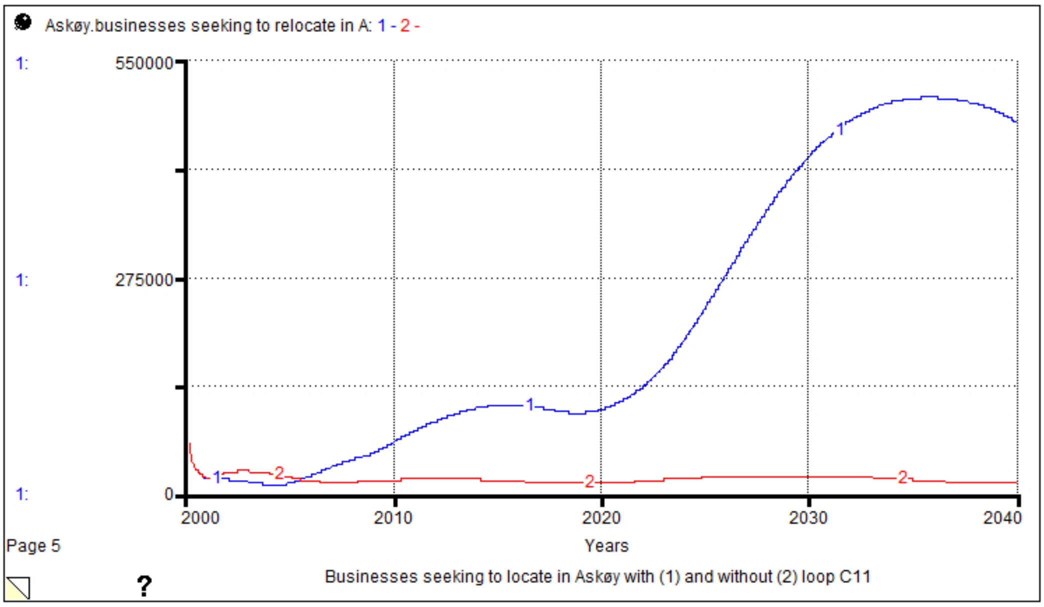

Figure 56. Comparison of businesses seeking to relocate in Askøy with (1) and without (2) loop C11.

Figure 57 illustrates, however, that this does not have a major influence on the businesses which are actually relocating to Askøy. The reason for this is that vacant business space is needed for relocation to be possible. And this is a constraint. The same is true for the rental price and clustering effect loops.

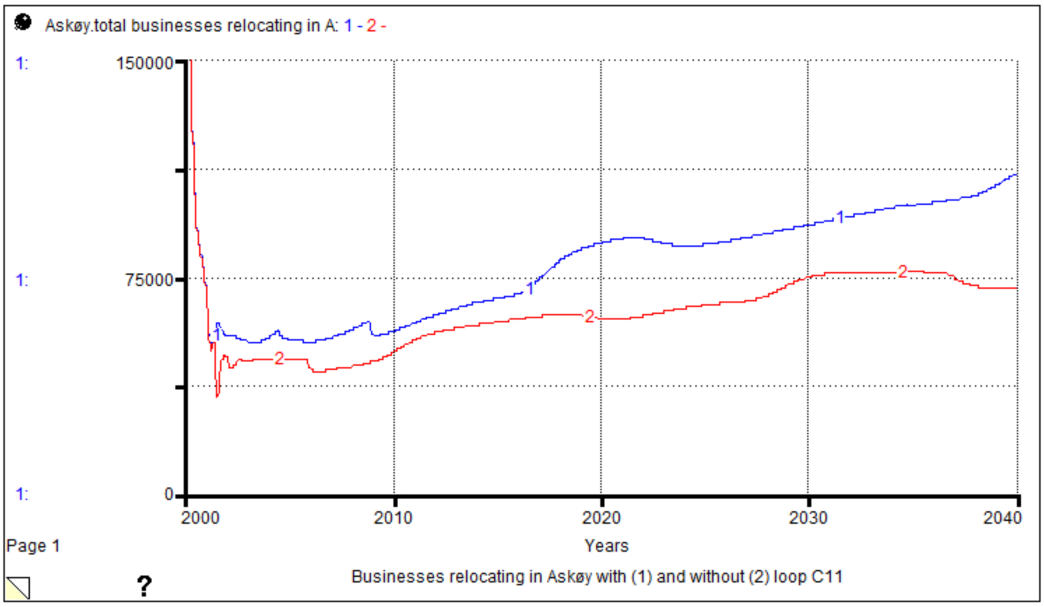

Figure 57. Comparison of businesses relocating in Askøy with (1) and without (2) loop C11.

Loop C12 “The vacant housing construction loop”

C12 indicates that vacant housing space slows down the housing construction. Loop C12 was cut by creating a long delay in perceiving the amount of vacant housing space. Figure 58 showing the housing construction in Askøy proves this assumption. Housing construction is higher and less volatile when not taking the vacant housing space into account.

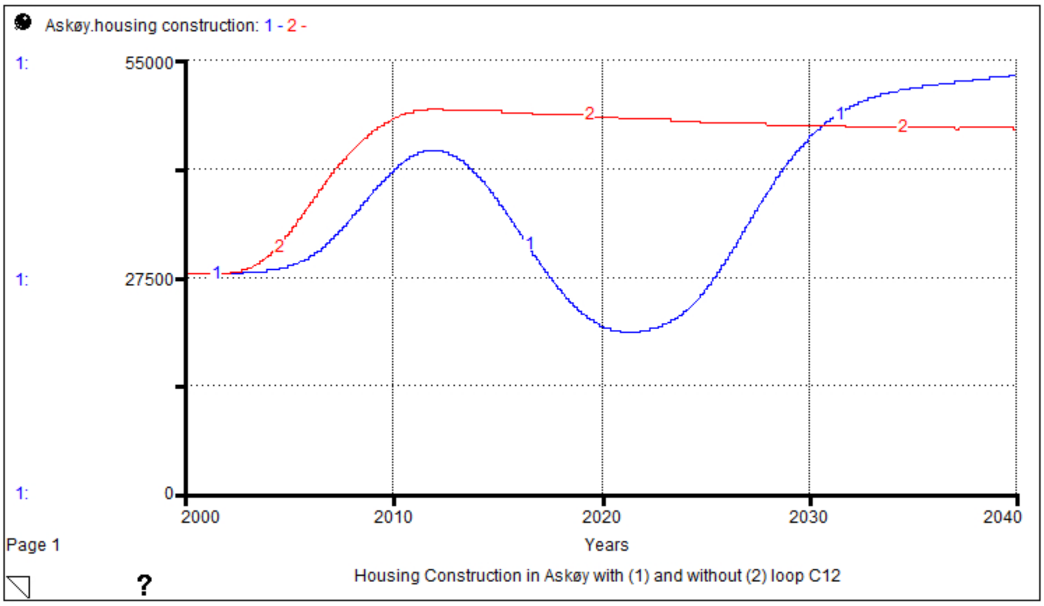

Figure 58. Comparison of the housing construction in Askøy with (1) and without (2) loop C12.

Loop R7 “The housing zoning loop”

According to loop R7, the increase in population should be the only factor influencing the amount of land zoned for housing in each planning period. To analyze the importance of this relationship, loop R7 is cut. This is done by setting the population forecast interval from originally ten to zero years. Figure 59 and Figure 60 show the modeled behavior with and without the loop. With the loop activated the amount of vacant land is increased in four year planning intervals and the number of housing units increases steadily. Without the loop however, the behavior is quite different. The vacant land zoned for housing is depleted because no more land is zoned. Accordingly, the number of housing units grows increasingly slowly until it reaches its maximum value of 11 300.

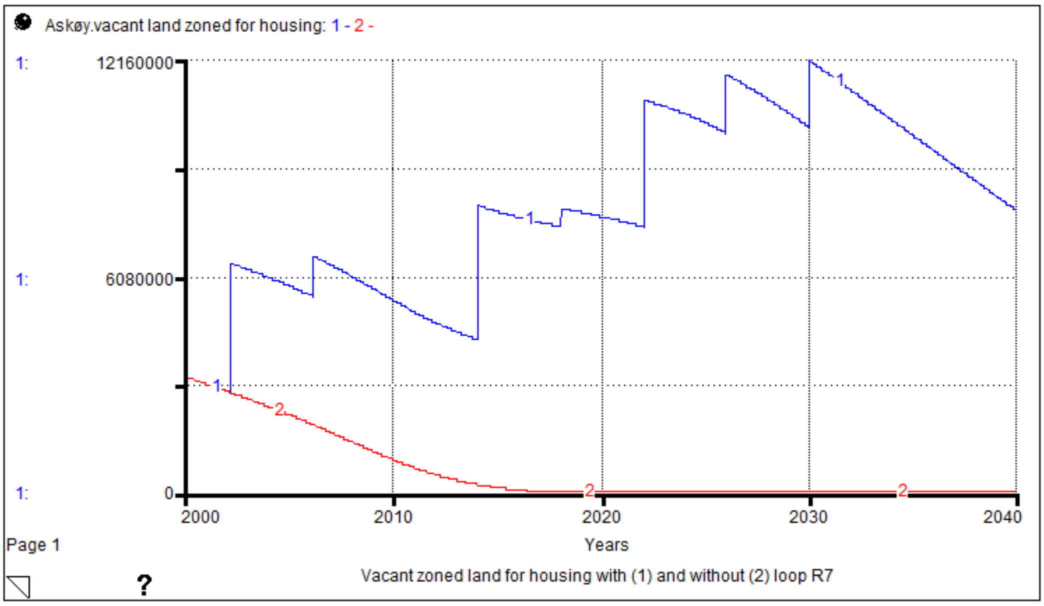

Figure 59. Vacant land zoned for housing with (1) and without (2) loop R7.

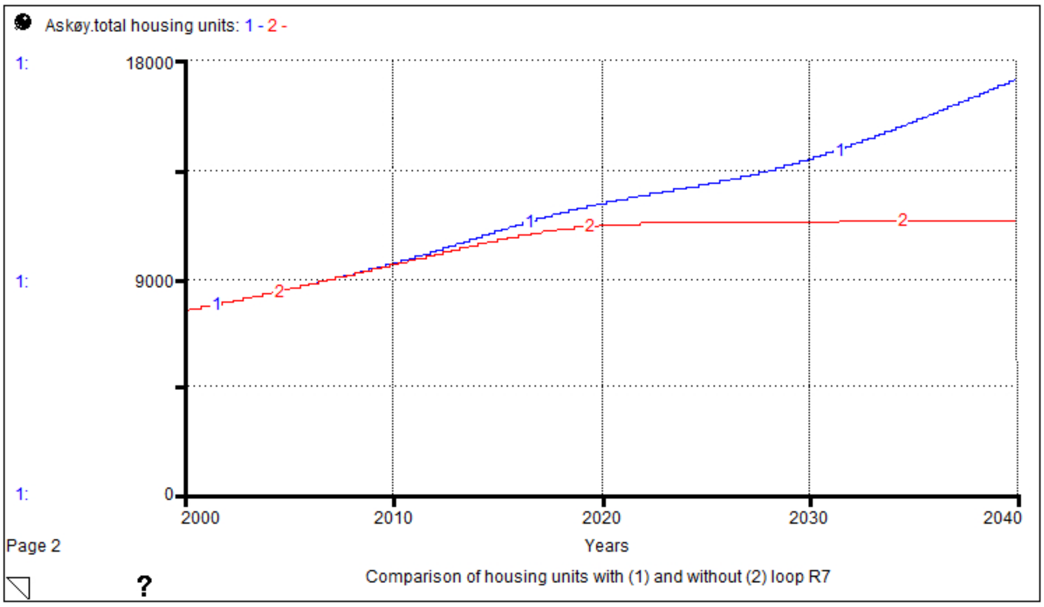

Figure 60. Number of housing units with (1) and without (2) loop R7.

<u>Loop C6 and C15 "The land availability loops"</u>

The model hypothesizes that the amount of vacant zoned land will influence the housing and business construction. The fewer land is available, the fewer construction takes place. So the loops C6 in the business sector and C15 in the housing sector are a constraint. This is based on expert interviews with Bergen Tomteselskap, Bergen Kommune and Stadsporten which revealed that some of the zoned land areas do not comply with the requirements and demands of real estate companies and businesses. To test this hypothesis, loop C6 and loop C15 were cut by setting the *effect of land fraction occupied on requested land for business/housing land* to 1. The observations in Figure 61 and Figure 62 support the hypothesis. Without the loops active, there are more jobs and more housing units.

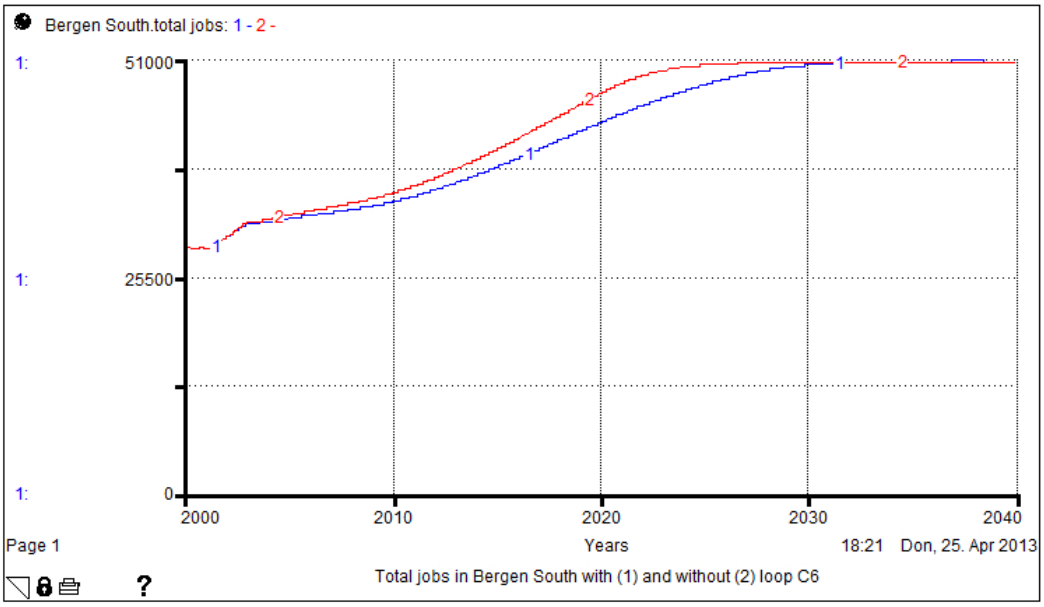

Figure 61. Comparison of jobs in Bergen South with (1) and without (2) loop C6.

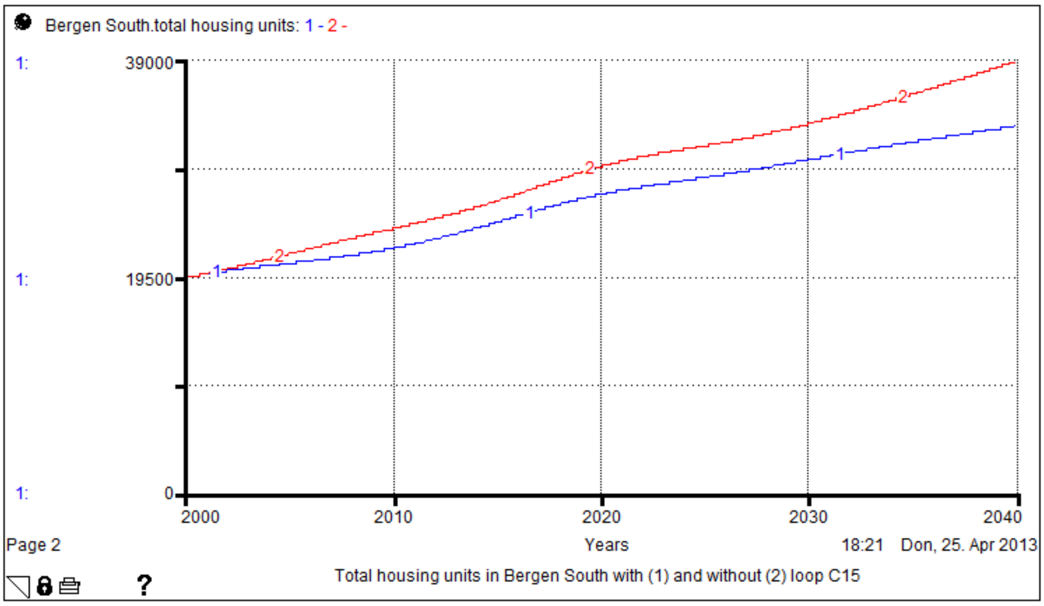

Figure 62. Comparison of housing units in Bergen South with (1) and without (2) loop C15.

<u>Loop R6 and C14 "Attracting population loops"</u>

According to the loops R6 and C14, the increase in population should be a delayed reaction to job vacancies (R6) and vacant housing space (C14). In order to see the effect of the loops, both are cut by making the effect of housing vacancy and job vacancy 1. Figure 63 reflects that population size is influenced by available housing and jobs. While job vacancies slightly constrain the population increase, housing vacancies lead to a higher population increase than without.

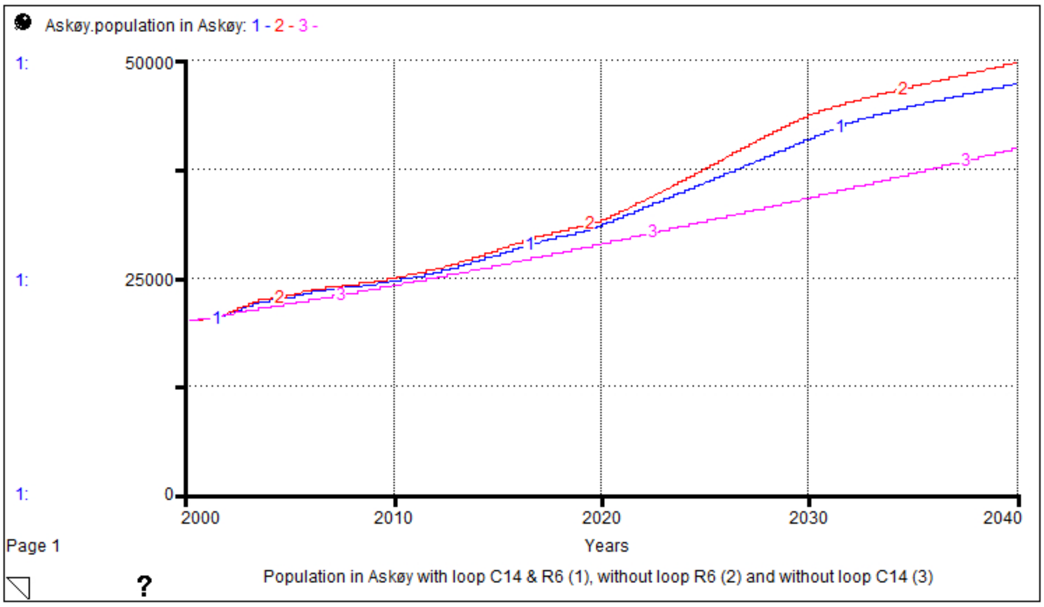

Figure 63. Comparison of the population in Askøy with loops C14 and R6 (1), without loop R6 (2) and without lop C14 (3).

Parameter Sensitivity Analysis

Local service employment ratio

A large part of the jobs are generated by multiplying the population with a *local service employment ratio* which represents local service positions such as teachers, doctors, and staff working at groceries in relation to the size of population. That there is a direct relationship between local service positions and the size of population is beyond doubt, however, the specific parameter is not known for Bergen. Therefore, the model's sensitivity to changes within the parameter was tested. Figure 64 shows three simulations runs: (1) the base run with the 0.18 for Bergen West, (2) with a ratio of 0.08 and (3) with a ratio of 0.28. As can be seen, the change in parameter had a visible effect but the general pattern stays the same.

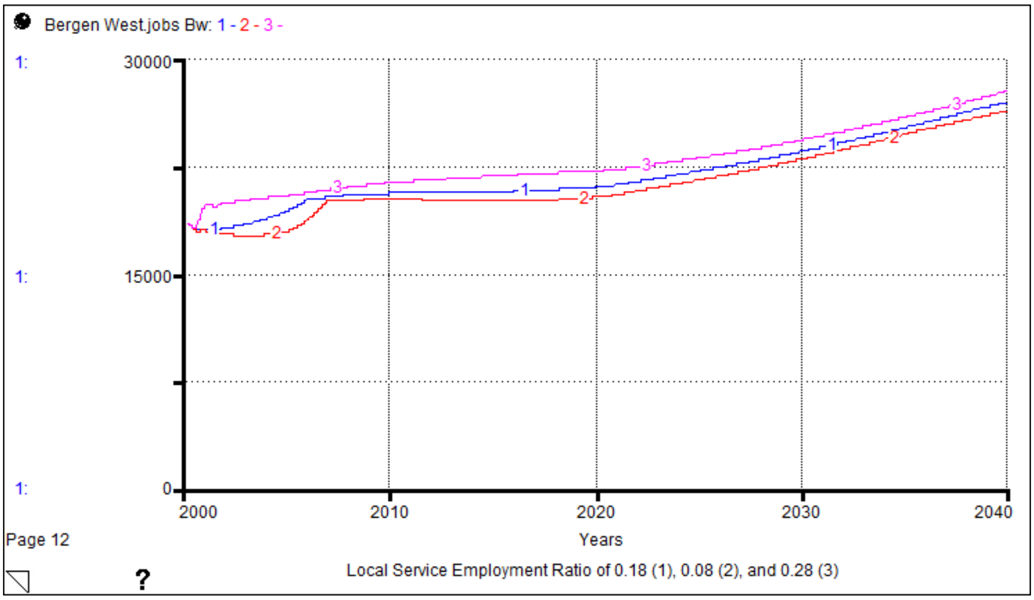

Figure 64. Sensitivity to three different local service employment ratios.

<u>Business demolition fraction</u>

According to earlier findings on the importance of business demolition and the construction of new business structures in Bergen, the model is potentially sensitive to changes in the *business demolition fraction*. Business demolition fractions of 0.1, 0.01 and 0.2 were tried. Figure 65 shows the parameter changes influencing the behavior of the first 15 years, while there a visible changes in behavior after 2015. This illustrates that a high demolition fraction of low-density business structures in the Bergen center is necessary for the further growth of jobs.

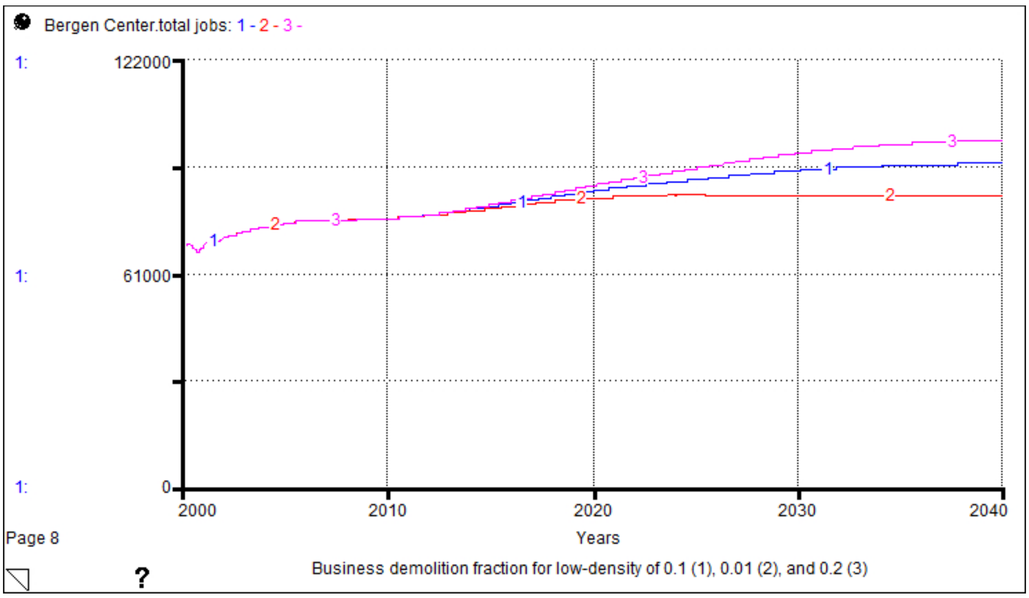

Figure 65. Sensitivity to three different business demolition fractions.

Space per worker

There is uncertainty regarding the space per worker in high- and low-density business structures. Therefore the model's sensitivity to changes in the parameter was tested. Simulation runs with 39 m² (1), 30 m² (2) and 80 m² (3) for high-density structures were undertaken. 39 m² is used in the Bergen center land use model. This value is obtained by dividing the total business space for high-density structures by the total high-density jobs[18]. 80 m² was tested because this is suggested by Opus Bergen (2012). Figure 66 shows that while the general trend is the same, there are big differences in the total number of jobs. The same is true for the *space per worker* for low-density structures.

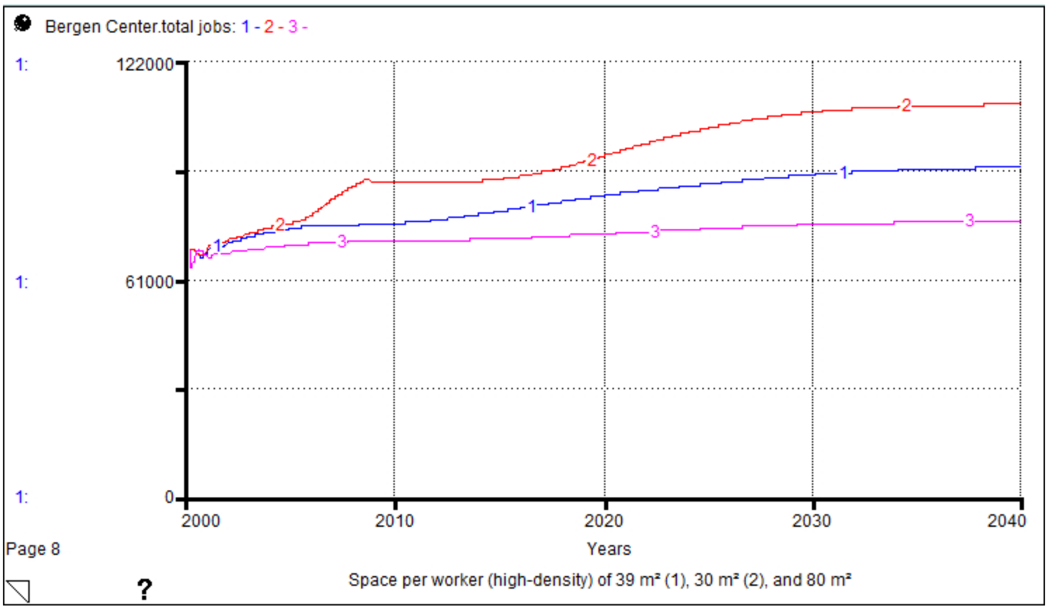

Figure 66. Sensitivity to three different values for the space per worker.

Average floor space ratio for high density business structures and housing units

The same test was also run on the floor space ratios used in the model. Figure 67 shows the model's behavior for the floor space ratio of high-density business structures of 2.3 (1), 1.5 (2) and 3 (3). Figure 68 shows the model's behavior with an *average floor space ratio* for high-density housing units of 1.8 (1), 1 (2) and 3 (3). A low floor space ratio limits the development of housing unit in Bergen center because of the limited land area. Similar behavior was observed when changes to the other floor space ratios in the model were made.

[18] Data obtained from the planning authorities in Bergen municipality. The division between high density and low density for structures and jobs is however difficult and contain a high uncertainty.

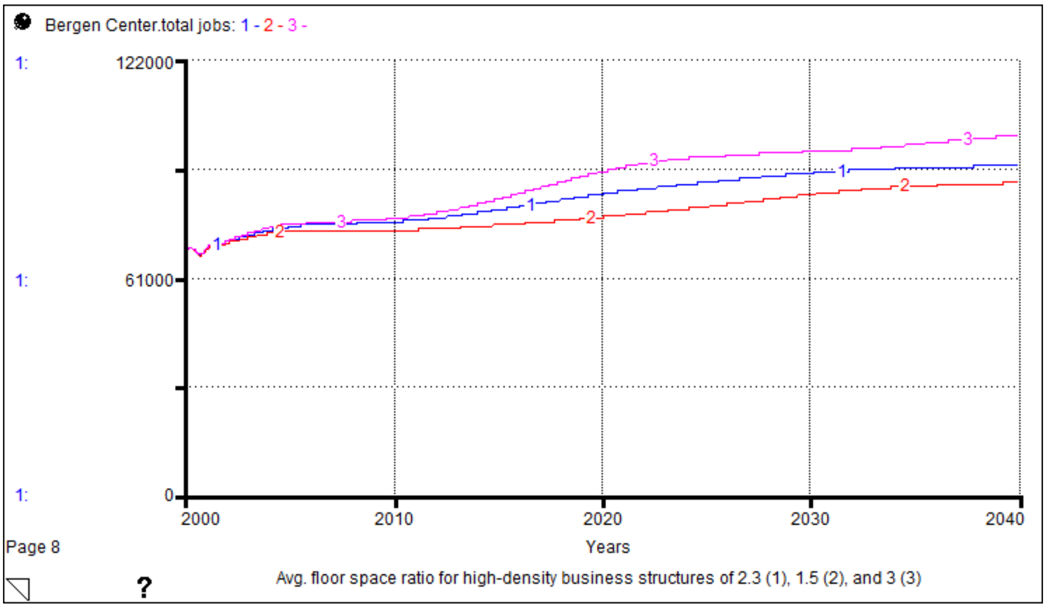

Figure 67. Sensitivity to three different floor space ratios for high-density business structures in Bergen Center of 2.3 (1), 1.5 (2) and 3 (3).

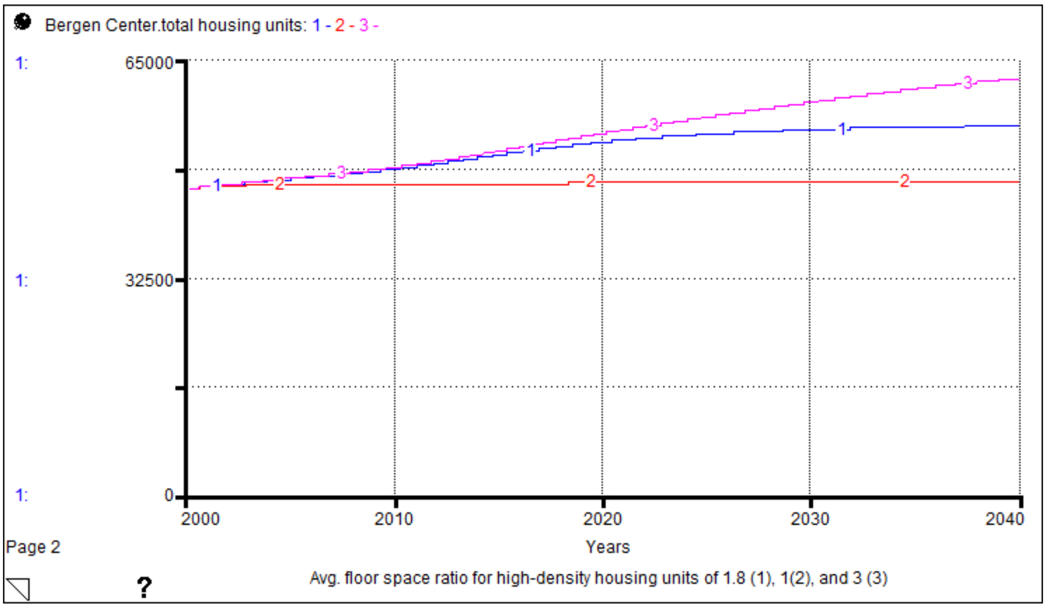

Figure 68. Sensitivity to three different floor space ratios for high-density housing units.

Zoned land for housing

Unfortunately, no reliable data for the amount of land zoned for housing and for business could be obtained. The numbers used in the model are rough estimations based on a general land use map of Bergen municipality. According to earlier findings, sensitivity to changes in the available zoned land is expected. Figure 69 and Figure 70 show that the number of jobs and housing units is significantly influenced by the amount of zoned land for business and housing.

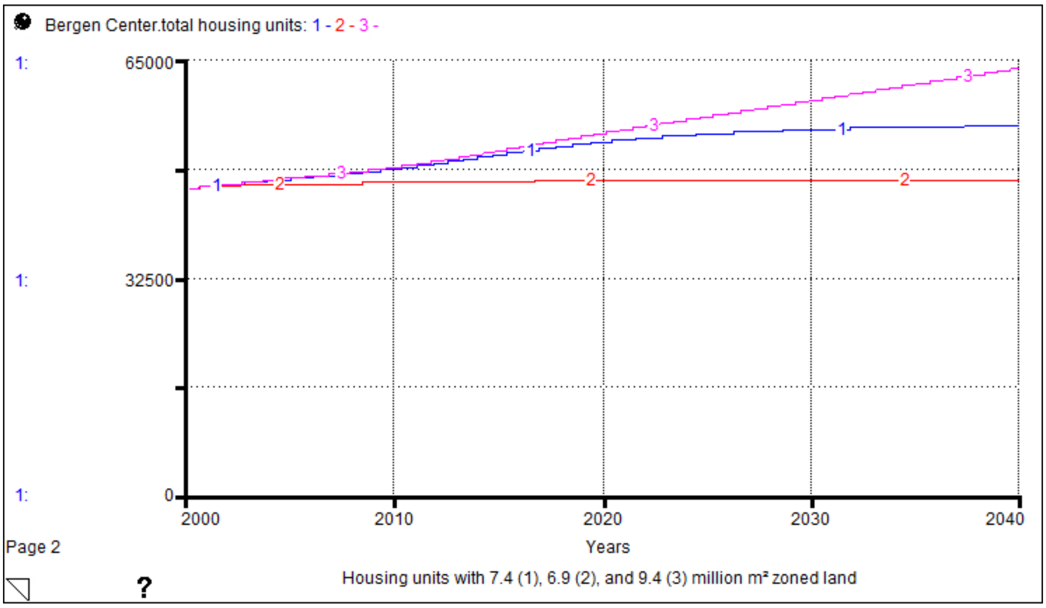

Figure 69. Comparison of total housing units in Bergen center with 7,4 (1), 6,9 (2) and 9,4 million square meters zoned land for housing.

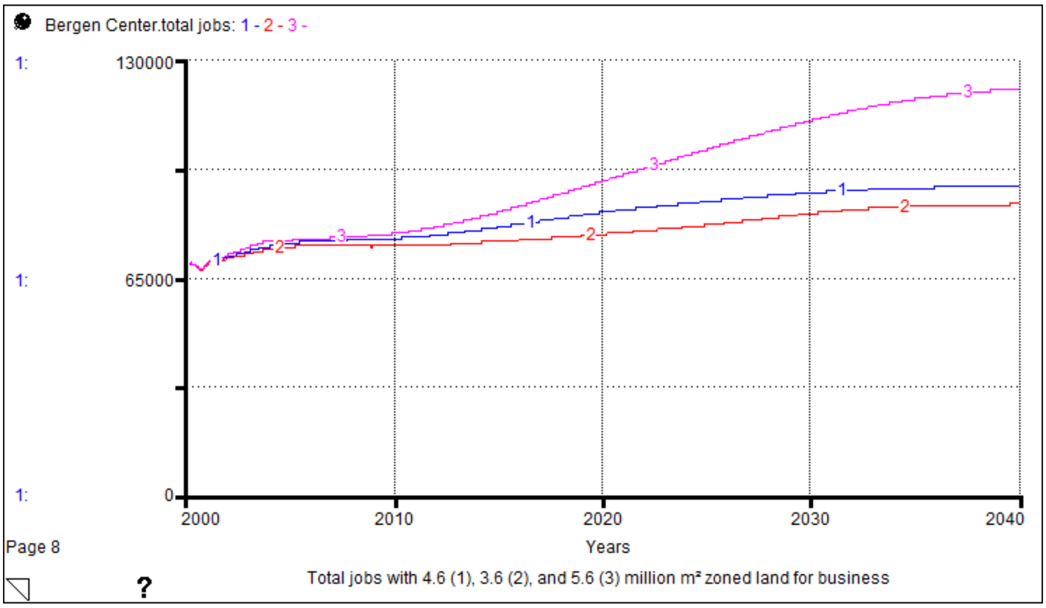

Figure 70. Sensitivity to changes in the land zoned for business.

Testing Table functions

Also, the shape of a table function is based on parameter assumptions which need further testing. The model comprises as many as 16 table functions within each land use sub-model. The shape of the table functions is identical for all land use sub-models. In the following, the model's sensitivity to those table functions that were identified to be part of important loops is presented.

Effect of land fraction occupied on requested land for housing/business

Numerous earlier findings suggest that the model is sensitive to changes in the land availability. Therefore, three different curves were tested for the *effect of land fraction occupied on requested land for housing/business* (see Figure 71). The first curve in the figure is used in the model: when more than 60 % of the zoned land is occupied, the requested land for construction decreases. The second curve suggests that only a land fraction occupied by more than 90 % will lead to changes in the desired construction. The third curve proposes a reduction in desired construction as soon as an occupied land fraction of 20 % has been reached. Figure 72 and Figure 73 show the resulting behavior. The model is slightly more sensitive in the business sector.

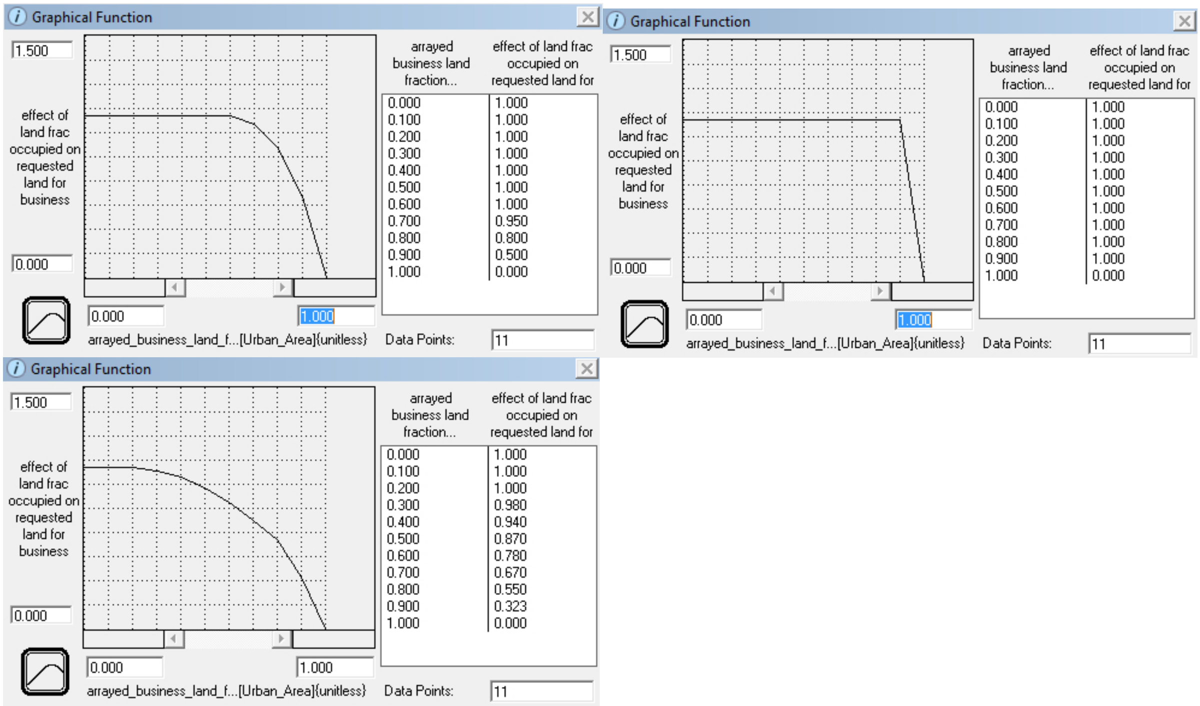

Figure 71. Three different curves for the effect of land fraction occupied on requested land for business.

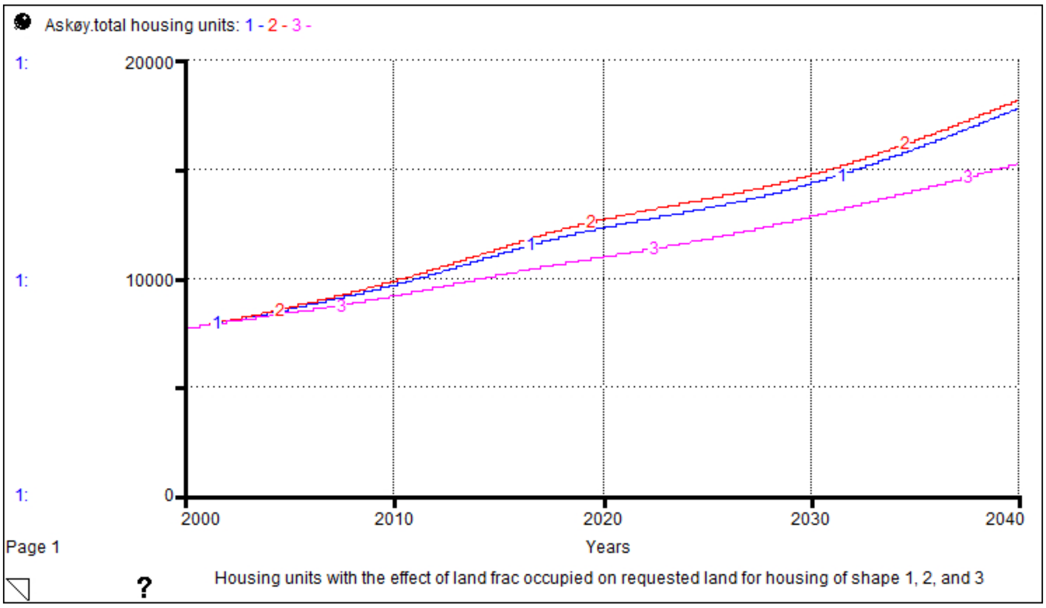

Figure 72. Sensitivity to the different curves for the effect of land fraction occupied on requested land for housing.

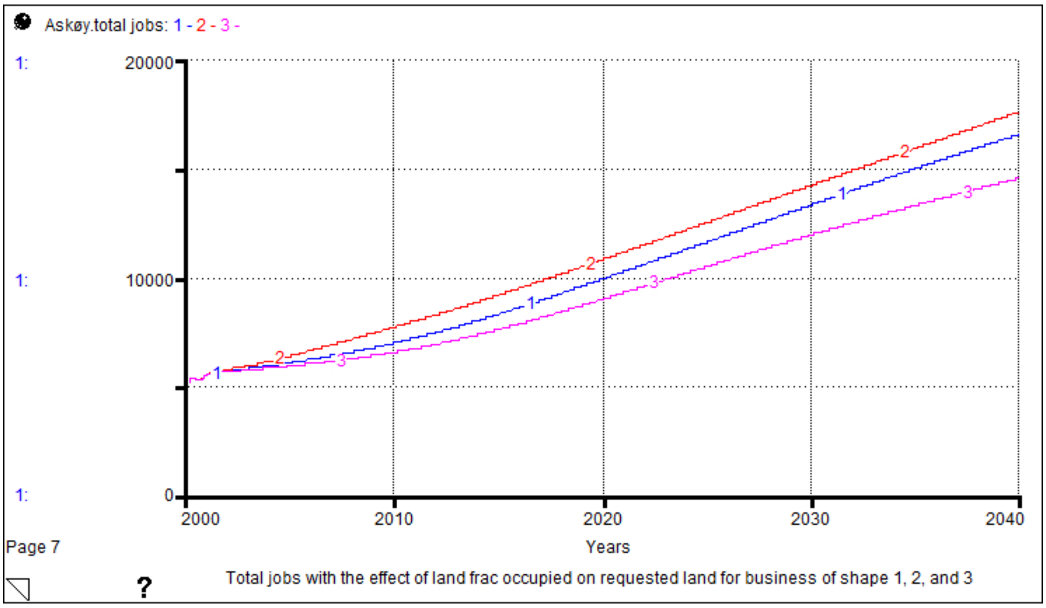

Figure 73. Sensitivity to the different curves for the effect of land fraction occupied on requested land for business.

Effect of housing/job vacancy on people seeking to move

Earlier findings also suggest that the vacancy of housing units and job vacancies play an important role on the migration of people and consequently the population which in turn influences the demand for housing units and the creation of local service positions. Therefore, three different shapes for the *effect of housing vacancy/job vacancy on people seeking to move* were tested. Changing the shape of the curve was found not to alter the behavior of the system (see Figure 74 and Figure 75). The shape of the first curve is the one used in the *Bergen Land Use Model*. This shape is based upon Forrester's table function describing migration in his *Urban Dynamics* model (Forrester, 1969). Forrester's table function describing the effect of housing availability on migration has been widely discussed and reviewed (Mass, 1974; Schroeder III et al., 1975). Even though Forrester uses different input (a ratio of people to housing) to the input used in this model (a ratio of vacant housing to total housing compared to the normal condition) the assumptions for the shape are the same: There is less migration when housing is scarce and more migration when housing is abundant. Small changes to the normal condition lead to rather big changes in the migration while the effect saturates at both extremes. While slightly more vacant housing units than normal cause migration to rise because more people seeking to move can actually do so, an abundant number of housing units does not necessarily attract many more migrants because the demand is mostly saturated. When fewer housing units are vacant, fewer people will migrate because their housing preferences (such as the neighborhood, school, type of housing unit, price) are less likely to be satisfied by the remaining units. However, the effect of the housing vacancy on people seeking to move never drops to zero because even if there are no housing units vacant some migrants might still move into occupied housing units – if they join their family or move in at their friend's place. The shape of the table function describing the effect of job vacancies is based on the table function described by Forrester in his *Urban Dynamics* model, (Forrester, 1969, p. 29) too. The shape of the table function can be seen in the first graph in Figure 76.

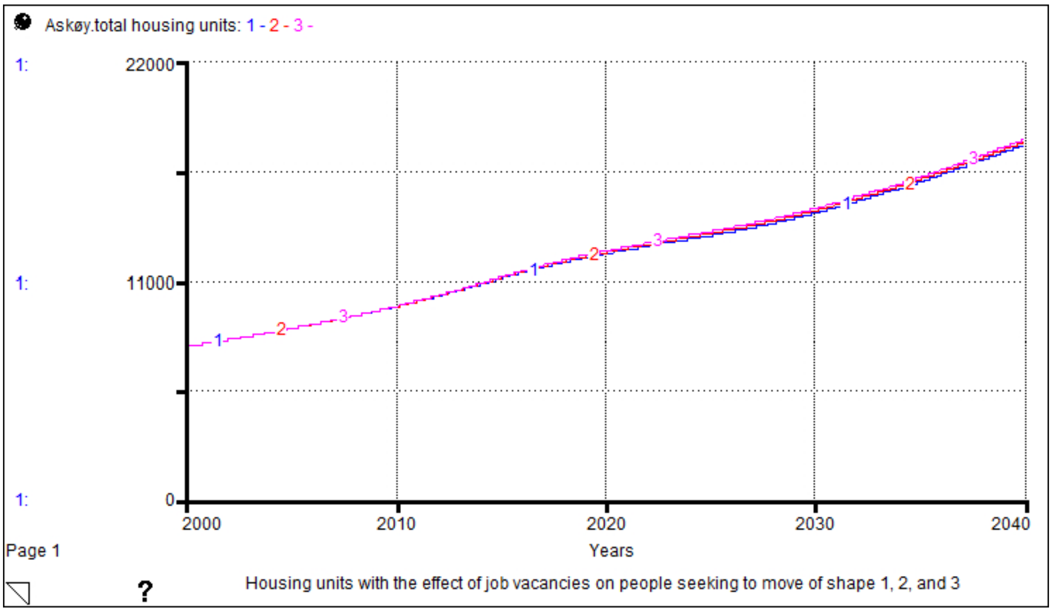

Figure 74. Sensitivity of housing units on the three different shapes of the effect of job vacancy on people seeking to move.

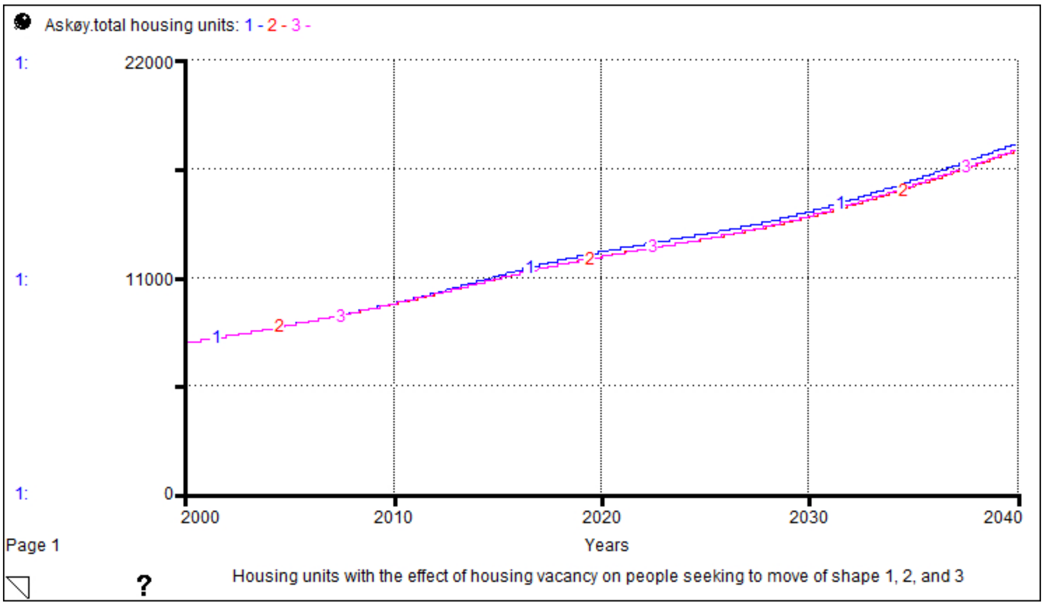

Figure 75. Sensitivity of housing units on the three different shapes of the effect of housing vacancy on people seeking to move.

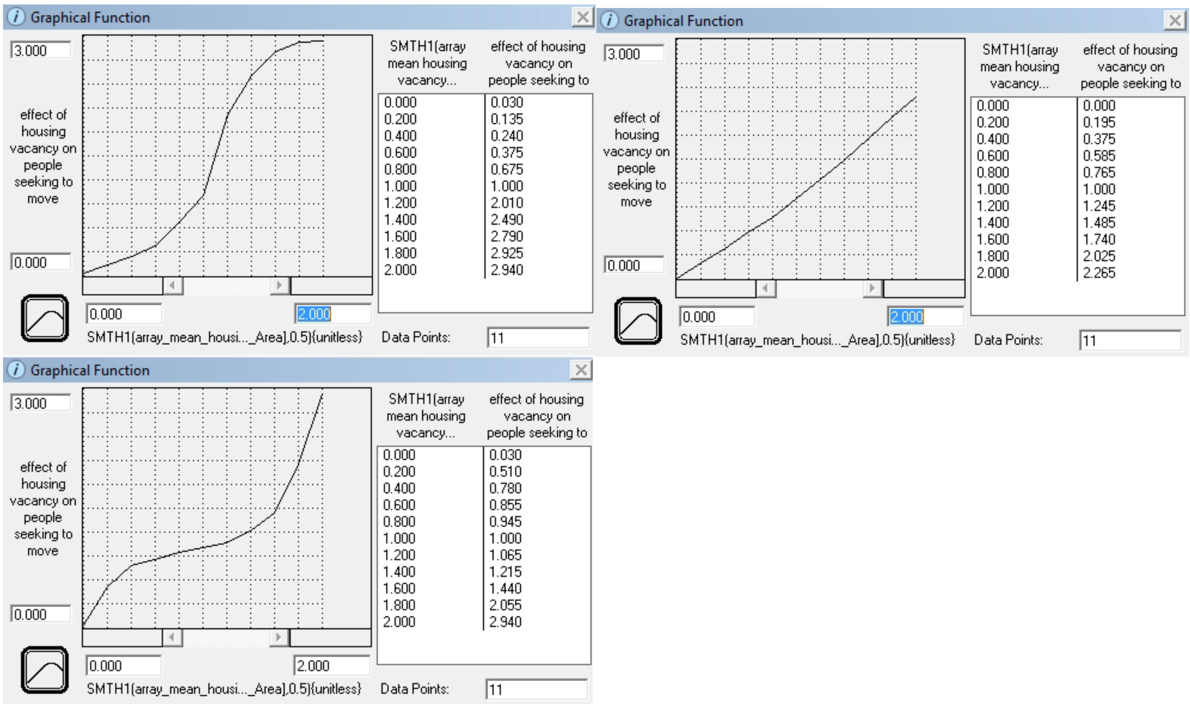

Figure 76. Three different curves for the effect of housing/job vacancy on people seeking to move.

<u>GDP effect on annual position growth</u>

As running the model with exogenous input suggested, the *GDP effect on annual position growth* plays an important role, at least for the Bergen center model. To test the model's sensitivity to changes in the table function, three different curves were tried. Changing the shape of the curve in Figure 77 was found not to alter the behavior of the system significantly (see

Figure 78). The curve used in the model is the first shown in the Figure. The shape is based on a scattered plot with the annual position growth in the Bergen from 2001 to 2011 on the y-axis and annual GDP growth in Norway from 2001 to 2011 on the x-axis.

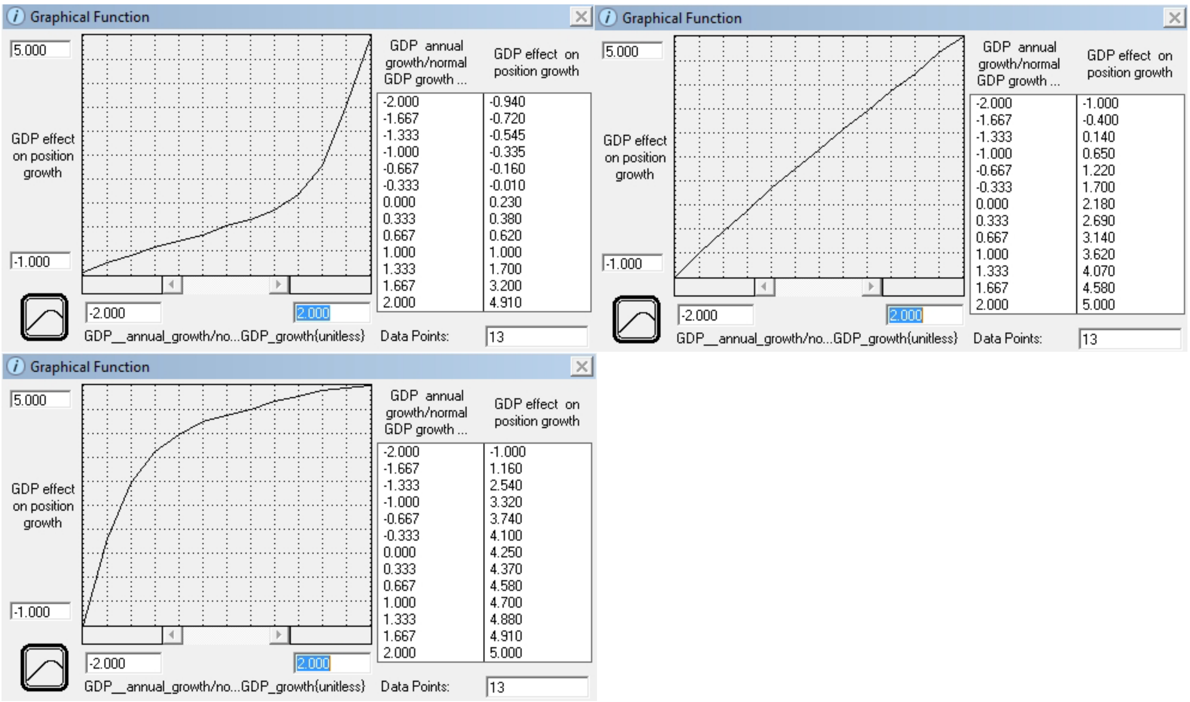

Figure 77. Three different curves for the GDP effect on position growth.

Figure 78. Sensitivity to changes in the GDP effect on position growth.

Effect of expansion possibility

The lack of possibility to expand the business plant at the current location is a main factor influencing the desire to relocate and the choice of location. This suggests that the model is sensitive to changes in the shape of the *effect of expansion possibility*. The three curves in Figure 79 were tested. The first curve suggests a linear relationship, the second assumes that small differences to the preferred situation lead to significant changes in the attractiveness of the area as a business location. The third curve hypotheses that small changes to the preferred situation do not affect the overall attractiveness, while big differences do. Changing the shape of the curve was found not to alter the behavior of the system in the first 15 years, however, changes are more significant in the years 2015 to 2040 (see Figure 80). The shape of the first table function is taken in the model.

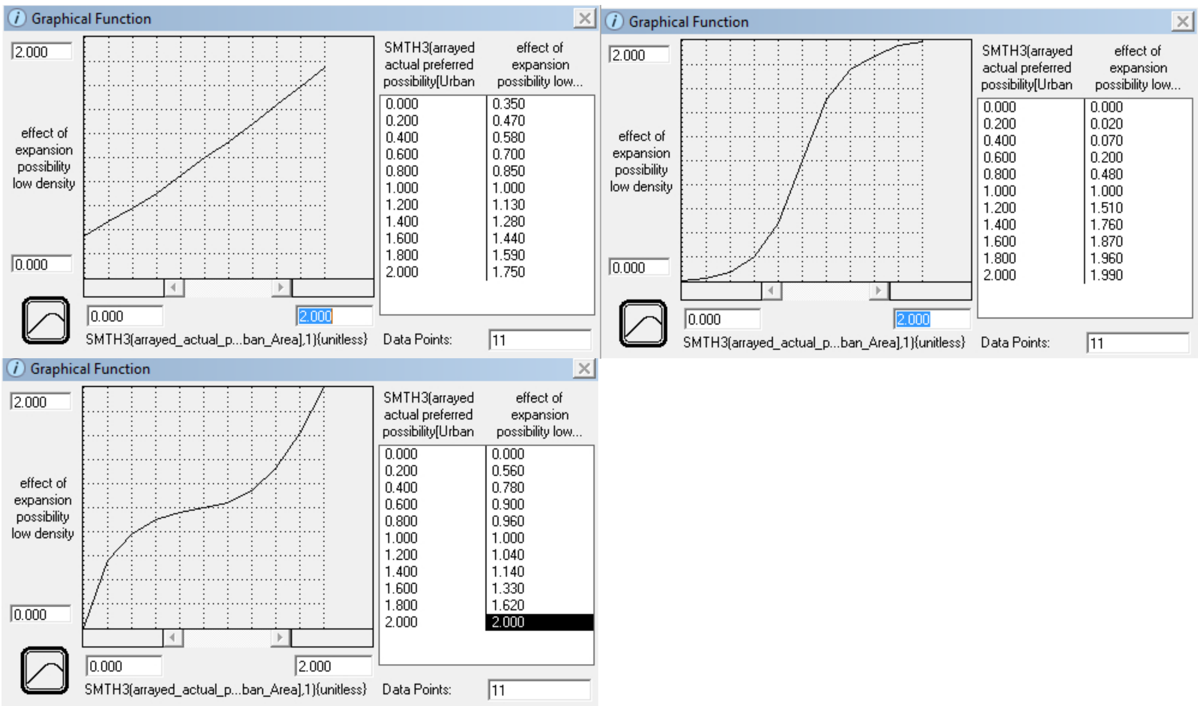

Figure 79.Three different curves tested for the effect of expansion possibility.

Figure 80. Sensitivity to changes in the effect of expansion possibility.

Clustering effect

The clustering effect is a well-described location factor for businesses, however, no definite numerical values exist describing the clustering effect in the Bergen region. As can be observed in Figure 81, changes to the effect did not alter the behavior of the system significantly for Bergen center. However significant numerical sensitivity can be observed for Askøy (see Figure 82). The shape of the first curve in Figure 83 was chosen in the model because it seemed to represent the behavior of the other land use models best. The curve suggests that the clustering effect increases at a decreasing rate until it saturates at 1.5 when the share in business space reaches 30 % of the total business space in the Bergen region.

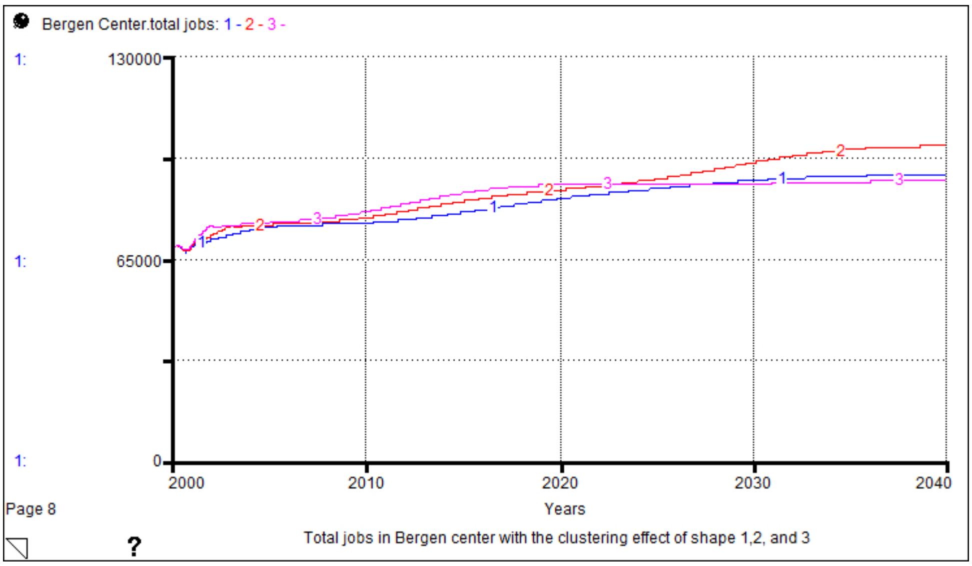

Figure 81. Sensitivity to changes in the clustering effect.

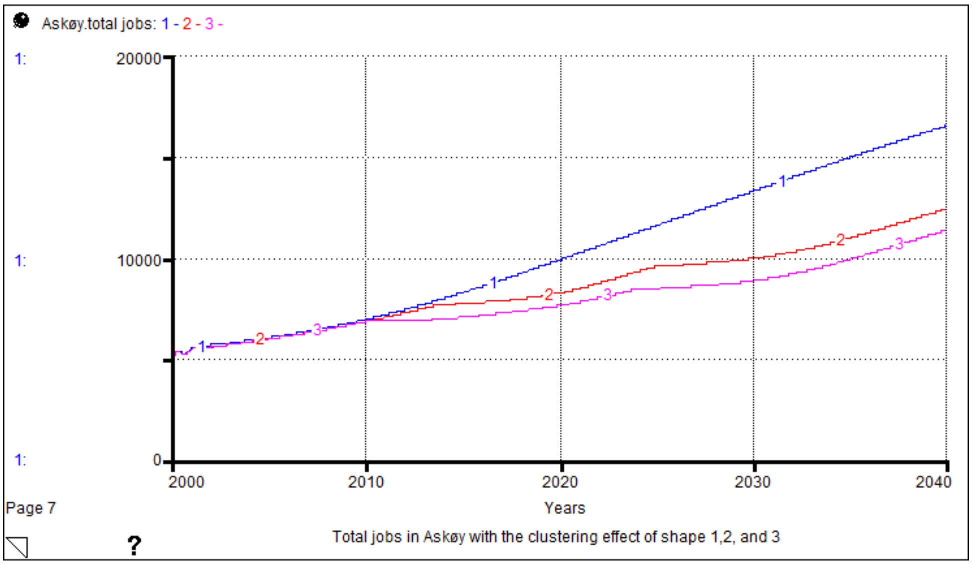

Figure 82. Sensitivity to changes in the clustering effect.

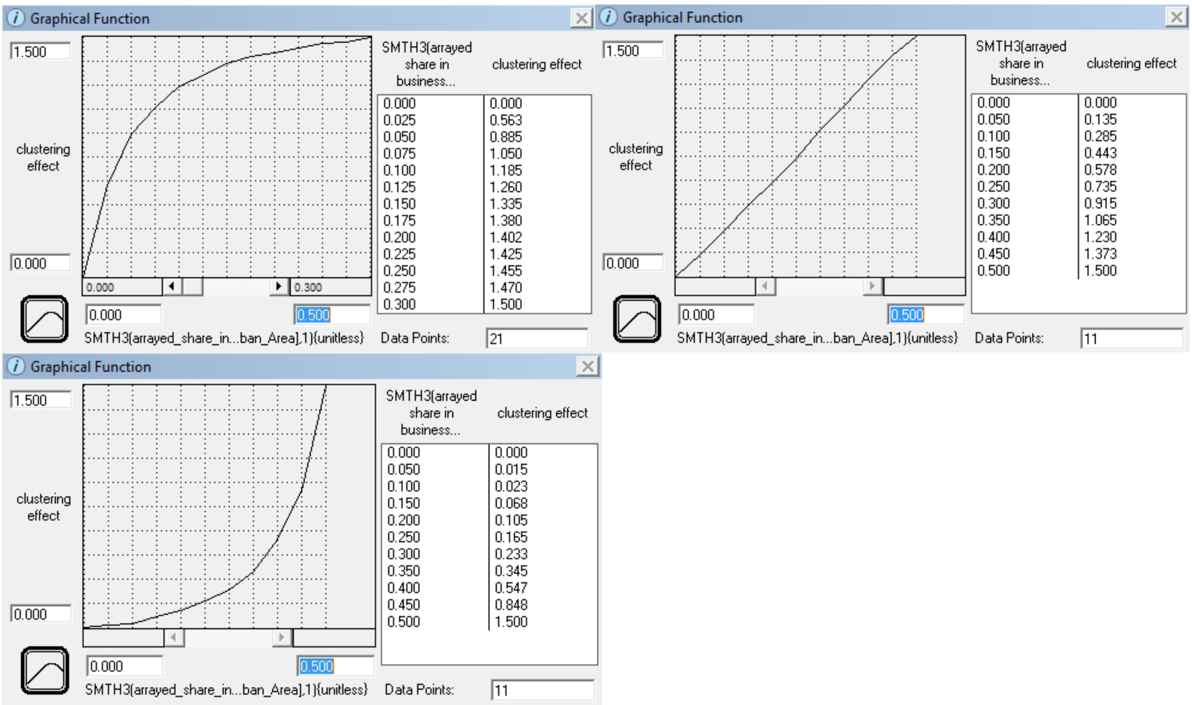

Figure 83. Three different curves for the clustering effect.

<u>Vacancy effect on the housing construction</u>

As earlier findings suggest, the fraction of vacant housing units influences housing construction. The model might be sensitive to changes in the table function. The three different curves shown in Figure 84, reveal, however, that during the first simulation years the model does not react very sensitively to changes (see Figure 85). The difference increases, however, over time. This is due to the long delays in the construction activities. The first table function in

Figure 84 was chosen in the model. It suggests that the demand for housing construction is twice as high as normal construction when there are no vacant housing units, while the demand for construction decreases when more housing units are vacant than normally. The little construction that still takes place when the housing vacancy fraction is more than twice as high as normal, is put down to private people building their own homes.

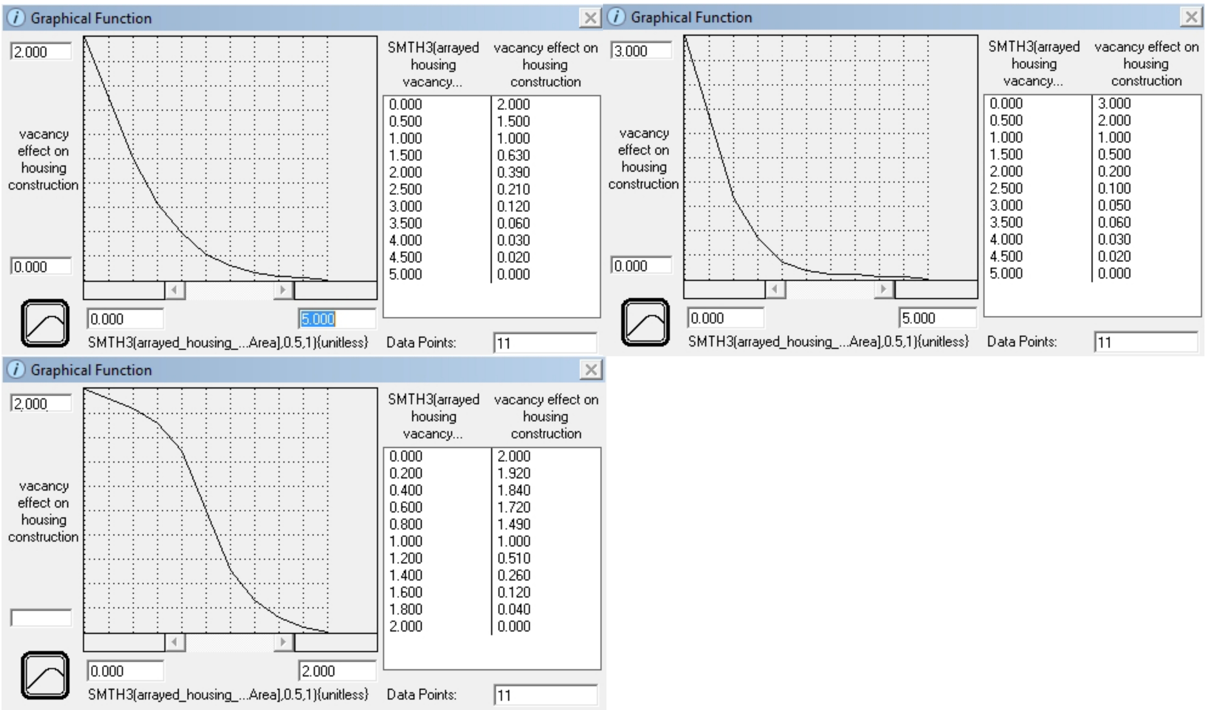

Figure 84. Three different curves for the vacancy effect on the housing construction.

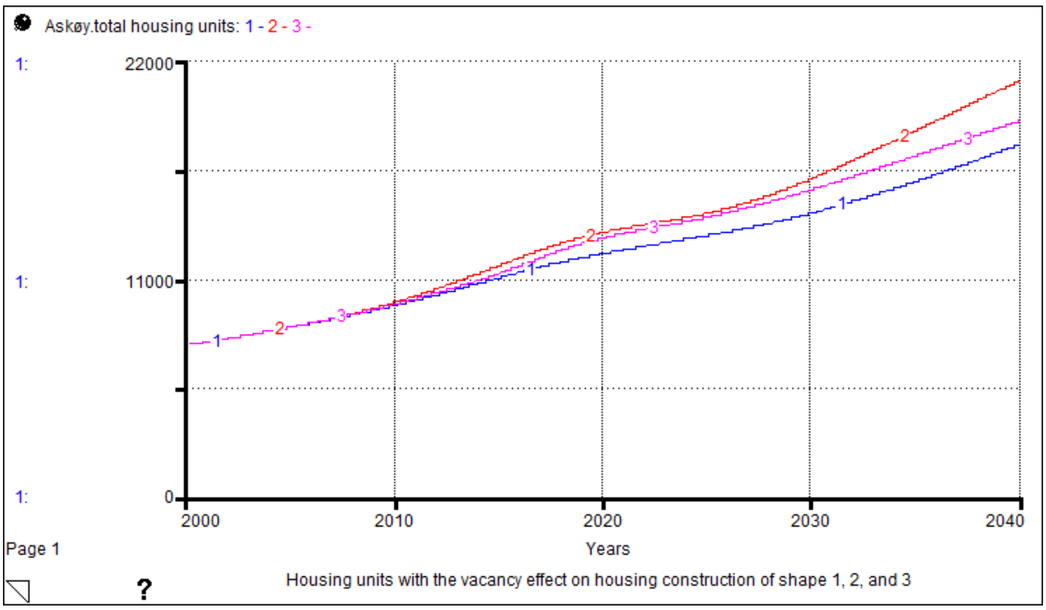

Figure 85. The model's sensitivity to changes in the vacancy effect.

<u>Effect of supply demand ratio on business construction</u>

The last sensitivity test described here, was conducted on the *effect of supply demand ratio on business construction*. Three simulation runs were conducted with the different curves shown in Figure 86. As can be seen in Figure 87, the model is sensitive to changes in the shape of the curve. The first curve was chosen because it represents the historic business construction best.

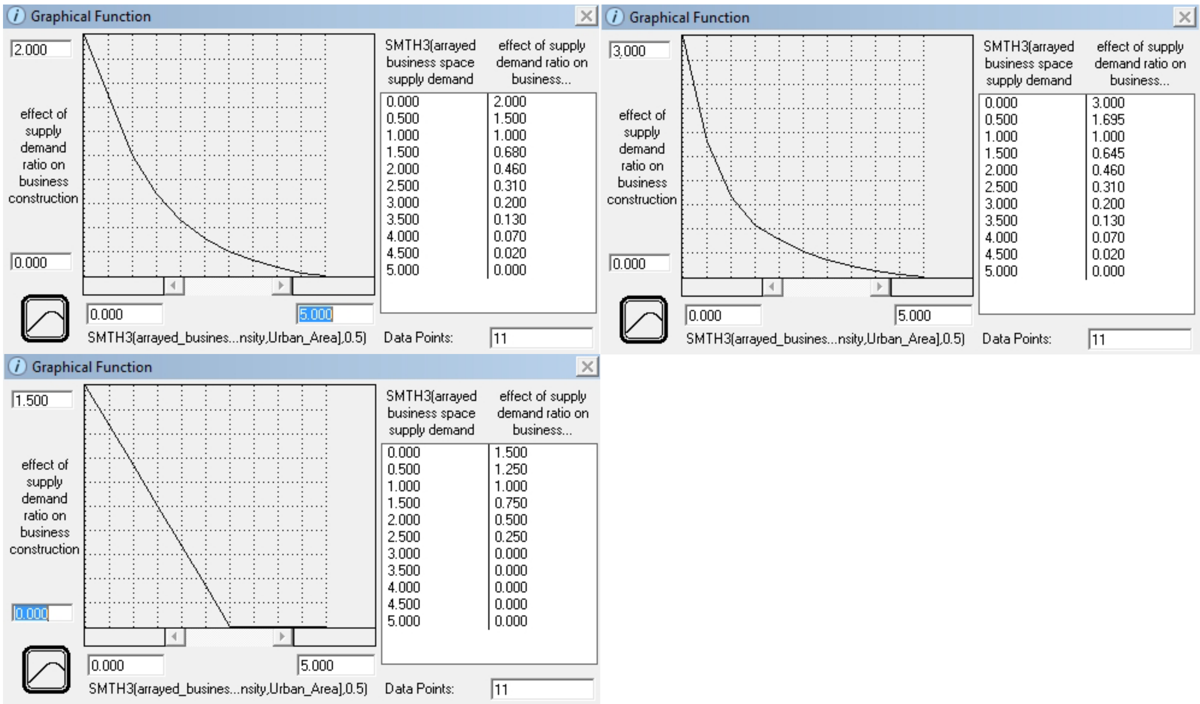

Figure 86. Three different curves for effect of supply demand ratio on business construction.

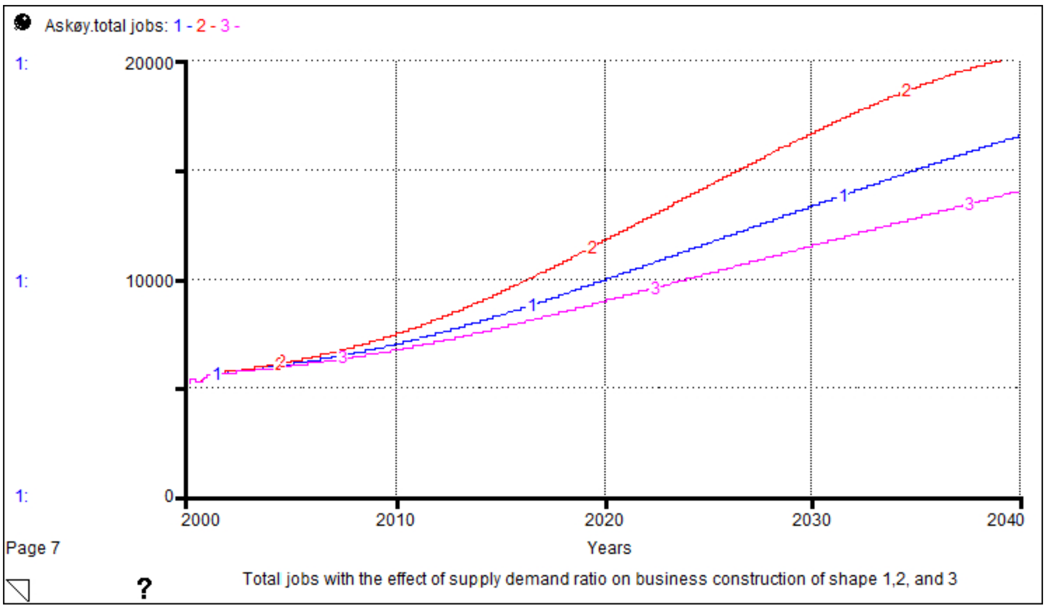

Figure 87. Sensitivity to changes in the effect of supply demand ratio on business construction.

Equilibrium Shock Test

To conduct this test the model was initialized in equilibrium and the system was then shocked with different inputs in the year 2002[19]. In the first test, the shock input consists of a sudden increase of 10 000 extra inhabitants to the population in each land use model. The shock also activates the net birth rate and the migration. This sudden shock to the population and the consequent increase should cause a rise in housing construction activity and lead to a rise in the number of local service jobs which in turn increases the business construction activity. This behavior was observed in Figure 88.

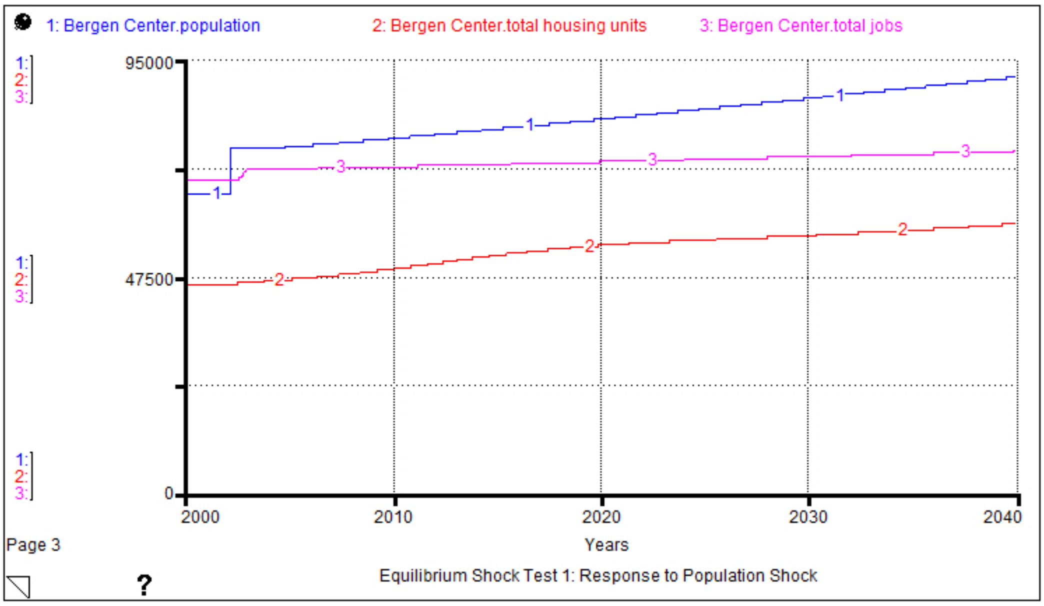

Figure 88. Response to Population Shock.

The second shock test challenges the system with a sudden relocation of businesses in each land use model. This test should result in increasing jobs. Figure 89 shows the expected behavior for Bergen center. Especially high-density businesses relocate to Bergen center and lead to a rising number in jobs. The uneven behavior of high-density businesses relocating to Bergen center is due to the fact that those businesses that seek to relocate can only do so when there is enough vacant business space.

[19] The enclosed version of the model in iThink includes switches to put the model in equilibrium and to perform different shocks to the system.

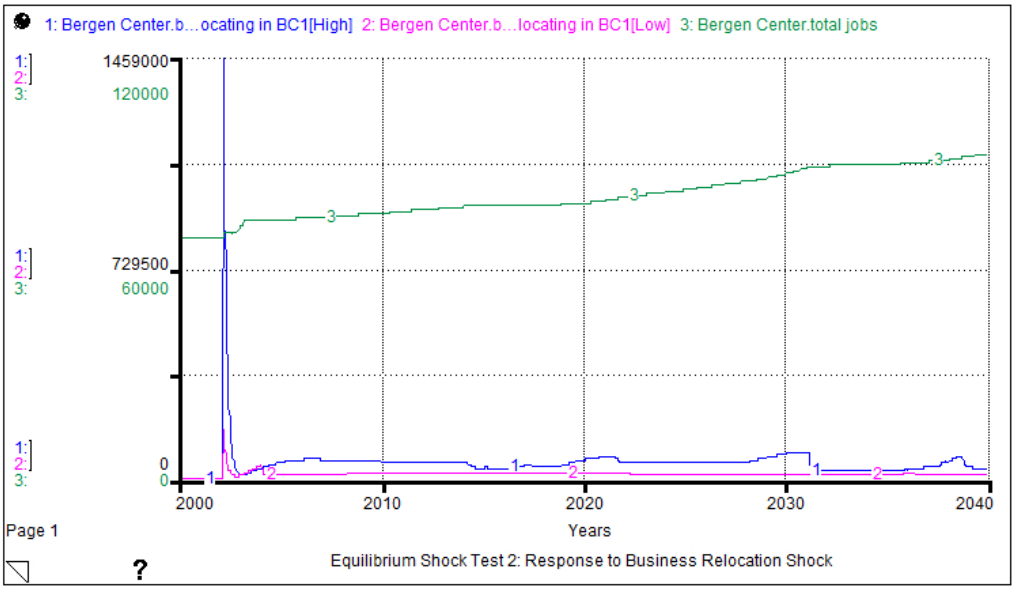

Figure 89. Response to a business relocation shock.

The third equilibrium test is not really a shock test but rather activates exogenous inputs such as the development in GDP and CPI. This allows analyzing their effect on the overall behavior. Figure 90 shows the simulated behavior compared to the data. Both in Askøy and Bergen center the number of jobs increases as expected. The exogenous input explains the development of jobs in Bergen Center quite well, while it doesn't reflect the behavior in Askoy accurately. The reason for this is that Norway experienced a strong growth in GDP between 2004 and 2007 which led to good employment conditions. Bergen center holds most jobs and was therefore affected more by the economic upturn than Askøy that mainly has local service jobs which are not much affected by economic development.

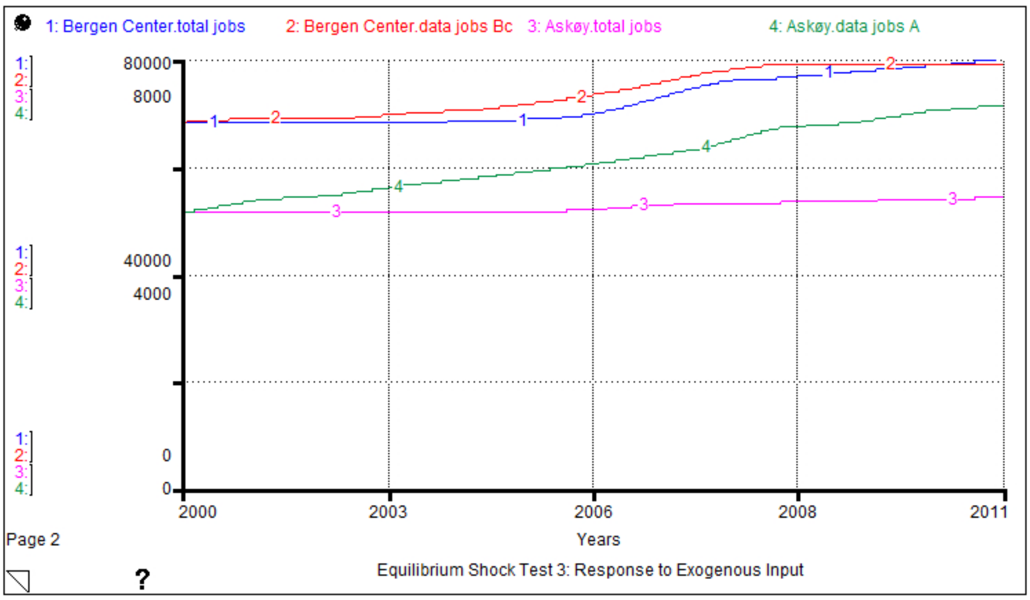

Figure 90. Model's response to exogenous input.

11.2 Policy Model Testing

Arranged Relocation Policy

To test whether the *Arranged Relocation Policy* is more effective when the clustering effect is increased, the policy was run with three different table functions for the clustering effect (see Figure 92). As can be seen in Figure 91, increasing the clustering effect did not have a significant effect on the number of jobs in Askøy.

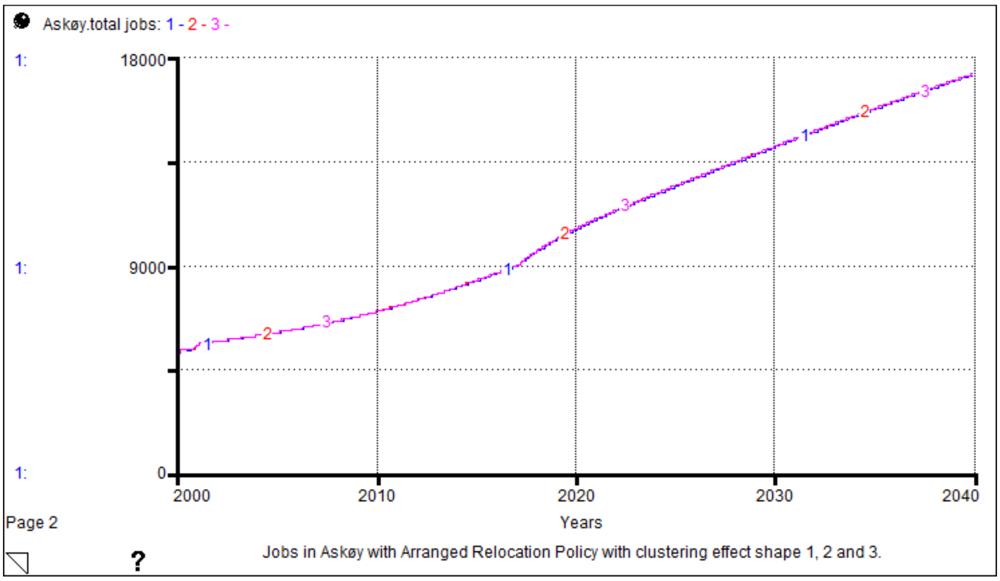

Figure 91. Jobs in Askøy with the *Arranged Relocation Policy* run with three different clustering effects.

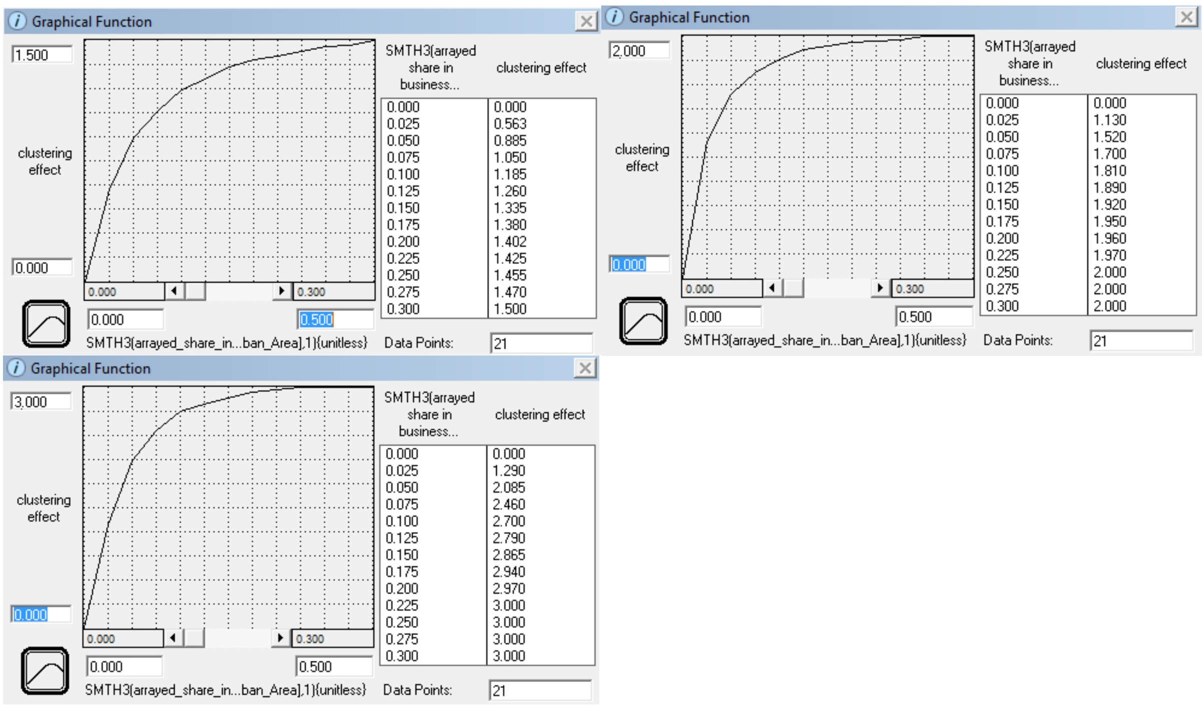

Figure 92. Three different table functions for the clustering effect.

The model's sensitivity was also tested in regard to changes in the effect of supply demand ratio on business construction when the *Arranged Relocation Policy* was active. The same three different curves for the table function were tried as in Figure 86. Figure 93 illustrates that the model is numerically sensitive to changes.

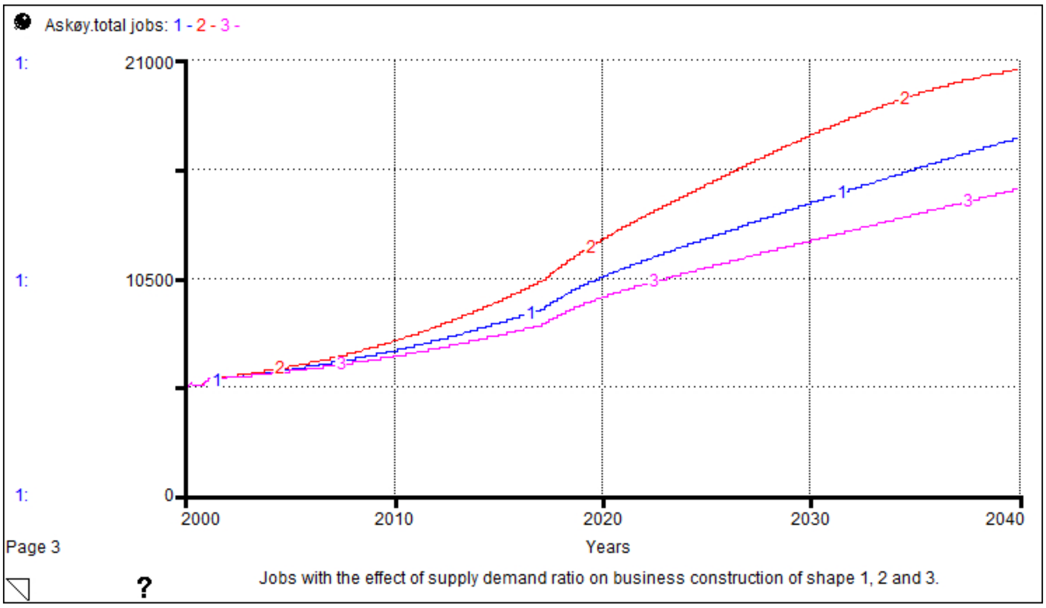

Figure 93. The model's sensitivity to changes in the effect of supply demand ratio on business construction with the *Arranged Relocation Policy*.

Rezoning Policy

The effect of the *Rezoning Policy* to a large extent depends on the floor space ratio used by the construction of the new structures. The policy was run with different *average statutory floor space ratios* for high-density structures in Bergen center to test the model's sensitivity to changes made to it. Figure 94 and Figure 95 illustrate the model's behavior regarding the number of jobs and housing units with a floor space ratio of 2 (curve 1), 3 (curve 2) and 1 (curve 3). As expected, jobs and housing units increase more, the higher the floor space ratio is.

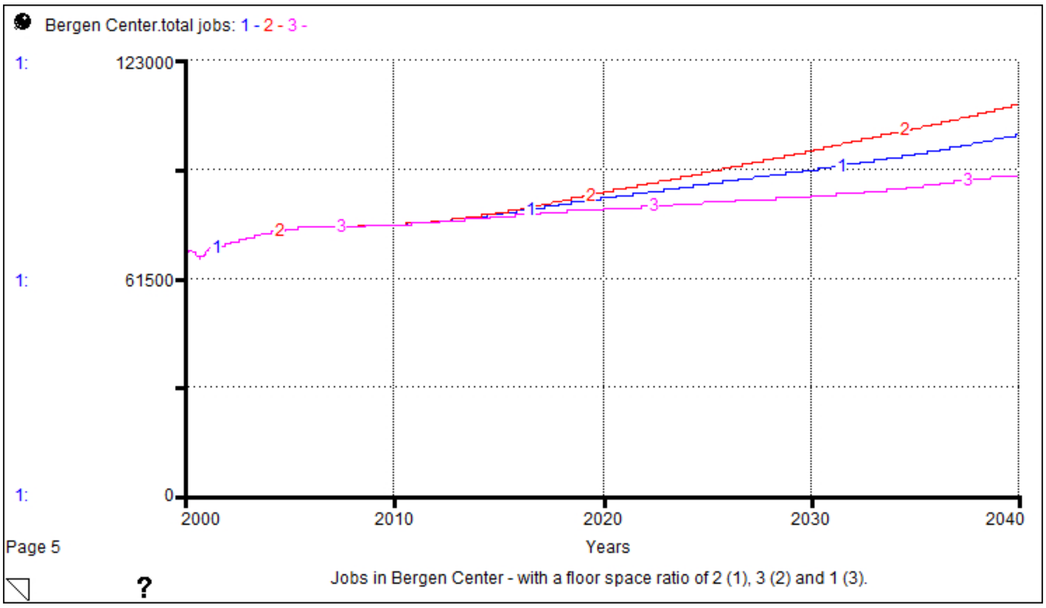

Figure 94. Number of jobs with three different average statutory floor space ratios for high-density structures in Bergen center with the *Rezoning Policy* activated.

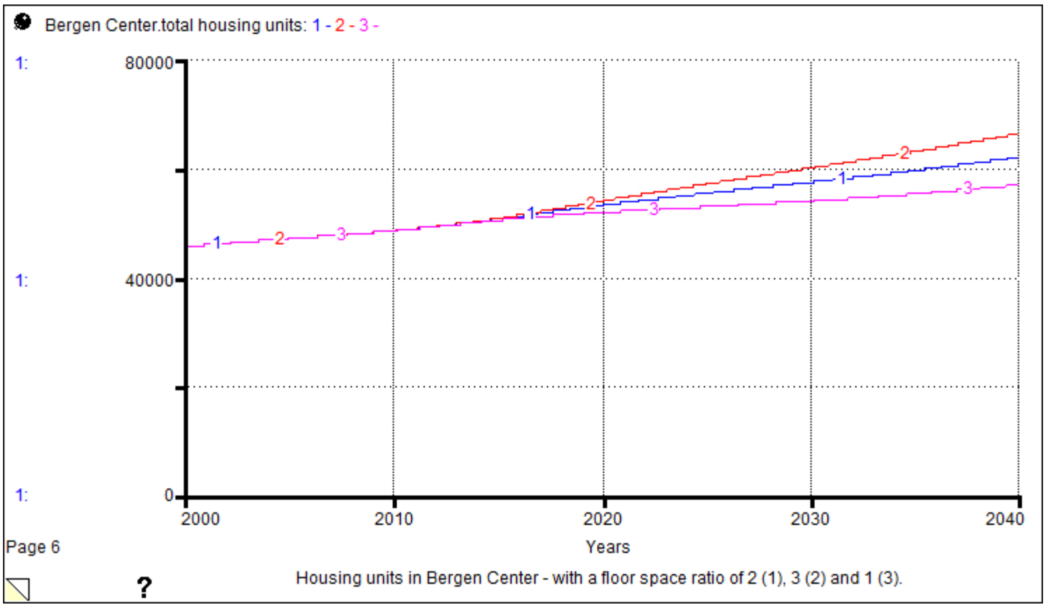

Figure 95. Number of housing units with three different average statutory floor space ratios for high-density structures in Bergen center with the *Rezoning Policy* activated.

Zoning Decision Rule Policy

The *Zoning Decision Rule Policy* is based on the assumption that the availability of vacant zoned land is a decisive factor influencing the development and the distribution of jobs and housing units in Bergen municipality. At the same time, there is a high uncertainty regarding the amount of zoned land in Bergen and Askøy. To test whether there are any policy sensitivity changes regarding the vacant land zoned for business and housing, the policy was run with different initial values for the vacant land zoned for business and housing. Figure 96 to Figure 101 illustrate the development of jobs and housing units in Bergen North, Askøy and Bergen Center with the Zoning Decision Rule activated. Simulation run (1) shows the "normal" situation, simulation run (2) presents the behavior with one million square meter extra vacant land zoned for business and housing. As can be seen in Figure 96 and Figure 97, this hardly leads to any changes in behavior in Bergen North. Figure 98 and Figure 99 illustrate that there is a more visible numerical sensitivity in the Askøy land use sub-model. And Figure 100 and Figure 101 show that changes in the vacant land zoned for business and housing lead to significant changes in the number of jobs and housing units in Bergen center. The imbalance is enforced. This illustrates once more the importance of obtaining data on the land availability.

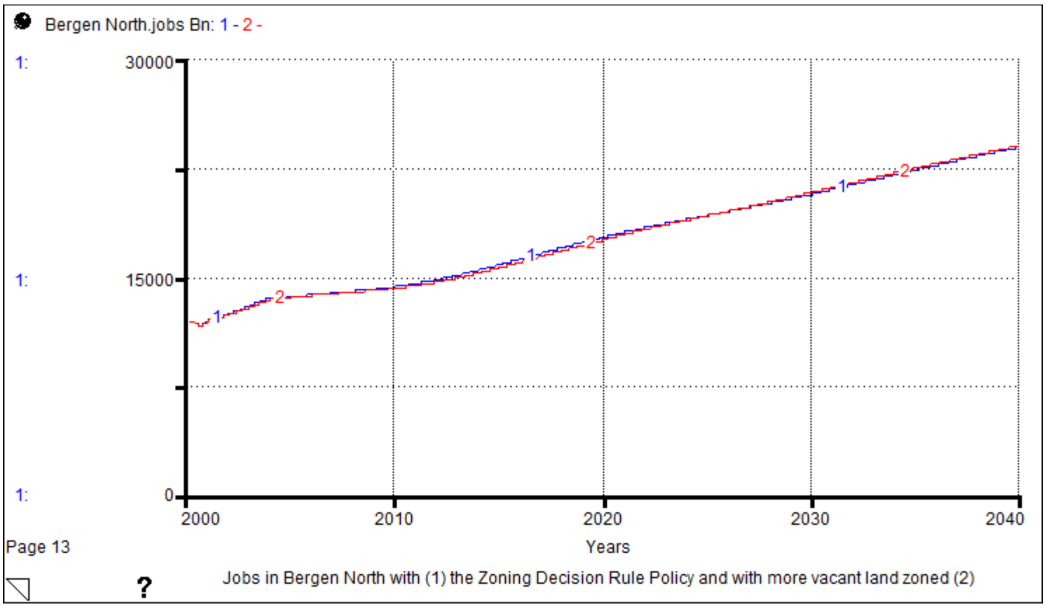

Figure 96. Jobs in Bergen North with the *Zoning Decision Rule Policy*: with (1) normal amount of vacant land zoned for business and (2) with a million square meters additional vacant land zoned for business.

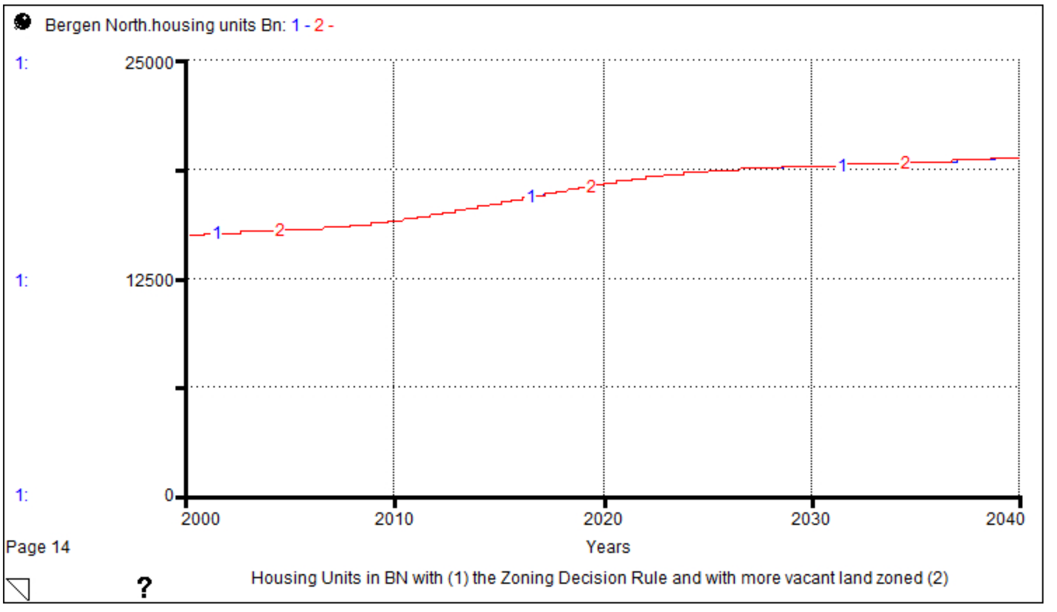

Figure 97. Housing units in Bergen North with the *Zoning Decision Rule Policy*: with (1) normal amount of vacant land zoned for housing and (2) with a million square meters additional vacant land zoned for housing.

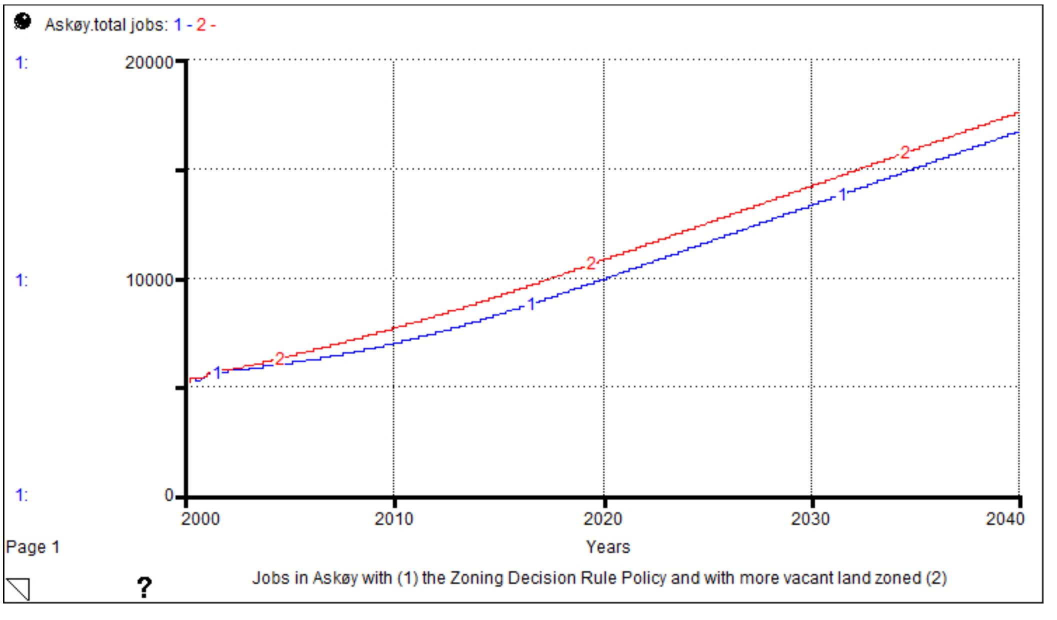

Figure 98. Jobs in Askøy with the *Zoning Decision Rule Policy*: with (1) normal amount of vacant land zoned for business and (2) with a million square meters additional vacant land zoned for business.

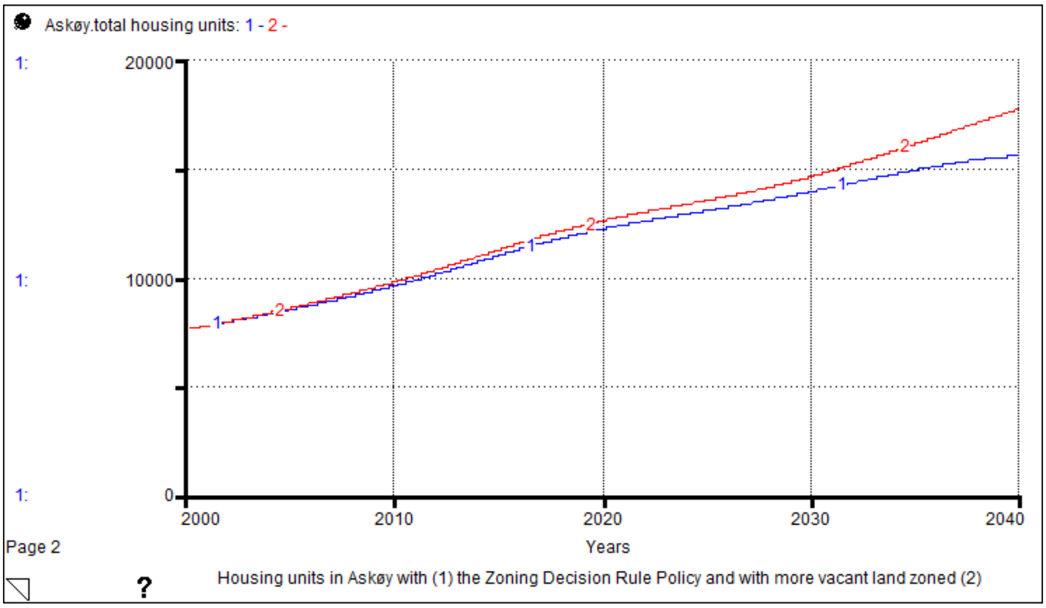

Figure 99. Housing units in Askøy with the *Zoning Decision Rule Policy*: with (1) normal amount of vacant land zoned for housing and (2) with a million square meters additional vacant land zoned for housing.

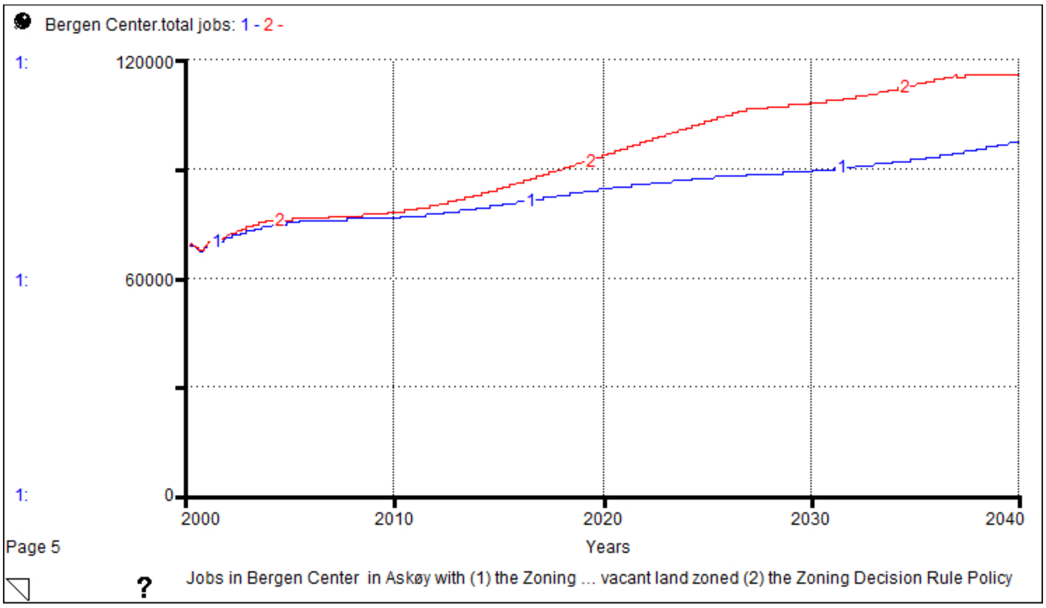

Figure 100. Jobs in Bergen Center with the *Zoning Decision Rule Policy*: with (1) normal amount of vacant land zoned for business and (2) with a million square meters additional vacant land zoned for business.

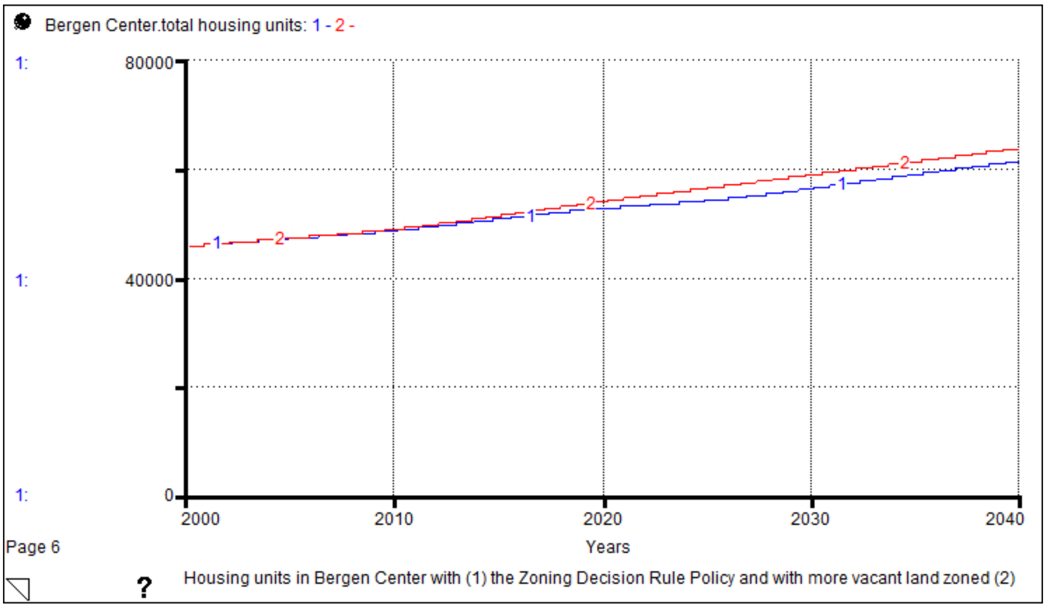

Figure 101. Housing units in Bergen center with the *Zoning Decision Rule Policy*: with (1) normal amount of vacant land zoned for housing and (2) with a million square meters additional vacant land zoned for housing.

11.3 Short Introduction to the Interactive Learning Environment

The model was designed in iThink version 9.1.4. The *Interactive Learning Environment* (ILE) created with the software provides valuable additional information on the problematic behavior, its underlying structure and the impact of the policies designed. To use the ILE and run the enclosed version of the model you need *iThink* or *isee PLAYER*. You can download the isee PLAYER for free at http://www.iseesystems.com/softwares/player/iseeplayer.aspx.

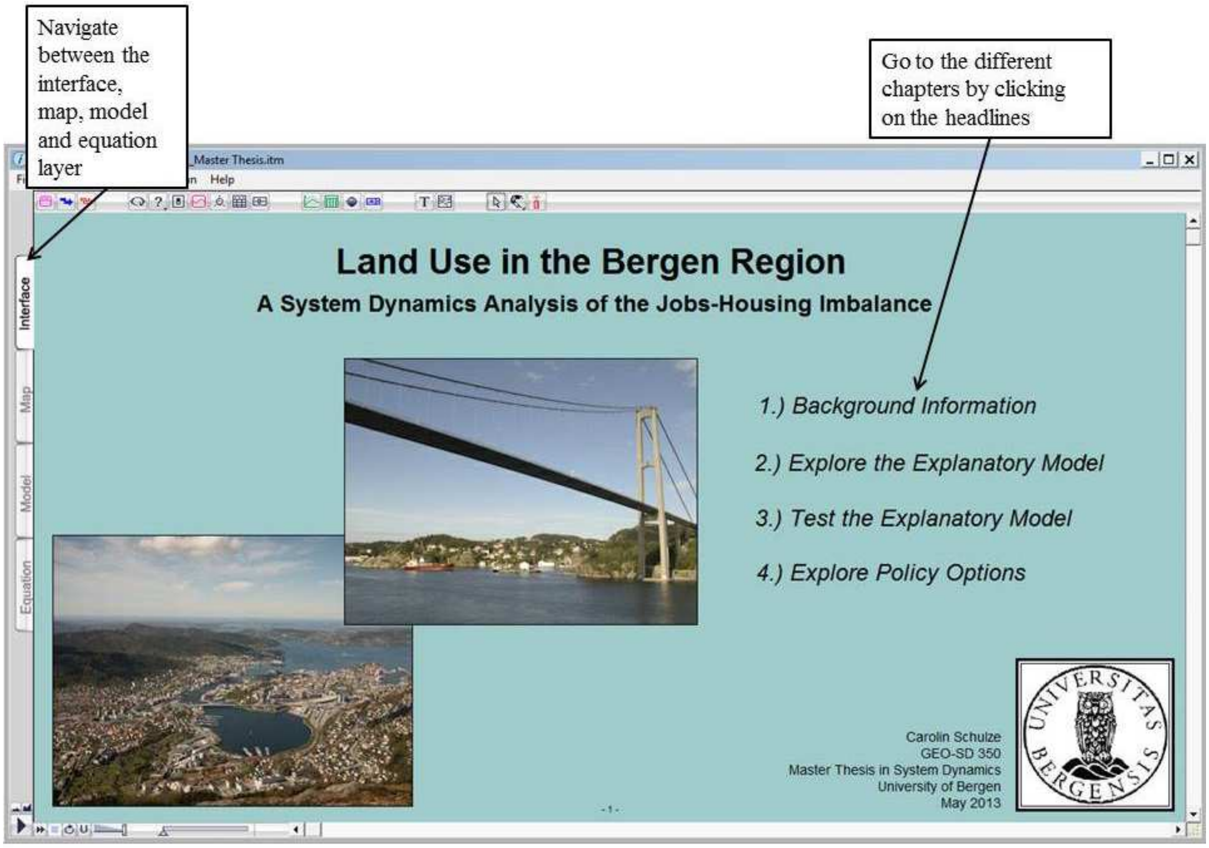

Figure 102. Start page of the *Interactive Learning Environment (ILE)*.

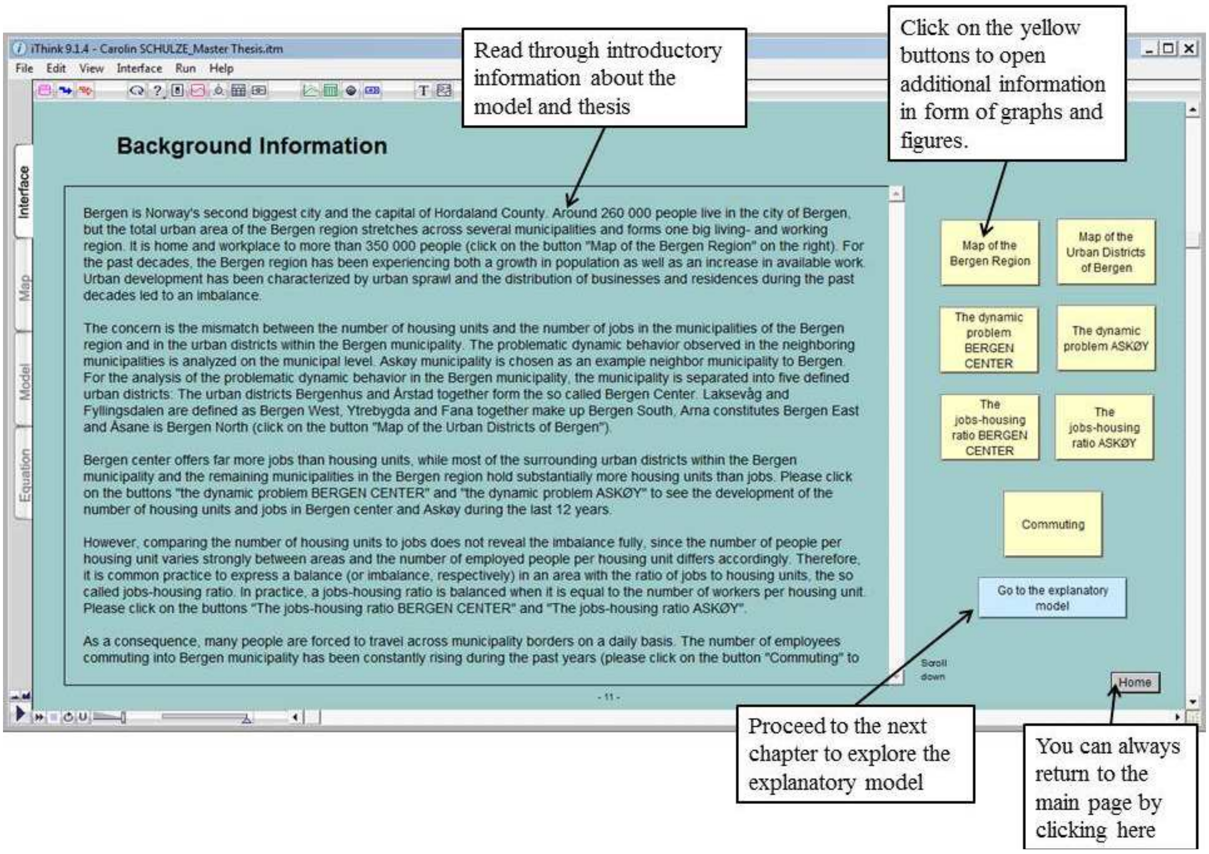

Figure 103. "Background Information" page of the ILE.

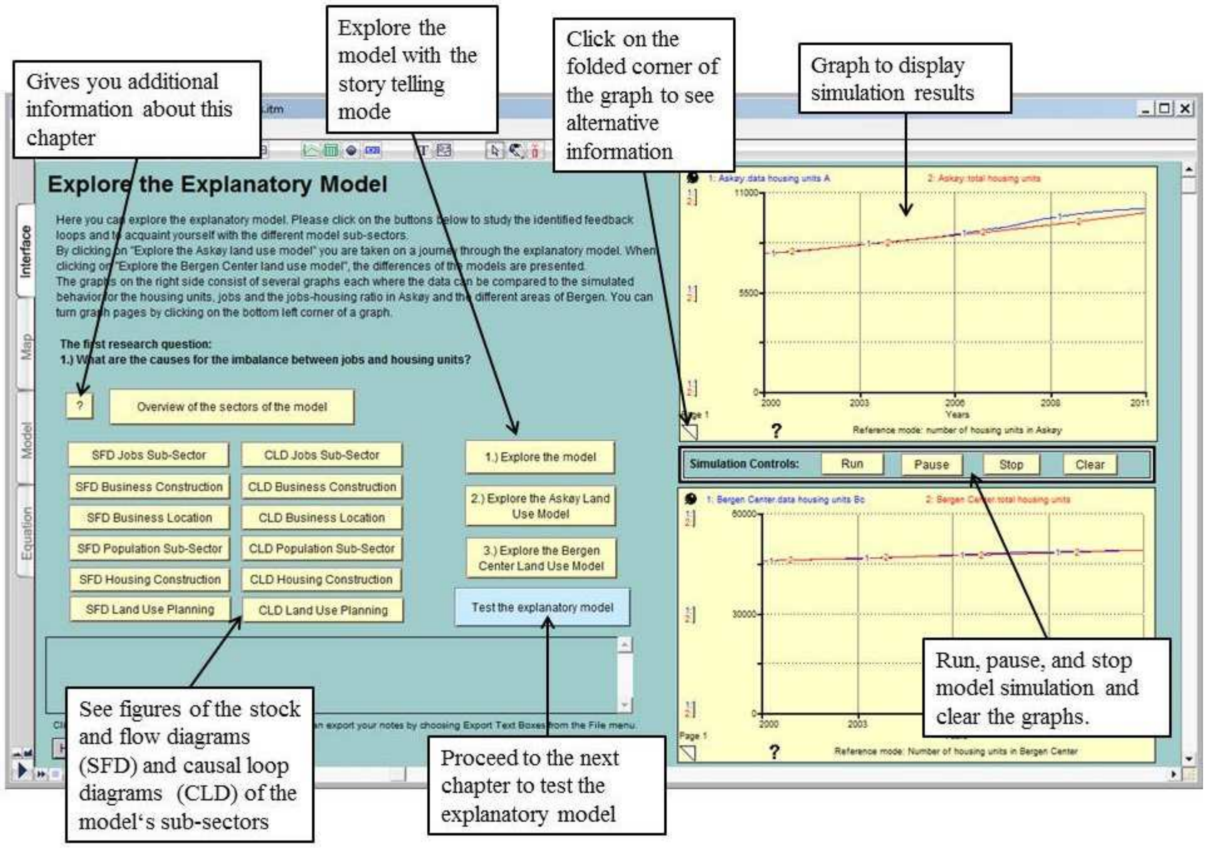

Figure 104. "Explore the Explanatory Model" page of the ILE.

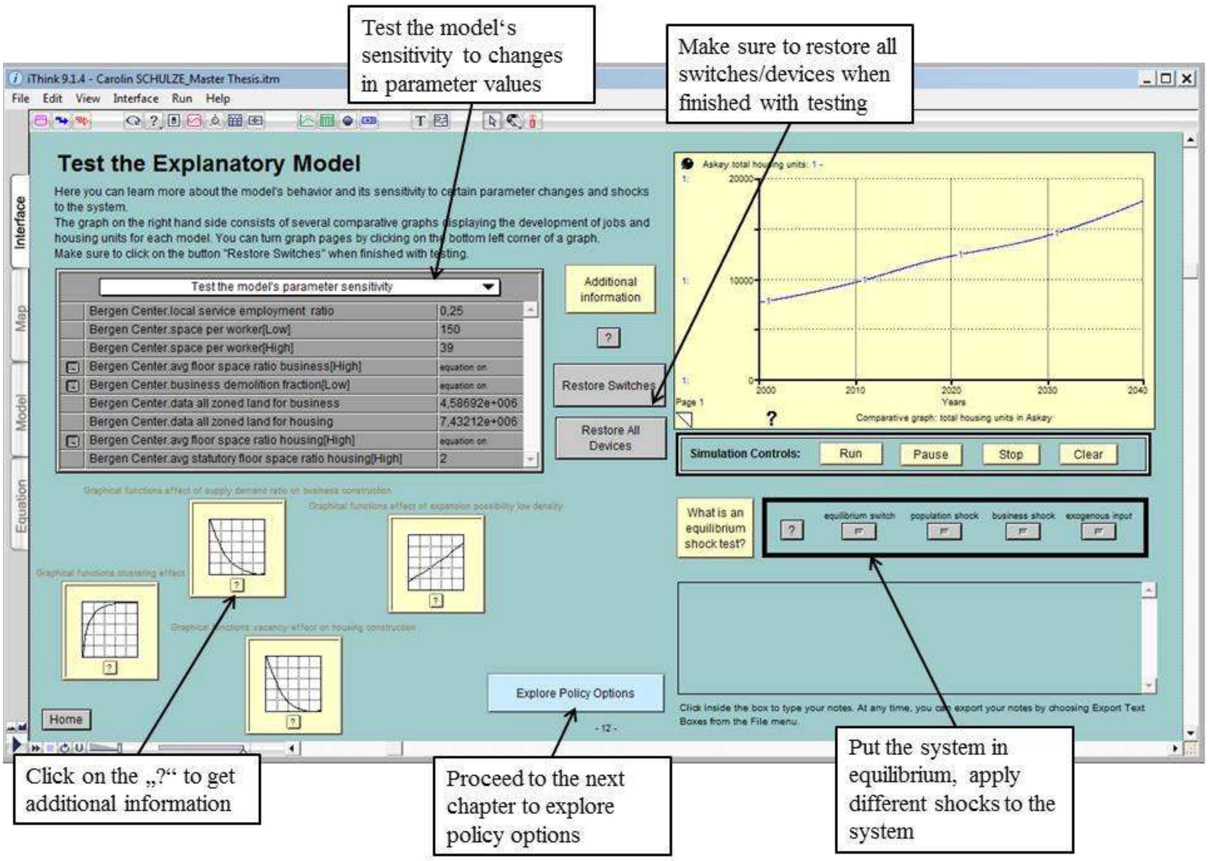

Figure 105. "Test the Explanatory Model" page of the ILE.

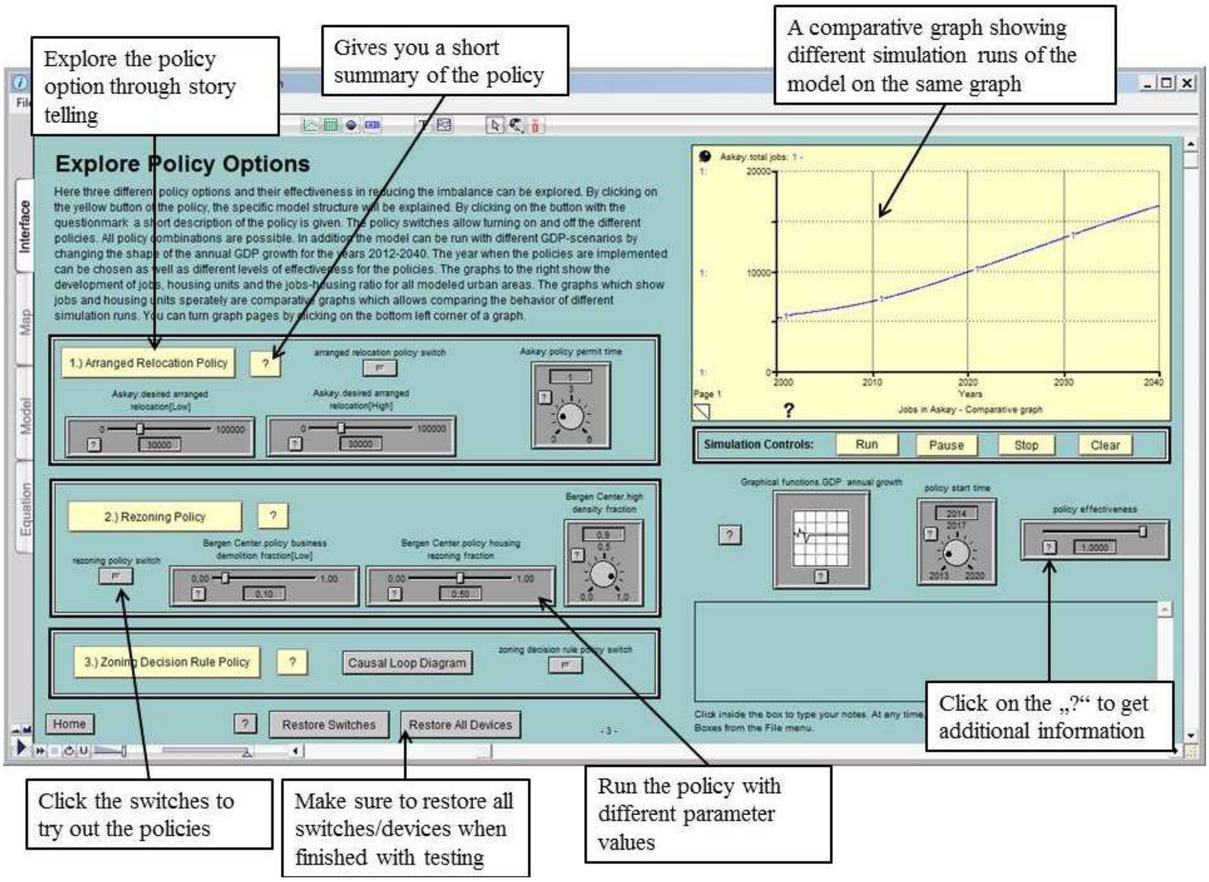

Figure 106. “Explore Policy Options” page of the ILE.

11.3 Model Equations

The model was designed in iThink using modules. These modules were used for the land use sub-models: *Askøy*, *Bergen Center*, *Bergen West*, *Bergen South*, *Bergen East*, and *Bergen North*. In addition a module called *Graphical functions* was designed which includes all graphical function for all land use sub-models. Two separate modules, *Askøy Story Telling* and *Bergen Center Story Telling*, were designed for the story telling feature for Bergen Center and Askøy because a lot of important links are not shown in the original land use sub-modules due to the collected graphical functions.

Only the equations for the Askøy module, Bergen Center module and Graphical function module are shown here. The equations for all modules can be found in the iThink version of the model.

businesses_in_A_seeking_to_relocate[Density] = Askøy.businesses_in_A_seeking_to_relocate_to_BR[Density]+Bergen_Center.businesses_in_A_seeking_to_relocate_to_Bc[Density]+Bergen_South.businesses_in_A_seeking_to_relocate_to_Bs[Density]+Bergen_West.businesses_in_A_seeking_to_relocate_to_Bw[Density]

{square meters}
businesses_in_Bc_seeking_to_relocate[Density] =
Askøy.businesses_in_Bc_seeking_to_relocate_to_A[Density]+Bergen_Center.businesses_in_Bc_seeking_to_relocate_to_Br[Density]+Bergen_East.businesses_in_Bc_seeking_to_relocate_to_Be[Density]+Bergen_North.businesses_in_Bc_seeking_to_relocate_to_Bn[Density]+Bergen_South.businesses_in_Bc_seeking_to_relocate_to_Bs[Density]+Bergen_West.businesses_in_Bc_seeking_to_relocate_to_Bw[Density]
{square meters}
businesses_in_Be_seeking_to_relocate[Density] = Bergen_Center.businesses_in_Be_seeking_to_relocate_to_Bc[Density]+Bergen_North.businesses_in_Be_seeking_to_relocate_to_Bn[Density]+Bergen_East.businesses_in_Be_seeking_to_relocate_to_Br[Density]+Bergen_South.businesses_in_Be_seeking_to_relocate_to_Bs[Density]
{square meters}
businesses_in_Bn_seeking_to_relocate[Density] = Bergen_Center.businesses_in_Bn_seeking_to_relocate_to_Bc[Density]+Bergen_East.businesses_in_Bn_seeking_to_relocating_to_Be[Density]+Bergen_North.businesses_in_Bn_seeking_to_relocate_to_Br[Density]
{square meters}
businesses_in_Br_seeking_to_relocate[Density] =
Askøy.businesses_in_BR_seeking_to_relocate_to_A[Density]+Bergen_Center.businesses_in_Br_seeking_to_relocate_to_Bc[Density]+Bergen_East.businesses_in_BR_seeking_to_relocate_to_Be[Density]+Bergen_North.businesses_in_Br_seeking_to_relocate_to_Bn[Density]+Bergen_South.businesses_in_BR_seeking_to_relocate_to_Bs[Density]+Bergen_West.businesses_in_BR_seeking_to_relocate_to_Bw[Density]
{square meters}
businesses_in_Bs_seeking_to_relocate[Density] =
Askøy.businesses_in_Bs_seeking_to_relocate_to_A[Density]+Bergen_Center.businesses_in_Bs_seeking_to_relocate_to_Bc[Density]+Bergen_East.businesses_in_Bs_seeking_to_relocating_to_Be[Density]+Bergen_South.businesses_in_Bs_seeking_to_relocate_to_BR[Density]+Bergen_West.businesses_in_Bs_seeking_to_relocate_to_Bw[Density]
{square meters}
businesses_in_Bw_seeking_to_relocate[Density] =
Askøy.businesses_in_Bw_seeking_to_relocate_to_A[Density]+Bergen_Center.businesses_in_Bw_seeking_to_relocate_to_Bc[Density]+Bergen_South.businesses_in_Bw_seeking_to_relocate_to_Bs[Density]+Bergen_West.businesses_in_BW_seeking_to_relocate_to_BR[Density]
{square meters}
job_vacancy_fraction = total_vacancies/total_jobs
{unitless}
total_jobs = ARRAYSUM(Bergen_Center.jobs[*])+ARRAYSUM(Askøy.jobs[*])+ARRAYSUM(Bergen_West.jobs[*])+ARRAYSUM(Bergen_South.jobs[*])+ARRAYSUM(Bergen_North.jobs[*])+ARRAYSUM(Bergen_East.jobs[*])
{persons}
total_vacancies = ARRAYSUM(Bergen_Center.vacancies[*])+ARRAYSUM(Askøy.vacancies[*])+ARRAYSUM(Bergen_West.vacancies[*])+ARRAYSUM(Bergen_South.vacancies[*])+ARRAYSUM(Bergen_North.vacancies[*])+ARRAYSUM(Bergen_East.vacancies[*])
{persons}
data_jobs_Askøy = GRAPH(TIME)
(2000, 5150), (2001, 5387), (2002, 5470), (2003, 5659), (2004, 5808), (2005, 5969), (2006, 6151), (2007, 6360), (2008, 6744), (2009, 6828), (2010, 7051), (2011, 7158)
data_jobs_Bergen = GRAPH(TIME)
(2000, 131728), (2001, 133113), (2002, 132599), (2003, 134822), (2004, 136246), (2005, 139358), (2006, 146515), (2007, 152252), (2008, 155668), (2009, 154963), (2010, 155379), (2011, 158780)
total_business_space_in_the_Bergen_region[Low] = GRAPH(TIME
{square meters})
(2000, 9.2e+006), (2001, 9.4e+006), (2002, 9.5e+006), (2003, 9.6e+006), (2004, 9.7e+006), (2005, 9.9e+006), (2007, 1e+007), (2008, 1e+007), (2009, 1e+007), (2010, 1.1e+007), (2011, 1.1e+007), (2012, 1.1e+007)

total_business_space_in_the_Bergen_region[High] =
TIME
{square meters})
(2000, 5.4e+006), (2001, 5.6e+006), (2002, 5.6e+006), (2003, 5.7e+006), (2004, 5.8e+006), (2005, 5.9e+006), (2006, 5.9e+006), (2007, 6e+006), (2008, 6.1e+006), (2009, 6.2e+006), (2010, 6.3e+006), (2011, 6.3e+006), (2012, 6.4e+006)

Askøy:

Bc__businesses_waiting_for_relocation[Density](t) = Bc__businesses_waiting_for_relocation[Density](t - dt) + (arranged_relocation_agreement[Density] - policy_relocating[Density]) * dt
INIT Bc__businesses_waiting_for_relocation[Density] = 0
{square meters}
INFLOWS:
arranged_relocation_agreement[Density] =
(PULSE(desired_arranged_relocation[Density],(.policy_start_time),0))*.arranged_relocation_policy+(1-.arranged_relocation_policy)*0
{square meters/year}
OUTFLOWS:
policy_relocating[Density] = IF time >= policy_relocation_time THEN
(MIN((vacant_business_space[Density]/time_to_relocate),(Bc__businesses_waiting_for_relocation[Density]/time_to_relocate))) ELSE 0
{square meters/year}
businesses_in_A_seeking_to_relocate_to_BR[Density](t) = businesses_in_A_seeking_to_relocate_to_BR[Density](t - dt) + (businesses_in_A_choosing_BR[Density] - Businesses_from_A_relocating_to_BR[Density]) * dt
INIT businesses_in_A_seeking_to_relocate_to_BR[Density] = dissatisfied_businesses[Density]*0.01
{square meters}
INFLOWS:
businesses_in_A_choosing_BR[Density] = (dissatisfied_businesses[Density]-.businesses_in_A_seeking_to_relocate[Density])*annual_frac_choosing_BR
{square meters/year}
OUTFLOWS:
Businesses_from_A_relocating_to_BR[Density] = businesses_in_A_seeking_to_relocate_to_BR[Density]*annual_frac_deciding_to_relocate_in_BR
{square meters/year}
businesses_in_Bc_seeking_to_relocate_to_A[Density](t) = businesses_in_Bc_seeking_to_relocate_to_A[Density](t - dt) + (businesses_in_Bc_choosing_A[Density] - businesses_from_Bc_relocating_to_A[Density]) * dt
INIT businesses_in_Bc_seeking_to_relocate_to_A[Density] = Bergen_Center.occupied__business_space[Density]*0.01
{square meters}
INFLOWS:
businesses_in_Bc_choosing_A[Density] = (Bergen_Center.dissatisfied_businesses[Density]-.businesses_in_Bc_seeking_to_relocate[Density])*fraction_leaning_to_Askoy[Density]
{square meters/year}
OUTFLOWS:
businesses_from_Bc_relocating_to_A[Density] =
MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Bc_seeking_to_relocate_to_A[Density]/time_to_relocate))
{square meters/year}
businesses_in_BR_seeking_to_relocate_to_A[Density](t) = businesses_in_BR_seeking_to_relocate_to_A[Density](t - dt) + (businesses_in_BR_choosing_A[Density] - businesses_from_BR_relocating_to_A[Density]) * dt
INIT businesses_in_BR_seeking_to_relocate_to_A[Density] = businesses_in_the_Bergen_region[Density]*0.005
{square meters}
INFLOWS:
businesses_in_BR_choosing_A[Density] = (businesses_in_the_Bergen_region[Density]*fraction_dissatisfied-.businesses_in_Br_seeking_to_relocate[Density])*fraction_leaning_to_Askoy[Density]

{square meters/year}
OUTFLOWS:
businesses_from_BR_relocating_to_A[Density] =
MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_BR_seeking_to_relocate_to_A[Density]/time_to_relocate))
{square meters/year}
businesses_in_Bs_seeking_to_relocate_to_A[Density](t) = businesses_in_Bs_seeking_to_relocate_to_A[Density](t - dt) + (businesses_in_Bs_choosing_A[Density] - businesses_from_Bs_relocating_to_A[Density]) * dt
INIT businesses_in_Bs_seeking_to_relocate_to_A[Density] = Bergen_South.occupied__business_space[Density]*0.01
{square meters}
INFLOWS:
businesses_in_Bs_choosing_A[Density] = (Bergen_South.dissatisfied_businesses[Density]-.businesses_in_Bs_seeking_to_relocate[Density])*fraction_leaning_to_Askoy[Density]
{square meters/year}
OUTFLOWS:
businesses_from_Bs_relocating_to_A[Density] =
MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Bs_seeking_to_relocate_to_A[Density]/time_to_relocate))
{square meters/year}
businesses_in_Bw_seeking_to_relocate_to_A[Density](t) = businesses_in_Bw_seeking_to_relocate_to_A[Density](t - dt) + (businesses_in_Bw_choosing_A[Density] - businesses_from_Bw_relocating_to_A[Density]) * dt
INIT businesses_in_Bw_seeking_to_relocate_to_A[Density] = Bergen_West.occupied__business_space[Density]*0.01
{square meters}
INFLOWS:
businesses_in_Bw_choosing_A[Density] = (Bergen_West.dissatisfied_businesses[Density]-.businesses_in_Bw_seeking_to_relocate[Density])*fraction_leaning_to_Askoy[Density]
{square meters/year}
OUTFLOWS:
businesses_from_Bw_relocating_to_A[Density] =
MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Bw_seeking_to_relocate_to_A[Density]/time_to_relocate))
{square meters/year}
business_space_under_construction[Low](t) = business_space_under_construction[Low](t - dt) + (business_construction[Low] - finishing_business_construction[Low]) * dt
INIT business_space_under_construction[Low] = construction_time_business*6530
{square meters}
business_space_under_construction[High](t) = business_space_under_construction[High](t - dt) + (business_construction[High] - finishing_business_construction[High]) * dt
INIT business_space_under_construction[High] = construction_time_business*526
{square meters}
INFLOWS:
business_construction[Density] = ((density_ratio_business[Density]*floor_space_ratio_business[Density]*annual_land_ready_for_business_construction)+PULSE(desired_arranged_relocation[Density],policy_construction_start_time,0))*.arranged_relocation_policy+(1-.arranged_relocation_policy)*(density_ratio_business[Density]*floor_space_ratio_business[Density]*annual_land_ready_for_business_construction)
{square meters/years}
OUTFLOWS:
finishing_business_construction[Density] = (business_space_under_construction[Density]/construction_time_business)
{square meters/year}
housing_space_under_construction[Low](t) = housing_space_under_construction[Low](t - dt) + (housing_construction[Low] - finishing_housing_construction[Low]) * dt
INIT housing_space_under_construction[Low] = construction_time_housing*22243
{square meters}

housing_space_under_construction[High](t) = housing_space_under_construction[High](t - dt) + (housing_construction[High] - finishing_housing_construction[High]) * dt
INIT housing_space_under_construction[High] = construction_time_housing*608
{square meters}
INFLOWS:
housing_construction[Density] = (density_ratio_housing[Density]*floor_space_ratio_housing[Density]*annual_land_prepared_for__housing_construction)
{square meters/years}
OUTFLOWS:
finishing_housing_construction[Density] = (housing_space_under_construction[Density]/construction_time_housing)
{square meters/years}
jobs[Low](t) = jobs[Low](t - dt) + (hiring_rate[Low] + jobs_moving_to_A[Low] - quitting_and_firing[Low] - jobs_leaving_A[Low]) * dt
INIT jobs[Low] = data_low_density_business_space_A*(1-0.06)/space_per_worker[Low]
{people}
jobs[High](t) = jobs[High](t - dt) + (hiring_rate[High] + jobs_moving_to_A[High] - quitting_and_firing[High] - jobs_leaving_A[High]) * dt
INIT jobs[High] = local_service_positions+non_local_service_positions[High]
{people}
INFLOWS:
hiring_rate[Density] = vacancies[Density]/hiring_time
{people/year}
jobs_moving_to_A[Density] = (businesses_relocating_to_A[Density]+policy_relocating[Density])/space_per_worker[Density]
{people/year}
OUTFLOWS:
quitting_and_firing[Density] = (jobs[Density]/avg_employment_time)-MIN((positions_gap[Density]/time_to_fire),0)
{people/year}
jobs_leaving_A[Density] = businesses_from_A_relocating[Density]/space_per_worker[Density]
{people/year}
non_local_service_positions[Low](t) = non_local_service_positions[Low](t - dt) + (change_in_positions[Low]) * dt
INIT non_local_service_positions[Low] = jobs[Low]
{people}
non_local_service_positions[High](t) = non_local_service_positions[High](t - dt) + (change_in_positions[High]) * dt
INIT non_local_service_positions[High] = total_initial_non_local_service_positions-non_local_service_positions[Low]
{people}
INFLOWS:
change_in_positions[Density] = (non_local_service_positions[Density]*annual_position_growth[Density])+jobs_moving_to_A[Density]-jobs_leaving_A[Density]
{people/year}
normal_rental_price[Density](t) = normal_rental_price[Density](t - dt) + (change_in_price[Density]) * dt
INIT normal_rental_price[Density] = 900
{Norwegian Kroner/square meter}
INFLOWS:
change_in_price[Density] = normal_rental_price[Density]*CPI
{Norwegian Kroner/square meter/year}
occupied_housing_space[Low](t) = occupied_housing_space[Low](t - dt) + (moving_in[Low] - moving_out[Low]) * dt
INIT occupied_housing_space[Low] = need_for__housing_space[Low]
{square meters}
occupied_housing_space[High](t) = occupied_housing_space[High](t - dt) + (moving_in[High] - moving_out[High]) * dt
INIT occupied_housing_space[High] = need_for__housing_space[High]

{square meters}
INFLOWS:
moving_in[Density] =
MAX(MIN((housing_space_gap[Density]/time_to_move),(vacant_housing_space[Density]/time_to_move)),0)
{square meters/years}
OUTFLOWS:
moving_out[Density] = -MIN((MAX((housing_space_gap[Density]/time_to_move),-
(occupied_housing_space[Density]/time_to_move))),0)
{square meters/year}
occupied_land_zoned_for_housing(t) = occupied_land_zoned_for_housing(t - dt) + (housing_land_permit_rate - abandoned_housing_land_area) * dt
INIT occupied_land_zoned_for_housing = (to-
tal_housing_space[Low]/floor_space_ratio_housing[Low])+(total_housing_space[High]/floor_space_ratio_housing[High])
{square meters}
INFLOWS:
housing_land_permit_rate = (DELAY3(ARRAYSUM(requested_land_for_housing[*]),permit_time))
{square meters/years}
OUTFLOWS:
abandoned_housing_land_area = (abandoned_housing_land[Low]+abandoned_housing_land[High])
{square meters/year}
occupied_land__zoned_for_business(t) = occupied_land__zoned_for_business(t - dt) + (busi-
ness_land_permit_rate + policy_permit_rate - abandoned_business_land_area) * dt
INIT occupied_land__zoned_for_business = (to-
tal_business_space[Low]/floor_space_ratio_business[Low])+(total_business_space[High]/floor_space_ratio_business[High])
{square meters}
INFLOWS:
business_land_permit_rate = (DELAY3(ARRAYSUM(requested_land_for_business[*]),permit_time))
{square meters/year}
policy_permit_rate = DE-
LAY3(ARRAYSUM(requested_land_for_arranged_relocation[*]),policy_permit_time)*.arranged_relocation_policy+(1-.arranged_relocation_policy)*0
{square meters/year}
OUTFLOWS:
abandoned_business_land_area = (abandoned_business_land[Low]+abandoned_business_land[High])
{square meters/year}
occupied__business_space[Low](t) = occupied__business_space[Low](t - dt) + (extend-
ing_and_moving_to_A[Low] - reducing_and_leaving[Low]) * dt
INIT occupied__business_space[Low] = jobs[Low]*space_per_worker[Low]
{square meters}
occupied__business_space[High](t) = occupied__business_space[High](t - dt) + (extend-
ing_and_moving_to_A[High] - reducing_and_leaving[High]) * dt
INIT occupied__business_space[High] = jobs[High]*space_per_worker[High]
{square meters}
INFLOWS:
extending_and_moving_to_A[Density] =
(MAX((business_space_gap[Density]/time_to_relocate),0)+businesses_relocating_to_A[Density]+policy_relocating[Density])
{square meters/year}
OUTFLOWS:
reducing_and_leaving[Density] = (-
MIN((business_space_gap[Density]/time_to_relocate),0)+businesses_from_A_relocating[Density])
{square meters/year}
population_in_Askøy(t) = population_in_Askøy(t - dt) + (population_net_change) * dt
INIT population_in_Askøy = initial_population_in_Askøy
{people}
INFLOWS:
population_net_change = anual_net_births+people_moving_to_A
{people/year}

total_land_available(t) = total_land_available(t - dt) + (abandoned_business_land_area + abandoned_housing_land_area - zoning_for_business - zoning_for_housing) * dt
INIT total_land_available = (data_total_land_available_for_construction-vacant_land__zoned_for_businesses-vacant_land_zoned_for_housing-occupied_land_zoned_for_housing-occupied_land__zoned_for_business)
{square meters}
INFLOWS:
abandoned_business_land_area = (abandoned_business_land[Low]+abandoned_business_land[High])
{square meters/year}
abandoned_housing_land_area = (abandoned_housing_land[Low]+abandoned_housing_land[High])
{square meters/year}
OUTFLOWS:
zoning_for_business = (PULSE(MIN(total_land_available,MAX((needed_land_for_business-vacant_land__zoned_for_businesses-
(abandoned_business_land_area*fraction_still_zoned_for_business)),0)),2002,zoning_interval)*.policy_effectiveness +(abandoned_business_land_area*fraction_still_zoned_for_business))*.zoning_policy+(1-.zoning_policy)*(PULSE((MIN(MAX(land_zoned_for_business,0),(total_land_available))),2002,zoning_interval)+(abandoned_business_land_area*fraction_still_zoned_for_business)){square meters/year}
zoning_for_housing = (PULSE(MIN(MAX((desired_land_for_housing-vacant_land_zoned_for_housing-
(abandoned_housing_land_area*fraction_still_zoned_for_housing)),0),total_land_available),2002,zoning_interval)*.policy_effectiveness+(1-.policy_effectiveness)*PULSE((MIN((MAX(((needed_land_area_for_housing)-
vacant_land_zoned_for_housing),0)),total_land_available)),2002,zoning_interval)+(abandoned_housing_land_area*fraction_still_zoned_for_housing))*.zoning_policy+(1-.zoning_policy)*(PULSE((MIN((MAX(((needed_land_area_for_housing)-
vacant_land_zoned_for_housing),0)),total_land_available)),2002,zoning_interval)+(abandoned_housing_land_area*fraction_still_zoned_for_housing))
{square meters/year}
vacancies[Low](t) = vacancies[Low](t - dt) + (advertised_vacancy_rate[Low] - hiring_rate[Low]) * dt
INIT vacancies[Low] = normal_job_vacancy_fraction*jobs[Low]
{people}
vacancies[High](t) = vacancies[High](t - dt) + (advertised_vacancy_rate[High] - hiring_rate[High]) * dt
INIT vacancies[High] = normal_job_vacancy_fraction*jobs[High]
{people}
INFLOWS:
advertised_vacancy_rate[Density] = MAX((positions_gap[Density]/advertising_time),0)
{person/year}
OUTFLOWS:
hiring_rate[Density] = vacancies[Density]/hiring_time
{people/year}
vacant_business_space[Low](t) = vacant_business_space[Low](t - dt) + (finishing_business_construction[Low] + reducing_and_leaving[Low] - extending_and_moving_to_A[Low] - business_demolition[Low]) * dt
INIT vacant_business_space[Low] = data_low_density_business_space_A-occupied__business_space[Low]
{square meters}
vacant_business_space[High](t) = vacant_business_space[High](t - dt) + (finishing_business_construction[High] + reducing_and_leaving[High] - extending_and_moving_to_A[High] - business_demolition[High]) * dt
INIT vacant_business_space[High] = data_high_density_business_space_A-occupied__business_space[High]
{square meters}
INFLOWS:
finishing_business_construction[Density] = (business_space_under_construction[Density]/construction_time_business)
{square meters/year}
reducing_and_leaving[Density] = (-MIN((business_space_gap[Density]/time_to_relocate),0)+businesses_from_A_relocating[Density])
{square meters/year}
OUTFLOWS:

extending_and_moving_to_A[Density] =
(MAX((business_space_gap[Density]/time_to_relocate),0)+businesses_relocating_to_A[Density]+policy_relocating[Density])
{square meters/year}
business_demolition[Density] = (vacant_business_space[Density]*business_demolition_fraction[Density])
{square meters/year}
vacant_housing_space[Low](t) = vacant_housing_space[Low](t - dt) + (finishing_housing_construction[Low] + moving_out[Low] - moving_in[Low] - housing_demolition[Low]) * dt
INIT vacant_housing_space[Low] = data_low_density_housing_space_A-occupied_housing_space[Low]
{square meters}
vacant_housing_space[High](t) = vacant_housing_space[High](t - dt) + (finishing_housing_construction[High] + moving_out[High] - moving_in[High] - housing_demolition[High]) * dt
INIT vacant_housing_space[High] = data_high_density_housing_space_A-occupied_housing_space[High]
{square meters}
INFLOWS:
finishing_housing_construction[Density] = (housing_space_under_construction[Density]/construction_time_housing)
{square meters/years}
moving_out[Density] = -MIN((MAX((housing_space_gap[Density]/time_to_move),-(occupied_housing_space[Density]/time_to_move))),0)
{square meters/year}
OUTFLOWS:
moving_in[Density] =
MAX(MIN((housing_space_gap[Density]/time_to_move),(vacant_housing_space[Density]/time_to_move)),0)
{square meters/years}
housing_demolition[Density] = (vacant_housing_space[Density]*housing_demolition_fraction[Density])
{square meters/years}
vacant_land_zoned_for_housing(t) = vacant_land_zoned_for_housing(t - dt) + (zoning_for_housing - housing_land_permit_rate) * dt
INIT vacant_land_zoned_for_housing = (data_initial_zoned_land_for_housing-occupied_land_zoned_for_housing)
{square meters}
INFLOWS:
zoning_for_housing = (PULSE(MIN(MAX((desired_land_for_housing-vacant_land_zoned_for_housing-(abandoned_housing_land_area*fraction_still_zoned_for_housing)),0),total_land_available),2002,zoning_interval)*.policy_effectiveness+(1-.policy_effectiveness)*PULSE((MIN((MAX(((needed_land_area_for_housing)-vacant_land_zoned_for_housing),0)),total_land_available)),2002,zoning_interval)+(abandoned_housing_land_area*fraction_still_zoned_for_housing))*.zoning_policy+(1-.zoning_policy)*(PULSE((MIN((MAX(((needed_land_area_for_housing)-vacant_land_zoned_for_housing),0)),total_land_available)),2002,zoning_interval)+(abandoned_housing_land_area*fraction_still_zoned_for_housing))
{square meters/year}
OUTFLOWS:
housing_land_permit_rate = (DELAY3(ARRAYSUM(requested_land_for_housing[*]),permit_time))
{square meters/years}
vacant_land__zoned_for_businesses(t) = vacant_land__zoned_for_businesses(t - dt) + (zoning_for_business - business_land_permit_rate - policy_permit_rate) * dt
INIT vacant_land__zoned_for_businesses = (data_initial_zoned_land_for_business-occupied_land__zoned_for_business)
{square meters}
INFLOWS:
zoning_for_business = (PULSE(MIN(total_land_available,MAX((needed_land_for_business-vacant_land__zoned_for_businesses-(abandoned_business_land_area*fraction_still_zoned_for_business)),0)),2002,zoning_interval)*.policy_effectiveness+(abandoned_business_land_area*fraction_still_zoned_for_business))*.zoning_policy+(1-

.zoning_policy)*(PULSE((MIN(MAX(land_zoned_for_business,0),(total_land_available))),2002,zoning_interval)+(abandoned_business_land_area*fraction_still_zoned_for_business)){square meters/year}
OUTFLOWS:
business_land_permit_rate = (DELAY3(ARRAYSUM(requested_land_for_business[*]),permit_time))
{square meters/year}
policy_permit_rate = DELAY3(ARRAYSUM(requested_land_for_arranged_relocation[*]),policy_permit_time)*.arranged_relocation_policy+(1-.arranged_relocation_policy)*0
{square meters/year}
abandoned_business_land[Density] = business_demolition[Density]/floor_space_ratio_business[Density]
{square meters/years}
abandoned_housing_land[Density] = housing_demolition[Density]/floor_space_ratio_housing[Density]
{square meters/years}
actual_fraction_satisfied_at_current_location[Density] =
MIN((all_effects[Density]*initial_fraction_satisfied[Density]),0.95)
{unitless}
actual_rental_price[Density] = normal_rental_price[Density]*Graphical_functions.effect_of_supply_demand_ratio_on_rental_price[Density,Askøy]
{Norwegian Kroner/square meter}
add_factor = 0.01
{1/year}
advertising_time = 1/12
{years}
all_effects[Low] = Graphical_functions.clustering_effect[Low,Askøy]*Graphical_functions.effect_of_driving_time_difference[Askøy]*Graphical_functions.effect_of_expansion_possibility_low_density[Askøy]*Graphical_functions.effect_of_rental_price_low_density[Low,Askøy]
{unitless}
all_effects[High] = Graphical_functions.clustering_effect[High,Askøy]*Graphical_functions.effect_of_driving_time_difference[Askøy]*Graphical_functions.effect_of_expansion_possibility_high_density[Askøy]*Graphical_functions.effect_of_rental_price_high_denisty[High,Askøy]*Graphical_functions.effect_of_travel_time_difference[High,Askøy]
{unitless}
all_housing_units[Density] = occupied__housing_units[Density]+vacant_housing_units[Density]
{housing unit}
annual_frac_choosing_BR = 0.01
{1/year}
annual_frac_deciding_to_relocate_in_BR = 0.01
{1/year}
annual_land_prepared_for__housing_construction = DELAY3(housing_land_permit_rate,time_for_preparation_of_land)
{square meters/years}
annual_land_ready_for_business_construction = DELAY3(business_land_permit_rate,time_for_preparation_of_land)
{square meters/years}
annual_position_growth[Density] = DELAYN(Graphical_functions.GDP_effect__on_position_growth*normal_annual_position_growth,1.5,10)
{1/year}
anual_net_births = population_in_Askøy*net_birth_rate
{people/year}
avg_driving_time_by_car_to_Bc = 0.9*free_flow_driving_time_by_car+0.1*rush_hour_driving_time_by_car
{hours}
avg_employment_time = 5
{years}
avg_statutory_floor_space_ratio_housing[Low] = 0.4
{unitless}
avg_statutory_floor_space_ratio_housing[High] = 2

{unitless}
avg_travel_time_by_public_transportation_to_Bc =
0.9*free_flow_travel_time_by_PT+0.1*rush_hour_travel_time_by_PT
{hours}
A_s_share_in_business_space[Density] = occu-
pied__business_space[Density]/.total_business_space_in_the_Bergen_region[Density]
{unitless}
businesses_from_A_relocating[Density] = Business-
es_from_A_relocating_to_BR[Density]+Bergen_Center.businesses_from_A_relocating_to_Bc[Density]+Berge
n_West.businesses_from_A_relocating_to_Bw[Density]+Bergen_South.businesses_from_A_relocating_to_Bs[
Density]
{square meters/year}
businesses_relocating_to_A[Density] = business-
es_from_Bc_relocating_to_A[Density]+businesses_from_BR_relocating_to_A[Density]+businesses_from_Bs_r
elocating_to_A[Density]+businesses_from_Bw_relocating_to_A[Density]
{square meters/year}
business_demolition_fraction[Low] = 0.07
{1/years}
business_demolition_fraction[High] = 0.07
{1/years}
business_land_fraction_occupied = occu-
pied_land__zoned_for_business/(vacant_land__zoned_for_businesses+occupied_land__zoned_for_business)
{unitless}
business_space_demand[Density] =
MAX((perceived_need_for_business_space[Density]+businesses_in_Bc_seeking_to_relocate_to_A[Density]+b
usiness-
es_in_Bs_seeking_to_relocate_to_A[Density]+businesses_in_Bw_seeking_to_relocate_to_A[Density]+business
es_in_BR_seeking_to_relocate_to_A[Density]),0.0001)
{square meters}
business_space_for_local_service_positions = local_service_positions*space_per_worker[High]
{square meters}
business_space_gap[Density] = recent_need_for_business_space[Density]-occupied__business_space[Density]
{square meters}
business_space_supply[Density] = MAX(vacant_business_space[Density],0.0001)
{square meters}
business_space_supply_demand_ratio[Density] = busi-
ness_space_supply[Density]/business_space_demand[Density]
{unitless}
capacity_for_new_inhabitants = peo-
ple_per_housing_unit*(vacant_housing_units[Low]+vacant_housing_units[High])
{people}
construction_time_business = 2
{years}
construction_time_housing = 2
{years}
data_initial_zoned_land_for_business = 2721500
{square meters}
data_initial_zoned_land_for_housing = 12139600
{square meters}
data_total_land_available_for_construction = 94432000
{square meters}
density_ratio_business[Density] = (DE-
LAYN((requested_land_for_business[Density]/ARRAYSUM(requested_land_for_business[*])),5,10))
{unitless}
density_ratio_housing[Density] = DE-
LAYN((requested_land_for_housing[Density]/ARRAYSUM(requested_land_for_housing[*])),5,10)
{unitless}
desired_arranged_relocation[Low] = 30000
{square meters/year}
desired_arranged_relocation[High] = 30000

{square meters/year}
desired_business_construction[Density] = nor-
mal_annual_business_construction[Density]*Graphical_functions.effect_of_supply_demand_ratio_on_business
_construction[Density,Askøy]
{square meters/year}
desired_housing_construction[Density] = nor-
mal_annual_housing_construction[Density]*Graphical_functions.vacancy_effect_on_housing_construction[Den
sity,Askøy]
{square meters/year}
desired_land_for_housing = (futu-
tu-
re_need_for_housing_units*0.6*housing_space_per_housing_unit[High]/avg_statutory_floor_space_ratio_hous
ing[High])+(future_need_for_housing_units*0.4*housing_space_per_housing_unit[Low]/avg_statutory_floor_s
pace_ratio_housing[Low])
{square meters}
dissatisfied_businesses[Low] = SMTH3((occupied__business_space[Low]*(1-
actual_fraction_satisfied_at_current_location[Low])),perception_time)
{square meters}
dissatisfied_businesses[High] = SMTH3(((occupied__business_space[High]-
business_space_for_local_service_positions)*(1-
actual_fraction_satisfied_at_current_location[High])),perception_time)
{square meters}
employed_people_working_in_Bc = AR-
RAYSUM(jobs[*])+ARRAYSUM(jobs[*])*expected_job_growth*pop_forecast_interval*people_per_job
{people}
employed_person_per_housing_unit = frac_employed_people*people_per_housing_unit
{people/housing unit}
existing_business_space = AR-
RAYSUM(occupied__business_space[*])+ARRAYSUM(vacant_business_space[*])+ARRAYSUM(business_s
pace_under_construction[*])
{square meters}
existing_housing_units = ((hous-
ing_space_under_construction[Low]+occupied_housing_space[Low]+vacant_housing_space[Low])/housing_sp
ace_per_housing_unit[Low])+((housing_space_under_construction[High]+occupied_housing_space[High]+vac
ant_housing_space[High])/housing_space_per_housing_unit[High])
{housing units}
expected_additional_population_in_10_yrs = (popula-
tion_in_Askøy*(expected_annual_population_growth+add_factor)*pop_forecast_interval)
{people}
expected_annual_population_growth = TREND(population_in_Askøy,1,0.02)
{1/year}
expected_future_workers = (popula-
tion_in_Askøy+expected_additional_population_in_10_yrs)*frac_employed_people
{people}
expected_job_growth = TREND(ARRAYSUM(jobs[*]),1,0.00)
{1/year}
expected_need_for_business_space = (ex-
pected_future_workers)*0.7*space_per_worker[High]+expected_future_workers*0.3*space_per_worker[Low]
{square meters}
expected_need_for_housing_units = (expec-
pec-
ted_additional_population_in_10_yrs/people_per_housing_unit)+((expected_additional_population_in_10_yrs/p
eople_per_housing_unit)*reserve)
{housing units}
expected_need_f_housing_units = employed_people_working_in_Bc/employed_person_per_housing_unit
{housing units}
floor_space_ratio_business[Low] = 0.2
{unitless}
floor_space_ratio_business[High] = 0.5
{unitless}

floor_space_ratio_housing[Low] = 0.12
{unitless}
floor_space_ratio_housing[High] = 0.4
{unitless}
fraction_dissatisfied = 0.25
{unitless}
fraction_leaning_to_Askoy[Density] =
SMTH3(MIN((all_effects[Density]*initial_frac_leaning_to_A[Density]),1),time_to_make_decision)
{1/year}
fraction_still_zoned_for_business = 0.75
{unitless}
fraction_still_zoned_for_housing = 0.75
{unitless}
future_need_for_business_space = MAX((expected_need_for_business_space-existing_business_space),0)
{square meters}
future_need_for_housing_units = MAX((expected_need_f_housing_units-existing_housing_units),0)
{housing units}
hiring_time = 3/12
{years}
housing_demolition_fraction[Low] = 0.02
{1/years}
housing_demolition_fraction[High] = 0.02
{1/years}
housing_land_fraction_occupied = occu-
pied_land_zoned_for_housing/(vacant_land_zoned_for_housing+occupied_land_zoned_for_housing)
{unitless}
housing_space_gap[Density] = need_for__housing_space[Density]-occupied_housing_space[Density]
{square meters}
housing_space_per_housing_unit[Low] = 143
{square meters/housing unit}
housing_space_per_housing_unit[High] = 126
{square meters/housing unit}
housing_vacancy_fraction[Low] = va-
cant_housing_space[Low]/(occupied_housing_space[Low]+vacant_housing_space[Low])
{unitless}
housing_vacancy_fraction[High] = va-
cant_housing_space[High]/(occupied_housing_space[High]+vacant_housing_space[High])
{unitless}
initial_fraction_satisfied[Density] = 0.75
{unitless}
initial_frac_leaning_to_A[Low] = 0.1
{unitless}
initial_frac_leaning_to_A[High] = 0.1
{1/year}
initial_population_in_Askøy = 19727
{people}
jobs_housing_ratio_Askøy = ARRAYSUM(jobs[*])/ARRAYSUM(all_housing_units[*])
{jobs/housing unit}
land_zoned_for_business = zoned_land_area_for_business-vacant_land__zoned_for_businesses-
occupied_land__zoned_for_business
{square meters}
local_service_employment__ratio = 0.17
{unitless}
local_service_positions = population_in_Askøy*local_service_employment__ratio
{people}
needed_land_area_for_housing = expec-
pec-
ted_need_for_housing_units*((housing_space_per_housing_unit[Low]/floor_space_ratio_housing[Low])+(hous
ing_space_per_housing_unit[High]/floor_space_ratio_housing[High]))
{square meters}

needed_land_for_business = (futu-
tu-
re_need_for_business_space*0.7)/floor_space_ratio_business[High]+(future_need_for_business_space*0.3)/flo
or_space_ratio_business[Low]
{square meters}
need_for_housing_units = (population_in_Askøy/people_per_housing_unit)
{housing units}
need_for__housing_space[Density] = (hous-
ing_space_per_housing_unit[Density]*need_for_housing_units*housing_preferences[Density])
{square meters}
normal_annual_business_construction[Low] = 7541
{square meters/year}
normal_annual_business_construction[High] = 6336
{square meters/year}
normal_annual_housing_construction[Low] = 27268
{square meters/year}
normal_annual_housing_construction[High] = 3747
{square meters/year}
normal_annual_position_growth = 0.0173
{1/year}
normal_GDP_growth = 0.0199
{1/year}
normal_housing_vacancy_fraction[Low] = 0.044
{unitless}
normal_housing_vacancy_fraction[High] = 0.044
{unitless}
normal_job_vacancy_fraction = 0.0575
{unitless}
normal_migration = 316
{people/year}
normal_supply_demand_ratio = 1
{unitless}
occupied__housing_units[Density] = occu-
pied_housing_space[Density]/housing_space_per_housing_unit[Density]
{housing units}
people_moving_to_A = MIN(((capacity_for_new_inhabitants/time_to_move)-
anual_net_births),people_seeking_to_move_to_A)
{people/year}
people_per_job = 1
{unitless}
people_seeking_to_move_to_A = nor-
mal_migration*Graphical_functions.effect_of_job_vacancies_on_people_seeking_to_move[Askøy]*Graphical_
functions.effect_of_housing_vacancies_on_people_seeking_to_move[Askøy]
{people/year}
perceived_need_for_business_space[Density] = (perceived_need_for_positions[Density]-
jobs[Density])*space_per_worker[Density]
{square meters}
perceived_need_for_positions[Low] = SMTH3((non_local_service_positions[Low]),0.5)
{people}
perceived_need_for_positions[High] =
SMTH3((non_local_service_positions[High]+local_service_positions),0.5)
{people}
perception_time = 2
{year}
permit_time = 5
{years}
policy_construction_start_time = .policy_start_time+policy_permit_time+time_for_preparation_of_land
{years}
policy_permit_time = 1
{year}

policy_relocation_time = construction_time_business+policy_construction_start_time
{year}
pop_forecast_interval = 10
{years}
positions_gap[Density] = required_positions[Density]-jobs[Density]
{people}
possibility_to_expand = Graphical_functions.effect_of_land_frac_occupied_on_possibility_to_expand[Askøy]
{unitless}
potential_positions[Density] = (occupied__business_space[Density]+vacant_business_space[Density])/space_per_worker[Density]
{people}
preferred_driving_time_by_car_to_Bc = 0.5
{hours}
preferred_possibility = 0.7
{unitless}
preferred_rental_price[Density] = Bergen_Center.actual_rental_price[Density]*0.9
{Norwegian Kroner/square meters}
preferred_travel_time = 0.75
{hours}
recent_need_for_business_space[Density] = jobs[Density]*space_per_worker[Density]
{square meters}
requested_land_for_arranged_relocation[Density] =
PULSE((desired_arranged_relocation[Density]/floor_space_ratio_business[Density]),.policy_start_time,0)
{square meters}
requested_land_for_business[Density] =
MAX(((desired_business_construction[Density]/floor_space_ratio_business[Density])*Graphical_functions.effect_of_land_frac_occupied_on_requested_land_for_business[Askøy]),0.0001)
{square meters/year}
requested_land_for_housing[Density] =
MAX(((desired_housing_construction[Density]/floor_space_ratio_housing[Density])*Graphical_functions.effect_of_land_frac_occupied_on_requested_land_for_housing[Askøy]),0.0001)
{m^2/year}
required_positions[Density] = MIN(perceived_need_for_positions[Density],potential_positions[Density])
{people}
reserve = 0.5
{unitless}
space_per_worker[Low] = 217
{square meters/person}
space_per_worker[High] = 45
{square meters/person}
time_for_preparation_of_land = 2
{years}
time_to_fire = 2/12
{years}
time_to_make_decision = 2
{year}
time_to_move = 3/12
{year}
time_to_relocate = 2/12
{years}
total_business_space[Density] = occupied__business_space[Density]+vacant_business_space[Density]
{square meters}
total_housing_space[Density] = occupied_housing_space[Density]+vacant_housing_space[Density]
{square meters}
total_housing_units = ARRAYSUM(all_housing_units[*])
total_initial_non_local_service_positions = 1796
{people}
total_jobs = ARRAYSUM(jobs[*])
vacant_housing_units[Density] = vacant_housing_space[Density]/housing_space_per_housing_unit[Density]
{housing units}

zoning_interval = 4
{years}
businesses_in_the_Bergen_region[Low] = GRAPH(TIME
{square meters})
(2000, 1.1e+006), (2001, 1.1e+006), (2002, 1.1e+006), (2003, 1.1e+006), (2004, 1.1e+006), (2005, 1.2e+006), (2006, 1.2e+006), (2007, 1.2e+006), (2008, 1.2e+006), (2009, 1.3e+006), (2010, 1.3e+006), (2011, 1.3e+006)
businesses_in_the_Bergen_region[High] = GRAPH(TIME
{square meters})
(2000, 454845), (2001, 470682), (2002, 471818), (2003, 473058), (2004, 487214), (2005, 495265), (2006, 505078), (2007, 522160), (2008, 532334), (2009, 548123), (2010, 564431), (2011, 577523)
CPI = GRAPH(TIME
{unitless})
(2000, 0.031), (2001, 0.03), (2002, 0.013), (2003, 0.025), (2004, 0.004), (2005, 0.016), (2006, 0.023), (2007, 0.008), (2008, 0.038), (2009, 0.021), (2010, 0.025), (2011, 0.012), (2012, 0.008)
data_high_density_business_space_A = GRAPH(TIME)
(2000, 166204), (2001, 166730), (2002, 169564), (2003, 175331), (2004, 184948), (2005, 194279), (2006, 200478), (2007, 211483), (2008, 213917), (2009, 225141), (2010, 233023), (2011, 238604), (2012, 242237)
data_high_density_housing_space_A = GRAPH(TIME)
(2000, 17499), (2001, 24329), (2002, 24329), (2003, 26243), (2004, 29113), (2005, 29595), (2006, 29687), (2007, 33163), (2008, 39339), (2009, 53264), (2010, 57614), (2011, 68263), (2012, 68689)
data_housing_units_A = GRAPH(TIME)
(2000, 7610), (2001, 7758), (2002, 7948), (2003, 8148), (2004, 8338), (2005, 8525), (2006, 8831), (2007, 9099), (2008, 9514), (2009, 9802), (2010, 10004), (2011, 10114)
data_jobs_A = GRAPH(TIME)
(2000, 5150), (2001, 5387), (2002, 5470), (2003, 5659), (2004, 5808), (2005, 5969), (2006, 6151), (2007, 6360), (2008, 6744), (2009, 6828), (2010, 7051), (2011, 7158)
data_low_density_business_space_A = GRAPH(TIME)
(2000, 408253), (2001, 414783), (2002, 426210), (2003, 430530), (2004, 434030), (2005, 438981), (2006, 446827), (2007, 449144), (2008, 458971), (2009, 479723), (2010, 490427), (2011, 492957), (2012, 498746)
data_low_density_housing_space_A = GRAPH(TIME)
(2000, 1.1e+006), (2001, 1.1e+006), (2002, 1.1e+006), (2003, 1.1e+006), (2004, 1.2e+006), (2005, 1.2e+006), (2006, 1.2e+006), (2007, 1.3e+006), (2008, 1.3e+006), (2009, 1.3e+006), (2010, 1.3e+006), (2011, 1.4e+006), (2012, 1.4e+006)
frac_employed_people = GRAPH(TIME
{unitless})
(2005, 0.51), (2006, 0.52), (2007, 0.53), (2008, 0.53), (2009, 0.52), (2010, 0.52), (2011, 0.52)
free_flow_driving_time_by_car = GRAPH(TIME
{hours})
(2000, 0.23), (2001, 0.23), (2002, 0.23), (2003, 0.23), (2004, 0.23), (2005, 0.23), (2006, 0.23), (2007, 0.23), (2008, 0.23), (2009, 0.23), (2010, 0.23), (2011, 0.23), (2012, 0.23), (2013, 0.23), (2014, 0.23), (2015, 0.23), (2016, 0.23), (2017, 0.23), (2018, 0.23), (2019, 0.23), (2020, 0.23)
free_flow_travel_time_by_PT = GRAPH(TIME
{hours})
(2000, 0.83), (2001, 0.8), (2002, 0.78), (2003, 0.77), (2004, 0.76), (2005, 0.76), (2006, 0.76), (2007, 0.76), (2008, 0.75), (2009, 0.75), (2010, 0.75), (2011, 0.75), (2012, 0.74), (2013, 0.74), (2014, 0.74), (2015, 0.74), (2016, 0.74), (2017, 0.74), (2018, 0.74), (2019, 0.75), (2020, 0.75)
GDP__annual_growth = GRAPH(TIME
{1/year})
(2000, 0.0199), (2001, 0.02), (2002, 0.015), (2003, 0.0098), (2004, 0.0396), (2005, 0.0259), (2006, 0.0245), (2007, 0.0265), (2008, 0.004), (2009, -0.017), (2010, 0.0068), (2011, 0.0145)
housing_preferences[Low] = GRAPH(TIME
{unitless})
(2000, 0.982), (2001, 0.981), (2002, 0.982), (2003, 0.978), (2004, 0.976), (2005, 0.976), (2006, 0.968), (2007, 0.962), (2008, 0.949), (2009, 0.94), (2010, 0.938), (2011, 0.937), (2012, 0.937), (2013, 0.937), (2014, 0.937), (2015, 0.937), (2016, 0.937), (2017, 0.937), (2018, 0.937), (2019, 0.937), (2020, 0.937), (2021, 0.937), (2022, 0.937), (2023, 0.937), (2024, 0.937), (2025, 0.937), (2026, 0.937), (2027, 0.937), (2028, 0.937), (2029, 0.937), (2030, 0.937)
housing_preferences[High] = GRAPH(TIME
{unitless})

(2000, 0.018), (2001, 0.019), (2002, 0.018), (2003, 0.022), (2004, 0.024), (2005, 0.024), (2006, 0.032), (2007, 0.038), (2008, 0.051), (2009, 0.06), (2010, 0.062), (2011, 0.063), (2012, 0.063), (2013, 0.063), (2014, 0.063), (2015, 0.063), (2016, 0.063), (2017, 0.063), (2018, 0.063), (2019, 0.063), (2020, 0.063), (2021, 0.063), (2022, 0.063), (2023, 0.063), (2024, 0.063), (2025, 0.063), (2026, 0.063), (2027, 0.063), (2028, 0.063), (2029, 0.063), (2030, 0.063)
net_birth_rate = GRAPH(TIME
{1/year})
(2000, 0.008), (2001, 0.008), (2002, 0.009), (2003, 0.008), (2004, 0.007), (2005, 0.009), (2006, 0.009), (2007, 0.009), (2008, 0.009), (2009, 0.01), (2010, 0.011), (2011, 0.009), (2012, 0.01)
people_per_housing_unit = GRAPH(time
{people/housing units})
(2000, 2.63), (2004, 2.63), (2008, 2.60), (2012, 2.60), (2016, 2.50), (2020, 2.50), (2024, 2.40), (2028, 2.40), (2032, 2.20), (2036, 2.10), (2040, 2.10)
rush_hour_driving_time_by_car = GRAPH(TIME
{hours})
(2000, 0.48), (2001, 0.48), (2002, 0.48), (2003, 0.48), (2004, 0.48), (2005, 0.48), (2006, 0.48), (2007, 0.48), (2008, 0.48), (2009, 0.48), (2010, 0.48), (2011, 0.48), (2012, 0.48), (2013, 0.48), (2014, 0.48), (2015, 0.48), (2016, 0.48), (2017, 0.48), (2018, 0.48), (2019, 0.48), (2020, 0.48)
rush_hour_travel_time_by_PT = GRAPH(TIME
{hours})
(2000, 0.72), (2001, 0.69), (2002, 0.67), (2003, 0.66), (2004, 0.66), (2005, 0.65), (2006, 0.65), (2007, 0.65), (2008, 0.65), (2009, 0.65), (2010, 0.65), (2011, 0.65), (2012, 0.65), (2013, 0.65), (2014, 0.65), (2015, 0.65), (2016, 0.65), (2017, 0.65), (2018, 0.65), (2019, 0.65), (2020, 0.65)
zoned_land_area_for_business = GRAPH(TIME
{square meters})
(2000, 3.8e+006), (2001, 3.8e+006), (2002, 3.8e+006), (2003, 3.8e+006), (2004, 3.8e+006), (2005, 5.2e+006), (2006, 5.2e+006), (2007, 5.2e+006), (2008, 5.2e+006), (2009, 5.2e+006), (2010, 6.7e+006), (2011, 6.7e+006)

Bergen Center:

businesses_in_A_seeking_to_relocate_to_Bc[Low](t) = businesses_in_A_seeking_to_relocate_to_Bc[Low](t - dt) + (businesses_in_A_choosing_Bc[Low] - businesses_from_A_relocating_to_Bc[Low]) * dt
INIT businesses_in_A_seeking_to_relocate_to_Bc[Low] = Askøy.occupied__business_space[Low]*0.005
{square meters}
businesses_in_A_seeking_to_relocate_to_Bc[High](t) = businesses_in_A_seeking_to_relocate_to_Bc[High](t - dt) + (businesses_in_A_choosing_Bc[High] - businesses_from_A_relocating_to_Bc[High]) * dt
INIT businesses_in_A_seeking_to_relocate_to_Bc[High] = Askøy.occupied__business_space[High]*0.05
{square meters}
INFLOWS:
businesses_in_A_choosing_Bc[Density] = (Askøy.dissatisfied_businesses[Density]-.businesses_in_A_seeking_to_relocate[Density])*fraction_leaning_to_Bergen_center[Density]
{square meters/year}
OUTFLOWS:
businesses_from_A_relocating_to_Bc[Density] = MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_A_seeking_to_relocate_to_Bc[Density]/time_to_relocate))
{square meters/year}
businesses_in_Bc_seeking_to_relocate_to_Br[Density](t) = businesses_in_Bc_seeking_to_relocate_to_Br[Density](t - dt) + (businesses_in_Bc_choosing_Br[Density] - businesses_from_Bc_relocating_to_Br[Density]) * dt
INIT businesses_in_Bc_seeking_to_relocate_to_Br[Density] = dissatisfied_businesses[Density]*0.01
{square meters}
INFLOWS:
businesses_in_Bc_choosing_Br[Density] = (dissatisfied_businesses[Density]-.businesses_in_Bc_seeking_to_relocate[Density])*annual_frac_choosing_BR
{square meters/year}
OUTFLOWS:
businesses_from_Bc_relocating_to_Br[Density] = businesses_in_Bc_seeking_to_relocate_to_Br[Density]*annual_frac_deciding_to_relocate_in_BR
{square meters/year}

businesses_in_Be_seeking_to_relocate_to_Bc[Low](t) = businesses_in_Be_seeking_to_relocate_to_Bc[Low](t - dt) + (businesses_in_Be_choosing_Bc[Low] - businesses_from_Be_relocating_to_Bc[Low]) * dt
INIT businesses_in_Be_seeking_to_relocate_to_Bc[Low] = Bergen_East.occupied__business_space[Low]*0.005
{square meters}
businesses_in_Be_seeking_to_relocate_to_Bc[High](t) = businesses_in_Be_seeking_to_relocate_to_Bc[High](t - dt) + (businesses_in_Be_choosing_Bc[High] - businesses_from_Be_relocating_to_Bc[High]) * dt
INIT businesses_in_Be_seeking_to_relocate_to_Bc[High] = Bergen_East.occupied__business_space[High]*0.05
{square meters}
INFLOWS:
businesses_in_Be_choosing_Bc[Density] = (Bergen_East.dissatisfied_businesses[Density]-.businesses_in_Be_seeking_to_relocate[Density])*fraction_leaning_to_Bergen_center[Density]
{square meters/year}
OUTFLOWS:
businesses_from_Be_relocating_to_Bc[Density] = MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Be_seeking_to_relocate_to_Bc[Density]/time_to_relocate))
{square meters/year}
businesses_in_Bn_seeking_to_relocate_to_Bc[Density](t) = businesses_in_Bn_seeking_to_relocate_to_Bc[Density](t - dt) + (businesses_in_Bn_choosing_Bc[Density] - businesses_from_Bn_relocating_to_Bc[Density]) * dt
INIT businesses_in_Bn_seeking_to_relocate_to_Bc[Density] = Bergen_North.occupied__business_space[Density]*0.02
{square meters}
INFLOWS:
businesses_in_Bn_choosing_Bc[Density] = (Bergen_North.dissatisfied_businesses[Density]-.businesses_in_Bn_seeking_to_relocate[Density])*fraction_leaning_to_Bergen_center[Density]
{square meters/year}
OUTFLOWS:
businesses_from_Bn_relocating_to_Bc[Density] = MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Bn_seeking_to_relocate_to_Bc[Density]/time_to_relocate))
{square meters/year}
businesses_in_Br_seeking_to_relocate_to_Bc[Density](t) = businesses_in_Br_seeking_to_relocate_to_Bc[Density](t - dt) + (businesses_in_BR_choosing_Bc[Density] - businesses_from_BR_relocating_to_Bc[Density]) * dt
INIT businesses_in_Br_seeking_to_relocate_to_Bc[Density] = businesses_in_the_Bergen_region[Density]*0.01
{square meters}
INFLOWS:
businesses_in_BR_choosing_Bc[Density] = (businesses_in_the_Bergen_region[Density]*fraction_dissatisfied-.businesses_in_Br_seeking_to_relocate[Density])*fraction_leaning_to_Bergen_center[Density]
{square meters/year}
OUTFLOWS:
businesses_from_BR_relocating_to_Bc[Density] = MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Br_seeking_to_relocate_to_Bc[Density]/time_to_relocate))
{square meters/year}
businesses_in_Bs_seeking_to_relocate_to_Bc[Low](t) = businesses_in_Bs_seeking_to_relocate_to_Bc[Low](t - dt) + (businesses_in_Bs_choosing_Bc[Low] - businesses_from_Bs_relocating_to_Bc[Low]) * dt
INIT businesses_in_Bs_seeking_to_relocate_to_Bc[Low] = Bergen_South.occupied__business_space[Low]*0.005
{square meters}
businesses_in_Bs_seeking_to_relocate_to_Bc[High](t) = businesses_in_Bs_seeking_to_relocate_to_Bc[High](t - dt) + (businesses_in_Bs_choosing_Bc[High] - businesses_from_Bs_relocating_to_Bc[High]) * dt
INIT businesses_in_Bs_seeking_to_relocate_to_Bc[High] = Bergen_South.occupied__business_space[High]*0.05
{square meters}
INFLOWS:

businesses_in_Bs_choosing_Bc[Density] = (Bergen_South.dissatisfied_businesses[Density]-.businesses_in_Bs_seeking_to_relocate[Density])*fraction_leaning_to_Bergen_center[Density]
{square meters/year}
OUTFLOWS:
businesses_from_Bs_relocating_to_Bc[Density] = MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Bs_seeking_to_relocate_to_Bc[Density]/time_to_relocate))
{square meters/year}
businesses_in_Bw_seeking_to_relocate_to_Bc[Low](t) = businesses_in_Bw_seeking_to_relocate_to_Bc[Low](t - dt) + (businesses_in_Bw_choosing_Bc[Low] - businesses_from_Bw_relocating_to_Bc[Low]) * dt
INIT businesses_in_Bw_seeking_to_relocate_to_Bc[Low] = Bergen_West.occupied__business_space[Low]*0.005
{square meters}
businesses_in_Bw_seeking_to_relocate_to_Bc[High](t) = businesses_in_Bw_seeking_to_relocate_to_Bc[High](t - dt) + (businesses_in_Bw_choosing_Bc[High] - businesses_from_Bw_relocating_to_Bc[High]) * dt
INIT businesses_in_Bw_seeking_to_relocate_to_Bc[High] = Bergen_West.occupied__business_space[High]*0.05
{square meters}
INFLOWS:
businesses_in_Bw_choosing_Bc[Density] = (Bergen_West.dissatisfied_businesses[Density]-.businesses_in_Bw_seeking_to_relocate[Density])*fraction_leaning_to_Bergen_center[Density]
{square meters/year}
OUTFLOWS:
businesses_from_Bw_relocating_to_Bc[Density] = MIN((vacant_business_space[Density]/time_to_relocate),(businesses_in_Bw_seeking_to_relocate_to_Bc[Density]/time_to_relocate))
{square meters/year}
business_space_under_construction[Low](t) = business_space_under_construction[Low](t - dt) + (business_construction[Low] - finishing_business_construction[Low]) * dt
INIT business_space_under_construction[Low] = construction_time_business*3131
{square meters}
business_space_under_construction[High](t) = business_space_under_construction[High](t - dt) + (business_construction[High] - finishing_business_construction[High]) * dt
INIT business_space_under_construction[High] = construction_time_business*43001
{square meters}
INFLOWS:
business_construction[Density] = (policy_density_ratio[Density]*avg_statutory_floor_space_ratio_business[Density]*annual_land_prepared_for_business_construction)*.rezoning_policy+(1-.rezoning_policy)*(density_ratio_business[Density]*avg_statutory_floor_space_ratio_business[Density]*annual_land_prepared_for_business_construction)
{square meters/years}
OUTFLOWS:
finishing_business_construction[Density] = (business_space_under_construction[Density]/construction_time_business)
{square meters/year}
housing_space_under_construction[Low](t) = housing_space_under_construction[Low](t - dt) + (housing_construction[Low] - finishing_housing_construction[Low]) * dt
INIT housing_space_under_construction[Low] = construction_time_housing*2426
{square meters}
housing_space_under_construction[High](t) = housing_space_under_construction[High](t - dt) + (housing_construction[High] - finishing_housing_construction[High]) * dt
INIT housing_space_under_construction[High] = construction_time_housing*31448
{square meters}
INFLOWS:
housing_construction[Density] = (policy_density_ratio[Density]*avg_statutory_floor_space_ratio_housing[Density]*annual_land_prepared_for_housing_construction)*.rezoning_policy+(1-

.rezoning_policy)*(density_ratio_housing[Density]*avg_statutory_floor_space_ratio_housing[Density]*annual_land_prepared_for_housing_construction)
{square meters/years}
OUTFLOWS:
finishing_housing_construction[Density] = (housing_space_under_construction[Density]/construction_time_housing)
{square meters/years}
jobs[Low](t) = jobs[Low](t - dt) + (jobs_moving_to_Bc[Low] + hiring_rate[Low] - quitting_and_firing[Low] - jobs_leaving_Bc[Low]) * dt
INIT jobs[Low] = initial_total_jobs_Bc-(local_service_positions+non_local_service_positions[High])
{people}
jobs[High](t) = jobs[High](t - dt) + (jobs_moving_to_Bc[High] + hiring_rate[High] - quitting_and_firing[High] - jobs_leaving_Bc[High]) * dt
INIT jobs[High] = (local_service_positions+non_local_service_positions[High])
{people}
INFLOWS:
jobs_moving_to_Bc[Density] = (businesses_from_A_relocating_to_Bc[Density]+businesses_from_Bw_relocating_to_Bc[Density]+businesses_from_Be_relocating_to_Bc[Density]+businesses_from_Bn_relocating_to_Bc[Density]+businesses_from_Bs_relocating_to_Bc[Density]+businesses_from_BR_relocating_to_Bc[Density])/space_per_worker[Density]
{people/year}
hiring_rate[Density] = vacancies[Density]/hiring_time
{people/year}
OUTFLOWS:
quitting_and_firing[Density] = (jobs[Density]/avg_employment_time)-MIN((positions_gap[Density]/time_to_fire),0)
{people/year}
jobs_leaving_Bc[Density] =
(Bc_businesses_relocating[Density]+Askøy.policy_relocating[Density])/space_per_worker[Density]
{people/year}
non_local_service_positions[Low](t) = non_local_service_positions[Low](t - dt) + (change_in_positions[Low]) * dt
INIT non_local_service_positions[Low] = jobs[Low]
{people}
non_local_service_positions[High](t) = non_local_service_positions[High](t - dt) + (change_in_positions[High]) * dt
INIT non_local_service_positions[High] = inital_jobs_high_density_Bc-local_service_positions
{people}
INFLOWS:
change_in_positions[Density] =
(non_local_service_positions[Density]*annual_position_growth[Density])+jobs_moving_to_Bc[Density]-jobs_leaving_Bc[Density]
{people/year}
normal_rental_price[Density](t) = normal_rental_price[Density](t - dt) + (change_in_price[Density]) * dt
INIT normal_rental_price[Density] = 1500
{Norwegian Kroner/square meters}
INFLOWS:
change_in_price[Density] = normal_rental_price[Density]*CPI
{Norwegian Kroner/square meter/year}
occupied_housing_space[Low](t) = occupied_housing_space[Low](t - dt) + (moving_in[Low] - moving_out[Low]) * dt
INIT occupied_housing_space[Low] = need_for__housing_space[Low]
{square meters}
occupied_housing_space[High](t) = occupied_housing_space[High](t - dt) + (moving_in[High] - moving_out[High]) * dt
INIT occupied_housing_space[High] = need_for__housing_space[High]
{square meters}
INFLOWS:
moving_in[Density] =
MAX(MIN((housing_space_gap[Density]/time_to_move),(vacant_housing_space[Density]/time_to_move)),0)

{square meters/years}
OUTFLOWS:
moving_out[Density] = -MIN((MAX((housing_space_gap[Density]/time_to_move),-(occupied_housing_space[Density]/time_to_move))),0)
{square meters/year}
occupied_land_zoned_for_housing(t) = occupied_land_zoned_for_housing(t - dt) + (housing_land_permit_rate - abandoned_housing_land_area) * dt
INIT occupied_land_zoned_for_housing = (total_housing_space[Low]/avg_floor_space_ratio_housing[Low])+(total_housing_space[High]/avg_floor_space_ratio_housing[High])
{square meters}
INFLOWS:
housing_land_permit_rate = DELAY3(ARRAYSUM(requested_land_for_housing[*]),permit_time)
{square meters/years}
OUTFLOWS:
abandoned_housing_land_area = (abandoned_housing_land[Low]+abandoned_housing_land[High])
{square meters/year}
occupied_land__zoned_for_business(t) = occupied_land__zoned_for_business(t - dt) + (business_land_permit_rate - abandoned_business_land_area) * dt
INIT occupied_land__zoned_for_business = (total_business_space[Low]/avg_floor_space_ratio_business[Low])+(total_business_space[High]/avg_floor_space_ratio_business[High])
{square meters}
INFLOWS:
business_land_permit_rate = DELAY3(ARRAYSUM(requested_land_for_business_construction[*]),permit_time)
{square meters/year}
OUTFLOWS:
abandoned_business_land_area = (abondoned_business_land[Low]+abondoned_business_land[High])
{square meters/year}
occupied__business_space[Low](t) = occupied__business_space[Low](t - dt) + (extending_and_moving_to_Bc[Low] - reducing_and_leaving_Bc[Low]) * dt
INIT occupied__business_space[Low] = jobs[Low]*space_per_worker[Low]
{square meters}
occupied__business_space[High](t) = occupied__business_space[High](t - dt) + (extending_and_moving_to_Bc[High] - reducing_and_leaving_Bc[High]) * dt
INIT occupied__business_space[High] = jobs[High]*space_per_worker[High]
{square meters}
INFLOWS:
extending_and_moving_to_Bc[Density] = MAX((business_space_gap[Density]/time_to_relocate),0)+businesses_from_A_relocating_to_Bc[Density]+businesses_from_Bw_relocating_to_Bc[Density]+businesses_from_Be_relocating_to_Bc[Density]+businesses_from_Bn_relocating_to_Bc[Density]+businesses_from_Bs_relocating_to_Bc[Density]+businesses_from_BR_relocating_to_Bc[Density]
{square meters/year}
OUTFLOWS:
reducing_and_leaving_Bc[Density] = -MIN((business_space_gap[Density]/time_to_relocate),0)+Bc_businesses_relocating[Density]+Askøy.policy_relocating[Density]
{square meters/year}
population(t) = population(t - dt) + (population_net_change) * dt
INIT population = initial_population_in_Bergen_center
{people}
INFLOWS:
population_net_change = people_moving_to_Bc+annual_net_births
{people/year}
population_in_Bergen(t) = population_in_Bergen(t - dt) + (population_bergen_net_change) * dt
INIT population_in_Bergen = 229496
{people}

INFLOWS:
population_bergen_net_change = (popula-
tion_net_change+Bergen_East.population_net_change+Bergen_North.population_net_change+Bergen_South.p
opulation_net_change+Bergen_West.population_net_change)
{people/year}
total_land_available(t) = total_land_available(t - dt) + (abandoned_business_land_area + aban-
doned_housing_land_area - zoning_for_busineess - zoning_for_housing) * dt
INIT total_land_available = data_total_land_available_for_construction-vacant_land_zoned_for_businesses-
vacant_land_zoned__for_housing-occupied_land_zoned_for_housing-occupied_land__zoned_for_business
{square meters}
INFLOWS:
abandoned_business_land_area = (abondoned_business_land[Low]+abondoned_business_land[High])
{square meters/year}
abandoned_housing_land_area = (abandoned_housing_land[Low]+abandoned_housing_land[High])
{square meters/year}
OUTFLOWS:
zoning_for_busineess = (PULSE(MIN(MAX((needed_land_for_business-vacant_land_zoned_for_businesses-
(aban-
doned_business_land_area*fraction_still_zoned_for_business)),0),total_land_available),2001,zoning_interval_
Ber-
gen)*.policy_effectiveness+(abandoned_business_land_area*fraction_still_zoned_for_business))*.zoning_polic
y+(1-
.zoning_policy)*(PULSE(MIN((land_zoned_for_business),total_land_available),2001,zoning_interval_Bergen)
+(abandoned_business_land_area*fraction_still_zoned_for_business))
{square meters/year}
zoning_for_housing = (PULSE(MIN(MAX((needed_land_for_housing-vacant_land_zoned__for_housing-
(aban-
doned_housing_land_area*fraction_still_zoned_for_housing)),0),total_land_available),2001,zoning_interval_B
ergen)*.policy_effectiveness+(1-
.policy_effectiveness)*PULSE((MIN((MAX(((needed_land_area_for_housing_in_Bergen*zoning_fraction_Ber
gen_center)-
va-
cant_land_zoned__for_housing),0)),total_land_available)),2001,zoning_interval_Bergen)+(abandoned_housing
_land_area*fraction_still_zoned_for_housing)+land_rezoned_for_housing)*.zoning_policy+(1-
.zoning_policy)*(PULSE((MIN((MAX(((needed_land_area_for_housing_in_Bergen*zoning_fraction_Bergen_
center)-
va-
cant_land_zoned__for_housing),0)),total_land_available)),2001,zoning_interval_Bergen)+(abandoned_housing
_land_area*fraction_still_zoned_for_housing)+land_rezoned_for_housing)
{square meters/year}
vacancies[Low](t) = vacancies[Low](t - dt) + (advertised_vacancy_rate[Low] - hiring_rate[Low]) * dt
INIT vacancies[Low] = normal_job_vacancy_fraction*jobs[Low]
{people}
vacancies[High](t) = vacancies[High](t - dt) + (advertised_vacancy_rate[High] - hiring_rate[High]) * dt
INIT vacancies[High] = normal_job_vacancy_fraction*jobs[High]
{people}
INFLOWS:
advertised_vacancy_rate[Density] = MAX((positions_gap[Density]/advertising_time),0)
{person/year}
OUTFLOWS:
hiring_rate[Density] = vacancies[Density]/hiring_time
{people/year}
vacant_business_space[Low](t) = vacant_business_space[Low](t - dt) + (finishing_business_construction[Low]
+ reducing_and_leaving_Bc[Low] - extending_and_moving_to_Bc[Low] - business_demolition[Low]) * dt
INIT vacant_business_space[Low] = data_low_density_business_space_Bc-occupied__business_space[Low]
{square meters}
vacant_business_space[High](t) = vacant_business_space[High](t - dt) + (finish-
ing_business_construction[High] + reducing_and_leaving_Bc[High] - extending_and_moving_to_Bc[High] -
business_demolition[High]) * dt
INIT vacant_business_space[High] = data_high_density_business_space_Bc-occupied__business_space[High]

{square meters}
INFLOWS:
finishing_business_construction[Density] = (busi-
ness_space_under_construction[Density]/construction_time_business)
{square meters/year}
reducing_and_leaving_Bc[Density] = -
MIN((business_space_gap[Density]/time_to_relocate),0)+Bc_businesses_relocating[Density]+Askøy.policy_rel
ocating[Density]
{square meters/year}
OUTFLOWS:
business_demolition[Density] = (vacant_business_space[Density]*business_demolition_fraction[Density])
{square meters/year}
extending_and_moving_to_Bc[Density] =
MAX((business_space_gap[Density]/time_to_relocate),0)+businesses_from_A_relocating_to_Bc[Density]+busi
ness-
es_from_Bw_relocating_to_Bc[Density]+businesses_from_Be_relocating_to_Bc[Density]+businesses_from_B
n_relocating_to_Bc[Density]+businesses_from_Bs_relocating_to_Bc[Density]+businesses_from_BR_relocatin
g_to_Bc[Density]
{square meters/year}
vacant_housing_space[Low](t) = vacant_housing_space[Low](t - dt) + (finishing_housing_construction[Low] +
moving_out[Low] - moving_in[Low] - housing_demolition[Low]) * dt
INIT vacant_housing_space[Low] = data_low_density_housing_space_Bc-occupied_housing_space[Low]
{square meters}
vacant_housing_space[High](t) = vacant_housing_space[High](t - dt) + (finishing_housing_construction[High]
+ moving_out[High] - moving_in[High] - housing_demolition[High]) * dt
INIT vacant_housing_space[High] = data_high_density_housing_space_Bc-occupied_housing_space[High]
{square meters}
INFLOWS:
finishing_housing_construction[Density] = (hous-
ing_space_under_construction[Density]/construction_time_housing)
{square meters/years}
moving_out[Density] = -MIN((MAX((housing_space_gap[Density]/time_to_move),-
(occupied_housing_space[Density]/time_to_move))),0)
{square meters/year}
OUTFLOWS:
moving_in[Density] =
MAX(MIN((housing_space_gap[Density]/time_to_move),(vacant_housing_space[Density]/time_to_move)),0)
{square meters/years}
housing_demolition[Density] = (vacant_housing_space[Density]*housing_demolition_fraction[Density])
{square meters/years}
vacant_land_zoned_for_businesses(t) = vacant_land_zoned_for_businesses(t - dt) + (zoning_for_busineess -
business_land_permit_rate) * dt
INIT vacant_land_zoned_for_businesses = data_all_zoned_land_for_business-
occupied_land__zoned_for_business
{square meters}
INFLOWS:
zoning_for_busineess = (PULSE(MIN(MAX((needed_land_for_business-vacant_land_zoned_for_businesses-
(aban-
doned_business_land_area*fraction_still_zoned_for_business)),0),total_land_available),2001,zoning_interval_
Ber-
gen)*.policy_effectiveness+(abandoned_business_land_area*fraction_still_zoned_for_business))*.zoning_polic
y+(1-
.zoning_policy)*(PULSE(MIN((land_zoned_for_business),total_land_available),2001,zoning_interval_Bergen)
+(abandoned_business_land_area*fraction_still_zoned_for_business))
{square meters/year}
OUTFLOWS:
business_land_permit_rate = DE-
LAY3(ARRAYSUM(requested_land_for_business_construction[*]),permit_time)
{square meters/year}

vacant_land_zoned__for_housing(t) = vacant_land_zoned__for_housing(t - dt) + (zoning_for_housing - housing_land_permit_rate) * dt
INIT vacant_land_zoned__for_housing = data_all_zoned_land_for_housing-occupied_land_zoned_for_housing
{square meters}
INFLOWS:
zoning_for_housing = (PULSE(MIN(MAX((needed_land_for_housing-vacant_land_zoned__for_housing-(abandoned_housing_land_area*fraction_still_zoned_for_housing)),0),total_land_available),2001,zoning_interval_Bergen)*.policy_effectiveness+(1-.policy_effectiveness)*PULSE((MIN((MAX(((needed_land_area_for_housing_in_Bergen*zoning_fraction_Bergen_center)-vacant_land_zoned__for_housing),0)),total_land_available)),2001,zoning_interval_Bergen)+(abandoned_housing_land_area*fraction_still_zoned_for_housing)+land_rezoned_for_housing)*.zoning_policy+(1-.zoning_policy)*(PULSE((MIN((MAX(((needed_land_area_for_housing_in_Bergen*zoning_fraction_Bergen_center)-vacant_land_zoned__for_housing),0)),total_land_available)),2001,zoning_interval_Bergen)+(abandoned_housing_land_area*fraction_still_zoned_for_housing)+land_rezoned_for_housing)
{square meters/year}
OUTFLOWS:
housing_land_permit_rate = DELAY3(ARRAYSUM(requested_land_for_housing[*]),permit_time)
{square meters/years}
abandoned_housing_land[Density] = housing_demolition[Density]/avg_floor_space_ratio_housing[Density]
{square meters/years}
abondoned_business_land[Density] = business_demolition[Density]/avg_floor_space_ratio_business[Density]
{square meters/years}
accepted_rental_price[Density] = SMTH1(normal_rental_price[Density],0.5)
actual_fraction_satisfied_at_current_location[Density] = MIN((all_effects[Density]*initial_fraction_satisfied[Density]),0.95)
{unitless}
actual_rental_price[Density] = normal_rental_price[Density]*Graphical_functions.effect_of_supply_demand_ratio_on_rental_price[Density,Bergen_Center]
{Norwegian Kroner/square meter}
additional_need_for_business_space = (MAX((expected_need_for_business_space-existing_business_space),0))
{square meters}
additional_need_for_housing_units = MAX((expected_need_f_housing_units-existing_housing_units),0)
{housing units}
advertising_time = 1/12
{years}
all_effects[Low] = Graphical_functions.clustering_effect[Low,Bergen_Center]*Graphical_functions.effect_of_driving_time_difference[Bergen_Center]*Graphical_functions.effect_of_expansion_possibility_low_density[Bergen_Center]*Graphical_functions.effect_of_rental_price_low_density[Low,Bergen_Center]*center_attractiveness
{unitless}
all_effects[High] = Graphical_functions.clustering_effect[High,Bergen_Center]*Graphical_functions.effect_of_driving_time_difference[Bergen_Center]*Graphical_functions.effect_of_expansion_possibility_high_density[Bergen_Center]*Graphical_functions.effect_of_rental_price_high_denisty[High,Bergen_Center]*Graphical_functions.effect_of_travel_time_difference[High,Bergen_Center]*center_attractiveness
{unitless}
all_housing_units_Bc[Density] = occupied__housing_units[Density]+vacant_housing_units[Density]
{housing unit}
annual_frac_choosing_BR = 0.01
{1/year}
annual_frac_deciding_to_relocate_in_BR = 0.01

{1/year}
annual_land_prepared_for_business_construction = DE-
LAY3(business_land_permit_rate,time_for_preparation_of_land)
{square meters/years}
annual_land_prepared_for_housing_construction = DE-
LAY3(housing_land_permit_rate,time_for_preparation_of_land)
{square meters/years}
annual_net_births = net_birth_rate*population
{people/year}
annual_position_growth[Density] = DE-
LAYN(Graphical_functions.GDP_effect__on_position_growth*normal_annual_position_growth,1.5,10)
{1/year}
avg_driving_time_by_car_from_Bc_to_Bc =
0.9*free_flow_driving_time_by_car+0.1*rush_hour_driving_time_by_car
{hours}
avg_employment_time = 5
{years}
avg_floor_space_ratio_business[Low] = 0.15
{unitless}
avg_floor_space_ratio_business[High] = 2.3
{unitless}
avg_floor_space_ratio_housing[Low] = 0.3
{unitless}
avg_floor_space_ratio_housing[High] = 1.8
{unitless}
avg_statutory_floor_space_ratio_business[Low] = 0.4
{unitless}
avg_statutory_floor_space_ratio_business[High] = 2
{unitless}
avg_statutory_floor_space_ratio_housing[Low] = 0.4
{unitless}
avg_statutory_floor_space_ratio_housing[High] = 2
{unitless}
avg_travel_time_by_public_transport_to_Bc =
0.9*free_flow_travel_time_by_PT+0.1*rush_hour_travel_time_by_PT
{hours}
Bc_businesses_relocating[Density] =
Askøy.businesses_from_Bc_relocating_to_A[Density]+businesses_from_Bc_relocating_to_Br[Density]+Berge
n_East.businesses_from_Bc_relocating_to_Be[Density]+Bergen_North.businesses_from_Bc_relocating_to_Bn[
Densi-
ty]+Bergen_South.businesses_from_Bc_relocating_to_Bs[Density]+Bergen_West.businesses_from_Bc_relocati
ng_to_Bw[Density]
Bergen_centers_share_in_business_space[Density] = occu-
pied__business_space[Density]/.total_business_space_in_the_Bergen_region[Density]
{unitless}
business_demolition_fraction[Low] = policy_business_demolition_fraction[Low]*.rezoning_policy+(1-
.rezoning_policy)*(0.1)
{1/years}
business_demolition_fraction[High] = policy_business_demolition_fraction[High]*.rezoning_policy+(1-
.rezoning_policy)*0.07
{1/years}
business_land_fraction_occupied = occu-
pied_land__zoned_for_business/(vacant_land_zoned_for_businesses+occupied_land__zoned_for_business)
{unitless}
business_space_demand[Density] =
MAX((perceived_need_for_business_space[Density]+businesses_in_A_seeking_to_relocate_to_Bc[Density]+b
usiness-
es_in_Be_seeking_to_relocate_to_Bc[Density]+businesses_in_Bn_seeking_to_relocate_to_Bc[Density]+busine
sses_in_Bs_seeking_to_relocate_to_Bc[Density]+businesses_in_Bw_seeking_to_relocate_to_Bc[Density]+busi
nesses_in_Br_seeking_to_relocate_to_Bc[Density]),0.0001)

{square meters}
business_space_for_local_service_positions = local_service_positions*space_per_worker[High]
{square meters}
business_space_gap[Density] = recent_need_for_business_space[Density]-occupied__business_space[Density]
{square meters}
business_space_supply[Density] = vacant_business_space[Density]
{square meters}
business_space_supply_demand_ratio[Density] = (business_space_supply[Density]/business_space_demand[Density])
{unitless}
capacity_for_new_inhabitants = people_per_housing_unit*(vacant_housing_units[Low]+vacant_housing_units[High])
{people}
center_attractiveness = 1.5
{unitless}
construction_time_business = 2
{years}
construction_time_housing = 2
{years}
data_all_zoned_land_for_business = 4586924
{square meters}
data_all_zoned_land_for_housing = 7432122
{square meters}
data_total_land_available_for_construction = 29944326
{square meters}
density_ratio_business[Density] = DELAYN((requested_land_for_business_construction[Density]/ARRAYSUM(requested_land_for_business_construction[*])),5,10)
{unitless}
density_ratio_housing[Density] = DELAYN(requested_land_for_housing[Density]/ARRAYSUM(requested_land_for_housing[*]),5,10)
{unitless}
desired_business_construction[Density] = normal_annual_business_construction[Density]*Graphical_functions.effect_of_supply_demand_ratio_on_business_construction[Density,Bergen_Center]
{square meters/year}
desired_housing_construction[Density] = normal_annual_housing_construction[Density]*Graphical_functions.vacancy_effect_on_housing_construction[Density,Bergen_Center]
{square meters/year}
dissatisfied_businesses[Low] = SMTH3((occupied__business_space[Low]*(1-actual_fraction_satisfied_at_current_location[Low])),perception_time)
{square meters}
dissatisfied_businesses[High] = SMTH3(((occupied__business_space[High]-business_space_for_local_service_positions)*(1-actual_fraction_satisfied_at_current_location[High])),perception_time)
{square meters}
employed_person_per_housing_unit = 0.76
{people/housing unit}
existing_business_space = ARRAYSUM(occupied__business_space[*])+ARRAYSUM(vacant_business_space[*])+ARRAYSUM(business_space_under_construction[*])
{square meters}
existing_housing_units = ((housing_space_under_construction[Low]+occupied_housing_space[Low]+vacant_housing_space[Low])/housing_space_per_housing_unit[Low])+((housing_space_under_construction[High]+occupied_housing_space[High]+vacant_housing_space[High])/housing_space_per_housing_unit[High])
{housing units}
expected_additional_population_in_12_yrs = population_in_Bergen*expected_annual_population_growth*forecast_interval

{people}
expected_annual_population_growth = TREND(population_in_Bergen,1,0.02)
{1/year}
expected_employed_people_living_in_Bc = expected_population*frac_employed
{people}
expected_employed_people_working_in_Bc = AR-
RAYSUM(jobs[*])+ARRAYSUM(jobs[*])*expected_job_growth*forecast_interval*people_per_job
{people}
expected_job_growth = TREND(ARRAYSUM(jobs[*]),1,0.00)
{1/year}
expected_need_for_business_space = (expec-
pec-
ted_employed_people_living_in_Bc)*0.9*space_per_worker[High]+expected_employed_people_living_in_Bc*
0.1*space_per_worker[Low]
{square meters}
expected_need_for_housing_units = (expec-
pec-
ted_additional_population_in_12_yrs/people_per_housing_unit_avg_Bergen)+(expected_additional_population
_in_12_yrs/people_per_housing_unit_avg_Bergen)
{housing units}
expected_need_f_housing_units = ex-
pected_employed_people_working_in_Bc/employed_person_per_housing_unit
{housing units}
expected_population = population+population*expected__population_growth*forecast_interval
{people}
expected__population_growth = TREND(population,1,0.00)
{1/year}
floor_space_ratio_housing_avg_Bergen[Low] = 0.16
{unitless}
floor_space_ratio_housing_avg_Bergen[High] = 0.92
{unitless}
forecast_interval = 12
{years}
fraction_dissatisfied = 0.25
{unitless}
fraction_leaning_to_Bergen_center[Density] =
SMTH3(MIN((all_effects[Density]*initial_frac_leaning_to_Bc[Density]),1),time_to_make_decision)
{1/year}
fraction_new_field_construction = IF (TIME > 2006) THEN 0.4 ELSE 0.8
{unitless}
fraction_still_zoned_for_business = (1-policy_housing_rezoning_fraction)*.rezoning_policy+(1-
.rezoning_policy)*0.75
{unitless}
fraction_still_zoned_for_housing = 0.75
{unitless}
frac_employed = 0.51
{unitless}
high_density_fraction = 0.9
{unitless}
hiring_time = 3/12
{years}
housing_demolition_fraction[Low] = 0.02
{1/years}
housing_demolition_fraction[High] = 0.02
{1/years}
housing_land_fraction_occupied = occu-
pied_land_zoned_for_housing/(vacant_land_zoned__for_housing+occupied_land_zoned_for_housing)
{unitless}
housing_space_gap[Density] = need_for__housing_space[Density]-occupied_housing_space[Density]
{square meters}

housing_space_per_housing_unit[Low] = 129
{square meters/housing unit}
housing_space_per_housing_unit[High] = 87
{square meters/housing unit}
housing_space_per_housing_unit_avg_Bergen[Low] = 143
{square meters/housing unit}
housing_space_per_housing_unit_avg_Bergen[High] = 93
{square meters/housing unit}
housing_vacancy_fraction[Density] = va-
cant_housing_space[Density]/(occupied_housing_space[Density]+vacant_housing_space[Density])
{unitless}
inital_jobs_high_density_Bc = 65579
{people}
initial_fraction_satisfied[Low] = 0.75
{unitless}
initial_fraction_satisfied[High] = 0.75
{unitless}
initial_frac_leaning_to_Bc[Low] = 0.1
{unitless}
initial_frac_leaning_to_Bc[High] = 0.1
{unitless}
initial_population_in_Bergen_center = 65390
{people}
initial_total_jobs_Bc = 68499
jobs_housing_ratio_Bergen_center = ARRAYSUM(jobs[*])/ARRAYSUM(all_housing_units_Bc[*])
{jobs/housing unit}
land_rezoned_for_housing = (aban-
doned_business_land_area*policy_housing_rezoning_fraction)*.rezoning_policy+(1-.rezoning_policy)*0
land_zoned_for_business = 0
{square meters}
local_service_employment__ratio = 0.25
{unitless}
local_service_positions = population*local_service_employment__ratio
{people}
needed_land_area_for_housing_in_Bergen = expec-
pec-
ted_need_for_housing_units*((housing_space_per_housing_unit_avg_Bergen[Low]/floor_space_ratio_housing_avg_Bergen[Low])+(housing_space_per_housing_unit_avg_Bergen[High]/floor_space_ratio_housing_avg_Bergen[High]))*fraction_new_field_construction
{square meters}
needed_land_for_business = (addition-
al_need_for_business_space*0.9)/avg_statutory_floor_space_ratio_business[High]+(additional_need_for_business_space*0.1)/avg_statutory_floor_space_ratio_business[Low]
{square meters}
needed_land_for_housing = addition-
al_need_for_housing_units*((housing_space_per_housing_unit[Low]/avg_statutory_floor_space_ratio_housing[Low])+(housing_space_per_housing_unit[High]/avg_statutory_floor_space_ratio_housing[High]))
{square meters}
need_for_housing_units = population/people_per_housing_unit
{housing units}
need_for__housing_space[Density] = (hous-
ing_space_per_housing_unit[Density]*need_for_housing_units*housing_preferances[Density])
{square meters}
normal_annual_business_construction[Low] = 3131
{square meters/year}
normal_annual_business_construction[High] = 43001
{square meters/year}
normal_annual_housing_construction[Low] = 3074
{square meters/year}
normal_annual_housing_construction[High] = 25651

{square meters/year}
normal_annual_position_growth = 0.0173
{1/year}
normal_housing_vacancy_fraction[Low] = 0.032
{unitless}
normal_housing_vacancy_fraction[High] = 0.032
{unitless}
normal_job_vacancy_fraction = 0.065
{unitless}
normal_migration = 800
{people/year}
normal_supply_demand_ratio = 1
{unitless}
occupied__housing_units[Density] = occu-
pied_housing_space[Density]/housing_space_per_housing_unit[Density]
{housing units}
people_moving_to_Bc = MIN(((capacity_for_new_inhabitants/time_to_move)-
annual_net_births),people_seeking_to_move_to_Bc)
{people/year}
people_per_housing_unit = 1.52
{people/housing units}
people_per_housing_unit_avg_Bergen = 2.03
{people/housing unit}
people_per_job = 1
{unitless}
people_seeking_to_move_to_Bc = nor-
mal_migration*Graphical_functions.effect_of_housing_vacancies_on_people_seeking_to_move[Bergen_Center
]*Graphical_functions.effect_of_job_vacancies_on_people_seeking_to_move[Bergen_Center]
{people/year}
perceived_need_for_business_space[Density] = (perceived_need_for_positions[Density]-
jobs[Density])*space_per_worker[Density]
{square meters}
perceived_need_for_positions[Low] = non_local_service_positions[Low]
{people}
perceived_need_for_positions[High] =
SMTH3((non_local_service_positions[High]+local_service_positions),0.5)
{people}
perception_time = 2
{year}
permit_time = 4
{years}
policy_business_demolition_fraction[Low] = 0.1
{unitless}
policy_business_demolition_fraction[High] = 0.07
{unitless}
policy_density_ratio[Low] = 1-high_density_fraction
{unitless}
policy_density_ratio[High] = high_density_fraction
{unitless}
policy_housing_rezoning_fraction = 0.5
{unitless}
positions_gap[Density] = required__positions[Density]-jobs[Density]
{people}
possibility_to_expand = Graph-
ical_functions.effect_of_land_frac_occupied_on_possibility_to_expand[Bergen_Center]
{unitless}
potential_positions[Density] = (occu-
pied__business_space[Density]+vacant_business_space[Density])/space_per_worker[Density]
{people}
preferred_driving_time_by_car = 0.5

{hours}
preferred_possibility = 0.7
{unitless}
preferred_travel_time_by_public_transport = 0.75
{hours}
recent_need_for_business_space[Density] = jobs[Density]*space_per_worker[Density]
{square meters}
requested_land_for_business_construction[Density] =
MAX(((desired_business_construction[Density]/avg_statutory_floor_space_ratio_business[Density])*effect_of_land_fraction_occupied_on_requested_land_for_business),0.0001)
{square meters/year}
requested_land_for_housing[Density] =
MAX(((desired_housing_construction[Density]/avg_statutory_floor_space_ratio_housing[Density])*effect_of_land_fraction_occpied_on_requested_land_for_housing),0.0001)
{m^2/year}
required__positions[Density] = MIN(perceived_need_for_positions[Density],potential_positions[Density])
{people}
space_per_worker[Low] = 150
{square meters/person}
space_per_worker[High] = 39
{square meters/person}
time_for_preparation_of_land = 1
{years}
time_to_fire = 2/12
{years}
time_to_make_decision = 2
{year}
time_to_move = 3/12
{years}
time_to_relocate = 2/12
{years}
total_business_space[Density] = occupied__business_space[Density]+vacant_business_space[Density]
{square meters}
total_housing_space[Density] = occupied_housing_space[Density]+vacant_housing_space[Density]
{square meters}
total_housing_units = ARRAYSUM(all_housing_units_Bc[*])
total_initial_non_local_service_positions = 52151
{people}
total_jobs = ARRAYSUM(jobs[*])
vacant_housing_units[Density] = vacant_housing_space[Density]/housing_space_per_housing_unit[Density]
{housing units}
zoning_fraction_Bergen_center = 0
{unitless}
zoning_interval_Bergen = 6
{years}
businesses_in_the_Bergen_region[Low] = GRAPH(TIME
{square meters})
(2000, 1.1e+006), (2001, 1.1e+006), (2002, 1.1e+006), (2003, 1.1e+006), (2004, 1.1e+006), (2005, 1.2e+006), (2006, 1.2e+006), (2007, 1.2e+006), (2008, 1.2e+006), (2009, 1.3e+006), (2010, 1.3e+006), (2011, 1.3e+006)
businesses_in_the_Bergen_region[High] = GRAPH(TIME
{square meters})
(2000, 454845), (2001, 470682), (2002, 471818), (2003, 473058), (2004, 487214), (2005, 495265), (2006, 505078), (2007, 522160), (2008, 532334), (2009, 548123), (2010, 564431), (2011, 577523)
CPI = GRAPH(TIME
{1/year})
(2000, 0.031), (2001, 0.03), (2002, 0.013), (2003, 0.025), (2004, 0.004), (2005, 0.016), (2006, 0.023), (2007, 0.008), (2008, 0.038), (2009, 0.021), (2010, 0.025), (2011, 0.012), (2012, 0.008)
data_high_density_business_space_Bc = GRAPH(TIME)

(2000, 2.8e+006), (2001, 2.8e+006), (2002, 2.8e+006), (2003, 2.9e+006), (2004, 2.9e+006), (2005, 2.9e+006), (2006, 3e+006), (2007, 3e+006), (2008, 3e+006), (2009, 3e+006), (2010, 3.1e+006), (2011, 3.1e+006), (2012, 3.1e+006)
data_high_density_housing_space_Bc = GRAPH(TIME)
(2000, 2.9e+006), (2001, 3e+006), (2002, 3e+006), (2003, 3e+006), (2004, 3e+006), (2005, 3e+006), (2006, 3.1e+006), (2007, 3.1e+006), (2008, 3.1e+006), (2009, 3.2e+006), (2010, 3.2e+006), (2011, 3.2e+006), (2012, 3.2e+006)
data_housing_units_Bc = GRAPH(TIME)
(2000, 45714), (2001, 46022), (2002, 46286), (2003, 46443), (2004, 46826), (2005, 47270), (2006, 47694), (2007, 48138), (2008, 48414), (2009, 48514), (2010, 48795), (2011, 49004), (2012, 49246), (2013, 49646)
data_jobs_Bc = GRAPH(TIME)
(2000, 68499), (2001, 69219), (2002, 68951), (2003, 70107), (2004, 70848), (2005, 72466), (2006, 74723), (2007, 77649), (2008, 79391), (2009, 79031), (2010, 79243), (2011, 79390)
data_low_density_business_space_Bc = GRAPH(TIME)
(2000, 465959), (2001, 469090), (2002, 470037), (2003, 473946), (2004, 475191), (2005, 487399), (2006, 529235), (2007, 560633), (2008, 570834), (2009, 584640), (2010, 584728), (2011, 589606), (2012, 615383)
data_low_density_housing_space_Bc = GRAPH(TIME)
(2000, 1.6e+006), (2001, 1.6e+006), (2002, 1.6e+006), (2003, 1.6e+006), (2004, 1.6e+006), (2005, 1.6e+006), (2006, 1.6e+006), (2007, 1.6e+006), (2008, 1.6e+006), (2009, 1.6e+006), (2010, 1.6e+006), (2011, 1.6e+006), (2012, 1.6e+006)
effect_of_land_fraction_occpied_on_requested_land_for_housing = GRAPH(housing_land_fraction_occupied
{unitless})
(0.00, 1.00), (0.05, 1.00), (0.1, 1.00), (0.15, 1.00), (0.2, 1.00), (0.25, 1.00), (0.3, 1.00), (0.35, 1.00), (0.4, 1.00), (0.45, 1.00), (0.5, 1.00), (0.55, 1.00), (0.6, 1.00), (0.65, 1.00), (0.7, 1.00), (0.75, 1.00), (0.8, 1.00), (0.85, 1.00), (0.9, 1.00), (0.95, 0.8), (1.00, 0.00)
effect_of_land_fraction_occupied_on_requested_land_for_business =
GRAPH(business_land_fraction_occupied
{unitless})
(0.00, 1.00), (0.05, 1.00), (0.1, 1.00), (0.15, 1.00), (0.2, 1.00), (0.25, 1.00), (0.3, 1.00), (0.35, 1.00), (0.4, 1.00), (0.45, 1.00), (0.5, 1.00), (0.55, 1.00), (0.6, 1.00), (0.65, 1.00), (0.7, 1.00), (0.75, 1.00), (0.8, 1.00), (0.85, 1.00), (0.9, 1.00), (0.95, 0.8), (1.00, 0.00)
free_flow_driving_time_by_car = GRAPH(TIME
{hours})
(2000, 0.1), (2001, 0.1), (2002, 0.1), (2003, 0.1), (2004, 0.1), (2005, 0.1), (2006, 0.1), (2007, 0.1), (2008, 0.1), (2009, 0.1), (2010, 0.1), (2011, 0.1), (2012, 0.1), (2013, 0.1), (2014, 0.1), (2015, 0.1), (2016, 0.1), (2017, 0.1), (2018, 0.1), (2019, 0.1), (2020, 0.1)
free_flow_travel_time_by_PT = GRAPH(TIME
{hours})
(2000, 0.15), (2003, 0.15), (2006, 0.15), (2009, 0.15), (2012, 0.15), (2015, 0.15), (2018, 0.15), (2021, 0.15), (2024, 0.15), (2027, 0.15), (2030, 0.15)
housing_preferances[Low] = GRAPH(TIME
{unitless})
(2000, 0.267), (2001, 0.266), (2002, 0.265), (2003, 0.265), (2004, 0.264), (2005, 0.261), (2006, 0.26), (2007, 0.258), (2008, 0.257), (2009, 0.257), (2010, 0.256), (2011, 0.255)
housing_preferances[High] = GRAPH(TIME
{unitless})
(2000, 0.733), (2001, 0.734), (2002, 0.735), (2003, 0.735), (2004, 0.736), (2005, 0.739), (2006, 0.73), (2007, 0.742), (2008, 0.743), (2009, 0.743), (2010, 0.744), (2011, 0.745)
net_birth_rate = GRAPH(TIME
{1/year})
(2000, -0.0003), (2001, -0.0001), (2002, -0.0003), (2003, 0.0003), (2004, 0.0029), (2005, 0.0052), (2006, 0.0039), (2007, 0.0055), (2008, 0.0049), (2009, 0.0049), (2010, 0.0056), (2011, 0.0051)
rush_hour_driving_time_by_car = GRAPH(TIME
{hours})
(2000, 0.15), (2001, 0.15), (2002, 0.15), (2003, 0.15), (2004, 0.15), (2005, 0.15), (2006, 0.15), (2007, 0.15), (2008, 0.15), (2009, 0.15), (2010, 0.15), (2011, 0.15), (2012, 0.15), (2013, 0.15), (2014, 0.15), (2015, 0.15), (2016, 0.15), (2017, 0.15), (2018, 0.15), (2019, 0.15), (2020, 0.15)
rush_hour_travel_time_by_PT = GRAPH(TIME
{hours})

(2000, 0.18), (2001, 0.18), (2002, 0.18), (2003, 0.18), (2004, 0.18), (2005, 0.18), (2006, 0.18), (2007, 0.18), (2008, 0.18), (2009, 0.18), (2010, 0.18), (2011, 0.18), (2012, 0.18), (2013, 0.18), (2014, 0.18), (2015, 0.18), (2016, 0.18), (2017, 0.18), (2018, 0.18), (2019, 0.18), (2020, 0.18)

Graphical functions:

arrayed_actual_preferred_possibility[Askøy] = Askøy.possibility_to_expand/Askøy.preferred_possibility
{unitless}
arrayed_actual_preferred_possibility[Bergen_West] = Bergen_West.possibility_to_expand/Bergen_West.preferred_possibility
{unitless}
arrayed_actual_preferred_possibility[Bergen_South] = Bergen_South.possibility_to_expand/Bergen_South.preferred_possibility
{unitless}
arrayed_actual_preferred_possibility[Bergen_East] = Bergen_East.possibility_to_expand/Bergen_East.preferred_possibility
{unitless}
arrayed_actual_preferred_possibility[Bergen_North] = Bergen_North.possibility_to_expand/Bergen_North.preferred_possibility
{unitless}
arrayed_actual_preferred_possibility[Bergen_Center] = Bergen_Center.possibility_to_expand/Bergen_Center.preferred_possibility
{unitless}
arrayed_business_land_fraction_occupied[Askøy] = Askøy.business_land_fraction_occupied
{unitless}
arrayed_business_land_fraction_occupied[Bergen_West] = Bergen_West.business_land_fraction_occupied
{unitless}
arrayed_business_land_fraction_occupied[Bergen_South] = Bergen_South.business_land_fraction_occupied
{unitless}
arrayed_business_land_fraction_occupied[Bergen_East] = Bergen_East.business_land_fraction_occupied
{unitless}
arrayed_business_land_fraction_occupied[Bergen_North] = Bergen_North.business_land_fraction_occupied
{unitless}
arrayed_business_land_fraction_occupied[Bergen_Center] = Bergen_Center.business_land_fraction_occupied
{unitless}
arrayed_business_space_supply_demand_ratio[Low,Askøy] = (Askøy.business_space_supply_demand_ratio[Low]/Askøy.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[Low,Bergen_West] = (Bergen_West.business_space_supply_demand_ratio[Low]/Bergen_West.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[Low,Bergen_South] = (Bergen_South.business_space_supply_demand_ratio[Low]/Bergen_South.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[Low,Bergen_East] = (Bergen_East.business_space_supply_demand_ratio[Low]/Bergen_East.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[Low,Bergen_North] = Bergen_North.business_space_supply_demand_ratio[Low]/Bergen_North.normal_supply_demand_ratio
{unitless}
arrayed_business_space_supply_demand_ratio[Low,Bergen_Center] = Bergen_Center.business_space_supply_demand_ratio[Low]/Bergen_Center.normal_supply_demand_ratio
{unitless}
arrayed_business_space_supply_demand_ratio[High,Askøy] = (Askøy.business_space_supply_demand_ratio[High]/Askøy.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[High,Bergen_West] = (Bergen_West.business_space_supply_demand_ratio[High]/Bergen_West.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[High,Bergen_South] = (Bergen_South.business_space_supply_demand_ratio[High]/Bergen_South.normal_supply_demand_ratio)

{unitless}
arrayed_business_space_supply_demand_ratio[High,Bergen_East] = (Bergen_East.business_space_supply_demand_ratio[High]/Bergen_East.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[High,Bergen_North] = (Bergen_North.business_space_supply_demand_ratio[High]/Bergen_North.normal_supply_demand_ratio)
{unitless}
arrayed_business_space_supply_demand_ratio[High,Bergen_Center] = (Bergen_Center.business_space_supply_demand_ratio[High]/Bergen_Center.normal_supply_demand_ratio)
{unitless}
arrayed_driving_time_by_car[Askøy] =
Askøy.avg_driving_time_by_car_to_Bc/Askøy.preferred_driving_time_by_car_to_Bc
{unitless}
arrayed_driving_time_by_car[Bergen_West] = Bergen_West.avg_driving_time_by_car_from_Bw_to_Bc/Bergen_West.preferred_driving_time_by_car
{unitless}
arrayed_driving_time_by_car[Bergen_South] = Bergen_South.avg_driving_time_by_car_from_Bs_to_Bc/Bergen_South.preferred_driving_time_by_car
{unitless}
arrayed_driving_time_by_car[Bergen_East] = Bergen_East.avg_driving_time_by_car_from_Be_to_Bc/Bergen_East.preferred_driving_time_by_car
{unitless}
arrayed_driving_time_by_car[Bergen_North] = Bergen_North.avg_driving_time_by_car_from_Bn_to_Bc/Bergen_North.preferred_driving_time_by_car
{unitless}
arrayed_driving_time_by_car[Bergen_Center] = Bergen_Center.avg_driving_time_by_car_from_Bc_to_Bc/Bergen_Center.preferred_driving_time_by_car
{unitless}
arrayed_housing_land_fraction_occupied[Askøy] = Askøy.housing_land_fraction_occupied
{unitless}
arrayed_housing_land_fraction_occupied[Bergen_West] = Bergen_West.housing_land_fraction_occupied
{unitless}
arrayed_housing_land_fraction_occupied[Bergen_South] = Bergen_South.housing_land_fraction_occupied
{unitless}
arrayed_housing_land_fraction_occupied[Bergen_East] = Bergen_East.housing_land_fraction_occupied
{unitless}
arrayed_housing_land_fraction_occupied[Bergen_North] = Bergen_North.housing_land_fraction_occupied
{unitless}
arrayed_housing_land_fraction_occupied[Bergen_Center] = Bergen_Center.housing_land_fraction_occupied
{unitless}
arrayed_housing_vacancy_fraction[Low,Askøy] =
Askøy.housing_vacancy_fraction[Low]/Askøy.normal_housing_vacancy_fraction[Low]
{unitless}
arrayed_housing_vacancy_fraction[Low,Bergen_West] = Bergen_West.housing_vacancy_fraction[Low]/Bergen_West.normal_housing_vacancy_fraction[Low]
{unitless}
arrayed_housing_vacancy_fraction[Low,Bergen_South] = Bergen_South.housing_vacancy_fraction[Low]/Bergen_South.normal_housing_vacancy_fraction[Low]
{unitless}
arrayed_housing_vacancy_fraction[Low,Bergen_East] = Bergen_East.housing_vacancy_fraction[Low]/Bergen_East.normal_housing_vacancy_fraction[Low]
{unitless}
arrayed_housing_vacancy_fraction[Low,Bergen_North] = Bergen_North.housing_vacancy_fraction[Low]/Bergen_North.normal_housing_vacancy_fraction[Low]
{unitless}
arrayed_housing_vacancy_fraction[Low,Bergen_Center] = Bergen_Center.housing_vacancy_fraction[Low]/Bergen_Center.normal_housing_vacancy_fraction[Low]
{unitless}
arrayed_housing_vacancy_fraction[High,Askøy] =
Askøy.housing_vacancy_fraction[High]/Askøy.normal_housing_vacancy_fraction[High]

{unitless}
arrayed_housing_vacancy_fraction[High,Bergen_West] = Bergen_West.housing_vacancy_fraction[High]/Bergen_West.normal_housing_vacancy_fraction[High]
{unitless}
arrayed_housing_vacancy_fraction[High,Bergen_South] = Bergen_South.housing_vacancy_fraction[High]/Bergen_South.normal_housing_vacancy_fraction[High]
{unitless}
arrayed_housing_vacancy_fraction[High,Bergen_East] = Bergen_East.housing_vacancy_fraction[High]/Bergen_East.normal_housing_vacancy_fraction[High]
{unitless}
arrayed_housing_vacancy_fraction[High,Bergen_North] = Bergen_North.housing_vacancy_fraction[High]/Bergen_North.normal_housing_vacancy_fraction[High]
{unitless}
arrayed_housing_vacancy_fraction[High,Bergen_Center] = Bergen_Center.housing_vacancy_fraction[High]/Bergen_Center.normal_housing_vacancy_fraction[High]
{unitless}
arrayed_job_vacancy_fraction[Askøy] = .job_vacancy_fraction/Askøy.normal_job_vacancy_fraction
{unitless}
arrayed_job_vacancy_fraction[Bergen_West] =
.job_vacancy_fraction/(Bergen_West.normal_job_vacancy_fraction)
{unitless}
arrayed_job_vacancy_fraction[Bergen_South] =
.job_vacancy_fraction/(Bergen_South.normal_job_vacancy_fraction)
{unitless}
arrayed_job_vacancy_fraction[Bergen_East] =
.job_vacancy_fraction/(Bergen_East.normal_job_vacancy_fraction)
{unitless}
arrayed_job_vacancy_fraction[Bergen_North] =
.job_vacancy_fraction/(Bergen_North.normal_job_vacancy_fraction)
{unitless}
arrayed_job_vacancy_fraction[Bergen_Center] =
.job_vacancy_fraction/(Bergen_Center.normal_job_vacancy_fraction)
{unitless}
arrayed_rental_actual_preferred_rental_price[Low,Askøy] =
Askøy.actual_rental_price[Low]/Askøy.preferred_rental_price[Low]
{unitless}
arrayed_rental_actual_preferred_rental_price[Low,Bergen_West] = Bergen_West.actual_rental_price[Low]/Bergen_West.preferred_rental_price[Low]
{unitless}
arrayed_rental_actual_preferred_rental_price[Low,Bergen_South] = Bergen_South.actual_rental_price[Low]/Bergen_South.preferred_rental_price[Low]
{unitless}
arrayed_rental_actual_preferred_rental_price[Low,Bergen_East] = Bergen_East.actual_rental_price[Low]/Bergen_East.preferred_rental_price[Low]
{unitless}
arrayed_rental_actual_preferred_rental_price[Low,Bergen_North] = Bergen_North.actual_rental_price[Low]/Bergen_North.preferred_rental_price[Low]
{unitless}
arrayed_rental_actual_preferred_rental_price[Low,Bergen_Center] = Bergen_Center.actual_rental_price[Low]/Bergen_Center.accepted_rental_price[Low]
{unitless}
arrayed_rental_actual_preferred_rental_price[High,Askøy] =
Askøy.actual_rental_price[High]/Askøy.preferred_rental_price[High]
{unitless}
arrayed_rental_actual_preferred_rental_price[High,Bergen_West] = Bergen_West.actual_rental_price[High]/Bergen_West.preferred_rental_price[High]
{unitless}
arrayed_rental_actual_preferred_rental_price[High,Bergen_South] = Bergen_South.actual_rental_price[High]/Bergen_South.preferred_rental_price[High]
{unitless}

arrayed_rental_actual_preferred_rental_price[High,Bergen_East] = Bergen_East.actual_rental_price[High]/Bergen_East.preferred_rental_price[High]
{unitless}
arrayed_rental_actual_preferred_rental_price[High,Bergen_North] = Bergen_North.actual_rental_price[High]/Bergen_North.preferred_rental_price[High]
{unitless}
arrayed_rental_actual_preferred_rental_price[High,Bergen_Center] = Bergen_Center.actual_rental_price[High]/Bergen_Center.accepted_rental_price[High]
{unitless}
arrayed_share_in_business_space[Low,Askøy] = Askøy.A_s_share_in_business_space[Low]
{unitless}
arrayed_share_in_business_space[Low,Bergen_West] = Bergen_West.Bergen_Wests_share_in_business_space[Low]
{unitless}
arrayed_share_in_business_space[Low,Bergen_South] = Bergen_South.Bergen_Souths_share_in_business_space[Low]
{unitless}
arrayed_share_in_business_space[Low,Bergen_East] = Bergen_East.Bergen_Easts_share_in_business_space[Low]
{unitless}
arrayed_share_in_business_space[Low,Bergen_North] = Bergen_North.Bergen_Norths_share_in_business_space[Low]
{unitless}
arrayed_share_in_business_space[Low,Bergen_Center] = Bergen_Center.Bergen_centers_share_in_business_space[Low]
{unitless}
arrayed_share_in_business_space[High,Askøy] = Askøy.A_s_share_in_business_space[High]
{unitless}
arrayed_share_in_business_space[High,Bergen_West] = Bergen_West.Bergen_Wests_share_in_business_space[High]
{unitless}
arrayed_share_in_business_space[High,Bergen_South] = Bergen_South.Bergen_Souths_share_in_business_space[High]
{unitless}
arrayed_share_in_business_space[High,Bergen_East] = Bergen_East.Bergen_Easts_share_in_business_space[High]
{unitless}
arrayed_share_in_business_space[High,Bergen_North] = Bergen_North.Bergen_Norths_share_in_business_space[High]
{unitless}
arrayed_share_in_business_space[High,Bergen_Center] = Bergen_Center.Bergen_centers_share_in_business_space[High]
{unitless}
arrayed_travel_time_by_PT[Askøy] = Askøy.avg_travel_time_by_public_transportation_to_Bc/Askøy.preferred_travel_time
{unitless}
arrayed_travel_time_by_PT[Bergen_West] = Bergen_West.avg_travel_time_by_public_transport_to_Bc/Bergen_West.preferred_travel_time_by_public_transport
{unitless}
arrayed_travel_time_by_PT[Bergen_South] = Bergen_South.avg_travel_time_by_public_transport_to_Bc/Bergen_South.preferred_travel_time_by_public_transport
{unitless}
arrayed_travel_time_by_PT[Bergen_East] = Bergen_East.avg_travel_time_by_public_transport_to_Bc/Bergen_East.preferred_travel_time_by_public_transport
{unitless}
arrayed_travel_time_by_PT[Bergen_North] = Bergen_North.avg_travel_time_by_public_transport_to_Bc/Bergen_North.preferred_travel_time_by_public_transport

{unitless}
arrayed_travel_time_by_PT[Bergen_Center] = Bergen_Center.avg_travel_time_by_public_transport_to_Bc/Bergen_Center.preferred_travel_time_by_public_transport
{unitless}
array_mean_housing_vacancy_fraction[Askøy] = ARRAYMEAN(Askøy.housing_vacancy_fraction[*])/ARRAYMEAN(Askøy.normal_housing_vacancy_fraction[*])
{unitless}
array_mean_housing_vacancy_fraction[Bergen_West] = ARRAYMEAN(Bergen_West.housing_vacancy_fraction[*])/ARRAYMEAN(Bergen_West.normal_housing_vacancy_fraction[*])
{unitless}
array_mean_housing_vacancy_fraction[Bergen_South] = ARRAYMEAN(Bergen_South.housing_vacancy_fraction[*])/ARRAYMEAN(Bergen_South.normal_housing_vacancy_fraction[*])
{unitless}
array_mean_housing_vacancy_fraction[Bergen_East] = ARRAYMEAN(Bergen_East.housing_vacancy_fraction[*])/ARRAYMEAN(Bergen_East.normal_housing_vacancy_fraction[*])
{unitless}
array_mean_housing_vacancy_fraction[Bergen_North] = ARRAYMEAN(Bergen_North.housing_vacancy_fraction[*])/ARRAYMEAN(Bergen_North.normal_housing_vacancy_fraction[*])
{unitless}
array_mean_housing_vacancy_fraction[Bergen_Center] = ARRAYMEAN(Bergen_Center.housing_vacancy_fraction[*])/(ARRAYMEAN(Bergen_Center.normal_housing_vacancy_fraction[*])/4)
{unitless}
normal_GDP_growth = 0.0166
{1/year}
clustering_effect[Density,Urban_Area] =
GRAPH(SMTH3(arrayed_share_in_business_space[Density,Urban_Area],1)
{unitless})
(0.00, 0.00), (0.025, 0.563), (0.05, 0.885), (0.075, 1.05), (0.1, 1.19), (0.125, 1.26), (0.15, 1.34), (0.175, 1.38), (0.2, 1.40), (0.225, 1.43), (0.25, 1.46), (0.275, 1.47), (0.3, 1.50), (0.325, 1.50), (0.35, 1.50), (0.375, 1.50), (0.4, 1.50), (0.425, 1.50), (0.45, 1.50), (0.475, 1.50), (0.5, 1.50)
effect_of_driving_time_difference[Urban_Area] =
GRAPH(SMTH3((arrayed_driving_time_by_car[Urban_Area]),1)
{unitless})
(0.00, 1.50), (1.00, 1.00), (2.00, 0.5), (3.00, 0.285), (4.00, 0.15), (5.00, 0.098), (6.00, 0.05), (7.00, 0.038), (8.00, 0.03), (9.00, 0.023), (10.0, 0.01)
effect_of_expansion_possibility_high_density[Urban_Area] =
GRAPH(SMTH3(arrayed_actual_preferred_possibility[Urban_Area],1)
{unitless})
(0.00, 0.5), (0.2, 0.6), (0.4, 0.7), (0.6, 0.8), (0.8, 0.9), (1.00, 1.00), (1.20, 1.10), (1.40, 1.20), (1.60, 1.30), (1.80, 1.40), (2.00, 1.50)
effect_of_expansion_possibility_low_density[Urban_Area] =
GRAPH(SMTH3(arrayed_actual_preferred_possibility[Urban_Area],1)
{unitless})
(0.00, 0.35), (0.2, 0.47), (0.4, 0.58), (0.6, 0.7), (0.8, 0.85), (1.00, 1.00), (1.20, 1.13), (1.40, 1.28), (1.60, 1.44), (1.80, 1.59), (2.00, 1.75)
effect_of_housing_vacancies_on_people_seeking_to_move[Urban_Area] =
GRAPH(SMTH1(array_mean_housing_vacancy_fraction[Urban_Area],0.5)
{unitless})
(0.00, 0.03), (0.2, 0.135), (0.4, 0.24), (0.6, 0.375), (0.8, 0.675), (1.00, 1.00), (1.20, 2.01), (1.40, 2.49), (1.60, 2.79), (1.80, 2.92), (2.00, 2.94)
effect_of_job_vacancies_on_people_seeking_to_move[Urban_Area] =
GRAPH(SMTH1((arrayed_job_vacancy_fraction[Urban_Area]),0.5)
{unitless})

(0.00, 0.01), (0.2, 0.06), (0.4, 0.16), (0.6, 0.34), (0.8, 0.6), (1.00, 1.00), (1.20, 1.96), (1.40, 2.54), (1.60, 2.76), (1.80, 2.88), (2.00, 2.94)
effect_of_land_frac_occupied_on_possibility_to_expand[Urban_Area] = GRAPH(arrayed_business_land_fraction_occupied[Urban_Area]
{unitless})
(0.00, 1.00), (0.1, 1.00), (0.2, 0.985), (0.3, 0.965), (0.4, 0.94), (0.5, 0.905), (0.6, 0.83), (0.7, 0.725), (0.8, 0.55), (0.9, 0.29), (1, 0.00)
effect_of_land_frac_occupied_on_requested_land_for_business[Urban_Area] = GRAPH(arrayed_business_land_fraction_occupied[Urban_Area]
{unitless})
(0.00, 1.00), (0.1, 1.00), (0.2, 1.00), (0.3, 1.00), (0.4, 1.00), (0.5, 1.00), (0.6, 1.00), (0.7, 0.95), (0.8, 0.8), (0.9, 0.5), (1, 0.00)
effect_of_land_frac_occupied_on_requested_land_for_housing[Urban_Area] = GRAPH(arrayed_housing_land_fraction_occupied[Urban_Area]
{unitless})
(0.00, 1.00), (0.1, 1.00), (0.2, 1.00), (0.3, 1.00), (0.4, 1.00), (0.5, 1.00), (0.6, 1.00), (0.7, 0.95), (0.8, 0.8), (0.9, 0.5), (1, 0.00)
effect_of_rental_price_high_denisty[Density,Urban_Area] = GRAPH(SMTH3(arrayed_rental_actual_preferred_rental_price[High,Urban_Area],1)
{unitless})
(0.00, 1.50), (0.2, 1.40), (0.4, 1.30), (0.6, 1.20), (0.8, 1.10), (1.00, 1.00), (1.20, 0.9), (1.40, 0.8), (1.60, 0.7), (1.80, 0.6), (2.00, 0.5)
effect_of_rental_price_low_density[Density,Urban_Area] = GRAPH(SMTH3(arrayed_rental_actual_preferred_rental_price[Low,Urban_Area],1)
{unitless})
(0.00, 2.00), (0.2, 1.80), (0.4, 1.60), (0.6, 1.40), (0.8, 1.20), (1.00, 1.00), (1.20, 0.8), (1.40, 0.6), (1.60, 0.4), (1.80, 0.2), (2.00, 0.001)
effect_of_supply_demand_ratio_on_business_construction[Density,Urban_Area] = GRAPH(SMTH3(arrayed_business_space_supply_demand_ratio[Density,Urban_Area],0.5)
{unitless})
(0.00, 2.00), (0.5, 1.50), (1.00, 1.00), (1.50, 0.68), (2.00, 0.46), (2.50, 0.31), (3.00, 0.2), (3.50, 0.13), (4.00, 0.07), (4.50, 0.02), (5.00, 0.00)
effect_of_supply_demand_ratio_on_rental_price[Density,Urban_Area] = GRAPH(SMTH3(arrayed_business_space_supply_demand_ratio[Density,Urban_Area],1)
{unitless})
(0.00, 1.25), (0.2, 1.20), (0.4, 1.15), (0.6, 1.10), (0.8, 1.05), (1.00, 1.00), (1.20, 0.95), (1.40, 0.9), (1.60, 0.85), (1.80, 0.8), (2.00, 0.75)
effect_of_travel_time_difference[Density,Urban_Area] = GRAPH(SMTH3((arrayed_travel_time_by_PT[Urban_Area]),1)
{unitless})
(0.00, 1.25), (0.2, 1.20), (0.4, 1.15), (0.6, 1.10), (0.8, 1.05), (1.00, 1.00), (1.20, 0.95), (1.40, 0.9), (1.60, 0.85), (1.80, 0.8), (2.00, 0.75)
GDP_effect__on_position_growth = GRAPH(GDP__annual_growth/normal_GDP_growth
{unitless})
(-2.00, -0.94), (-1.67, -0.72), (-1.33, -0.545), (-1.00, -0.335), (-0.667, -0.16), (-0.333, -0.01), (-3.33e-016, 0.23), (0.333, 0.38), (0.667, 0.62), (1, 1.00), (1.33, 1.70), (1.67, 3.20), (2.00, 5.00)
GDP__annual_growth = GRAPH(TIME
{1/year})
(2000, 0.0199), (2001, 0.02), (2002, 0.015), (2003, 0.0098), (2004, 0.0396), (2005, 0.0259), (2006, 0.0245), (2007, 0.0265), (2008, 0.004), (2009, -0.017), (2010, 0.0068), (2011, 0.0145), (2012, 0.0145), (2013, 0.0145), (2014, 0.0145), (2015, 0.0145), (2016, 0.0145), (2017, 0.0145), (2018, 0.0145), (2019, 0.0145), (2020, 0.0145), (2021, 0.0145), (2022, 0.0145), (2023, 0.0145), (2024, 0.0145), (2025, 0.0145), (2026, 0.0145), (2027, 0.0145), (2028, 0.0145), (2029, 0.0145), (2030, 0.0145), (2031, 0.0145), (2032, 0.0145), (2033, 0.0145), (2034, 0.0145), (2035, 0.0145), (2036, 0.0145), (2037, 0.0145), (2038, 0.0145), (2039, 0.0145), (2040, 0.0145)
vacancy_effect_on_housing_construction[Density,Urban_Area] = GRAPH(SMTH3(arrayed_housing_vacancy_fraction[Density,Urban_Area],0.5,1)
{unitless})
(0.00, 2.00), (0.5, 1.50), (1.00, 1.00), (1.50, 0.63), (2.00, 0.39), (2.50, 0.21), (3.00, 0.12), (3.50, 0.06), (4.00, 0.03), (4.50, 0.02), (5.00, 0.00)

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