Paper presented at the 35th International Conference of the System Dynamics Society,
July 16-20, 2017, Cambridge, MA, U.S.A.

"Boom Without Limits?" – An Analysis of the Stuttgart Real Estate Market

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Version 1.0

June 2017

Prior research for this paper was conducted at the ESB Business School, Reutlingen University as part of Eleftheria Kapourani's Bachelor thesis under the supervision of Florian Kapmeier.

Abstract

Real estate markets are known to fluctuate. The real estate market in Stuttgart, Germany, has been booming for more than a decade: square-meter price hit top levels and real estate agents claim that market prices will continue to increase. In this paper, we test this market understanding by developing and analyzing a system dynamics model that depicts the Stuttgart real estate market. Simulating the model explains oscillating behavior arising from significant time delays and endogenous feedback structures – and not necessarily oscillating interest rates, as market experts assume. Scenarios provide insights into the system's behavior reacting to changes exogenous to the model. The first scenario tests the market development under increasing interest rates. The other scenario deals with possible effects on the real estate market if the regional automotive economy suffers from intense competition with new market players entering with alternative fuel vehicles and new technologies. With a policy run we test market structure changes to eliminate cyclical effects. The paper confirms that the business cycle in the Stuttgart real estate market arises from within the system's underlying structure, thus emphasizing the importance of understanding feedback structures.

Keywords: cyclical markets, real estate market, real estate cycles, oscillation, simulation

Introduction: The Stuttgart Real Estate market

Housing prices have been skyrocketing in many major German cities in the last few years. Among those, Stuttgart, the capital of the state of Baden-Württemberg, has experienced particularly aggressive price movements (Buchenau, 2015; 2016; Reichel, 2014). Average prices for apartments have reached almost 3,250 Euro per square meter (€/m^2), while the premium segment has even hit peak values of approximately 15,400 €/m^2 (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2016, p. 5). According to the head of the city's Real Estate Expert Committee, there is not any sign of end of the price increase because of increasing population, increasing number of households, low interest rates, and good economic conditions (Jäger, cited in Buchenau, 2016).

However, historical price developments reveal that today's prices of the Stuttgart real estate market have not grown gradually over time. Instead, the price index in Figure 4 illustrates a cyclical behavior with booms and busts over more than 30 years. The current real estate boom observed in Stuttgart challenges the question whether real estate prices are continuing to increase or whether there will be a bust. If the latter is possible, the question arises where the cyclical dynamics originate from.

Cyclical behavior is common in commodity markets, where the interplay of supply and demand determines the market (Sterman, 2000). However, these markets, including real estate, are highly complex as they consist of numerous components. Consequently, it is difficult to understand and analyze them. Still, literature provides different analysis approaches to overcome such difficulties (Pyhrrn et al., 1999). While some involve macroeconomic perspectives (as cited in Pyhrrn et al., 1999), others relate the oscillating behavior to the endogenous structures of the real estate market (DiPasquale & Wheaton, 1992). The latter studies imply causal relationships among influencing variables as well as feedback structures consisting of the interaction between supply and demand.

In this paper we analyze the Stuttgart real estate market and expose the main drivers of its actual cyclical behavior to achieve a better understanding of the underlying structure. We test whether market prices will continue to grow, as the city's Real Estate Expert Committee (Jäger, cited in Buchenau, 2016) and other experts (Haar, 2017) claim. Policy design and scenario settings will deliver profound insight in order to experience the long-term ramifications of the systems current behavior.

In the following, we first explain the research approach. Subsequently, we provide background information about the Stuttgart real estate market. We then explain and test the system dynamics model on the Stuttgart real estate market. Afterwards, we test scenarios on an increase of interest rates as well as on a serious decline in households and a policy run on considering underway construction and discuss the insight. The paper closes with conclusions.

Research Approach

In order to analyze the Stuttgart real estate market, we combine designing a case study (Yin, 2003) with developing a quantitative system dynamics model (Forrester, 1961; Sterman, 2000). Although simulation models are mainly based on quantitative data, qualitative input is also essential throughout the modeling process (Luna-Reyes & Andersen, 2004, p. 271; Sterman, 2000, p. 853). Therefore, the research approach of this paper entails a mixed methods research, which uses both qualitative and quantitative data according to (Creswell, 2003) (Figure 1).

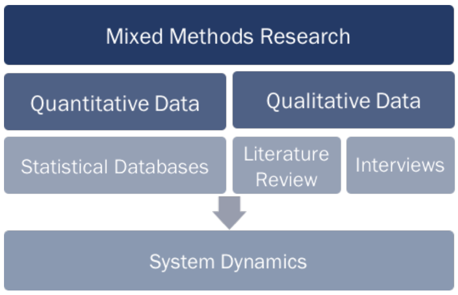

Figure 1: Applied research methodologies in the paper (authors' representation).

We collected quantitative data through secondary research, primarily from the Statistical Offices of the federal state of Baden-Württemberg as well as of the city of Stuttgart. Since quantitative data account only for a fraction of all the information available that is "crucial for understanding and modeling complex systems" (Sterman, 2000, p. 853), qualitative research serves as an additional methodological basis for the study.

Instead of an isolated use, several methods have been triangulated within the qualitative research approach in this study. According to its original form, triangulation implies different qualitative research methods being applied in one study thus diminishing limitations of single methods when used separately (Denzin, 2012; Patton, 1999; Yin, 2003). From the different types defined by Denzin (2012) and Patton (1999), we combined *multiple qualitative* research methods - literature review and expert interviews - with system dynamics. First, the literature review provided profound background on commodity markets in general and on real estate markets in particular. Thus, it provided a firm basis for the system dynamics modeling process as it helped to frame the problem and to develop the dynamic hypothesis.

Second, in addition to secondary research, we carried out primary research in order to obtain in-depth information about the market. We collected qualitative data through expert interviews conducted with employees of one of the Stuttgart-based real estate companies. Interviews, supplemented with other research methods of quantitative and qualitative nature, supported the outline of the dynamic hypothesis as well as the actual design of the simulation model (Sterman, 1987; 2000).

As semi-structured interviews offer an effective way for the purpose of this study (Sterman, 2000), we conducted the interviews as "guided conversations rather than structured queries" (Yin, 2003, p. 89) to underpin certain information retrieved from secondary research and to confirm assumptions for the system dynamics model (Yin, 2003, p. 90). For this reason, the design of the interview guideline was based on open-ended questions. Before the actual interviews, we conducted 'dry runs' with a person of similar background who is not involved in the study.

We interviewed four real estate experts, among those a director of the private real estate sector and a managing general partner of a renowned Stuttgart-based real estate company in the fall of 2015. Interviews ran about 60-90 minutes. We transcribed the interviews and analyzed them to explain and verify the model and investigate scenario and policy runs.

Literature Review of System Dynamics on Real Estate

Real estate cycles have been observed and analyzed with system dynamics in various regions and cities around the world from Netherlands (Eskinasi, 2014), over Istanbul (Barlas et al., 2007) to Boston (Genta, 1989) and Taiwan (Hu & Lo, 1992). Eskinasi (2014), for example, aims at systematically linking real estate economics and system dynamics, by presenting several projects and case studies from the Netherlands. Among those, the Haaglanden project describes the entire "model building project about new housing construction, urban renewal and the impact of both processes on a regional social housing market" (Eskinasi et al., 2009, p. 182). In a further case, he addresses housing policy effectiveness for the Dutch housing market (Eskinasi, 2014). Eskinasi (2014) transfers DiPasquale and Wheaton's (1992) model into a simple system dynamics model and extends it by adding "institutional aspects like land use planning, rent regulation, fiscal mortgage support and residual land pricing policy" (p. 18). Two descendants of Eskinasi's second case are the Middle Incomes and the Mortgage model. The former model evaluates the Dutch state support regulation while the latter analyzes the dynamics of mortgage debts of Dutch households (Eskinasi, 2014).

Further, Mashayekhi et al. (2009) address the cyclical dynamics in the owner-occupied real estate market in Iran. By comparing it with the properties of Wheaton's (1999) rental market model, Mashayekhi et al. (2009) simulate the differences in cyclicality that arise from the vacancy structure employed in the owner-occupied model only. Furthermore, an integrated model combines both markets, thus demonstrating cyclical effects resulting from the combination of both subsystems' structures. Mashayekhi et al. (2009) conclude that the interrelationship of different cycle-producing mechanisms increases complexity and deliver different dynamic behavior.

Atefi et al. (2010) base their model on Mashayekhi et al. (2009) to study the real estate market in Iran with a focus on housing affordability. Their main conclusion draws on supporting financial structures that may regulate the fluctuations in the Iranian market.

Barlas et al. (2007) aim at enhancing the understanding of cyclical dynamics of the real estate market in Istanbul. The model is developed from a major construction firm's perspective, assuming an oligopoly in the construction sector. The analysis reveals that time delays in the supply chain strongly influence the cyclical behavior of the real estate market. Considering this effect, one of the proposed policy designs takes into account the houses under construction with the result of reducing price oscillations. In their sensitivity analysis, Özbaş et al. (2008) point out the variables construction time and sales time having the highest impact on the period and amplitude of the oscillations, while profit margins determine the price level.

Similar to Barlas et al. (2007), Hu and Lo (1992) study the structure of the real estate market in Taiwan. Their simulation demonstrates "that the cyclical behavior pattern is influenced by the structure of the housing market itself" (Hu & Lo, 1992, p. 256). The limitation of the model is the assumption of unlimited land supply, which however is fairly unrealistic in the specific case of the island of Taiwan.

As one of the first system dynamics works in the field of real estate is Genta's (1989) analysis of the real estate market in Boston. The model takes into account a broad set of exogenous variables including population growth, regional economic factors as well as interest rates to explain the rapid rise in Boston's housing prices (Genta, 1989). It is further used for foresight and policy design with the aim of studying falling prices to balance demand and supply.

Thornton's (1992) analysis provides insights into the field of real estate by identifying "organizational learning disabilities that influence developers' mental models and cause less optimal development decisions" (p.2). Thornton (1992) illustrates the difficulties that real estate professionals have in understanding the complex system of the real estate market despite their expertise. In addition, his work demonstrates how systems thinking can improve strategic planning and decision making in the real estate sector.

Finally, Sterman (2000) addresses cycles in real estate markets in general and emphasizes the impact of the endogenous structure of the system thereby (pp. 698-708). The model we developed for our analysis draws profoundly on Sterman's (2000) general model structure.

System Dynamics Analysis of the Stuttgart Real Estate Market

Similar to the markets described above, times of boom and bust have also shaped numerous German real estate markets. Being rather "calm for many years" (Deutsche Bundesbank, 2013, p. 14), the German real estate market has become especially attractive for international investors as alternative investment options after the bursting housing bubble in the middle of 2000s in the United States and several European markets in contrast to "optimistic economic expectations" in Germany (Deutsche Bundesbank, 2013). Consequently, Germany's so-called *big seven*, the cities of Berlin, Cologne, Düsseldorf, Hamburg, Frankfurt am Main, Munich, and Stuttgart, have been in particular focus in recent years. These cities have experienced the largest increases in housing prices compared to other German cities or rural areas (Deutsche Bundesbank, 2014b; 2014b, p. 64; Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2015; Reichel, 2017).

Stuttgart's real estate market consists of many attractive prime locations in residential real estate, commercial real estate and industrial real estate. The former makes up the largest share of Stuttgart's real estate segments (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2015), which is where our focus of analysis lies. Market experts expect the prices in this area to increase further (Haar, 2017) because of the city's characteristics (Jäger, cited in Buchenau, 2016). We shed light on the drivers the experts identify: population and households, economy, and geography.

Development of Population and Households
Stuttgart's population has experienced a rapid increase in recent years, surpassing 600,000 inhabitants in 2013 (Statistisches Landesamt Baden-Württemberg, 2017). Although one would assume that such a large city has developed with a steady increasing population over decades, a closer look on Stuttgart's population development shows ups and downs over a 40+ years period between 1970 and 2014 (Figure 2, blue).

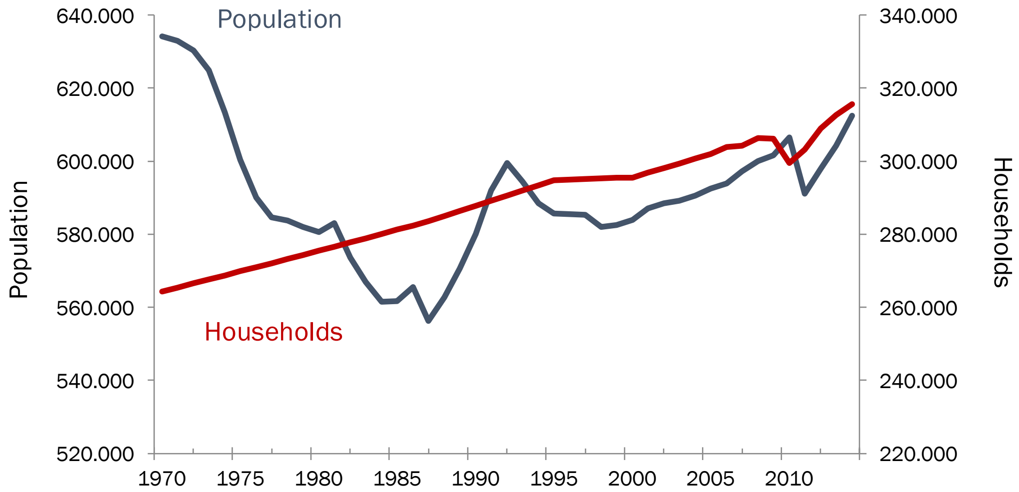

Figure 2: Population and household development in Stuttgart (adapted from Statistisches Amt Stuttgart, 2015b; Statistisches Landesamt Baden-Württemberg, 2014c).

In 1970, more than 630,000 people lived in Stuttgart. Subsequently, the population decreased to less than 560,000 people in 1987, followed by a sharp increase over 10 years to more than 600,000 people. The number of inhabitants slowly decreased in order to increase again to slightly more than 600,000 people in 2013. The fact that Stuttgart's population today is smaller than in the early 1970s can be explained by the post-war baby boom in the 1960s and the increasing wealth after the second world war resulting in a rising population, which reached its peak in the early 1970s (Schmitz-Veltin, 2009, p. 326). Afterwards, birth rates decreased due to the economic crisis in the beginning of the 1970s, new forms of birth control and changing society's values, leading to negative population balance and a declining population (Schmitz-Veltin, 2009, p. 326). We observe another upward trend during the 1990s due to an "echo boom" of births, i.e. the children of the first baby boomer generation, as well as declining death rates (Schmitz-Veltin, 2009, p. 326).

The unsteady population development tempts to the conclusion that demand in housing has developed accordingly. However, demand in housing is primarily generated by the number of households. In contrast to its population, the growth rate of households has been almost linear over the examined period (Figure 2, red).

Increasing wealth and social changes have transformed the household composition so that nowadays over one third of the households consist of only one person (Heilweck-Backes & Strauß, 2007). At the same time, it can be observed that with a declining number of persons per household, the living space per capita continues to rise (Eskinasi et al., 2009). Whereas in 1990, Stuttgart's inhabitants had on average less than 35 m^2, today the average living space per capita exceeds 40 m^2 (Statistisches Amt Stuttgart, 2015a; 2015b). Concluding, despite the irregular population development of Stuttgart, the number of households has increased nearly linearly since 1970, thus increasing demand in housing.

Regional Economy

A driver of the lately increasing number of people living in Stuttgart, according to the market experts (Jäger, cited in Buchenau, 2016), is also the booming economy in the region since the mid-1980s. The economy of the greater Stuttgart area is dominated by the automotive industry, including the two OEMs Daimler AG and Dr. Ing. h.c. F. Porsche AG, and the 1st tier supplier Robert Bosch GmbH, that all have their headquarters and major production facilities in Stuttgart. In addition, many world-leading as well as economically successful small and medium-sized enterprises are present in the region (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2015). Therefore, the city has emerged to be one of the most prospering economic areas among Germany's larger cities, granting its path to the top five leading economic regions in Germany and even top 15 within the European Union (Statistisches Landesamt Baden-Württemberg, 2016). Consequently, Stuttgart is highly attractive for many prospective employees from all over the world – and thus another stimulus of increasing housing demand in the real estate market.

Geographic Scope of Study

In addition, many inhabitants find the city’s location attractive. As illustrated in Figure 3, the city’s downtown (‘Mitte’) is located in a basin between hills and vineyards. In the context of Stuttgart's real estate market, the characteristic topographical structure constrains Stuttgart's territorial expansion, thus setting a natural limit to new real estate development. Hence, increasing demand cannot be satisfied with new housing construction, since building land is scarce (Reichel, 2014). Several districts, in particular those situated on the hillsides and offering panoramic views over the city center, enjoy increased popularity. This is why real estate prices have been skyrocketing especially in these areas in recent years (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2011; 2016; Real Estate Advisor 2, personal communication, September 23, 2015).

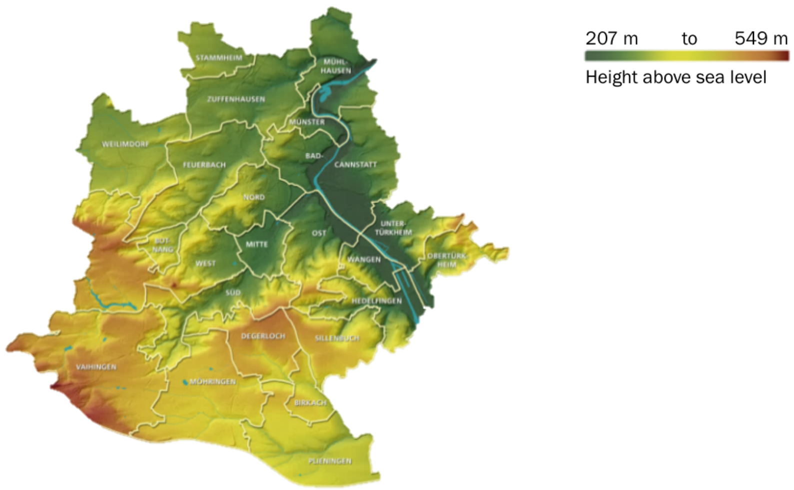

Figure 3: The city of Stuttgart with its districts. ‘Mitte’ is where the city center is located (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2015).

Considering the three aspects described above, the trend of an increasing number of households, the prospering economy, increasing demand for more space per resident, and the city's attractive topography shape Stuttgart's real estate market. Stuttgart's regional economic strength increases the city's attractiveness and attracts increasingly more people to move into the city, who demand more space per capita, thus increasing demand for housing. The city's topography, however, reinforces the lack of available housing space, since new construction is restricted by Stuttgart's basin. Market experts refer to the term 'Kessellage' in this context (Heilweck-Backes & Strauß, 2007; Real Estate Advisor 1; Real Estate Advisor 2, personal communication, September 23, 2015). Or, as one interviewee states, "the accumulated economic power, combined with its proximity to nature and the topographical position makes the city so appealing to me and many of our customers" (Real Estate Advisor 2, personal communication, September 23, 2015).

The consequences of increasing demand and simultaneous shortage in supply are skyrocketing housing prices (Eskinasi et al., 2009; Heilweck-Backes & Strauß, 2007). In 2015, Stuttgart's prices per square meter hit an all-time high of 3,250 € for purchased apartments on average, and 5,075 €/m^2 for newly constructed apartments, while peak values surpassed 15,400 €/m^2 and are expected to reach a record level of 17,000 €/m^2 for certain properties (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2016; Hahn, 2016).[1] One interviewee states that "the market is crazy. Yes, these are prices that we have never seen before. They had never been realized before" (Real Estate Director, personal communication, September 23, 2015).

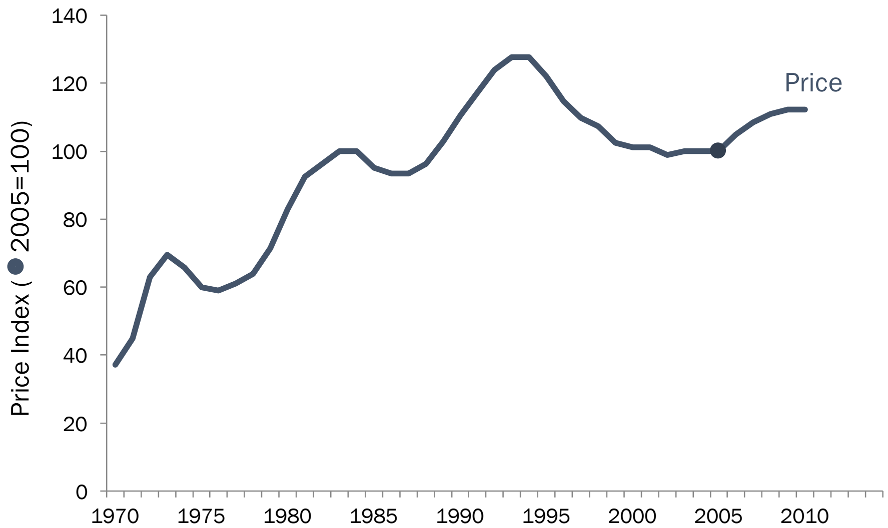

Figure 4: Reference Mode I: Average prices for owner-occupied apartments in Stuttgart (adapted from Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2011, p. 13).

While high demand and increasing prices have determined the Stuttgart real estate market for the past years, the city had previously experienced persistent cyclical instability (Eskinasi et al., 2009; Heilweck-Backes & Strauß, 2007). Figure 4 illustrates the oscillating price movements since 1970. The price index for owner-occupied apartments in Stuttgart exhibits reoccurring cycles, yet, with an overall rising price level. Bust times, in general, are ascribed to weak economic conditions, leading to low demand as it happened around the turn of the millennium in Stuttgart (1995 - early 2000s). At that time, high unemployment rates, a weak economy in particular affecting the strongly export-driven region of Stuttgart, as well as the rather uncertain future in the context of the European Union and the Maastricht Treaty (i.e. change of national currency to Euro) made it difficult to place real estate objects on the market (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 1995). Real estate was still regarded as secure investment opportunities, not with a very attractive return on investment though (Gutachterausschuss für die Ermittlung von

[1] To put this into perspective, comparing prices in real terms among Germany and United States might lead to the false conclusion that German housing prices are on a much lower level. However, considering prices against average income in Germany and the United States results in almost converging ratios (The Economist Data Team, 2016).

Grundstückswerten in Stuttgart, 2001). Our interviewees confirm the cyclical movements, i.e., when saying that "this is like a wave trough. And it is exactly like this: you can observe it every seven years. Now, we are maybe on a higher price level" (Real Estate Advisor 1, personal communication, September 23, 2015). The market experts' understanding of the market is obviously not coherent: while some acknowledge cycles in the real estate market – but primarily because of oscillating interest rates – they only see continuously rising prices, With our model we analyze Stuttgart's real estate cycle and try to better understand its price behavior and shed light on the underlying structure as the origin of the behavior.

System Dynamics Model of the Stuttgart Real Estate Market

Our model of the Stuttgart real estate market considers the theoretical background on real estate in general as well as Stuttgart's individual development and characteristics. Various concepts used in our analysis approach comply with Rahmandad & Sterman's (2012) reporting guideline as well as Sterman's (2000) modeling tools.

Model Scope

In contrast to traditional econometric models that primarily rely on exogenous variables, our system dynamics model encompasses largely endogenous variables according to the aim to seek "endogenous explanations of phenomena" (Sterman, 2000, p. 95). Endogenous factors are the pillars of the model structure and drive model behavior. They include housing price, demand, the real-estate supply chain, and the formation of expectations. Exogenous inputs influence the endogenous factors, yet latter arise outside the model boundary. Among those model parameters are some that remain constant, whereas others, such as the number of households, construction costs and interest rates were retrieved as real data from statistical time series and added to the model. In addition, there are variables that are relevant for understanding the real estate market in general, but lie outside the boundary of our model as we seek to keep the model as simple as possible but as adequate as necessary to analyze and understand the system's behavior (Table 1).

Endogenous	**Exogenous**	**Excluded**

· Price
· Demand
· Supply Chain including
  · Buildings under construction
  · Buildings completed
  · Buildings occupied
· Formation of Expectations (in price, costs, excess demand and profit)
	· Households
	· Construction costs
	· Interest Rates
	· A set of parameters (i.e., adjustment times, sensitivity values)
	· A set of table functions (i.e., for effects)
		· Regional employment
		· National economy (e.g., GDP)
		· Consumption and disposable income of households
		· Financial sector (e.g., mortgages)
		· Rest of construction industry (e.g., capacities, labor force)
		· Available building land

Table 1: Model boundary chart.

Time Horizon and Reference Modes

According to Sterman (2000), "two of the most useful processes are establishing reference modes and explicitly setting the time horizon" (p. 90). The time horizon is set from 1970 to 2045, enabling us to capture a few cycles of Stuttgart's real estate market in the past 47 years. Extending the horizon to 2045 provides us with an outlook long enough to understand future behavior of the market in our simulation runs.

Secondary research and personal interviews helped to identify housing price as the central key variable. All interviewees stated that Stuttgart has experienced the hog cycle effect in the give time horizon and thus, oscillating prices as well (Real Estate Advisor 1; Real Estate Advisor 2; Real Estate Director; Real Estate General Manager, personal communication, September 23, 2015). The city's statistics confirm the cyclical price development in housing as illustrated in Figure 4. For simplicity matters, we take median prices of owner-occupied apartments as indicator throughout the present analysis, without distinguishing newly constructed and old buildings. Note that data for the price as illustrated in Figure 4 is not deflated, as it is directly taken on from Stuttgart's 'Stadtmessungsamt' (Gutachterausschuss für die Ermittlung von Grundstückswerten in Stuttgart, 2011,

p. 13). Data for construction costs are similarly retrieved. We use both datasets to calibrate the model. Unfortunately, time series with absolute numbers on both, real estate prices and construction costs, are not available. Note further that deflated prices and costs, however, increase oscillations attitudes by their own cyclical behavior. Figure 5 illustrates the available total stock in housing buildings in Stuttgart, captured by the variable 'Buildings occupied' in Table 1 and our model. In contrast to price, it shows a nearly linear growth.

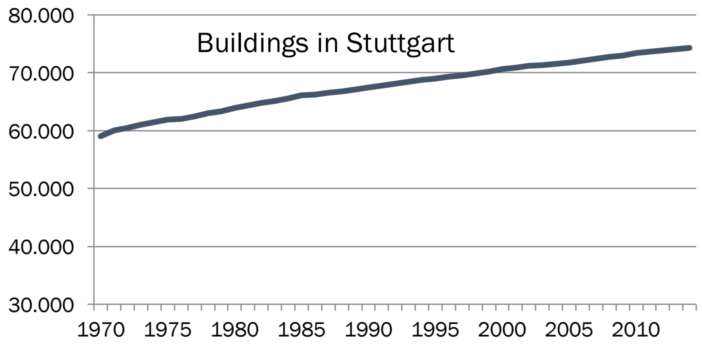

Figure 5: Reference Mode II: Housing buildings in Stuttgart (Statistisches Landesamt Baden-Württemberg, 2014d).

Simulation Model

Figure 6 shows the basic structure of the Stuttgart real estate market model in a highly aggregated causal loop diagram (CLD), depicting only the most important variables and the two balancing feedback loops that capture common macroeconomic assumptions (Mankiw, 2010, p. 9): the balancing loop B1 - 'Demand response' describes that prices *decrease* if supply exceeds demand. Lower prices stimulate demand and consequently the supply/demand ratio decreases. This again, causes prices to *rise* – contrary to the initial price movement. Hence, the balancing loop B1 regulates demand and prevents it from increasing infinitely. At the same time, when prices *decrease*, profits decline in the balancing loop B2 - 'Supply response'. Thus, less new construction is supplied, resulting in a decreasing stock of supplied housing. This will also reduce the supply/demand ratio, which in turn results in an *increase* of prices.

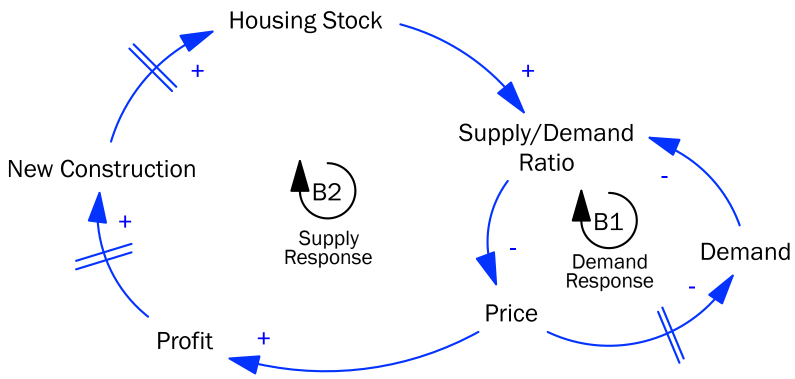

Figure 6: Causal loop diagram for the Stuttgart real estate market (author's representation following Sterman (2000)).

Thus, the real estate market creates two negative feedback loops that attempt to balance both demand and supply through the price. They are characterized by several time delays, as indicated on the respective arrows. In the balancing loop B1 - 'Demand response', price movements stimulate demand. Yet, due to a low elasticity of demand, the response time is fairly long (Muth, 1988, p. 351; Sterman, 2000, p. 708). On the supply side (B2 - 'Supply response'), profit developments stimulate new construction, which requires planning time before construction can actually start. Moreover, construction takes its own time until new housing is completed, thus creating a second delay in B2.

Generally speaking, balancing feedback loops cause variables to adjust discrepancies in quantities supplied and demanded. Hence, the system undertakes corrective actions, such as supplying additional housing to satisfy increased demand, to bring the market back to equilibrium. However, the presence of the indicated time delays in both negative loops "cause corrective actions to continue even after the state of the system reaches its goal, forcing the system to adjust too much, and triggering a new correction in the opposite direction" (Sterman, 2000, p. 114). Consequently, the system constantly over- and undershoots its equilibrium, resulting in an oscillating behavior.

We developed the simulation model of the **ST**uttgart **R**eal **E**state **M**arket (**STREM**-model) based on the model depicted in Figure 6. It entails several sub-structures from existing system dynamics works, including Barlas et al. (2007), Eskinasi (2014), Eskinasi et al. (2009) and Sterman (2000). The complete simulation report is provided in the appendix, including the complete model structure (Appendix A), simulation settings (Appendix B and C), as well as all model equations (Appendix D). Key equations are presented along with corresponding substructures below.

Aging Chain of Supplied Buildings

On the supply side, we expand the housing stock variable to a classic aging chain structure of the real estate market, following Sterman (2000). As shown in Figure 7, it begins with the inflow of the 'Construction start rate'. We assume an 'Average planning time' for new construction projects to start as a constant parameter of four years, considering planning to meet future demand and the average time it takes for selecting building sites and for the formal construction permission process. Our interviewees underline these long time delays, stating that "it is very difficult to receive a building permit. Sometimes, it takes months to get one" (Real Estate Director, personal communication, September 23, 2015). The flow accumulates in the first stock 'Buildings under construction'. Note that all initial values of the stocks, indicated with the prefix IN, are based on statistical data of the Stuttgart real estate market (Statistisches Amt Stuttgart, 2015a; Statistisches Landesamt Baden-Württemberg, 2014a; 2014b).

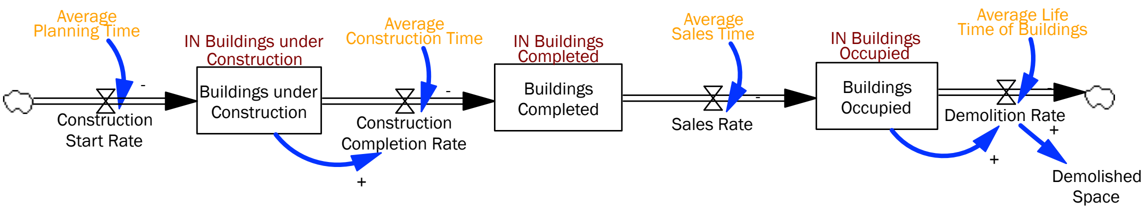

Figure 7: Substructure: Aging chain structure for buildings in Stuttgart.

CSR = MAX (0, DNC/APT)	(1)	where	CSR	Construction start rate
			DNC	Desired new construction
			APT	Average planning time
BUC = IN BUC + CSR – CCR	(2)	where	BUC	Buildings under construction
			CCR	Construction completion rate

After an assumed average construction time of 1.75 years, 'Construction completion rate' adds new buildings into the stock of 'Buildings completed', which represents the number of vacant buildings. After the buildings are sold, they flow into the third stock 'Buildings occupied' via the 'Sales rate'. Here, the 'Average sales time' is set at a nine-month period.

CCR = BUC/ACT	(3)	where	CCR	Construction completion rate
			ACT	Average construction time
BC = IN BC + CCR – SR	(4)	where	BC	Buildings completed
			SR	Sales rate
SR = PS/AST	(5)	where	PS	Potential sales
			AST	Average sales time

We further assume that 'Buildings occupied' are demolished after an 'Average lifetime of buildings' of 100 years. When there are not enough apartments available, people who are forced to move out, start to look for new housing. Consequently, 'Demolished space' will generate new demand, and thus needs to be linked with the demand structure of the model.

$BO = IN\ BO + SR - DR$ (6) where BO Buildings occupied
DR Demolition rate

$DR = BO/ALTB$ (7) where ALTB Average life time of buildings

Demand Creation

'Demolished space' and the 'Households Net Growth Rate' determine the 'Potential Demand' on real estate in Stuttgart (Figure 8). The 'Household net growth' rate aggregates the inflow and the outflow of the stock, thus comprising both growth and decline in Stuttgart's households.

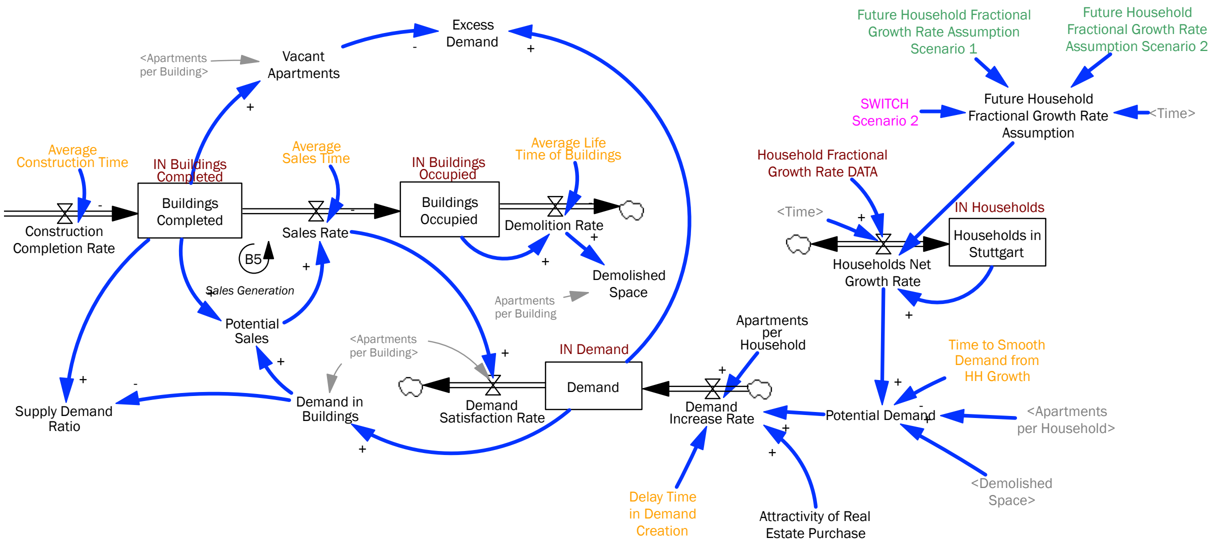

Figure 8: Substructure: Demand formation.

$PD = HNGR/TSD + DS/APH$ (8) where PD Potential demand
HNGR Households net growth rate
DS Demolished space
APH Apartments per household

The exogenous input for future household growth rate assumptions, indicated in dark green in Figure 8, is set for the period 2017-2045. We estimated its value on the average growth rate of real data of the last twenty years. It may be changed for scenario runs. The net growth in households determines 'Potential demand' – if it is positive, 'Potential demand' increases. So, both, the higher the natural household growth and the more space is demolished, the higher is the 'Demand increase rate', assuming one household demanding one apartment ('Apartments per household'). 'Attractivity of real estate purchase' is a further variable affecting demand by incorporating demand reactions to varying price levels of housing as well as exogenous drivers like interest rates (see explanation of balancing loop B1 below). Note that the stock 'Demand' considers a 'Delay time in demand creation'.

$DIR = (AREP*PD*APH)/DTDC$ (9) where DIR Demand increase rate
AREP Attractivity of Real Estate Purchase
DTDC Delay Time in Demand Creation

'Demand' in apartments is synthesized in 'Demand in buildings' with an average of four 'Apartments per building' according to Stuttgart's data (Heilweck-Backes & Strauß, 2007, p. 118). On the one hand, 'Demand in buildings' and the stock of 'Buildings completed' induce the 'Supply demand ratio', i.e., the ratio of empty houses to demand. On the other hand, ‘Demand in buildings’ defines 'Potential sales'. This closes the balancing feedback loop B5 - 'Sales generation', that regulates that completed buildings are only sold if demand is available.

Price Setting

Considering the balance between supply and demand, the 'Supply demand ratio' affects the price setting mechanism of the model (Figure 9). The structure, partially adopted from Barlas et al. (2007) and Sterman (2000), comprises the two expectation formation structures on price expectations and expectation of future construction costs. Adaptive expectations signify information delays and refer to perceived values that gradually adjust to the actual value of the corresponding variables while the adjustment time determines how fast expectations are corrected (Sterman, 2000, p. 428).

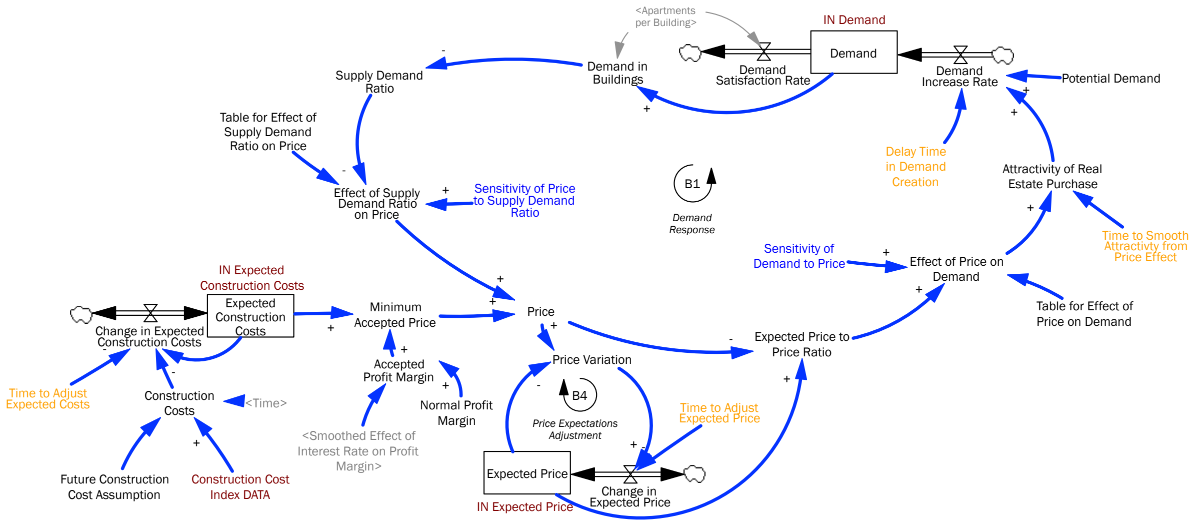

Figure 9: Substructure: Price setting and feedback loop 'Demand response'.

First, regarding the formation of construction costs, the 'Construction costs index', actual construction cost data, determines the actual average construction costs in Stuttgart's real estate market. Real estate suppliers form an expectation on construction costs on the basis of the actual ‘Construction costs’ with an information delay, following Sterman (2000). This delay, the 'Time to adjust expected costs', represents the time it takes to gather and process new construction costs data.

$$CECC = (CC - ECC)/TAEC \quad (10)$$

where

CECC	Change in exp. construction costs
CC	Construction costs
ECC	Expected construction costs
TAEC	Time to adjust expected costs

The costs depend on various factors, including fixed and variable costs, such as wages and materials – which are outside the model boundary and are thus excluded from the model. Based on 'Expected construction costs', suppliers set a 'Minimum accepted price' for housing prices. We model this with an 'Accepted profit margin' and assume a 'Normal profit margin' of 25%. In addition, suppliers also take into account the actual interest rates when making a decision on whether to build new housing (Real Estate Advisor 1, personal communication, September 23, 2015). If the interest rate decreases, so does the ‘Accepted profit margin’. With current interest rates of close to zero percent, investors also accept profit margins of about 3% (Dalcomo, 2016).

The interest rate structure influences the profit margin as follows: the actual 'Interest rate' is determined by the exogenous variable 'Interest rate data', which contains the actual interest rates since 1970 in Germany.
The 'Smoothed effect for interest rate on profit margin' converts the interest rate development in such a way that low interest rates have a decreasing effect on the 'Accepted profit margin', while higher interest rates claim an

increased profit margin. Thus, the varying 'Interest rates' influence the 'Minimum accepted price' of the market, which in turn affects the actual 'Price'.

'Price' is determined by both, the 'Minimum accepted price' and the 'Supply demand ratio'. A decreasing non-linear table function generates an 'Effect of supply demand ratio on price'. It captures that people are willing to pay higher prices when supply is short, while oversupply reduces prices (Mankiw, 2010, p. 9). 'Sensitivity of price to supply demand ratio' adjusts the degree of how sensitive the 'Price' responds to changes in the 'Supply demand ratio'. Accordingly, the price for housing is affected by the minimum accepted price, the linked construction costs and interest rates as well as the balance between supply and demand at any point of time.

'Price' affects both, supply and demand. Both react according to their expectations of price developments (Deutsche Bundesbank, 2013). Thus, the model structure to capture price and price expectation is similar to the structure that captures ‘Construction costs’ and ‘Expected construction costs’. As 'Price' varies according to the availability of supplied housing, it differs from the price perceived by both, suppliers and potential buyers. Hence, suppliers and buyers form their expectations on price by adjusting the 'Expected price' to eliminate the 'Price variation' between the current and perceived value. Since real prices are not reported on a regular basis, the 'Change in expected price' adjusts with an information time delay. There is an inflow to the stock when 'Price' is higher than 'Expected price'. Vice versa, an outflow exists when 'Price' drops under 'Expected price'. Because of its structural formulation, the 'Time to adjust expected price' results into a smoother and lagging development of 'Expected price' as reaction to variations in 'Price'.

For simplicity, we assume demand and supply determine prices adjustments with the same time delay. Yet, we are aware that in reality, real estate experts, such as developers and consultants, might form their expectations differently compared to potential customers that plan to purchase an apartment.

Eventually, market players on the demand side respond to changes in price by assessing 'Expected price to price ratio', i.e. the change in 'Expected price' relative to the current 'Price'. When 'Expected price' over 'Price' changes, there needs to be an opposing effect on demand. Hence, the non-linear, increasing S-shaped table function determines the 'Effect of price on demand', and regulates the 'Demand increase rate': Demand *decreases* when the 'Expected price to Price Ratio' *increases*; vice versa, demand *rises* when a *decline* in prices is perceived. The parameter 'Sensitivity of demand to price' determines the degree of changes in the behavior of demand. Muth (1988) assumes demand to be rather inelastic to changes in real estate prices.

$$EPPR = EP/P \qquad (11)$$

where
EPTPR Expected price to price ratio
EP Expected price
P Price

$$EPD = (TEPD*EPPR)^{\wedge}SDP \qquad (12)$$

where
EPD Effect of price to demand
TEPD Table for effect of price on demand
SDP Sensitivity of demand to price

$$TEPD = f(x);\ f' \geq 0;\ f''_{x<x_{ref}} \geq 0;\ f''_{x>x_{ref}} \leq 0; \qquad (13)$$

The price setting mechanism of the STREM-model closes the first balancing feedback loop B1 - 'Demand response'. On the one hand, assuming an *increase* in demand, initiated by a positive 'Households net growth rate' and a subsequent increase in 'Potential demand', the 'Supply demand ratio' declines. The latter has a diverging effect on 'Price', so that 'Price' increases when supply becomes scarce. On the other hand, a price increase creates a 'Price variation', so that 'Expected price' is adjusted respectively, yet with a time delay. Hence, an initial increase in price translates into a declining 'Expected price to price ratio' at first. Then, the effect of price variation on demand is modeled with the variable 'Effect of price on demand', which involves a lookup table and a sensitivity parameter to determine the price elasticity of demand. In general, demand in real estate is found to be not very elastic (Sterman, 2000; Muth, 1988). Further, the effect of price determines the 'Attractivity of real estate purchase'. The latter variable affects demand by incorporating not only the demand side's reactions to varying price levels of housing but also the effect of interest rates. 'Attractivity of real estate purchase' is increasing with lower prices, and vice versa, declining with an increasing price level. In addition, interest rates determine real estate attractiveness as an investment option in contrast to other financial products, such as bank account savings, bonds or stocks. Low interest rates make real estate a promising investment opportunity, thus, raising its attractiveness – and vice versa. Consequently, demand *declines* because prices have increased, contrary to the starting point. As already indicated in the CLD (Figure 6), demand is regulated by a balancing feedback loop that adjusts demand and prices towards market equilibrium (Figure 9, B2 - 'Demand response').

Profit Generation
The price setting mechanism, and in particular 'Expected price' determines the supply response to changes in 'Price' (Figure 10). For this reason, the supply side calculates its 'Expected profit' by taking into account 'Expected price' as well as 'Expected construction costs'. *Increasing* prices boost profitability while construction costs lead to a reduction. Profitability is the key driver of the supply side, as suppliers' investment decisions are determined by financially aspects. Therefore, when prices rise above construction costs, investors' expected profitability increases, too. Thus, higher 'Expected profit' stimulates more new construction. We model this with a table function that causes a change in 'Expected profit' to have a positive 'Effect of expected profitability' on 'Desired new construction'. 'Desired new construction' feeds into the inflow of the aging chain of the model, thus pushing the 'Construction start rate' to rise. Thereby, it closes the second balancing feedback loop B2 - 'Profit-driven supply'.

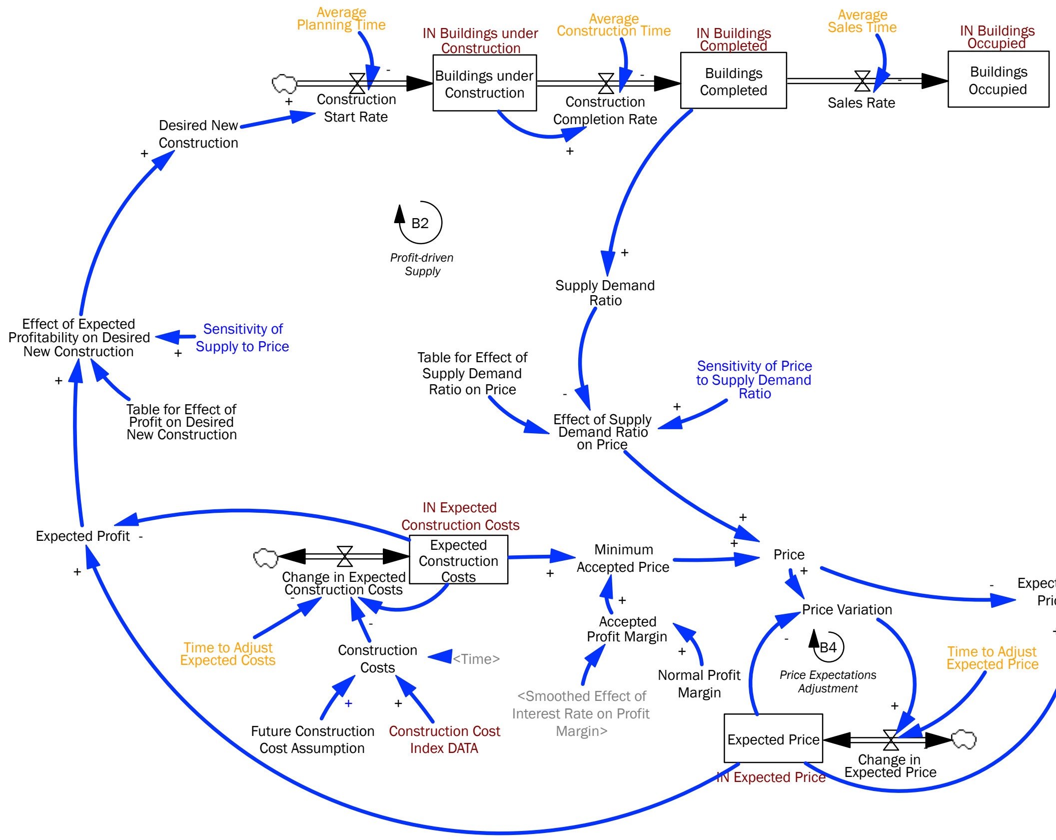

Figure 10: Substructure: Profit generation.

New construction eventually accumulates in the stock 'Buildings completed'. Subsequently, as increasingly more available housing is supplied to the Stuttgart real estate market, the 'Supply demand ratio' increases as well. As described above, the balance between demand and supply has a negative effect on 'Price'. Hence, more supply results in *decreasing* prices, as people are not willing to pay as much as before. Here again, as the price movement is opposite to the initial assumption (B2 - 'Profit-driven supply'), it regulates the supply side, in terms of the quantity supplied (i.e., new construction) and prices, seeking equilibrium in the Stuttgart real estate market.

Furthermore, the supply side aims at satisfying demand. Thereby, constructors are aware of the oversupply resulting in increasing vacancy rates and newly completed buildings cannot be sold. Unsold buildings or new apartments implicate no revenues, so that suppliers are left with uncovered costs and insolvency risk. For this reason, they try to forecast excess demand in the real estate market as accurately as possible. The according structure in the STREM-model is described in the following.

Excess Demand

Investors on the supply side react to demand as "assumptions about future demand and performance are essential for many business decisions" (Lyneis, 2000, p. 3). Yet, as they cannot know the precise actual *excess demand*, they estimate it (Figure 11). We model the structure similar to the price and cost expectations, as described above. Once again, it takes time to form expectations, so 'Expected excess demand' is adjusted by an average delay time ('Time to form expectation of excess demand').

The aim of the supply side is to meet 'Expected excess demand'. 'Desired new construction' emerges from 'Excess demand in buildings' and initiates new construction to be planned, thus determining the inflow into the aging chain, 'Construction start rate'. If 'Excess demand' *increases*, so does 'Expected excess demand' after a time delay, boosting 'Desired new construction'. After construction has begun and finally ends up as new 'Buildings completed', the number of 'Vacant apartments' grows likewise. These, in turn, reduce 'Excess demand', which is contrary to the starting point. Hence, this substructure entails the balancing feedback loop B3 - 'Supply line control', which keeps the supply line under control in terms of construction activity. Thus, new construction is only started according to given excess demand in the market.

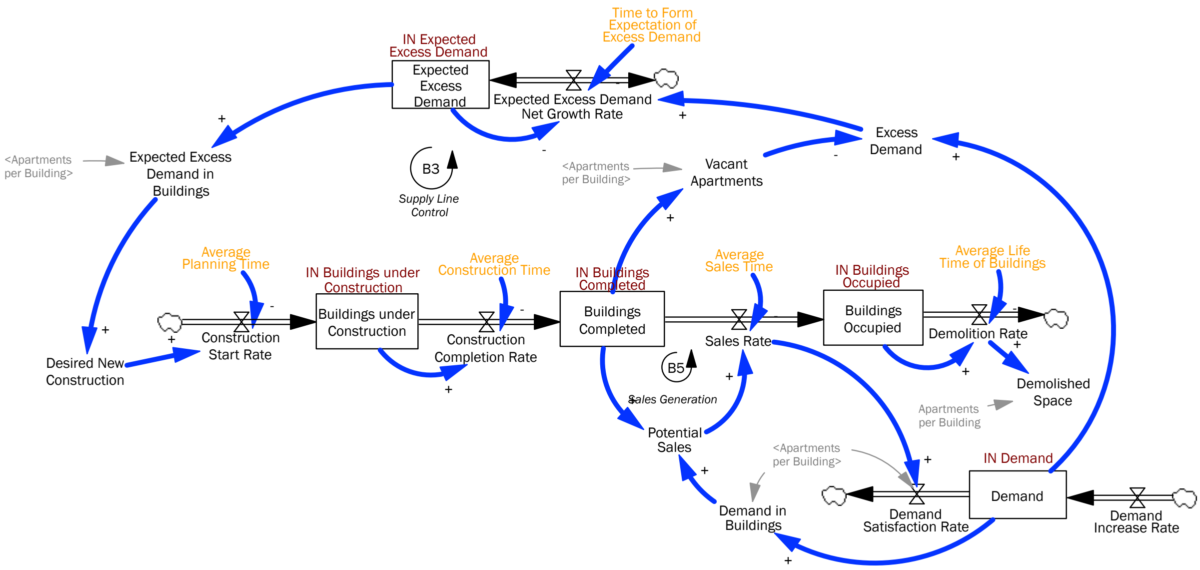

Figure 11: Substructure: Excess demand.

Combining the above-presented substructures of the STREM-model, Figure 12 illustrates the complete model structure. As already explained with the CLD (Figure 6), two balancing feedback loops B1 and B2 primarily determine the structure. On the one hand, demand responses to changes in price, on the other hand, the supply side reacts with new construction if it is profitable. Next, the model is tested and validated. An extended overview of the STREM-model is also provided in Appendix A, including all variable types specified.

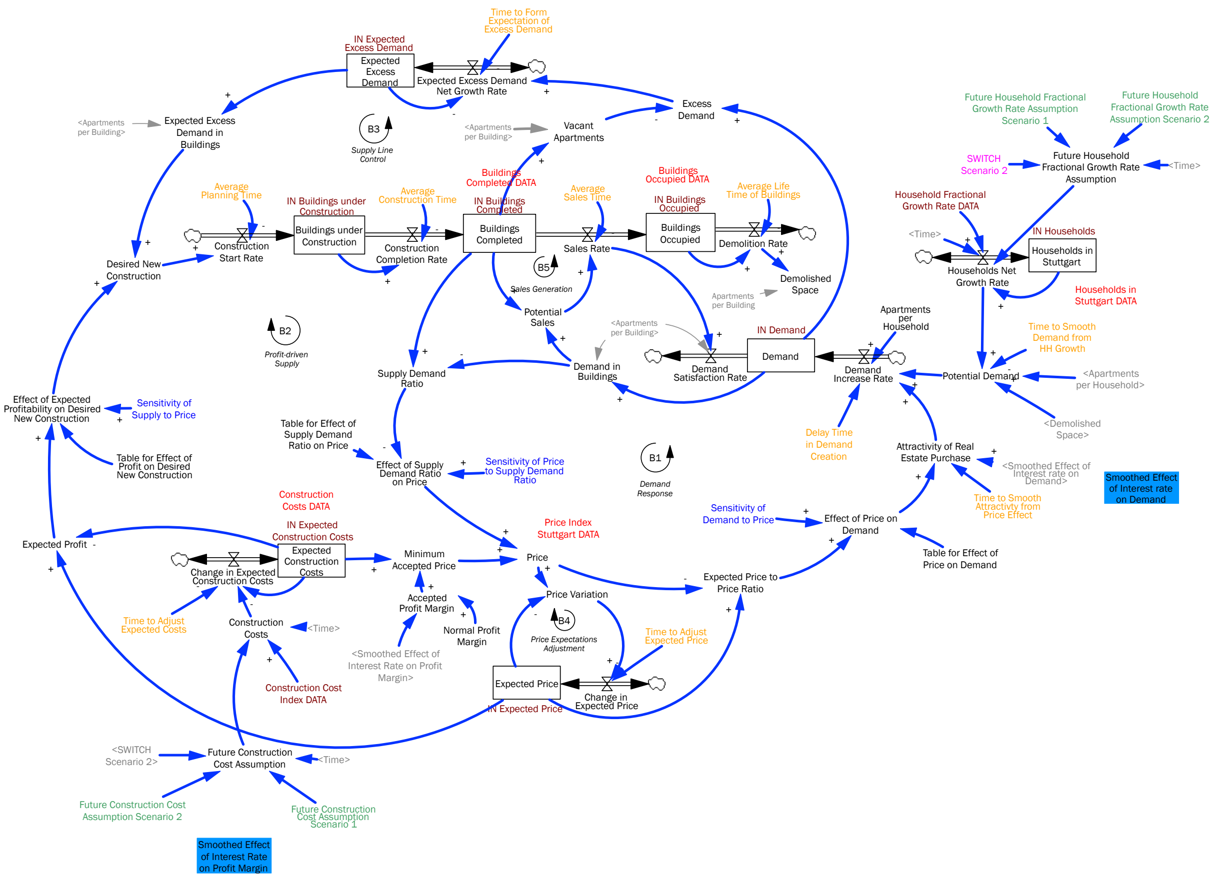

Figure 12: Stuttgart real estate market model (STREM) – full model.

Model Validation and Testing

Sterman (2000) describes model validation as a "continuous process of testing and building confidence in the model" (p.81). Nonetheless, models can never be validated in the sense of verified, as they are simplified representations of the real world's systems (Sterman, 2000, p. 846). Still, model testing is a crucial step in the system dynamics modeling process. For this purpose, there is a wide range of testing methods that can be applied in order to increase confidence in the model (Sterman, 2000, pp. 859-861). They are categorized into behavior and structural testing.

Structural Testing

Model Boundary Adequacy Test

The model boundary has been laid out above in the form of a model boundary chart (Table 1) and a causal loop diagram. By reviewing adequate literature and from the insights gained from the expert interviews, we identified variables and causalities relevant for the system's behavior. In doing so, we modeled important variables endogenous to the system, while others needed to be left as exogenous input or even omitted.

Structure Assessment Test

Structure assessment testing refers to the consistency between the model and the real system in the context of the model's purpose (Sterman, 2000, p. 863-864). Tools used in boundary assessment can be applied likewise. Existing literature and expert's statements have helped to model the system's structures and formulate valid equations compared to the real system. An important question to ask is whether the model adopts basic physical laws (Sterman, 2000, p. 846). The Stuttgart real estate market is especially constrained by its topographical site, yet the simulation model does not capture this aspect of natural limits to expansion. As the supply chain of the model involves a source and sink, it implies infinite in- and outflow. However, adjustment times and other variables control accumulation and depletion of stocks and prevent them from generating surrealistic behavior. For instance, ‘Construction start rate' can only start to flow when 'Desired new construction' is available.

Dimensional Consistency Test
We tested the model for dimensional consistency throughout the entire modeling process. All variables are specified with units. We distinguish between the units *buildings* and *apartments* since supply constructs buildings whereas households demand apartments. In order to link the variables, the units are transformed where necessary with the parameter 'Apartments per Building'. With an average of four apartments per buildings, the parameter is set as an actual value of the Stuttgart's housing market (Heilweck-Backes & Strauß, 2007, p. 104).

The variables 'Price' and 'Construction costs' are specified as indexes, and thus are consistent. Yet, the base value is set at two different years, creating a limitation of the model. However, as they are not directly linked in the model, the limitation is mitigated. For instance, 'Accepted minimum price' takes into account only 'Expected construction costs' and computes 'Accepted profit margin' only based on costs.

Parameter Assessment Test
Several parameter values of the model are estimations based on qualitative data retrieved from literature and personal interviews. Where available, they have been adopted as numerical data from other references. In those cases, their sources are cited either in the text when described or in the model equations. Statistical methods, as proposed by Sterman (2000) to estimate parameters should be considered in future research and optimization of the model. Despite some weaknesses of the model assessed through structural testing, e.g., capacity constraints, price indexes, parameter estimations, the following behavioral testing helped to further build confidence in the model.

Behavioral Testing

Extreme Conditions
Behavioral testing involves assessing the system's behavior under extreme conditions. It reflects whether the system's behavior and the model equations still make sense when the model is exposed to extreme values of inputs (Sterman, 2000, p. 869-870). This way, one extreme condition tests the model under the assumption that demand drops to zero. A physical reaction would be, for example, that supply does not initiate any new construction projects, so that the inflow 'Construction start rate' falls to zero as well. A simulation under this condition shows that the model responds plausibly to unavailable demand (Figure 13).

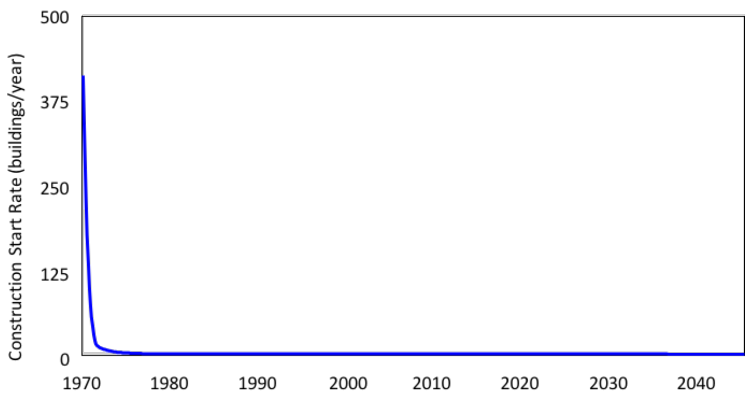

Figure 13: Extreme condition: zero demand.

We conducted further tests under likewise extreme conditions, such as shocks in supply or extremely high profit margins that result in reasonable price movements, strengthening the confidence in the model.

Partial Testing
Partial testing helps reducing complexity in a model's behavior by cutting feedback loops or 'switching off' certain variables (Morecroft, 1985; 1988). This way, we tested several substructures of the model when developing the model on whether they behave in a reasonable manner. In order to be able to analyze the drivers

of the real estate cycles, we conducted several partial tests. This also increased our understanding of the behavior of the full model. For instance, to analyze the origins of the cyclical 'Price' behavior, the substructures encompassing interest rates and construction costs were cut off. The effects on prices are shown in Figure 14: Regularly recurring oscillations are visible throughout the simulated time horizon (dashed and dotted-dashed). The partial test thus confirms that oscillatory behavior arises from within the system, and is not caused by irregular developments in costs and interest rates. Including exogenous inputs rather mitigates oscillations (base run, solid), whereas partial testing without interest rates result in intensified cycles (dashed). In addition, feeding the model with actual data on construction costs over the given time period, accounts for a likewise upward development in housing prices. Thus, cutting off these costs results in an almost constant average price index (an equilibrium), around which oscillations reoccur in approximately ten-year intervals (dotted-dashed).

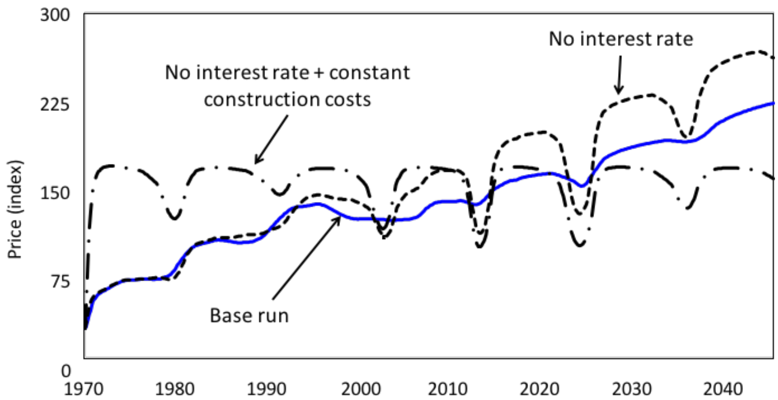

Figure 14: Partial testing: Oscillating price behavior continuous.

Behavior Reproduction

The behavior testing method assesses whether the model reproduces the real system's behavior as illustrated in the reference modes (Figure 4 and 5). "The good fit between simulation run and real world data is an important step in ensuring that the model structure correctly estimates short-term and long-term interdependencies between variables and depicts realistically the development of (...) market data" (Kapmeier et al., 2011, p. 16). Considering the reference mode of price development in the Stuttgart real estate market, the base run of the STREM-model reproduces the real price movement well (Figure 15, left graph), yet, overestimating actual price since the beginning of the 1990s.

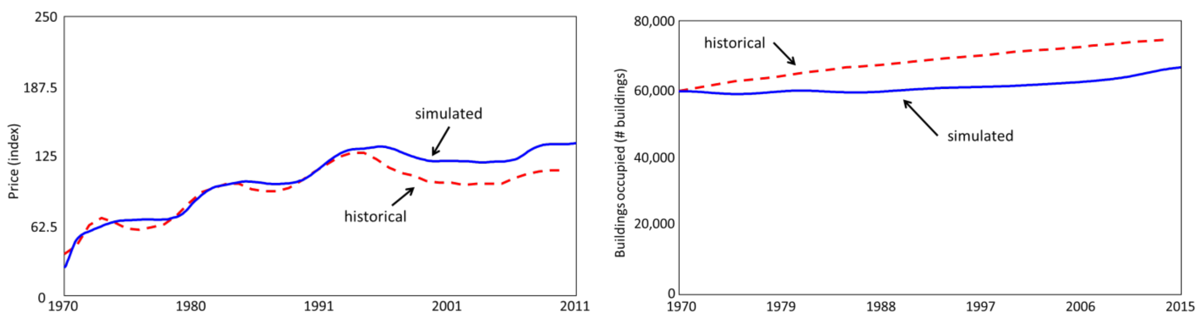

Figure 15: Behavior reproduction for 'Price' (left) and 'Buildings occupied' (right).

Likewise, the construction activity of the supply side results in a simulated growth rate of housing stock similar to the real data, yet not with a same good fit as the price behavior (Figure 15, right graph). The simulation is underestimating actual data. An explanation might be that the aging chain is too simplified and omits several factors of the construction side, which might result in the observed inaccuracy.

Sensitivity Analysis

Since various parameters needed to be estimated when no real data are available, a sensitivity analysis helps to determine to understand how sensitive the model reacts to certain parameters. Parameters included in the model encompass adjustment times, such as 'Average planning time' and 'Average construction time' as well as elasticity of demand and supply ('Sensitivity of demand to price' and 'Sensitivity of supply to price'). The sensitivity analysis has been conducted by assessing the sensitivity of the several parameters on the key variable 'Price'.

As Figure 16 illustrates, selected parameters cause different behavior of 'Price'. 'Price', for example, exhibits highest sensitivity when the parameter 'Sensitivity of price to demand supply ratio' takes on values ranging from zero to ten. Consequently, the parameter strongly influences the oscillating behavior of 'Price', in particular the amplitudes. Compared to that, the remaining sensitivity parameters, 'Sensitivity of demand to price' and 'Sensitivity of supply to price', result in a lower sensitivity of 'Price'. In addition, the lower left chart of Figure 16 indicates that time delay in the aging chain, i.e., supply chain of the model, influences the cyclicality in price movement. Testing the sensitivity of price on a ranging 'Average planning time' between zero and ten years, the chart shows the sensitivity of price in terms of its oscillatory behavior.

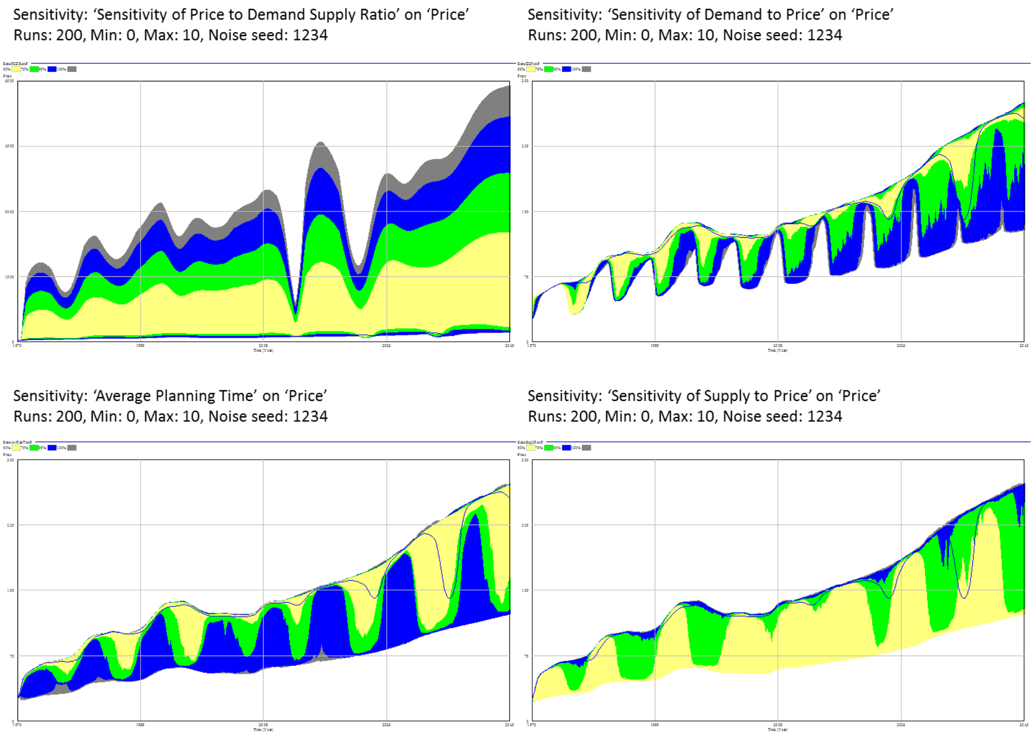

Figure 16: Sensitivity analysis: Sensitivity of price to demand supply ratio on Price, Sensitivity of demand to price on Price, Sensitivity of supply to price on Price, Average planning time on Price (clock-wise from upper left).

After conducting several tests according to recommendations given by Sterman (2000) and Morecroft (1985; 1988), including structural and behavior testing, the model can be assessed as valid. In the following section, its behavior is analyzed in a simulation base run.

Model Base Run

The base run is conducted for the predefined time horizon of 1970 to 2045 and comprises available historical data. A 'business as usual' (BAU) strategy is applied, which adopts a continuation in several parameters' behavior as usual. Accordingly, it is assumed that the household growth rate continues to rise with its average growth rate of the last 20 years. Similarly, the exogenous construction costs take on the average value of the last 20 years. The interest rate remains constant as of its last available data in 2016 (Österreichische Nationalbank, 2017). Future developments in households, construction costs and interest rates will play a significant role in scenarios, so that their assumed values are comprised as separate variables in the model (highlighted in green in the STREM-model; Figure 12): 'Future household growth rate assumption', 'Future construction cost assumption', and 'Future interest rate assumption'. Settings of the base run, scenarios and policy are provided in Appendix C.

The following figures depict the behavior of selected variables in the STREM-model over the time horizon. As shown in the left graph in Figure 17, 'Demand' oscillates despite an almost linear increase in 'Households of Stuttgart'. Thus, the oscillation originates not from 'Households' but from another source: The balancing feedback loop B1 is the driver that makes 'Demand' to respond to changes in 'Price' and vice versa, resulting in a cyclical behavior. As the balancing loop B1 - 'Demand response' is strongly interacting with the second one on the supply side, B2 - 'Profit-driven supply', it correspondingly affects the demand cycles as well.

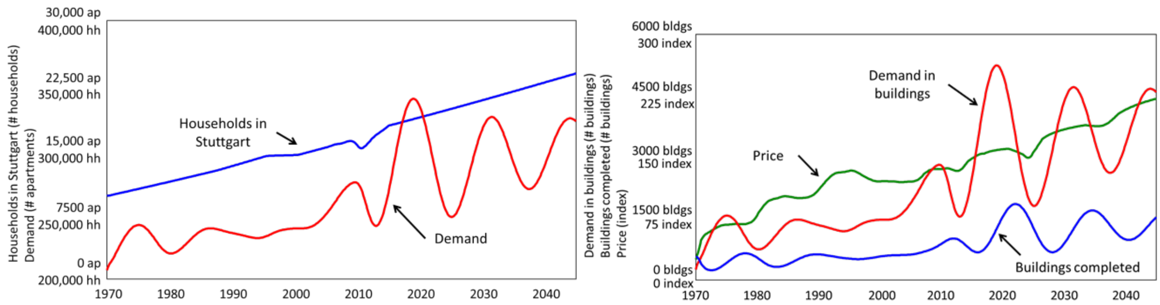

Figure 17: Base run: Behavior in 'Households' and 'Demand' (left) and Behavior in 'Price', 'Demand in buildings', and 'Buildings completed' (right).

The right graph in Figure 17 depicts that the supply side responds with a lag to the demand development, due to the time delays in the stock and flow structure of the model, i.e., in the supply chain, as well as in the forecasting process of expected excess demand. With increasing demand, prices also increase. Consequently, expected profitability increases, which makes new real estate construction attractive. Due to the time delays in the supply side's response to satisfy new demand, buildings are only completed years later, which is reflected in lagging cycles (see 'Buildings completed' in Figure 17). After reaching a peak in 2020, high prices make demand fall again according to the macroeconomic law of demand. This reverse behavior translates into declining prices, which in turn offset declining demand. Consequently, demand starts to increase again, starting a new cycle.

The delays in the aging chain are illustrated in Figure 18: When 'Desired new construction' is assessed (blue), the behavior of the aging chain is initiated. However, the 'Average planning time' delays new construction, so that the 'Buildings under construction' are lagging behind (red). After construction projects are started, it takes the 'Average construction time' until the buildings are completed and ‘flow’ into the stock 'Buildings completed' (green). One can clearly observe that the peaks as well as the lowest turning points of the three variables are lagging one after the other. Thus, completed buildings are placed on the market relatively late to satisfy the prior increased demand. In contrary, when apartments are ready for sale, demand is in decline again. Consequently, the balancing loop B2 inhibits 'Desired new construction' in response to lower demand, lower prices and lower expected profitability and turns the cyclical behavior in the aging chain into a reverse movement. The variations in amplitudes of the supply chain result from the varying demand cycles (Figure 17, red), as well as from differences in feasible construction capacities.

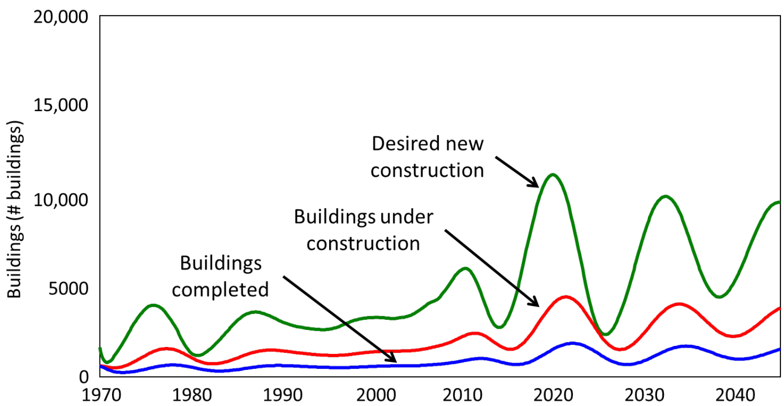

Figure 18: Base run: Behavior in Aging Chain.

The oscillating behavior of supplied buildings is also present in reality as indicated with the red line in Figure 19. Since the STREM-model is only a simplified structure of the actual supply chain and is not constrained by significant factors, such as construction capacity or available building land, the amplitudes of the simulated cycles do not reproduce the behavior of real data.

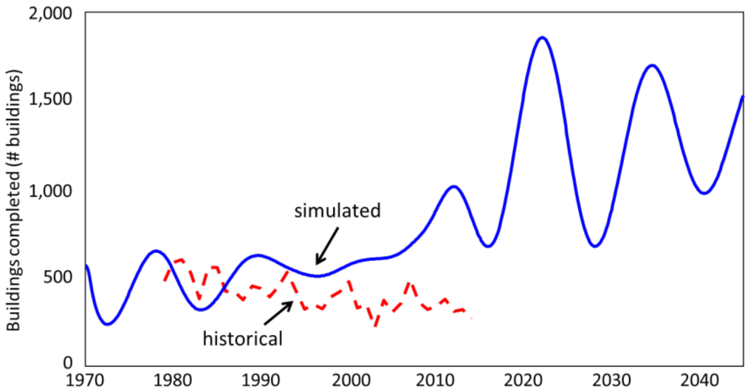

Figure 19: Base run: Behavior in 'Buildings completed'.

Consequently, the observed real estate cycles arise due to significant delays and a diverging interplay between overshooting and undershooting variables. These time delays include the supply side responding to changing demand by forecasting excess demand. The time delay it takes for the completion of new buildings, including both 'Average planning time' and 'Average construction time', causes prices to increase in that period, as demand cannot be satisfied and shortage in supply dominates the market, or, as the Real Estate Director states in the interview, "there is just little supply" (personal communication, September 23, 2015). Another interviewee confirms that "the supply of high quality real estate is really short" (Real Estate Advisor 1, personal communication, September 23, 2015).

When construction is finished, the stock ‘Buildings completed’ accumulates. However, since demand in the meantime has decreased as a consequence to increased prices, supply excesses demand. This way, the variables of the STREM-model undertake corrective actions that result in a new cyclical period.

The base run based on a BAU setting results into a model behavior that reproduces the behavior of the Stuttgart real estate market as observed and described by the interviewees. Moreover, by comparing it to the reference modes, i.e., real data, the confidence in the model is increased. Hence, it can be continued with experimental runs that comprise different scenarios as well as policy design.

Scenario 1: Increasing Interest Rates

As our interviewees stress that interest rates play a significant role for the Stuttgart real estate market, we analyze the impact of changing interest rates in more detail in the first scenario. Interest rates in Germany have reached an all-time low in the observed time horizon (Österreichische Nationalbank, 2017). The downturn in financial markets has resulted in an increased "attractiveness of non-financial assets (real estate)" (Deutsche Bundesbank, 2014a, p. 46). 'Cement gold' as Real Estate Advisor 1 (personal communication, September 23, 2015) states, determines the current trend in capital investment. Notably, our interviewees all agree that interest rates do have a large impact on the development of the real estate market. The Real Estate General Manager (personal communication, September 23, 2015), for example, emphasizes that the demand side is strongly driven by the interest situation. He continues that in situations of low interest rates, clients tell him that:

> ’I am not selling.’ And when many more people act likewise, supply will collapse. Supply is just very short. And when you have hundreds [of people] waiting in the waiting line who say ‘I want to buy a real estate; I don’t want to have my money laying around on my bank account. And anyway, the credit conditions are so attractive! Now or never! Now it is just great!’ And what happens then? Then, demand will continue to increase. If supply is decreasing and demand increasing, what happens with prices?

They will increase. This is the mechanism that has occurred since 2010/2011. (Real Estate General Manager, personal communication, September 23, 2015)

He continues explaining that clients call him saying "'Ah, I have money on my bank account. Don't you have some nice real estate for me? It could also be a house, or an apartment building, or two or three apartments or whatever'" (Real Estate General Manager, personal communication, September 23, 2015). So, it seems as if people just continue buying to whatever price, which makes the boom stronger. Real Estate Advisor 1 further explains that:

> People always live in some real estate. And if it is not necessarily a castle which will collapse in the near future, people just buy it immediately. For example, there is really high demand on investment property for speculation as there are currently no investment alternatives. These days, you can offer property for four or five percent [per year] only. (Real Estate Advisor 1, personal communication, September 23, 2015)

Consequently, while the market gets short, demand is increasing also at low return rates. Real Estate Advisor 2 (personal communication, September 23, 2015) also considers the demand side when saying that "the second player in this market that have led to real estate scarcity and to this high demand are those who can, with these low interest rates, afford to buy their own place instead of paying rent".

When asked for the real estate supply, the Private Real Estate Director (personal communication, September 23, 2015) characterizes it as "a market with low supply". Real Estate Advisor 1 (personal communication, September 23, 2015) is convinced that "(…) it will always stay like this, supply is just too tight." It seems as if the expert believes the situation is out of control, as he admits that "usually, the market is determined by supply and demand". And this is all due to the interest level (Real Estate General Manager, personal communication, September 23, 2015).

At the end of 2015 however, the Federal Reserve raised the interest rates in the United states for the first time in nearly a decade (Wiebe, 2015) and just recently for the third time since the financial crisis (The Economist Newspaper Limited, 2017). One could assume that the European Central Bank will follow eventually. Contrary to the base run, where interest rates remain as low as of 2015, the first scenario assumes a gradually increase in interest rates after the end of 2016. Hence, 'Future interest rate assumption' entails an increase up to seven percent, leaving the current low-interest environment behind. Regarding the insights gained from the interviews, it is expected that prices will decline along with increasing interest rates (Real Estate Advisor 2, 2015; Real Estate General Manager, personal communication, September 23, 2015). Figure 20 illustrates real estate losing attractiveness (dotted-dashed), which translates into declining demand compared to the base run (solid).

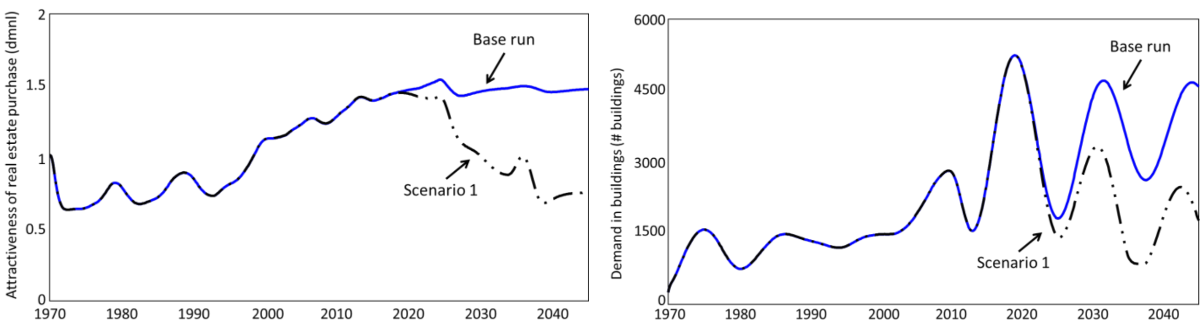

Figure 20: Scenario 1: Increasing interest rates resulting in declining attractiveness of real estate (left) and demand (right).

Figure 21 presents the simulated behavior of model under the defined conditions of Scenario 1 exemplified by the variable 'Price' (dotted-dashed).

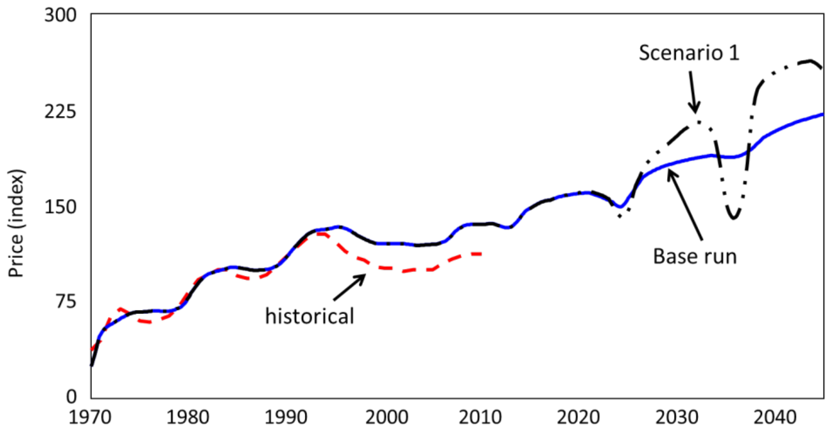

Figure 21: Scenario 1: Increasing interest rates and Behavior of 'Price'.

Contrary to the initial expectation, 'Price' in this scenario (dotted-dashed) first behaves similar to the base run (solid). The drop in 2025, however, is a little steeper, but it increases at a higher rate after 2025. Yet, in this scenario, there is another sharp drop in the mid-2030s. After that, price recovers and increases on a higher level than in the base run. Possible explanations for its behavior is the 'Minimum accepted price' that is determined by the interest rates. As explained earlier, increasing interest rates cause suppliers to claim higher profit margins and thus raise the minimum accepted price level. Consequently, the market price increases likewise. However, the drop in demand (between 2030 and 2040) is reflected by a decline in price as well. Despite the interviewees' statement that interest rate affect demand in real estate, a study by the Deutsche Bundesbank (2014a) indicates that "interest rates seem to play a subordinate role in determining house prices (...), instead, the recent price increases are more likely the result of households' productivity and income expectations" (p. 23). Hence, modeling causal relations between interest rates and variables endogenous to the STREM-model needs to be assessed carefully.

Scenario 2: Decline in Households

The second scenario is based on the previous one, assuming a light increase in interest rates. In addition, we assume a drastic decline in households. Stuttgart's attractiveness highly depends on its regional economic strength, as laid out above, in particular on its cluster of automotive manufacturers and suppliers. In this scenario we assess the effect of a declining economic importance of the automotive industry over a period of 30 years (2015-2045). This might happen, for instance, consequently to possible future competitors like Tesla, Google, or Apple, capturing higher market share with highly innovative, self-driving, and electric cars and making the resident automotive manufacturers less important (Afhüppe et al., 2016). In this scenario, latter cut back jobs.

Although the STREM-model does not comprise any variables representing Stuttgart's regional economy directly, this scenario can be modeled by a rapid decline in 'Future household fraction growth rate assumption Scenario 2'. Naturally, as the city becomes less attractive and many inhabitants are not employed anymore, people are moving away, resulting in a negative 'Household net growth rate' which gradually depletes the stock 'Households in Stuttgart'. A weak regional economy may also affect the construction industry, so that we assume a slight decline in construction costs as well, modeled by 'Future construction cost assumption Scenario 2'.

The following figures illustrate the resulting behavior of the STREM-Model of scenario 2 compared to the base run. In Figure 22, after 2020, when the number of households decline (dashed), demand decreases faster (dashed) than in the base run (solid) and continues to decline even further, while demand in the base run is already turn upwards (around 2025). The rapid drop in demand leaves the supply side immensely overshooting its equilibrium, which is reflected in Figure 23.

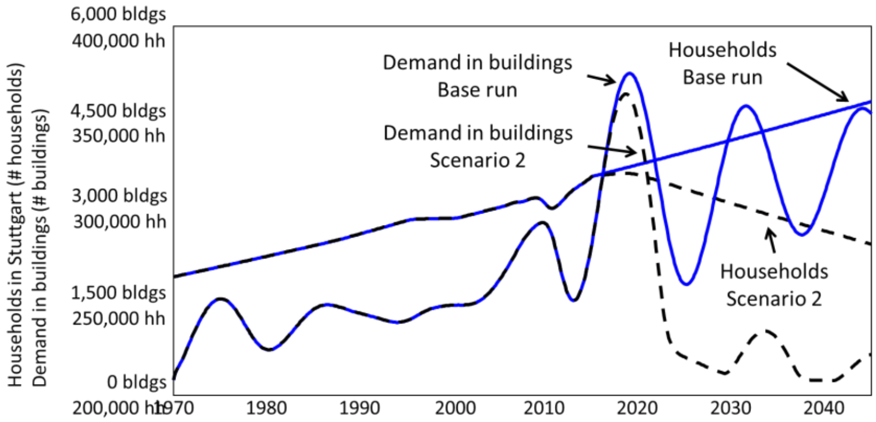

Figure 22: Scenario 2: Declining households leading to a drop in 'Demand'

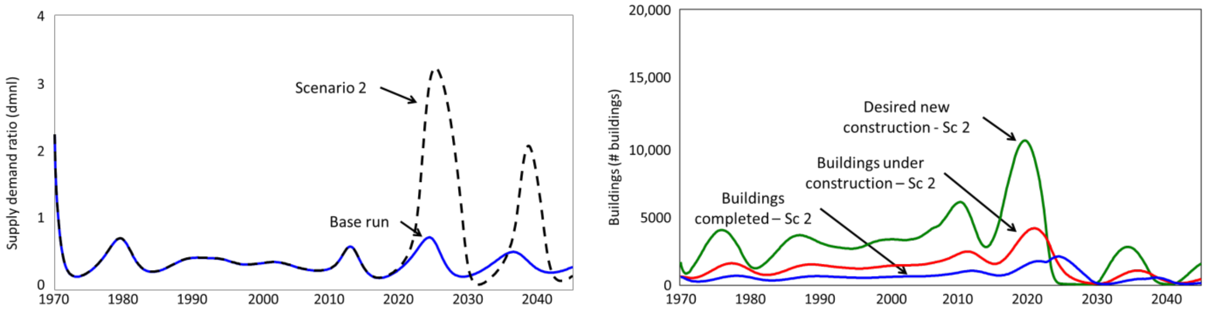

Figure 23: Scenario 2: Declining households leading to supply overshooting.

In this scenario, 'Supply demand ratio' exhibits intensified amplitudes to the decline in households and its corresponding demand (Figure 23, dashed in left chart). Moreover, the supply side responds with a rapid decrease in 'Desired new construction' to almost zero after reaching its peak in 2020 (Figure 23, blue in right chart) with lagging cycles in the aging chain (see 'Buildings under construction' in red and 'Buildings completed' in green). Consequent to the high oversupply of housing, prices drop accordingly (Figure 24, dashed). Low prices make real estate an attractive investment though, so that demand rises eventually and subsequently prices as well. Nonetheless, as Figure 24 illustrates, the decline in households in Scenario 2 leave price on a lower level in average (dashed) compared to the base run (solid).

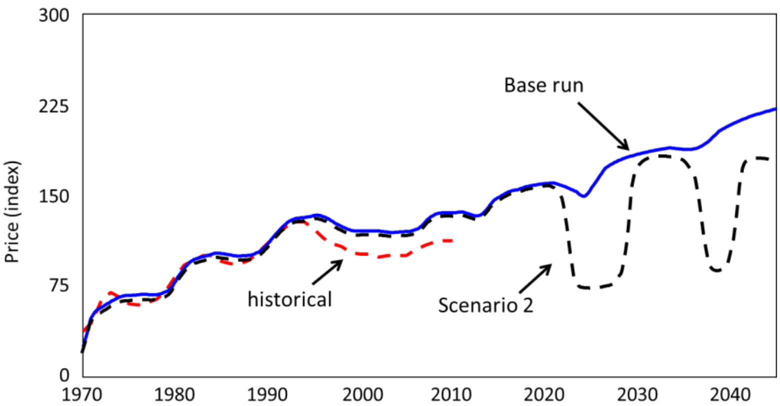

Figure 24: Scenario 2: Declining households leading to a drop in 'Price'.

The behavior of the model though needs to be assessed with care since several variables, in particular construction capacities take on surrealistic values consequently to leave out constraints and natural capacities of the Stuttgart real estate market.

The second scenario simulates possible effects of a demand shock on the Stuttgart real estate market. In reality, Real Estate Advisor 2 described a similar scenario, when referring to a weak economy affecting the Stuttgart real estate market:

> I do remember well that during a time when Daimler Benz was in financial struggle way back, the entire region of Böblingen and Sindelfingen, where many Daimler Benz employees live, was struggling. Prices did suddenly go down. As many former employees needed to leave the region, they threw their houses on the market. (Real Estate Advisor 2, personal communication, September 23, 2015)

Interestingly, this statement came from the most experienced market expert. His younger colleagues have not experienced a former bust market situation. So, this might lie outside of their range of thoughts.

Policy: Consideration of Underway Construction

The last experimental run implies a policy design, which is partially adopted from Barlas et al. (2007). Although it is difficult to change the feedback structure of the STREM-model, this experimental setup aims at reducing the strong cyclical dynamics. To counteract the cyclical movements in certain variables that are ascribed to substantial time delays as described above, underway construction is considered and incorporated it into planning when estimating 'Desired new construction'. This way, the supply side should be able to better respond to changes in demand in order to avoid extreme over-/undershooting of its equilibrium that come along the time delays within the aging chain. Therefore, the structure of the model needs to be adjusted by linking the two stocks 'Buildings under construction' and 'Buildings completed' directly with 'Desired new construction' as highlighted in Figure 25.

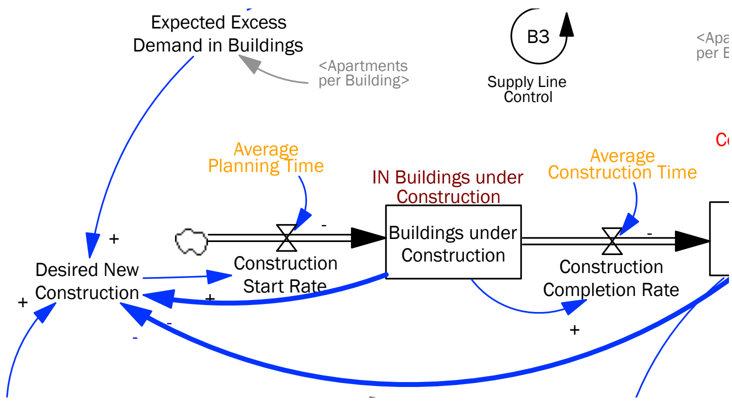

Figure 25: Policy: Consideration of underway construction in the model.

Accordingly, the equation of the variable 'Desired new construction' needs to be changed to:

$$DNC = (EEDB - BUC - BC) * EPDNC \quad (14)$$

where

DNC	Desired new construction
EEDB	Expected excess demand in buildings
BUC	Buildings under construction
BC	Buildings completed
EPDNC	Effect of Expected Profitability on Desired New Construction

The resulting behavior is illustrated in Figure 26, where, indeed, the cycles are reduced. 'Desired new construction' (Figure 26, dashed in left chart) is significantly flatter than in the base run (solid), while the stock 'Buildings completed' respectively exhibits almost linear behavior (policy in dashed vs. base run in solid). The policy prevents excess supply that arises when underway construction is ignored. Consequently, the 'Supply demand ratio' is fairly balanced, following an almost stable development until the end of the simulation. It is indicated with a dotted line while the solid line shows the base run (Figure 26, right chart). Since cycles in the aging chain are almost balanced out, the model does not exhibit major lagging booms and bust any longer. This behavior is transferred to the demand side accordingly with the result of the almost linear 'Supply demand ratio' offsetting cyclical price movements as presented in Figure 27.

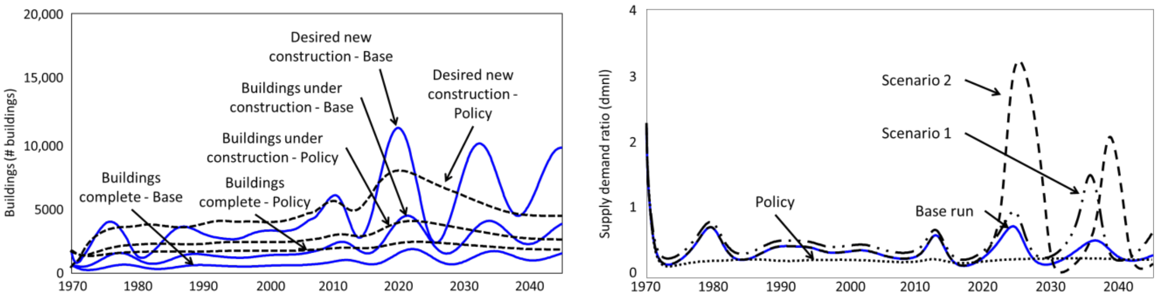

Figure 26: Policy: Consideration of underway construction reducing cycles in the construction stock-and-flow (left) as well as in 'Supply demand ratio' (right).

The effect of offset cycles in key variables as described above lead to smoothened amplitudes in price (Figure 27, dotted). Since supply is not over- and undershooting demand time after time, price reacts with likewise balanced developments over the simulated time horizon.

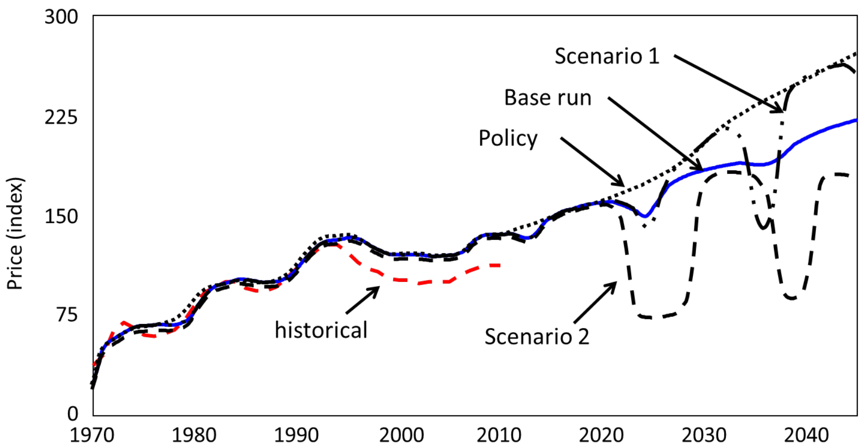

Figure 27: Policy: Consideration of underway construction affecting price cycles.

Given the current design of the STREM-model, this policy accomplishes smoother behavior with almost offset cycles, on both demand and supply side. Hence, this experimental run indicates that policy design in general can be leveraged far more on the system's dynamics. Therefore, the dominant feedback loops of the model should be changed by "redesigning the stock and flow structure, eliminating time delays, changing the flow and quality of information available at key decision points, or fundamentally reinventing the decision processes of the actors in the system" (Sterman, 2000, p. 104).

Discussion and Conclusions

Although often not commonly perceived as a commodity, real estate belongs to those construction industries in which long manufacturing times and asset lifetimes determine the market behavior. Similar to other markets, such as raw materials, e.g., copper, aluminum and coffee, and also aircraft and shipbuilding, real estate markets in general exhibit cyclical dynamics (Sterman, 2000). However, the market's complexity oftentimes prevents decision-makers from capturing the underlying structure and thus understanding the origins of cyclical behavior.

The real estate market of the city of Stuttgart has seen an unprecedented increase in prices for the last decade. Market experts expect prices to further increase. We have transferred findings from secondary data in the literature and from conducting semi-structured interviews into a simulation model to gain further insights in how market experts perceive the market and increase validity.

Yet, we acknowledge several limitations of our simulation model when assessing the results of the paper. For example, our model omits several structures that may be relevant, i.e., further aspects of the construction side (e.g., capacities and available building land) or financial factors affecting demand, such as mortgages and loans but also disposable income.

In addition, the model comprises weaknesses in numerical data and its equations. The utilized indices of price and construction costs are valid for the Stuttgart real estate market, yet, they are not scaled to the same base years. As a further limitation, we needed to estimate several model parameters, as secondary data was not available for the specific case of Stuttgart.

Despite the limitations, our analysis reveals some valuable insights for decision makers and academics, which we discuss in the following. First, the model reproduces the behavior of the reference modes, indicating a decent fit between simulation and real world data on price, for example. The model structure might not be as sophisticated as it could be. Yet, it succeeds in simplifying a complex system, and thus enabling an understanding and further analysis of accordingly complex structures.

Second, our analysis shows that cyclical dynamics do exist in the Stuttgart real estate market, like in many other real estate markets that have been analyzed before. The market experts we interviewed acknowledge the comparison with the hog cycle – but when asked about possible future price development, they seem to neglect possible market cycles. Instead, they point to the cyclical behavior of interest rates as the driver for an oscillating real estate market: According to their mental model, the real estate market oscillates because interest rates go up and down. Yet, our analysis reveals that the origins of oscillating behavior are created endogenously. Housing prices react to changes in related variables, i.e., the balance between demand and supply. As both sides, demand and supply, imply negative feedback loops characterized by significant time delays, the system is constantly over- and undershooting its equilibrium. Thus, the system exhibits persistent cyclical instability. In particular, the lagging supply of desired new construction leads to unsatisfied demand, hence increasing prices. When new construction is completed, demand has decreased again as a response to the previously increased prices. The subsequent supply surplus reduces prices and thus expected profits, so that construction activity is lower in the following period. It is the ongoing interplay of over- and undershooting variables results in the oscillating behavior – which explains the hog cycle effect in the real estate market and not the interest rate's ups and downs.

Third, the two scenarios provide additional insights into the system's behavior responding to exogenous changes that are not influenced by the real estate market itself. The scenario in which we assume that interest rates will increase again shows oscillating and increasing prices. In the second scenario we test, how the market will behave when there is a period of economic downturn because of a change in the structure of the automotive industry – which is discussed in the media but seems to be considered as an extreme scenario by many people. Here, the market will go down – until finally demand and supply meet after a long period of excess demand. Afterwards, prices will again increase. By designing a policy on how to manage the market differently, real estate cycles could be almost eliminated. While cycles originating from the supply chain could be reduced significantly, the policy design did not accomplish a similar effect on prices. Yet, the price level did not decrease due to increasing construction costs accompanied by high profit margins – an assumption which could be challenged in future research.

Fourth, Thornton (1992) as well as the personal interviews conducted show that real estate experts have difficulties in assessing the impact of the endogenous feedback structure dominating real estate markets. This is ascribed to both the complexity itself, but also to the physical time period between each cycle, so that many professionals have not yet experienced a complete cycle. Although all our interviewees are aware of cycles in the real estate markets, they do not ascribe as much significance to endogenous causalities, rather, their focus remains on macroeconomic factors, exogenous to the model.

Concluding, the paper has illustrated that endogenous structures play *the* critical role in dynamic system, and thus should not be underestimated. With this analysis approach, difficulties in human information processing can be overcome, resulting in more effective decision-making in any business environment.

Although the paper presents various relevant aspects of the real estate market, future research suggestions involve a further extension of the model to a more sophisticated structure. Therefore, the model boundary could be expanded by additional structures, i.e., capturing more accurately demand creation, capacity constraints and interest rates for demand. Also, model equations could be redefined. In particular, the model's parameters as well as the table functions could be tested and analyzed further.

The future outlook of the paper also reflects aspects of the problem statement that have been completely left out. Considering the current situation with regard to concerning migration, the tremendous rise in the number of refugee seeking asylum in the European Union boosts housing demand. Thus, the resulting increased housing needs must be reassessed for the upcoming years. Appropriate policy design and effective decision-making today will pay off in the near future.

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Appendix

Appendix A. Full Model and Legend of Variable Types

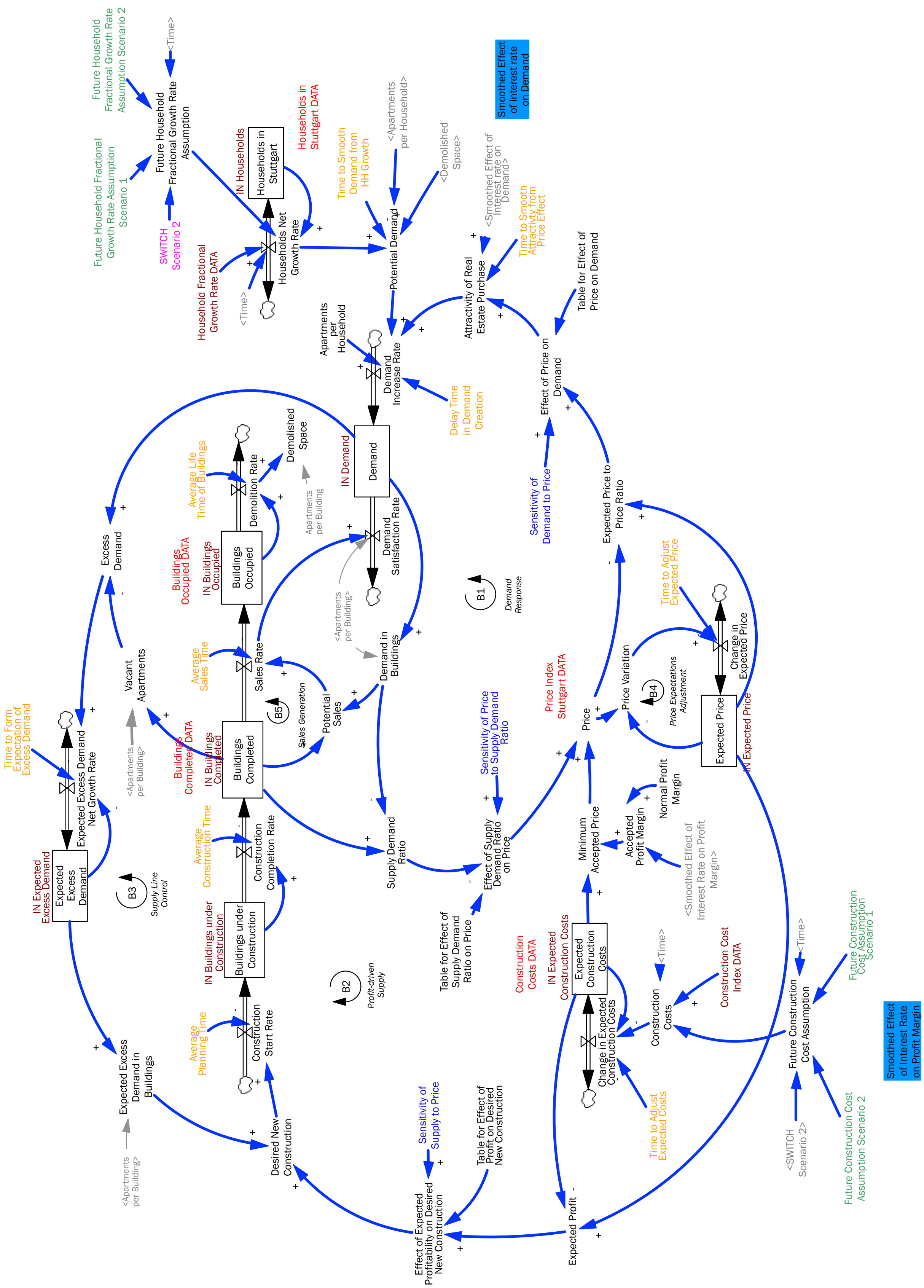

Figure A1: Full STREM-model.

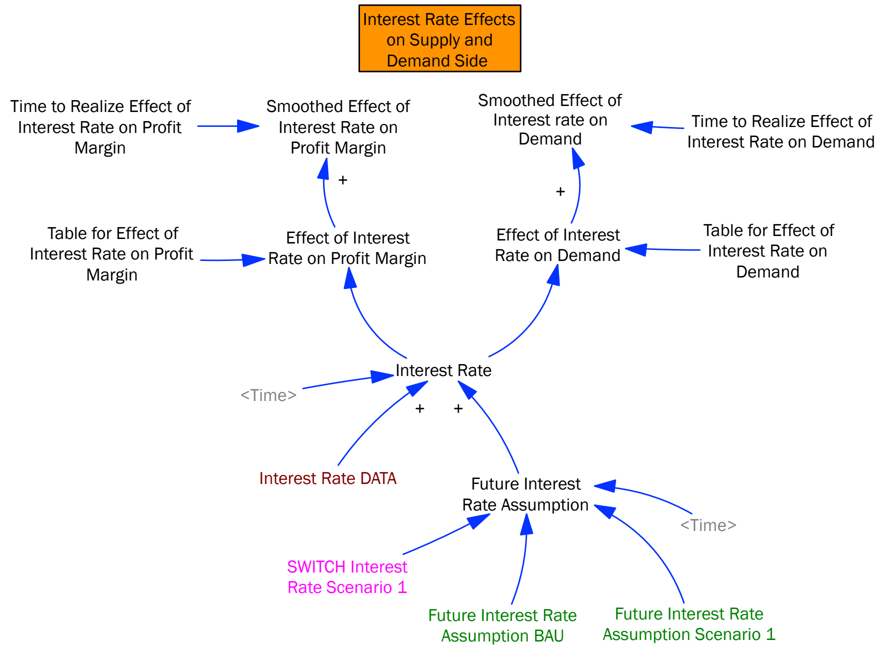

Figure A2: Substructure of STREM-model: Interest rate effects on supply and demand side.

Color	Variable Type
	Endogenous variables, determined by the system's behavior as well as table functions of effects
	Exogenous input added (e.g., real data of times series and initial values)
	Constant parameters implicating information delays (e.g., time adjustments)
	Constant parameters implicating sensitivity of variables
	Shadow variables: defined elsewhere and used to avoid clutter and overlapping of structures
	Variables including future assumptions and estimations
	Real data, which simulated variables are compared to

Table A1: Legend of STREM-model.

Appendix B. General Simulation Settings

The model was implemented in Vensim PLE for Macintosh, Version 6.3, and Vensim DSS for Windows Version 6.3 Double Precision (x32). Model settings are described below (Table A2):

Initial Time	1970
Final Time	2045
Time Step	0.125
Units for Time	Year
Integration Type	Euler

Table A2: Model settings in Vensim.

The experimental runs were executed in Vensim PLE for Macintosh, Version 6.3 with a MacBook Air and in Vensim 6.3 Double Precision with a ThinkPad. Exogenous data was imported through vdf-files and respective variables are indicated in red and with the suffix 'DATA' in STREM-model (Figure A1).

Appendix C. Experimental Runs Settings

The settings described in Table A3 were used to execute all runs – base, scenarios and policy runs.

	Base Run: Business as usual	**Scenario 1: Increasing Interest Rates**	**Scenario 2: Decline in Households**	**Policy: Consideration of Underway Construction**
Description		Interest rate increases again assuming a step- by-step increase by the ECB.	Scenario 1, plus simulation of a collapsing regional automotive industry leading to a sharp decrease in demand, i.e. growth rate of households declines.	Scenario 1, plus Policy Design: Supply side considers underway-construction, thus being able to estimate more accurately desired new additions in order to meet excess demand.
SWITCH 'Interest Rate Scenario 1' 0 = Increase in interest rates as of 2017 1 = Interest rates remain as low as of 2015 at *0.005*	0	1	1	1
SWITCH 'Scenario 2' 0 = Future Household Fractional Growth Rate assumed constant at *0.004* 1 = Sharp decline in households between 2017-2021, followed by constant Fractional Growth Rate at -*0.005*	0	0	1	0

Table A3: Run settings.

Appendix D. Equations

Equations and Comments	**Units**
(01) Accepted Profit Margin= Normal Profit Margin*Smoothed Effect of Interest Rate on Profit Margin The accepted profit margin is determined by the annual interest rate level. Therefore, the effect variable adjusts the normal profit margin as follows: Supply side accepts lower profit margins when interest rates are respectively low. They claim higher profit margins during periods of high interest rates. Eventually, the accepted profit margin determines the minimum acceptable price by taking into account the construction costs.	Dimensionless (Dmnl)
(02) Apartments per Building=4 In average each building is constructed in such way as to yield four apartments. This average number is based on real data of the real estate market Stuttgart. Source: http://service.stuttgart.de/lhs-services/komunis/documents/7251_1_Wohnungsmarkt_Stuttgart_2006.PDF (retrieved October 29, 2015)	apartments/building
(03) Apartments per Household=1 It is assumed that each household occupies one apartment. This variable helps to equal units, i.e. 1 household = 1 apartment.	apartments/household
(04) Attractivity of Real Estate Purchase=SMOOTH(Smoothed Effect of Interest rate on Demand*Effect of Price on Demand, Time to Smooth Attractivity from Price Effect) Variable expresses the Attractivity of purchasing real estate by taking into account the effect of changing prices as well as interest rates on demand.	Dmnl
(05) Average Construction Time=1.75 The average time to construct a building.	Year
(06) Average Life Time of Buildings=100 The average life time of buildings until the building is fully demolished.	Year
(07) Average Planning Time=4 The average time to plan the construction of a new building before the actual construction starts.	Year
(08) Average Sales Time=0.75 The average time it takes to sell a building.	Year
(09) Buildings Completed= INTEG (Construction Completion Rate-Sales Rate, IN Buildings Completed) The stock accumulates the fully constructed buildings.	buildings
(10) Buildings Completed DATA :INTERPOLATE: Data was inserted into model for all buildings completed retrieved November 2015 from http://www.statistik.baden-wuerttemberg.de/SRDB/Tabelle.asp?H=ProdGew&U=01&T=07015011&E=KR&R=KR111	buildings
(11) Buildings in planning DATA :INTERPOLATE: Data was inserted into model for all buildings in planning retrieved November 2015 from http://www.statistik.baden-wuerttemberg.de/SRDB/Tabelle.asp?H=ProdGew&U=01&T=07015011&E=KR&R=KR111	buildings
(12) Buildings Occupied= INTEG (Sales Rate-Demolition Rate, IN Buildings Occupied) The stock accumulates all buildings sold and thus occupied. The buildings being demolished are deducted through the outflow Demolition Rate.	buildings
(13) Buildings Occupied DATA :INTERPOLATE: Data was inserted into model for all buildings in planning retrieved November 2015 from http://statistik1.stuttgart.de/statistiken/tabellen/193/jb193.php	buildings
(14) Buildings under Construction= INTEG (Construction Start Rate-Construction Completion Rate,IN Buildings under Construction) The stock of buildings that are constructed.	buildings
(15) Change in Expected Construction Costs=(Construction Costs-Expected Construction Costs)/Time to Adjust Expected Costs The flow adjusts the stock of Expected Construction Costs based on the input of the average construction costs per unit.	price index/Year
(16) Change in Expected Price=Price Variation/Time to Adjust Expected Price This inflow changes the expected price in response to the gap between the indicated price and the current expected price.	price index/Year
(17) Construction Completion Rate=Buildings under Construction/Average Construction Time This variable transforms the stock of buildings under construction into the stock of completed buildings. The higher the value the faster are buildings constructed.	buildings/Year
(18) Construction Cost Index DATA ([(1970,0)-(2016,200)],(1970,31.2),(1971,34.2),(1972,36.4), (1973,39.1), (1974,41), (1975,41.2), (1976,42.3), (1977,44.2), (1978,47.3),(1979,51.8),(1980,57.5), (1981,60.2), (1982,60.7),(1983,61.5), (1984,63.1), (1985,63), (1986,63.7), (1987,65.1), (1988,66.6), (1989,69.2),(1990,73.9), (1991,78.9), (1992,82.8),(1993,85), (1994,85.4), (1995,86.2), (1996,84.8), (1997,83.6), (1998,84),(1999,84.2),(2000,85.2), (2001,85.9),(2002,86.1), (2003,85.6), (2004,86.7), (2005,87.3), (2006,89.4), (2007,95.7), (2008,98.5), (2009,99.1), (2010,100),(2011,103), (2012,105.5), (2013,107.4),(2014,109.6), (2015,111.9),(2016,114.5)) This table contains the index of construction costs for the federal state of Baden-Württemberg for 1970-2016, retrieved from: hhttp://www.statistik.baden-wuerttemberg.de/GesamtwBranchen/KonjunktPreise/BPI_LR.jsp (February 28, 2017) / Baupreisindex BW --- After 2017: Data is calculated based on average growth rate of previous 10 years (1996-2016) and is returned through the variable "Future Construction Costs Assumptions"	price index

(19) Construction Costs=IF THEN ELSE(Time<2017 , Construction Cost Index DATA(Time) , Future Construction Cost Assumption) — price index

This is the exogenous input of Construction Costs per apartment indicated as an index. For 1970-2016 real data is returned via the variable "construction Cost Index DATA", whereas, after 2017, Data is calculated based on average growth rate of previous 10 years (1996-2016) and is returned through the variable "Future Construction Costs Assumptions"

---

(20) Construction Costs DATA :INTERPOLATE: — price index

Data was inserted into model for the index of construction costs for the federal state of Baden-Württemberg for 1970-2016, retrieved from: hhttp://www.statistik.baden-wuerttemberg.de/GesamtwBranchen/KonjunktPreise/BPI_LR.jsp (February 28, 2017).

---

(21) Construction Start Rate=MAX (0,Desired New Construction/Average Planning Time) — buildings/Year

The Construction Start Rate is the first inflow into the supply aging chain and takes into account the amount of desired new construction projects. The MAX function adjusts the inflow not to become negative at any point of time.

---

(22) Delay Time in Demand Creation=1 — Year

This is the time people need to create actual demand in housing, meaning that people do not react immediately to changes in price, rather it takes time to decide to move into a new apartment.

---

(23) Demand= INTEG (Demand Increase Rate-Demand Satisfaction Rate, IN Demand) — apartments

This is the stock that accumulates demand in housing, i.e. how many buildings are demanded in total in a certain point of time.

---

(24) Demand in Buildings=IF THEN ELSE (Demand/Apartments per Building>0, Demand/Apartments per Building, 0) — buildings

Demand of apartments transformed into number of buildings demanded

---

(25) Demand Increase Rate=SMOOTH(Attractivity of Real Estate Purchase*Potential Demand*Apartments per Household , Delay Time in Demand Creation) — apartments/Year

This is the net growth rate of demand. When positive, demand is created, otherwise, when negative demand is satisfied. The smooth function reflects the delay in demand formation, since people do not react to price changes immediately.

---

(26) Demand Satisfaction Rate=Sales Rate*Apartments per Building — apartments/Year

The Demand Satisfaction Rate decreases the stock Demand along with the Sales Rate, i.e. when an apartment is sold/occupied.

---

(27) Demolished Space=Demolition Rate*Apartments per Building — apartments/Year

This variable calculates the total demolished space in units of apartments. Demolished space results in new demand for apartments.

---

(28) Demolition Rate=Buildings Occupied/Average Life Time of Buildings — buildings/Year

The outflow adjusts the stock Buildings Occupied since buildings need to be demolished after the average life time of a building.

---

(29) Desired New Construction=Expected Excess Demand in Buildings*Effect of Expected Profitability on Desired New Construction — buildings

Desired New Construction to satisfy Expected Excess Demand is supplied depending on Profitability High Profitability = high supply of new construction Low profitability = decreases supply Equation for Policy 1: (Expected Excess Demand in Buildings-Buildings under Construction-Buildings Completed)*Effect of Expected Profitability on Desired New Construction

---

(30) Effect of Expected Profitability on Desired New Construction=Table for Effect of Profit on Desired New Construction(Expected Profit)^Sensitivity of Supply to Price — Dmnl

Desired capacity is adjusted above or below current capacity in response to the expected profitability of new investment.

---

(31) Effect of Interest Rate on Demand=Table for Effect of Interest Rate on Demand(Interest Rate*100) — Dmnl

This is the effect that interest rates have on the demand. Low interest rates make Real Estate an attractive investment opportunity, thereby increasing the attractiveness of purchasing Real Estate. Whereas, the higher interest rates increase the attractiveness of alternative investment options for potential real estate purchasers, such as financial assets, savings on bank account.

---

(32) Effect of Interest Rate on Profit Margin=Table for Effect of Interest Rate on Profit Margin(Interest Rate*100) — Dmnl

This is the effect that interest rates have on developer's Profit Margins. Low interest rates reduce profit margins, higher interest rates result in higher profit margins.

---

(33) Effect of Price on Demand=Table for Effect of Price on Demand(Expected Price to Price Ratio)^Sensitivity of Demand to Price — Dmnl

Expected Price higher than current Price -> Demand decreases
Expected Price lower than current Price --> Demand increases

---

(34) Effect of Supply Demand Ratio on Price=Table for Effect of Supply Demand Ratio on Price(Supply Demand Ratio)^Sensitivity of Price to Supply Demand Ratio — Dmnl

The effect of the supply demand ratio on price is a power function of the demand/supply ratio. The Sensitivity of Price to the demand coverage controls the magnitude of the response. The higher the sensitivity of price to the demand/supply ratio, the greater the change in price induced by any imbalance. Price rises when demand/supply ratio is less than normal, and falls when it is greater.

---

(35) Excess Demand=MAX(0 , Demand-Vacant Apartments) — apartments

This is the gap in housing, i.e. the discrepancy between the supplied space (the stock 'Buildings Completed') and the demanded space (the stock 'Demand'). It is a goal seeking function. If positive, it is the excess of space demanded over space supplied. If negative, it is the excess in supply over demand.

---

(36) Expected Construction Costs= INTEG (Change in Expected Construction Costs, IN Expected Construction Costs) — price index

Expected Construction Costs represent beliefs among market participants about the unit costs of production (variable and fixed, including normal profit margins). Expected Costs therefore represent beliefs about what a 'fair' price would be, or the long-run equilibrium price. Expected costs adjust to the actual costs with a delay representing the time required for gain information and adjust beliefs about costs. Exogenous for partial model test.

---

(37) Expected Excess Demand= INTEG (Expected Excess Demand Net Growth Rate, IN Expected Excess Demand) — apartments

It is a first order information delay stock that represents the supply side's expectation of real desired space.

---

(38) Expected Excess Demand in Buildings=Expected Excess Demand/Apartments per Building — buildings

The value transforms the value of the stock Expected Excess Demand in such a way as to yield the unit of buildings.

---

(39) Expected Excess Demand Net Growth Rate=(Excess Demand-Expected Excess Demand)/Time to Form Expectation of Excess Demand — apartments/Year

It takes into account both the vacant space (=the gap between supplied and demanded space) and the demolished space. Since it cannot be accurately known, it is estimated by the supply side through an information delay structure.

---

(40) Expected Price= INTEG (Change in Expected Price, IN Expected Price) — price index

The price market makers and traders believe would clear the market if demand and supply were in balance, and no other pressures to change price existed.

---

(41) Expected Price to Price Ratio=ZIDZ(Expected Price, Price) — Dmnl

When expected price increases the effect on demand shall decrease. When expected price decreases the effect on demand shall increase, having a positive effect on demand.

---

(42) Expected Profit=(Expected Price-Expected Construction Costs)/Expected Price — Dmnl

This is the expected profit of the supply side based on the expected price and expected costs.

---

(43) FINAL TIME = 2045 — Year

The final time for the simulation.

---

(44) Future Construction Cost Assumption=IF THEN ELSE (SWITCH Scenario 2=0, Future Construction Cost Assumption Scenario 1 (Time), Future Construction Cost Assumption Scenario 2 (Time)) — price index

The variable delivers the construction cots price index under each specified scenario.

---

(45) Future Construction Cost Assumption Scenario 1 ([(2017,100)-(2045,200)],(2017,116.02),(2018,117.56), (2019,119.12),(2020,120.71), (2021,122.31), (2022,123.94), (2023,125.58),(2024,127.25),(2025,128.95),(2026,130.66), (2027,132.4),(2028,134.16), (2029,135.94), (2030,137.75), (2031,139.58), (2032,141.43), (2033,143.31), (2034,145.22), (2035,147.15), (2036,149.11), (2037,151.09),(2038,153.1),(2039,155.13), (2040,157.19),(2041,159.28), (2042,161.), (2043,163.55), (2044,165.72),(2045,167.92)) — price index

This table indicates the assumption for future construction costs for the period from 2017 until the end of the simulation run (2045) for the Base Run, Scenario 1, Policy 1 assuming "Business as usual" - i.e. Construction costs increase with a rate of the last 10 years average.

(46)	Future Construction Cost Assumption Scenario 2 ([(2017,100)-(2045,200)],(2017,116.02),(2018,117.56), (2019,119.12), (2020,120.7), (2021,122.31), (2022,120.7), (2023,120.7),(2024,120.7),(2025,119.7),(2026,119.7), (2027,119.2), (2028,118.5), (2029,118), (2030,117.5), (2031,117), (2032,116.5), (2033,116),(2034,115.5),(2035,115), (2036,114.5), (2037,114), (2038,113.5), (2039,113), (2040,112.5), (2041,112), (2042,111.5),(2043,111),(2044,110.5),(2045,110)) This table indicates the assumption for future construction costs for the period from 2017 until the end of the simulation run (2045) in Scenario 2: assuming a drop of construction costs along with decline in HH, due to weak economy in Stuttgart's area.	price index
(47)	Future Household Fractional Growth Rate Assumption=IF THEN ELSE (SWITCH Scenario 2=0, Future Household Fractional Growth Rate Assumption Scenario 1(Time), Future Household Fractional Growth Rate Assumption Scenario 2 (Time)) This variable takes on values of variables 'Future Household Fractional Growth Rate Assumption', that change in Scenario 1 and 2.	1/Year
(48)	Future Household Fractional Growth Rate Assumption Scenario 1 ([(2017,0)-2045,1)],(2017,0.004), (2018,0.004), (2019,0.004), (2020,0.004), (2021,0.004), (2022,0.004), (2023,0.004),(2024,0.004), (2025,0.004),(2026,0.004), (2027,0.004), (2028,0.004),(2029,0.004), (2030,0.004), (2031,0.004), (2032,0.004), (2033,0.004), (2034,0.004),(2035,0.004), (2036,0.004), (2037,0.004), (2038,0.004), (2039,0.004),(2040,0.004), (2041,0.004),(2042,0.0037), (2043,0.004), (2044,0.004), (2045,0.004)) This table indicates the assumption for future household growth for the period from 2017 until the end of the simulation run (2045) in the Base Run, Scenario 1 and Policy 1: assuming a Steady growth in the Households of Stuttgart.	1/Year
(49)	Future Household Fractional Growth Rate Assumption Scenario 2 ([(2017,-0.007)-(2045,0.005)], (2017,0.0015), (2018,0.001), (2019,-0.001), (2019.97,-0.004), (2021,-0.005),(2022,-0.005),(2023,-0.005), (2024,-0.005),(2025,-0.005),(2026,-0.005),(2027,-0.005),(2028,-0.005),(2029,-0.005), (2030,-0.005),(2031,-0.005),(2032,-0.005),(2033,-0.005), (2034,-0.005), (2035,-0.005),(2036,-0.005),(2037,-0.005),(2038,-0.005),(2039,-0.005),(2040,-0.005), (2041,-0.005),(2042,-0.005),(2042,-0.005),(2043,-0.005),(2044,-0.005),(2045,-0.005)) This table indicates the assumption for future household growth for the period from 2017 until the end of the simulation run (2045) under SCENARIO 2 (a Drop in Households Growth Rate due to decline in market's economy).	1/Year
(50)	Future Interest Rate Assumption=IF THEN ELSE (SWITCH Interest Rate Scenario 1=0, Future Interest Rate Assumption BAU(Time), Future Interest Rate Assumption Scenario 1(Time)) The variable delivers the interest rate assumption under each specified scenario.	Dmnl
(51)	Future Interest Rate Assumption BAU([(2017,0.004)-(2045,0.005)],(2017,0.005), (2018,0.005),(2019,0.005), (2020,0.005),(2021,0.005), (2022,0.005), (2023,0.005), (2024,0.005),(2025,0.005),(2026,0.005),(2027,0.005),(2028,0.005), (2029,0.005), (2030,0.005),(2031,0.005), (2032,0.005), (2033,0.005), (2034,0.005), (2035,0.005), (2036,0.005),(2037,0.005), (2038,0.005), (2039,0.005), (2040,0.005), (2041,0.005), (2042,0.005), (2043,0.005),(2044,0.005), (2045,0.005)) This table indicates the assumption for future interest rate development for the period from 2017 until the end of the simulation run (2045) for the Base Run assuming "Business as usual" - i.e. interest rates remain as low as of 2015 (as defined in the variable "Interest Rate DATA").	Dmnl
(52)	Future Interest Rate Assumption Scenario 1 ([(2017,0.006)-(2045,0.08)],(2017,0.006), (2018,0.015),(2019,0.021), (2020,0.028), (2021,0.032), (2022,0.037), (2023,0.039),(2024,0.044),(2025,0.049),(2026,0.051),(2027,0.055), (2028,0.057), (2029.03,0.062), (2030.17,0.068019), (2032,0.071),(2035,0.075), (2037,0.0755), (2040,0.078),(2042,0.08),(2045,0.08)) This table indicates the assumption for future interest rate development for the period from 2017 until the end of the simulation run (2045) In Scenario 1, 2 and Policy 1: an increase in interest rates as of 2017.	Dmnl
(53)	Household Fractional Growth Rate DATA([(1970,-0.03)-(2016,0.03)],(1970,0.0041), (1971,0.0041), (1972,0.0041), (1973,0.0041), (1974,0.0041), (1975,0.0041), (1976,0.0041),(1977,0.0041),(1978,0.0041),(1979,0.0041), (1980,0.0041), (1981,0.0041), (1982,0.0041), (1983,0.0041), (1984,0.0041), (1985,0.0041), (1986,0.0041),(1987,0.0041), (1988,0.0049), (1989,0.0049),(1990,0.0049), (1991,0.0049), (1992,0.0049), (1993,0.0049),(1994,0.0049),(1995,0.0049), (1996,0.0005), (1997,0.0005), (1998,0.0005), (1999,0.0005), (2000,0.0005), (2001,0.0043), (2002,0.0043),(2003,0.0043), (2004,0.0043), (2005,0.0043),(2006,0.0064),(2007,0.0012), (2008,0.0069), (2009,-0.0008), (2010,-0.0217),(2011,0.0125),(2012,0.0189), (2013,0.0122),(2014,0.0095),(2015,0.0158),(2016,0.0116)) This is the lookup of the fractional household growth rate in Stuttgart from 1970 until 2030 calculated on basis of the households data of Stuttgart. For missing data, the annual compound method is used to calculate fractional growth rates between two given values. Source Households 1970-1995: http://www.statistik.baden-wuerttemberg.de/SRDB/Tabelle.asp?H=1&U=07&T=99025080&E=GE&K=111&R= GE111000 (Retrieved October 3, 2015) Source Households since 1995: http://statistik1.stuttgart.de/statistiken/tabellen/4699/jb4699.php (Retrieved February 27, 2016).	1/Year
(54)	Households in Stuttgart= INTEG (Households Net Growth Rate,IN Households) This stock accumulates all households in Stuttgart	households
(55)	Households in Stuttgart DATA :INTERPOLATE: Source Households 1970-1995: http://www.statistik.baden-wuerttemberg.de/SRDB/Tabelle.asp?H=1&U=07&T=99025080&E=GE&K=111&R= GE111000 (Retrieved October 3, 2015)	households
(56)	Households Net Growth Rate=IF THEN ELSE(Time<2015 , Household Fractional Growth Rate DATA(Time)*Households in Stuttgart , Future Household Fractional Growth Rate Assumption*Households in Stuttgart) This flow changes the stock of households in Stuttgart.	households/Year
(57)	IN Buildings Completed= INITIAL(566) The initial value of Buildings completed is estimated based on the number of buildings existing in Stuttgart in 1970 and 1971. Data is retrieved from http://www.statistik.baden-wuerttemberg.de/SRDB/Tabelle.asp?H=ProdGew&U=05&T=07055011&E=KR&R=KR111 (November 14, 2015).	buildings
(58)	IN Buildings Occupied= INITIAL(59036) The initial value, 59036 buildings in 1970, is retrieved from Stuttgart data. From http://statistik1.stuttgart.de/statistiken/tabellen/193/jb193.php (November 16, 2015).	buildings
(59)	IN Buildings under Construction= INITIAL(570) The initial value of Buildings under Construction is estimated based on the number of buildings completed after two years (in 1972) considering the fact that the constructions turn into completed buildings after 2 years on average. The data for buildings completed is retrieved from http://www.statistik.baden-wuerttemberg.de/SRDB/Tabelle.asp?H=ProdGew&U=05&T=07055011&E=KR&R=KR111 (November 14, 2015)	buildings
(60)	IN Demand= INITIAL(1000) The initial value of demand is assumed at 1000.	apartments
(61)	IN Expected Construction Costs= INITIAL(31.2) The initial value of the Construction Cost index for 1970 retrieved from http://www.statistik.baden-wuerttemberg.de/Konjunkturspiegel/buildCostIndex.asp	price index
(62)	IN Expected Excess Demand= INITIAL(3000) The initial value of expected excess demand is assumed at 3000.	apartments
(63)	IN Expected Price= INITIAL(37) The initial value of expected price is assumed at 37, close to actual price in beginning of time horizon.	price index
(64)	IN Households= INITIAL(264312) The initial value of households is retrieved from http://www.statistik.baden-wuerttemberg.de/SRDB/Tabelle.asp?H=1&U=07&T=99025080&E=GE&K=111&R= GE111000 (Retrieved October 3, 2015)	households
(65)	INITIAL TIME = 1970 The initial time for the simulation.	Year
(66)	Interest Rate=IF THEN ELSE(Time<2016 , Interest Rate DATA(Time) , Future Interest Rate Assumption) The function returns the values of real interest rate data for 1970 until 2015. After 2016 the Table for Interest Rate Assumption is returned.	Dmnl
(67)	Interest Rate DATA ([(1970,0)-(2015,0.2)], (1970,0.082), (1971,0.082),(1972,0.082),(1973,0.095),(1974,0.106), (1975,0.0868), (1976,0.0804), (1977,0.0653), (1978,0.0613),(1979,0.0758),(1980,0.0843), (1981,0.1013), (1982,0.0894), (1983,0.0808), (1984,0.0798), (1985,0.0704), (1986,0.0617), (1987,0.0624), (1988,0.0648), (1989,0.0703), (1990,0.0883), (1991,0.0851), (1992,0.0791), (1993,0.0651), (1994,0.0687), (1995,0.0685), (1996,0.0622), (1997,0.0564), (1998,0.0457), (1999,0.0449), (2000,0.0526),(2001,0.048), (2002,0.0478), (2003,0.0407), (2004,0.0404), (2005,0.0335), (2006,0.0376), (2007,0.0422), (2008,0.0398), (2009,0.0322), (2010,0.0274), (2011,0.0261), (2012,0.015), (2013,0.0157),(2014,0.0116), (2015,0.005), (2016,0.0009)) Exogenous input: interest rates for Germany from 1975-2016 retrieved from http://de.statista.com/statistik/daten/studie/201419/umfrage/entwicklung-des-kapitalmarktzinssatzes-in-deutschland/ --- Data for 1970-1974 retrieved from http://www.digitalis.uni-koeln.de/Geldwesen/geldwesen279-284.pdf and http://www.helmut-creutz.de/pdf/grafiken/c/creutz_083.pdf	Dmnl
(68)	Minimum Accepted Price=Expected Construction Costs*(1+Accepted Profit Margin) This is the minimum price that the supply side accepts, based on expected costs plus an accepted profit margin.	price index
(69)	Normal Profit Margin=0.25 This is the normal profit margin for the construction side. It determines the accepted profit margin on basis of the annual interest rate level. See variable Accepted Profit Margin.	Dmnl

(70)	Potential Demand=SMOOTH(Households Net Growth Rate , Time to Smooth Demand from HH Growth)+(Demolished Space/Apartments per Household)	households/Year
	Variable delivers potential demand calculated by the net growth in Households as well as Demolished space.	
(71)	Potential Sales=MAX(0, MIN(Demand in Buildings, Buildings Completed))	buildings
	The MIN-Function returns the smaller value of either Demand or Buildings Completed. The function prevents Potential Sales, i.e. the number of buildings sold, from exceeding the existing demand in any point of time as naturally buildings can only be sold until total demand is satisfied.	
(72)	Price=Minimum Accepted Price*Effect of Supply Demand Ratio on Price	price index
	Trader's set prices by adjusting their belief about the underlying equilibrium price in response to market pressures such as the supply/demand balance, here represented by inventory coverage relative to the normal level, and unit costs.	
(73)	Price Index Stuttgart DATA :INTERPOLATE:	price index
	Price index with 2010=100 retrieved from Grundstücksmarktbericht 2011, Stadtmessungsamt Stuttgart	
(74)	Price Variation=Price-Expected Price	price index
	The difference between Price and Expected Price adjusts the change in expected price.	
(75)	Sales Rate=Potential Sales/Average Sales Time	buildings/Year
	The Sales Rate is the outflow that reduces the stock of Buildings completed. However, it is calculated on basis of Potential Sales since the number of buildings completed that can be sold must not exceed the given demand.	
(76)	SAVEPER = TIME STEP	Year
	The frequency with which output is stored.	
(77)	Sensitivity of Demand to Price=0.5	Dmnl
	This is the demand elasticity, which adjusts the effect of price on demand. Demand in real estate market is found to be rather inelastic (see Sterman, 2000; Muth, 1988). The lower the value, the less price sensitive is demand.	
(78)	Sensitivity of Price to Supply Demand Ratio=0.75	Dmnl
	Controls the response of price to the supply/demand coverage. Must be positive for high demand to lead to higher prices. Higher absolute values lead to greater price changes for any given demand coverage level.	
(79)	Sensitivity of Supply to Price=1	Dmnl
	This is the supply elasticity, which adjusts the effect of price on supply. Supply in real estate market is found to be pretty elastic (DiPasquale,1999; Muth, 1988). The higher the value, the more price sensitive is supply. The effect of elasticity is determined by this variable together with the lookup "Table for Effect of Profit on Desired New Construction".	
(80)	Smoothed Effect of Interest rate on Demand=SMOOTH(Effect of Interest Rate on Demand , Time to realize effect of interest rate on demand)	Dmnl
	This is the smoothed effect that interest rates have on the demand side. See also 'Table for Effect of Interest Rate on Demand'.	
(81)	Smoothed Effect of Interest Rate on Profit Margin=SMOOTH(Effect of Interest Rate on Profit Margin , Time to realize effect of interest rate on profit margin)	Dmnl
	This is the smoothed effect that interest rates have on developer's Profit Margins. Low interest rates reduce profit margins, higher interest rates result in higher profit margins.	
(82)	Supply Demand Ratio=XIDZ(Buildings Completed, Demand in Buildings, 30)	Dmnl
	The supply demand ratio is the balance between demand and supply, expressed as a dimensionless ratio. Supply is equal to the stock of buildings completed.	
(83)	SWITCH Interest Rate Scenario 1=0	Dmnl
	This is a switch 0 = BAU 1 = Scenario 1, Scenario 2, Policy 1	
(84)	SWITCH Scenario 2=0	Dmnl
	This is a switch 0 = Base Run, Scenario 1, Policy 1 1 = Scenario 2	
(85)	Table for Effect of Interest Rate on Demand ([(0,0)-(12,2)],(0.3,1.5), (0.635438,1.495), (1.29735,1.46667), (1.85336,1.45714), (2.56823,1.41905), (3.37271,1.37143), (4.05703,1.27619),(4.7169,1.18095),(5.35234,1.08571), (6,1), (6.64766,0.895238), (7.45417,0.790476),(8.26069,0.742857),(8.96945,0.704762), (9.62933,0.685714), (10.387,0.657143), (11.0957,0.638095), (12.0489,0.619048))	Dmnl
	Table determines the effect of interest rates on the attractiveness of purchasing real estate (i.e. demand) based on Germany's interest rates. Low interest rates generate higher demand since investing into Real Estate seems as a better option, compared to high interest rates that moderate demand, since alternative investment options become more attractive with higher interest rates (e.g. financial assets).	
(86)	Table for Effect of Interest Rate on Profit Margin ([(0,0)-(13,1)],(0.0264766,0.05),(0.608961,0.0571429),(1.29735,0.0666667), (2.19756,0.0809524), (3.09776,0.12), (4.26273,0.209524),(5.13646,0.319048),(5.85132,0.504762), (6.83096,0.795238), (7.96945,0.933333), (9.29328,0.992857),(11,1))	Dmnl
	Table determines the acceptable profit margin based on Germany's interest rates. Low interest rates decrease the profit margin acceptable, whereas higher interest rate requests a higher profit margin.	
(87)	Table for Effect of Price on Demand ([(0,0)-(2,2)],(0.03,0.23),(0.13442,0.247619),(0.3,0.27),(0.5,0.37),(0.7,0.55),(0.843177,0.752381), (1,1),(1.1,1.21), (1.2,1.45), (1.33605,1.70476),(1.491,1.84762),(1.6,1.92),(1.8,1.98),(2,2))	Dmnl
	The S-shaped Table function adjusts demand as follows: When Expected Price increases -> effect decreases demand When expected price to price ratio decreases -> effect increases demand	
(88)	Table for Effect of Profit on Desired New Construction ([(-0.5,0)-(1,8)], (-0.5,0.1),(-0.2,0.15),(-0.15,0.26),(-0.0997963,0.419048),(-0.0448065,0.647619), (0.00101835,0.876191), (0.05,1.25), (0.098778,1.67619), (0.15,2.1), (0.202648,2.81905), (0.25,3.3), (0.294297,3.73333),(0.35,3.9),(0.404277,4),(0.45,4),(0.5,4),(1,4))	Dmnl
	Table for Effect of Profit on Desired New Buildings. Depending on the expected profits, suppliers adjust the desired new constructions, with the assumptions that high profits stimulate an increase in desired new constructions, while lower profits decrease the desired new constructions.	
(89)	Table for Effect of Supply Demand Ratio on Price ([(0,0)-(6,2)],(0,1.49), (0.385321,1.42105), (0.7,1.28),(0.844037,1.14035),(1,1), (1.24771,0.815789), (1.72477,0.614035), (2.47706,0.535088), (3.37615,0.517544),(5,0.5),(6,0.5))	Dmnl
	When Supply > Demand = Effect on Price less 1 = decreases Price due to oversupply (low demand) When Supply < Demand = Effect on Price greater 1 = increases Price due to supply shortage/high demand, based on Barlas, 2007.	
(90)	TIME STEP = 0.125	Year
	The time step for the simulation.	
(91)	Time to Adjust Expected Costs=0.5	Year
	The time to form expectations about the construction costs.	
(92)	Time to Adjust Expected Price=1.5	Year
	The expected price adjusts to actual prices over this time period.	
(93)	Time to Form Expectation of Excess Demand=2	Year
	Estimated time that is needed in order to form the expectation of how much additional space is desired. It generates an information delay.	
(94)	Time to realize effect of interest rate on demand=2	Year
	This is the time it takes until the effect of interest rates reach demand side.	
(95)	Time to realize effect of interest rate on profit margin=2	Year
	This is the time it takes until the effect of interest rates reach supply side.	
(96)	Time to Smooth Attractivity from Price Effect=0.75	Year
	This is the time that smooths Attractivity: Attractivity of houses resulting from price changes (Effect of price on demand) does not translate into demand immediately but with the given time delay.	
(97)	Time to Smooth Demand from HH Growth=2.5	Year
	This delay time smooths the amplitudes in Potential Demand.	
(98)	Vacant Apartments=Buildings Completed*Apartments per Building	apartments
	Variable calculates the number of vacant apartments based on buildings assumed being vacant once completed.	

Table A4: Equations and comments of STREM-model.

Appendix E. Supporting Material

A Vensim file of the STREM-model is attached, including all experimental runs conducted and described in the present paper. In addition, a vdf-file entails data time series that were used as real data input for validation purposes.

Attachments:

- Vensim file of the "STREM-model", including
- Experimental runs:
  - Base Run: Business as Usual
  - Scenario 1: Increasing Interest Rates
  - Scenario 2: Decline in Households
  - Policy: Consideration of Underway Construction