Beyond Student Housing:
A Systems Approach to Understand the Student Housing Crisis in Amsterdam

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Course: EPA1341 - Advanced System Dynamics

***Abstract*— The ongoing student housing shortage in Amsterdam underscores the need for policies accounting for complex housing market dynamics and ensuring future availability and affordability of housing for students. This paper employs a System Dynamics approach, aiming to develop a holistic understanding of the intricate mechanisms among three subsystems: supply, demand, and rent, to analyze the path dependencies driving the evolution of the student housing crisis. A backward-looking analysis revealed that past policies mainly targeted the rent subsystem to stimulate housing affordability and availability for students. Current policies often neglect the private housing market trajectory, prompting this paper to encourage policymakers to view the "student housing crisis" more broadly. The policy proposal aims to augment the existing National Student Housing Action Plan by capping rent to control growing reliance on private housing while utilizing its total capacity.**

Keywords: *student housing; housing policy; system dynamics; scenario analysis; Amsterdam*

INTRODUCTION

The shortage of affordable housing for young people has become a major issue in most European cities (Bugeja-Bloch, 2012). The Netherlands, facing one of the most severe student housing crises with a shortage of 26.500 student spaces, is no exception (Kences, 2021). Despite general awareness and previous governmental measures, the crisis has accelerated in the last few years (ASVA Student Union, 2022). The effects of this crisis are especially prominent for students residing away from home as they mostly rely on university-provided housing. The affordable rent prices, standardized procedures, and the opportunity to secure housing before their studies are the main advantages of purpose-built student housing (referred to hereafter as student housing) (Fang and van Liempt, 2021). In particular, it is relevant for international students as they have limited knowledge and tools to find affordable options on the private market, e.g., language barriers and limited local contacts (Obeng-Odoom, 2012).

The Netherlands have a knowledge-based economy - attracting foreign talents and retaining them after their studies is necessary. To ensure the availability of student housing "without jeopardizing the benefits of internationalization" Persbureau (2022), the Dutch government announced the National Student Housing Plan (NSHAP) in 2022 (Hanneke, 2022). It aims to provide 60.000 more affordable student housing by 2030 and sets a long-term plan for municipalities and universities. The mixed reactions illustrate a heated debate and room for improvement (Delta, 2021).

Young people are forced to jump between short-term housing solutions as they struggle with upward mobility due to affordability issues: even with a rise in income, they cannot move to better-quality housing progressively (Boztas, 2023). This changing dynamic has been investigated using a pathway approach (Clapham, 2002, 2005; Clapham et al., 2012). However, despite the growing body of literature, student mobility patterns are ignored and often do not account for the existence of a separate student housing market and its current shortage (Hochstenbach and Boterman, 2015). Furthermore, they are often qualitative descriptions lacking insights about future scenarios (Uyttebrouck et al., 2020; Adabre et al., 2021).

In addition, governmental policies often lack specific measures and address affordable housing crises solely as a supply issue. NSHAP aims to build 60.000 new student houses; Canada has announced to invest $2 Billion in affordable housing supply (Rijksoverheid, 2022; Lord, 2022), and the Urban Agenda for the European Union announced a Housing Partnership Action Plan to increase the affordable housing supply (EU, 2018). Those policies frequently fail to consider the complex interdependencies between different housing markets, such as the student and private housing markets, and hence neglect the opportunity for dynamic policy measures affecting the transition between the markets.

This study aims to analyze the housing movements of students residing away from home by considering the intricate mechanisms of the housing market. By utilizing data from Amsterdam, a bottom-up and holistic understanding was developed. The assumption that building more student houses alone will solve the ongoing crisis is questioned, and the scope is extended beyond the housing supply. For this purpose, the following research questions are addressed:

Q1 - Based on the existing trajectories of the housing market and the newly proposed (NSHAP), will housing for students be sufficiently available and affordable for the present and the future?

Q2 - What underlying socio-economic feedback influenced the mental models of existing policies and the proposed NSHAP?

Q3 - Concerning the above questions, what policy approach can foster sustainable developments to provide available and affordable housing to meet growing demands?

The two KPIs are introduced to systematically examine the behaviours of availability and affordability that characterise the research questions. Throughout the paper, the two Key Performance Indicators (KPIs), Average Rent Prices and Total Students Housed are used to examine the behaviours of affordability and availability methodically, pertinent to the research questions.

- (Affordability) *Average Rent Prices* - the average rent comprises both the rent price of student housing and other forms of private housing.
- (Availability) *Total Students Housed* - the relation between the number of students that come to Amsterdam looking for housing and those that manage to find accommodation.

In the upcoming chapter, this paper conceptualizes the systemic characteristics of the student housing crisis in Amsterdam. Next, the paper delves into the model's fit-for-purpose by discussing validation tests and uncertainty assessments. Lastly, the policy analysis section tackles the research questions by outlining the expected behaviours (Q1), mental models (Q2), and the proposed policy (Q3).

METHODS

Understanding the dynamics of the student housing market requires a comprehensive approach. System Dynamics overcomes the limitations of our cognition in grasping complexities and offer an effective mean to analyse the dynamics within a multi-faceted socio-economic system like the housing market (Malmir and Spicar, 2014; Sterman, 2000). Houses are appropriately represented as stocks since they accumulate through construction and dissipate through demolishment. Delays in the construction and planning stages play a crucial role in the housing market through their influences on the housing supply. Finally, System Dynamics enables the modelling of feedback mechanisms, critical in capturing the interactions between the housing demand and housing supply subsystems. Hence, System Dynamics is an appropriate method to investigate the root causes of the student housing crisis through the implementation and analysis of purpose-designed scenario-based experiments.

Dynamic Hypothesis

The expected behaviour of the overall problem is associated with the 'Fixes That Fail' system archetype (Lane, 1993). This happens when a *fix* is implemented as a response to an undesirable *problem* but ends up exacerbating the issue through *unintended outcomes*. This archetype describes situations where solutions are implemented without a thorough system understanding. In this context, these archetypal elements are as follows:

- Problem: The inability of students to find affordable housing is falling because the availability of student housing is insufficient.
- Fixes: Market forces would cause a shift in demand for accommodation from student housing to private housing, escalating a greater dependency on private housing for students.
- Unintended Outcome on Affordability: This dependency on private housing increases rent prices due to increasing demands.
- Unintended Outcome on Availability: The dependency on private housing also shifts construction volume from private housing to student housing because it is more lucrative (rent increases).

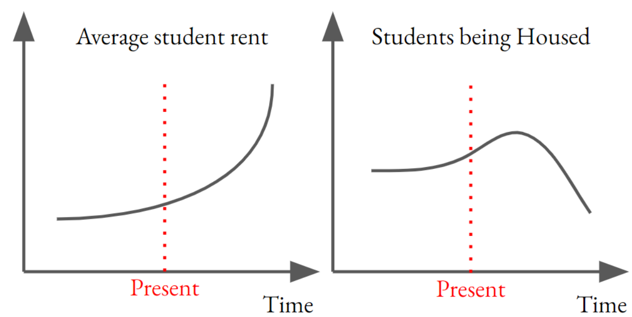

Fig. 1: Dynamic hypothesis of the behaviour of the model's main KPI

The overall behaviour on affordability is driven by the unintended effects on rent; there is reinforcing feedback on the dependencies on private housing. The average student rent will experience exponential growth due to the increase in student rent for private housing and the proportion of students housed in private housing, as illustrated in Figure 1.

The overall behaviour on availability is caused by a combination of unintended consequences on rent and supply; students likely being housed will exhibit an overshoot and collapse (Figure 1, Right). Initially, there will be growth in students housed due to more private housing accommodations for students. However, students being housed will eventually collapse because rents will skyrocket, and students will not be able to afford them.

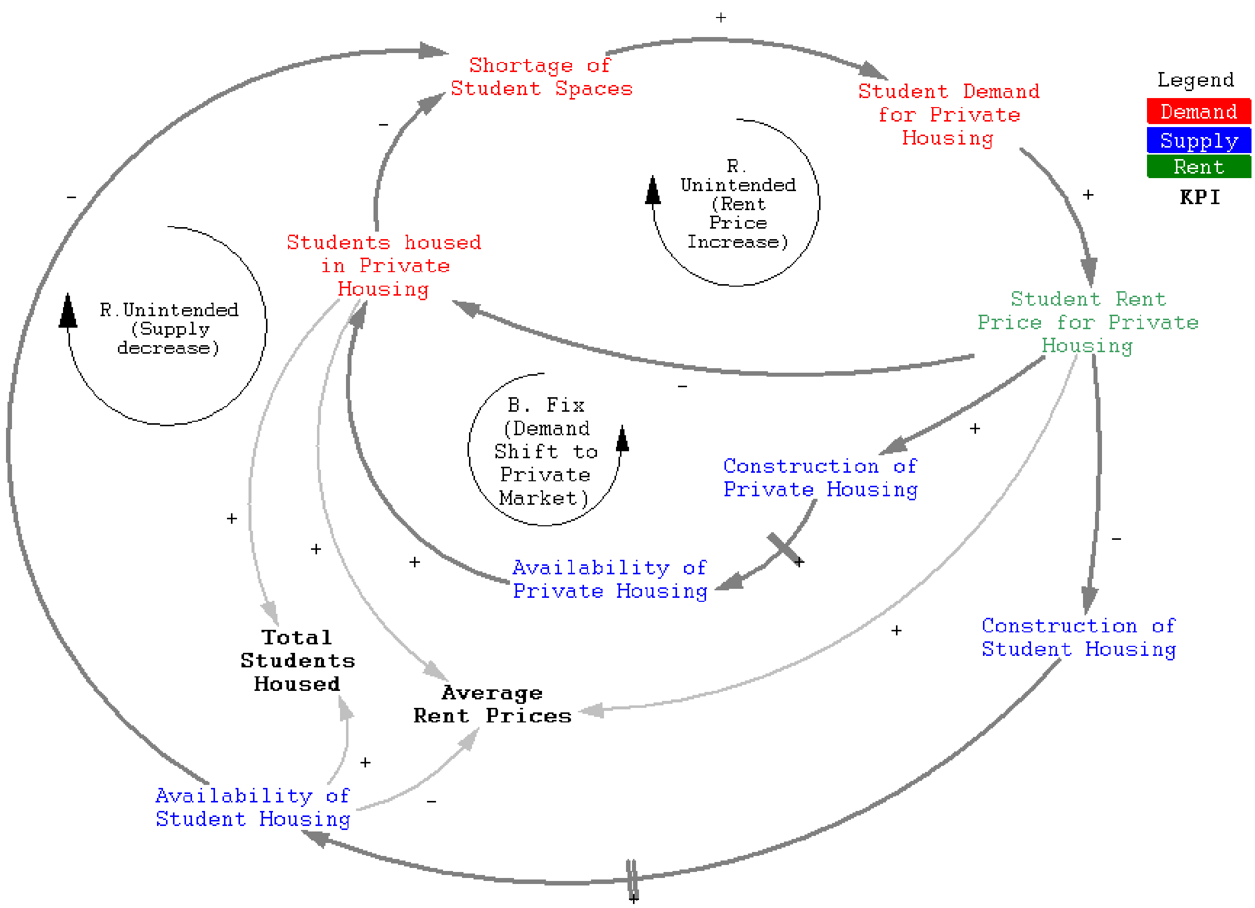

Fig. 2: Aggregated Causal Loop Diagram (CLD) displaying the three subsystems

Model Conceptualisation

The inherent student housing crisis is conceptualized as an emergent result of the three subsystems - supply, demand, and rent (Figure 2). Moreover, the model comprises three main feedback loops. The balancing loop describes the fix that students facing housing shortage will implement: moving towards the private housing market. As a consequence of this fix, two reinforcing loops create the unintended consequences of increasing private housing rent and reducing the supply of student housing.

B. Fix (Demand Shift to Private Market):
The increase in *Shortage of Student Spaces* causes the *Student demand for Private Housing* to increase. Consequentially, *Student Rent Price for Private Housing* will also increase. To a certain extent, *Construction of Private Housing* is preferred by construction companies because it can be more lucrative (Persbureau, 2022) - as such, more private houses are constructed over student housing. The increase in the *Availability of Private Housing* will allow for more *Students housed in Private Housing*, balancing the supply and demand of student spaces (Fang and van Liempt, 2021).

R. Unintended (Rent Price Increase):
However, B. Fix could have an unintended consequence on the *Average Rent Prices*. With the increase in *Student Demand for Private Housing*, *Student Rent Prices for Private Housing* would rise to the point that it becomes unaffordable for students and result in fewer students moving to private housing. This decreases the overall number of *Students housed in Private Housing*, and this shortage further reinforces rent price increases for private housing (DiPasquale and Wheaton, 1996).

R. Unintended (Supply Decrease):
There is another unintended consequence of B. Fix. With a higher *Student Rent Price for Private Housing*, *Construction of Private Housing* is preferred over *Construction of Student Housing* due to the greater expected return on investment. This decreases the *Availability of Student Housing* in the long run and, consequentially, the *Total Students Housed*. The same narrative continues, and rent prices will continue to rise (Ruming and Dowling, 2017).

Model Scoping

The model aims to understand how supply-side interactions of the housing market affect the affordability and availability of housing for students. The demand side of this housing market will also be included, although with a higher degree of aggregation, to account for necessary feedback in the market dynamics for construction and rent. As a result, the model focuses primarily on the endogenous interlinkages between the different subsystems. However, the internal mechanisms within the subsystems could be superficially endogenous or exogenous. The structural aggregation of each conceptual type of variable is reflected in Appendix A.

The crux of the analysis is to capture how the shift in supply and demand between student housing and private housing influences the affordability and availability of accommodation for students. As such, the housing typologies (e.g., shared apartments and independent accommodations) are not differentiated, assuming that housing quality is price inelastic. Social housing is omitted because the room for growth in social housing is assumed to be marginal and is not competing with the supply of student and private housing. Finally, the life-cycle (e.g., planning, construction, and demolishment) of student and private housing stock will be fully represented as it is essential in understanding the supply subsystem.

Experimental Set-up

Succeeding the qualitative conceptualisation, this model will be further quantified as a stock-and-flow diagram. With verification and validation, a base model is produced with a certain standard of fitness-for-purpose. In line with the research questions, scenarios are conducted to analyze the trajectories and mental models of the different policy mechanisms (i.e. existing policies and NSHAP) and additionally test meaningful policies. The specifics of these tests will be elaborated alongside the results in the section of *Policy Analysis.*

The model settings were tuned according to the previous model conceptualisation. An Euler integration method is utilized to account for the discontinuous nature of the system, which arises from discrete or discontinuous functions (e.g., min/max and lookups). Although Euler is suitable for such models, its precision is inadequate unless a very small time interval is chosen (Pruyt, 2013). Therefore, the model's time step was progressively reduced until there was no noticeable difference in its outputs, and ultimately, a time step of 0.0625 (roughly 23 days) was chosen. The time horizon spans from 2012 to 2042, starting after the housing crisis and extending to the present day, with an additional 20-year projection into the future. Also, the number of simulations is a default of 200 runs for all univariate and multivariate sensitivity analyses conducted.

Verification and Validation

Verification ensures an error-free and consistent model that executes the intended functions accurately (Balci, 2013). Some verification tests include dimension analysis (unit check), numerical errors (integration method and steps), and code checks. These tests were performed simultaneously as part of the modelling process.

Validation is addressed to increase the confidence level in the model, identify strengths and weaknesses, and assess the fitness for the introduced purpose (Senge and Forrester, 1980). Hence, structural and behavioural validation has been conducted. Some of which are implicit in the modelling process.

This section will describe the explicit behavioural validation tests conducted: Extreme Condition Test, Sensitivity Analysis, and Boundary Adequacy Test (discussed in Structural Uncertainties).

Extreme Condition Test

An indirect extreme condition test was conducted to assess the model's fitness and further understand its dynamics in the context of our overarching research questions. The tests were performed using *SyntheSim* feature in Vensim. Extreme values were given to variables in the supply, demand, and rent subsystems, and their effects on KPIs and other important variables were observed. Some results are discussed below:

In the supply subsystem, the *initial construction volume for potential student spaces* was tested at 0, resulting in the *total number of students housed* decreasing much faster. This is as expected. In the demand subsystem, the *fraction of available private housing afforded by students*, the lookup has been adapted to either 0 or 1 to test price elasticity. As expected, with a decrease, the overall rate of *shifting in (p)* decreases, and the *total number of students housed* decreases much more quickly over time. In the rent subsystem, the *rent information delay* is increased to 10 years. This results in delayed behaviour for both *average student rent* and the *total number of students housed*. This is also as expected.

Sensitivity Analysis

Subsystem Interaction: Based on the problem conceptualization (Figure 2), the interactions between all the subsystems are the most significant to our model behaviour. In the formulation, these interactions are captured by lookup functions that capture the relationship between the two variables. However, for a model of such a specific scale as the student housing market, it is challenging to model this accurately even though the general relational behaviour (e.g., exponential, sigmoid, linear) of interaction might be known. Hence, the sensitivity analysis will be univariate with 200 simulation runs, aiming to test these functions' reliability by slightly varying the parameters, such as growth rate and the asymptotic limits. The variables assessed are presented below, and the exact details and results are shown in Appendix F:

- *Preference factor*: It captures the relationship between student rent (Rent) and construction volume (Construction). ±10% change is applied to its base value.
- *Percentage change in rent based on shortage*: It demonstrates the interaction between the shortage (Demand) and student rent (Rent). Three different exponential relations were tested: Base, High Growth Rate, and Low Growth Rate.
- *Fraction of available private housing afforded by students*: It reflects the linkage of student rent (Rent) to shifting in (Demand). Three different sigmoid relations were tested: Base, High Growth Rate, and Low Growth Rate.

All three variables present some numerical sensitivity but little to no behavioural sensitivity. In descending order, the most sensitive variables were: *Preference factor for construction*, *Fraction of available private housing afforded by students*, and *Percentage change in rent based on shortage*. Also, numerical sensitivity tends to occur after 2022. This shows that the model has larger reliability in pre-2022 conditions, but it shows a higher degree of uncertainty when looking into the future. This points out to a greater weight of these endogenous inter-subsystem interactions for policy implications.

Exogenous variables: The exogenous variables used in the model also served to test key assumptions. While data was available until 2022, the model required extrapolations based on predictions from different sources for data beyond that period. Thus, it was crucial to test the validity of these predictions. The variable of interest is listed below, where detailed information can be found in Appendix B:

- *Percentage change in construction volume*: It determines the changes in construction volume over the years. The base growth pattern follows a goal-seeking curve, but sensitivity is tested by experimenting with slower goal-seeking growth and linear growth.

Like previous results, *Percent change in construction volume* leads to only a numerical sensitivity in the model, mainly after 2030. However, it is almost negligible, indicating that the degree of uncertainty in the predicted data has a minimal impact on the overall result of the model.

Review of Uncertainties

A crucial aspect of modelling complex systems is to assess and acknowledge uncertainties, as they can significantly impact the system's behaviour (Auping, 2018). The following section reviews the model's numerical and structural uncertainties, enhancing its robustness to strengthen the basis of the following policy analysis.

Numerical Uncertainties

This model focuses on a subset of the larger student housing crisis and the housing market. This level of aggregation increased the numerical uncertainties as values used in the system were scaled down linearly or interpolated from data with a higher level of aggregation, such as the student housing shortage in the Netherlands. To assess the relevance of these uncertainties, a multivariate sensitivity analysis was conducted of 200 runs with a ±10 % variation in all the initial values of the stocks and the *Base rent for students*. The results of this analysis show numerical sensitivity, particularly in the mid-term, with values converging towards 2042 for the model's main output variables (Appendix C). Also, extending the simulation beyond the time horizon shows that all variables will converge at equilibrium after 2042. Hence, the overall behaviour of the variables of interest remains unchanged, showing limited behavioural sensitivity to the stocks' initial values.

Structural Uncertainties

The model lacks endogenous representation of multiple phenomena that could significantly influence the system. Two adequacy tests were conducted to assess structural boundary uncertainty to ensure the model's fitness for purpose.

Land scarcity was not included since the model focused on student housing, representing only a fraction of Amsterdam's housing environment. However, the housing market in Amsterdam is influenced by the prevalence of land scarcity, constraining the construction volume. Land scarcity was conceptualized as a feedback relation that constrains the construction volume modifying *Initial construction volume for potential student spaces* to assess the impact. This caused an oscillating accumulation of student and private housing stocks due to the dependence of new house construction on available land (Appendix D). Conversely, the problem behaviour remained unchanged because it affected both construction subsystems proportionally, having little influence on the decision-making process to prioritize one type of construction.

Repurposing, which describes the choice by private landlords to start offering their properties to students in light of increasing rents, is currently not represented in the model. A sigmoidal relationship between average private rent and repurposing was used. The implementation caused the model's behaviour to be delayed but not profoundly modified, validating the structure of the private housing supply subsystem. Furthermore, policy tests do not distinguish between private housing initially built to house students and private houses repurposed, indicating that the model is representative and fit for purpose.

Deep Uncertainties

Choice modelling is recognized as a common relevant source of deep uncertainty in System Dynamics as it is usually reduced to a purely economic choice (Kubli, 2020; Kahneman, 2003). In the model, economic choice for construction and demand represents one of the main endogenous drivers influencing the affordability and availability of student housing. As data was rather limited, the choice was modelled by calibrating functions from the literature using a base value derived from historical data (Appendix F). Nonetheless, these variables only presented numerical sensitivity and negligible behavioural sensitivity.

As policy recommendations from System Dynamics models often focus on the behaviour rather than specific forecasted values (Auping, 2018), these sources of uncertainty do not jeopardize the model's fitness-for-purpose. The most extreme extent of behaviour sensitivity observed is the minor delays of behaviours. They still are useful in describing the inevitable outcomes, but the prediction of time and magnitude lacks accuracy. This could be improved by gathering better data for future studies (limitations in Appendix H).

Policy Analysis

To develop a novel policy, it is crucial to understand the historical legacy of conventional policy approaches and current policies. Therefore, the analysis strongly emphasizes understanding the mental models behind the policies and investigates the relation between existing policies and the three subsystems. Through this examination and the application of the model, an adaptive policy framework is developed and empirically evaluated.

Existing: Private Housing to Relief Shortage

In 2006, the Dutch government implemented the 'Huurtoeslag' program, which provided financial assistance to students struggling with housing expenses. It was based on the underlying assumption that providing subsidies to students could alleviate the problem of the student housing shortage. This way, the policy aimed at enabling students to shift to private housing to overcome the housing shortage. Consequently, more and more students moved to private housing, increasing the competition between young professionals and families and shared student apartments. In response to the unregulated influx of students, the municipality of Amsterdam announced the 'Huisvestingsverordening' in 2017. This policy regulated the amount of private housing available for students through a hard-capped permit system.

- (Subsidies) *Fraction of available private housing afforded by students*: decrease rent input by 1000 EUR/Year from 2006
- (Family Policy) *Spaces to housing ratio (p)*: decrease by 15 percent after 2017

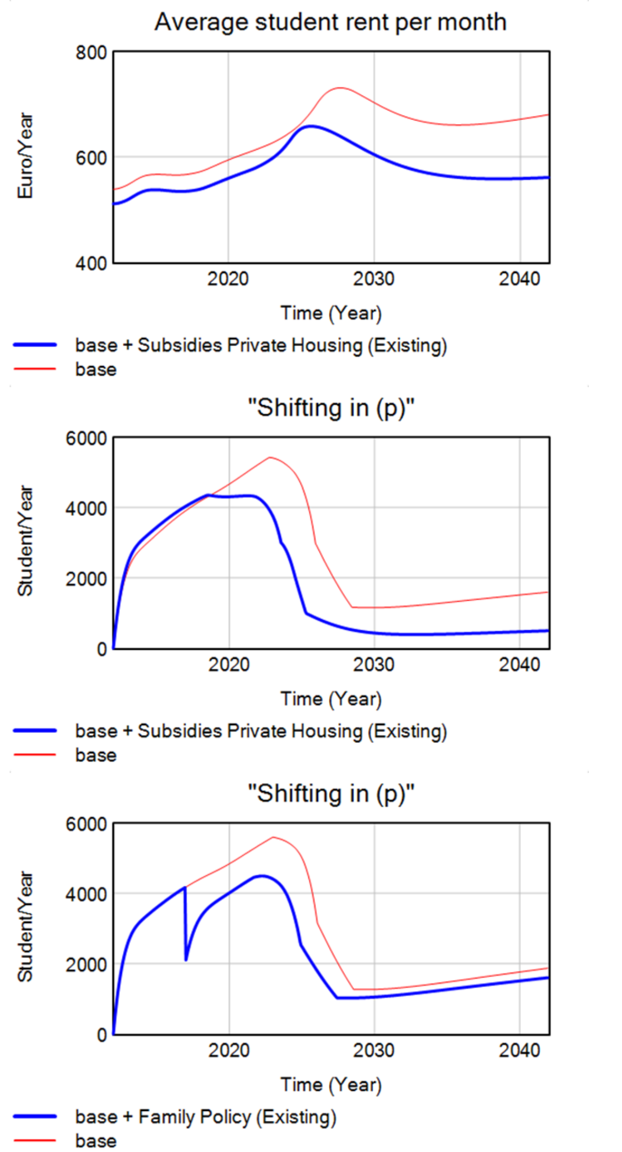

Fig. 3: Results of rent subsidies and family policy

The rental subsidies policy decreases the *Average student rent* slightly (Figure 3, Top) since the policy only aims to aid a small minority of students accommodated by private housing. In addition, it increases the number of students *shifting in* private housing reasonably from 2012-2018 (Figure 3, Centre). However, the reliance on private housing has begun around this time, as seen from the rising number of shifts.

As a response, the family policy started in 2017, limiting the effective amount of housing that students could rent. This is shown by the dip of *Shifting in (p)* in Figure 3, Bottom), where it tries to curb this reliance on private housing using a static policy.

The two analyzed policies indicate the prevailing mental model of policymakers, which understood the crux of the stu-

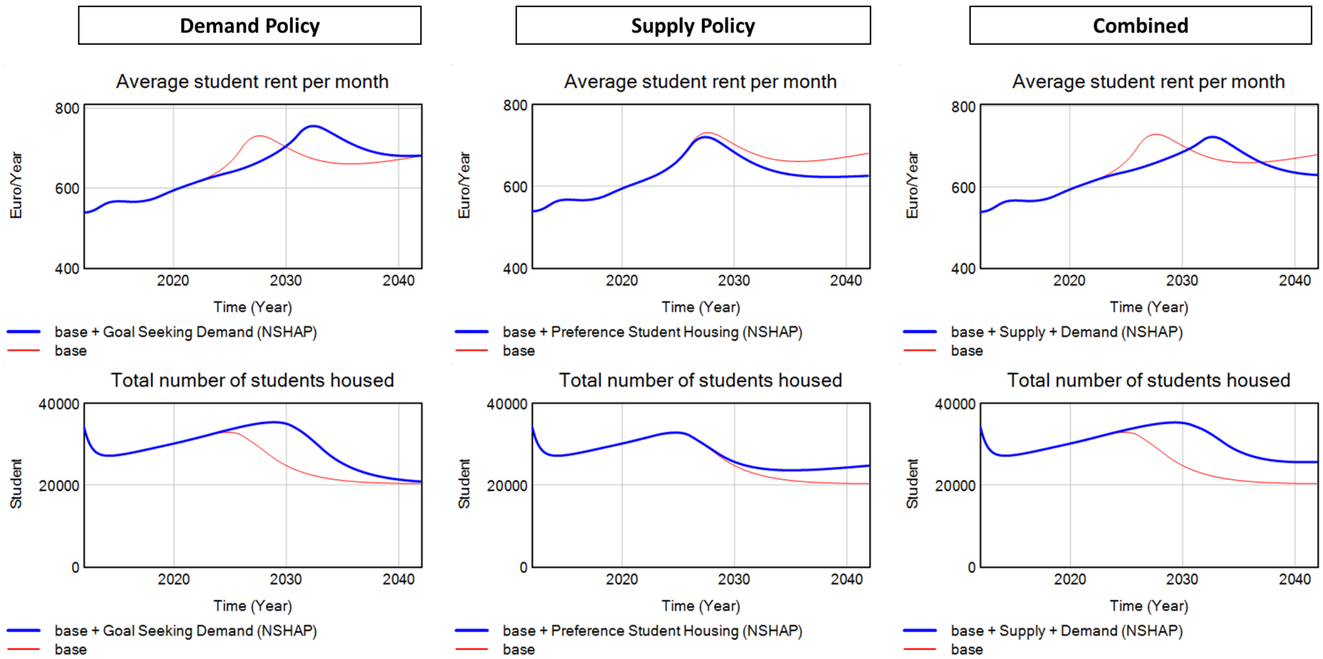

Fig. 4: Results of NSHAP

dent housing shortage primarily as an issue of affordability. Consequently, it was assumed that rent subsidies would make private housing more affordable for students, increasing the available housing supply. Overall, the policy relates to the B. Fix feedback loop in the CLD (Figure 2) as it encourages students to shift to private housing to overcome the student housing shortage.

Current: National Student Housing Action Plan

The student housing crisis continues to worsen despite implementing the previously described policies. Thus, in 2022, the government announced NSHAP, a comprehensive policy framework for the student housing market (Rijksoverheid, 2022). The proposed policies read vague and focus more on promoting communication between stakeholders such as municipalities and universities. However, in essence, it is interpreted that NSHAP focuses on influencing the supply and demand subsystems of student housing; their policies aim to increase the availability of student housing and decrease the number of incoming students to resolve the housing deadlock and ensure sufficient availability of affordable housing.

As the policy is recently introduced, its lasting effects on housing availability and affordability are uncertain. The forward-looking approach of System Dynamics proves useful as it enables simulations of the policy over an extended period and sheds light on its potential long-term impacts. The following two policy approaches derived from NSHAP are analyzed in greater detail using the model.

Firstly, the demand policy reduces the number of students eligible for housing. This approach aims to reduce the demand for student housing, which will, in turn, reduce the pressure on the existing housing supply.

- (Demand Policy) *Student demand* shows goal-seeking behaviour after 2022

Secondly, the supply policy provides incentives to construct student housing to increase the supply of affordable student housing. As no exact numbers are provided by NSHAP, this was approximated by the change in *Preference ratio of private to student housing* for construction. This way, construction companies will shift towards a general preference for building more student houses.

- (Supply Policy) *Preference factor* decreases from 1.3 to 1 after 2022

The demand policy is found to have primarily short-term benefits in the housing sector. It is observed that this policy delays the collapse for *Total number of student housed*, as illustrated in Figure 4. However, eventually, it converges at the same value in 2040. This can be explained by the *Average student rent* where the rental spike is delayed because the shortage of student housing (which drives rent) is temporarily suppressed by the demand policy. This shows that the demand policy cannot be relied upon to solve the housing crisis. It can, however, be useful in addressing the current housing affordability and availability issues.

The supply policy is most effective in the long-term. As seen from Figure 4, it decreases the *Average student rent* and increases the *Total number of students housed*. This implies that affordability and availability will slowly improve over time.

The combined policy is effectively a numerical sum of the two effects; it does aid the problems in the present (2022-2030) and the distant future (2040 and beyond). However, it does not address the collapse between these two periods. The current policies are insufficient to tackle a dominant issue of the crisis – where the availability of private housing will eventually plummet because of its affordability.

Compared to the previous policies, the underlying mental model of NSHAP about the student housing crisis has shifted from a problem of affordability to a problem of supply and demand of *Student housing*. It aims to provide a robust solution through short-term (demand) and long-term (supply) strategies, to achieve sustainable growth in *Student housing*.

However, NSHAP might have overlooked the effects caused by the over-reliance on *Private housing for students*. Concerning our conceptual model (Figure 2), NSHAP tackles the unintended effects (R. Unintended) of *Supply decrease* but missed out on dealing with another important feedback (*Rent increase*). where the private housing market has a significant influence on the total availability through affordability.

None of NSHAP's policies could deal with the collapse of availability caused by the fast transition out of *Private housing* due to affordability reasons (Figure 5). This is unideal as even though *Student housing* could be the long-term solution, *Private housing* is still needed until the *Student housing* supply is sufficient.

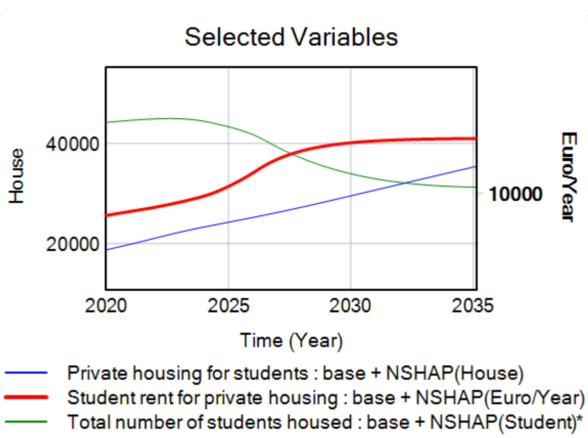

Fig. 5: Collapse of Total number of students due to the dynamics of the housing market

Proposed: Regulation of Private Housing

The analysis of existing and current policies underlines the need for a more comprehensive and robust approach to overcome the introduced challenges of the housing market for students. It can be acknowledged that NSHAP has shifted the problem understanding from being solely an affordability issue to a more nuanced perspective that recognizes the interplay between demand and supply. However, it lacks the complex representation of the supply subsystem and does not consider the strong dependency on the private market to house students. As a result, the forces of the private housing market are not controlled, which significantly impacts the affordability and availability of student spaces, causing the housing availability to collapse in the mid-term due to increasing unaffordability before the new student houses are completed.

To prevent this collapse, an additional policy aims to supplement NSHAP's approach of shifting the dependency toward student housing through construction by reinforcing the capacities of private housing until the necessary student houses are completed. Different policies can be implemented to maintain the inflow of students towards private housing despite the market's tendency to raise rent to an unaffordable level. Rent subsidies, in line with the previous policy approach, will continue to favour the construction of private housing, representing a superficial solution. On the other hand, finding innovative policies to control the rent of private housing available for students can reduce the dominance of the unintended consequence feedback loop. Such a policy was tested in the model by inducing a cap to the average rent for private houses for students at 920 EUR per month. The policy utilizes the private housing market to bridge the critical transition toward an increased student housing supply. It circumvents the affordability problem driven through the private housing market.

The results suggest that the combination of increasing supply and controlling private student housing generates a plateau in *Average student rent* at around 600 EUR/Month (Figure 6 Top) as a direct effect of the rent cap policy. Implementing the proposed policy does not generate a fall in student rent after 2027, which is present in NSHAP. However, the trade-off is the increase in the *Total number of student housed* (Figure 6 Centre), which is a small compromise to achieve this crucial goal.

The underlying mechanic for this behaviour can be seen through the *Fraction of students in private housing* (Figure 6 Bottom), where it is approximately kept at 0.4 and reaches a steady state in the long-term. This represents how private housing is maximized for students yet prevents the unhealthy growth in dependency on private housing.

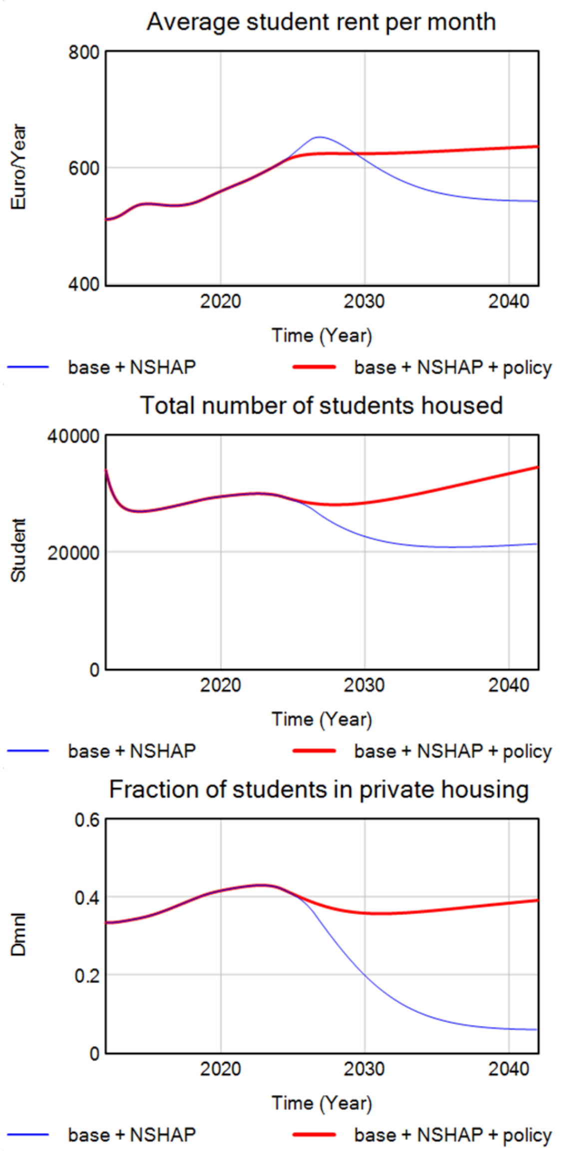

Fig. 6: Results of the rent cap policy

Conclusion and Discussion

The suggestion of a rent cap represents efforts aimed at safeguarding the interests and values of students during this extensive crisis by ensuring that the transition from private to student housing does not adversely affect the affordability and availability of accommodations. The need for sustainable transitions has been overlooked due to the limitations inherent in the mental models of NSHAP and existing policies; our approach underscores the importance of accounting for dynamic changes within all aspects (e.g., subsystems) of the Dutch housing system.

Values in a Multi-actor System

Our system conceptualization not only identifies the main subsystems contributing to the student housing crisis but also implicitly various actors with distinct values and goals invoking the interactions within the subsystems.

- The *supply* subsystem is based on the perspective of construction companies. Its choices on what type of houses to construct are based on profit maximization.
- The *demand* subsystem is based on the perspective of students who desire lower rents and greater availability of houses.
- The *rent* subsystem is based on landlords and rental companies. Their focus lies on rent pricing as a means of maximizing profits.

These three subsystems are inherently linked, and the model displays direct competition between the goals of these actors because of the tight interdependent relationships. The most prominent example would be the landlord's desire to maximize profits, but the decrease in rent, as desired by students, will not be easy for them to accept. Especially in our case, where housing resources are inevitable, a policy must pursue a healthy compromise between actors' interests to not only reach a Pareto-efficient outcome but also a socially responsible one.

As such, a clear understanding of the three subsystems and their interactions has to be achieved. A failure to do so will lead to an incomplete solution being prescribed or even potentially worsening the situation.

Mental Models and Policy Legacies

In our analysis, it can be observed how the mental models of the various sets of policies initiated have changed based on the development of the crisis - from the "existing policies" in which the dependency on private housing was supported, to NSHAP, which focuses on the growth in student housing (Figure 7). It appears that the mental models have evolved but were weak in acknowledging the lasting effects of the preceding policy on the system. In particular, NSHAP's lack of focus on the private housing market, whose growing influence was a direct result of the existing policies enacted.

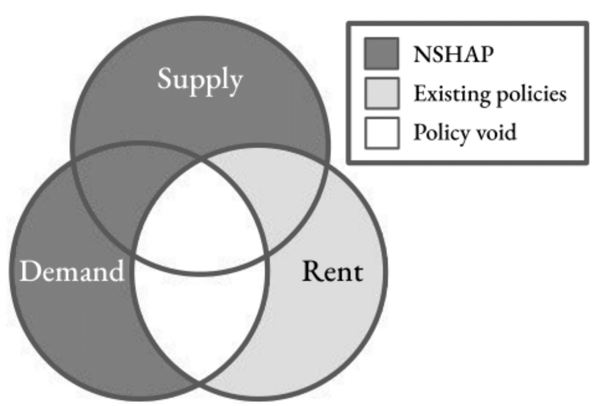

Fig. 7: Illustration of policy mental models concerning the various subsystems

The reactive approach of current policies to focus on newly observed behaviour is inadequate. Especially with the complexity of the housing crisis, this advocates for policy analysis to study crucial path dependencies as a means to produce systemic changes.

In reflection, the commonplace semantic of a ”student housing crisis” could represent that the system boundaries of existing mental models were not drawn adequately to include the influential impacts of ”private housing”. Thus, there is the potential benefit of broadening the agenda from the ”student housing crisis” towards a general ”housing crisis for students” that might affect the problem understanding; and, thus, the effectiveness of policy recommendations.

Recommendation

This paper should inspire policymakers and researchers to guide future debate and research on the housing market dynamics. The theoretical findings suggest that implementing a rent cap for private housing can potentially alleviate the ongoing housing crisis for students. Moreover, the socio-economic analysis of actor values and mental models has provided insights into how these factors can be incorporated into effective policy-making on a national scale, as students' movement is not limited by administrative boundaries. To translate these findings into policy, we must consider the political aspect of framing policy.

There are various ways of achieving an effective rent cap for students in the private housing market on a national level. We emphasize strategies that align with the stakeholder values and support the discussed mental model shift. In particular, a government-regulated cap could be counterproductive as it does not align with stakeholder values as landlords aim to maximize profits. A policy should rather focus on setting incentives to establish a rent cap for students naturally. As this can only be achieved collaboratively, we stress the importance of stakeholder dialogue and management. This aspect should be a crucial part of the policy communication strategy that effectively conveys the benefits of proposed measures nationwide.

Policymakers can test different approaches in pilot projects and provide valuable insights from the real world. At the same time, researchers can continue to assess the dynamics of the housing market and provide additional understanding and proposals. Continuing this dynamic exchange between practice and research will be key to developing a comprehensive policy framework that addresses the housing needs of students and contributes to a more equitable and sustainable housing market in the Netherlands.

Supplementary Materials

The supplementary materials can be accessed through our GitHub Repository.

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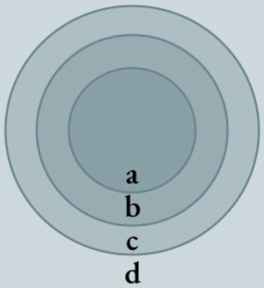
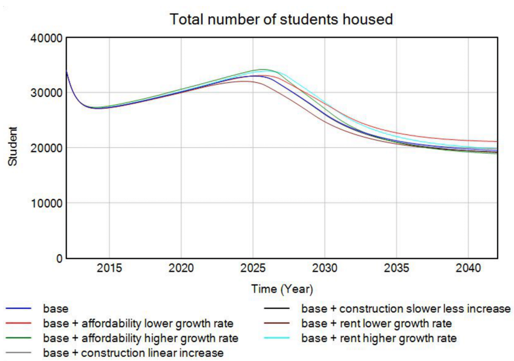
Appendix

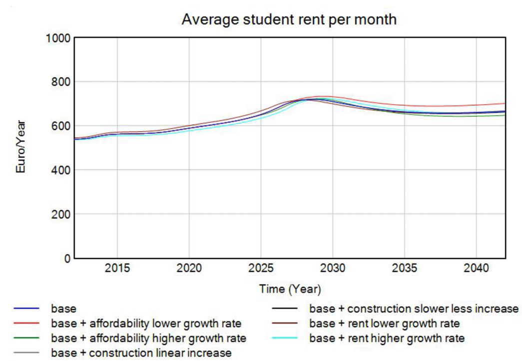
A. Model Conceptualisation - Bullseye Diagram

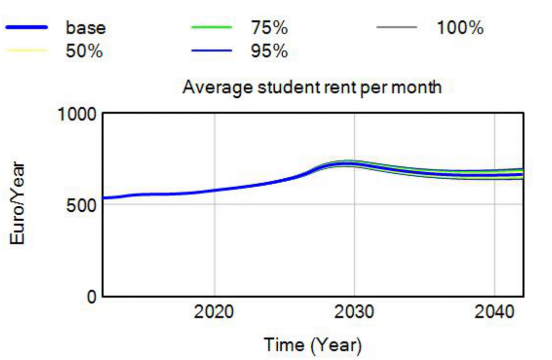


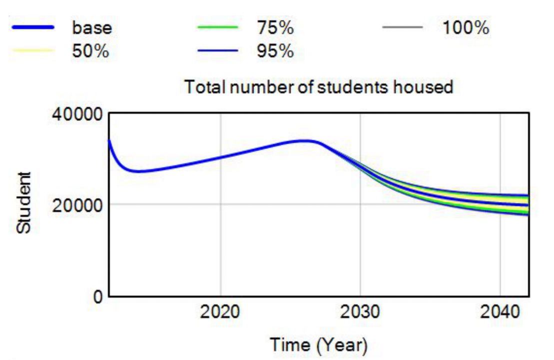
a) Endogenous	- Construction and housing stock accumulation - Types of housing for students (Student housing and Private housing) - Constructions choices - Rent prices
b) Superficially Endogenous	- Student housing demand - Base construction volume
c) Exogenous	- Housing and construction policies
d) Omitted	- Physical resources (land, materials, investments) - Macroeconomics (inflation, interest rate) - Shocks - Other types of housing used by students

B. Validation - Sensitivity Analysis





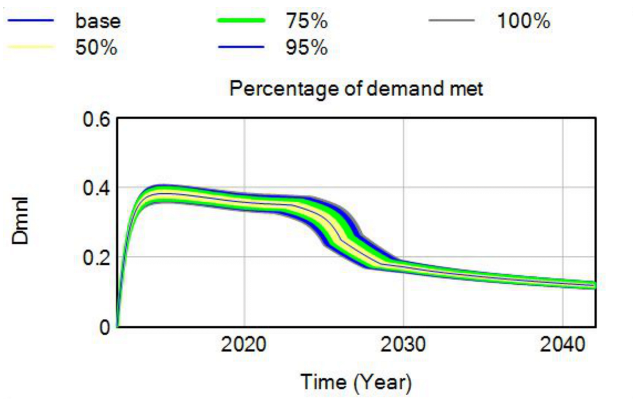


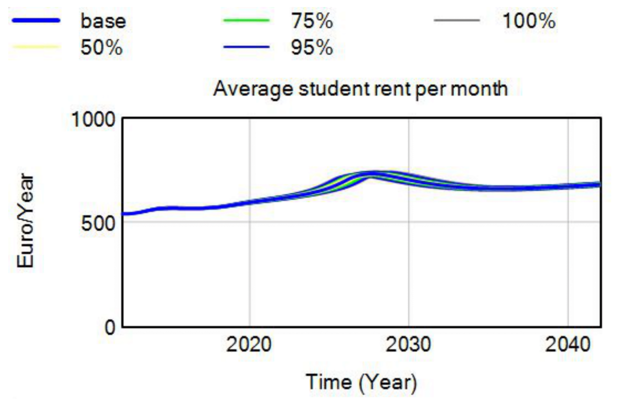


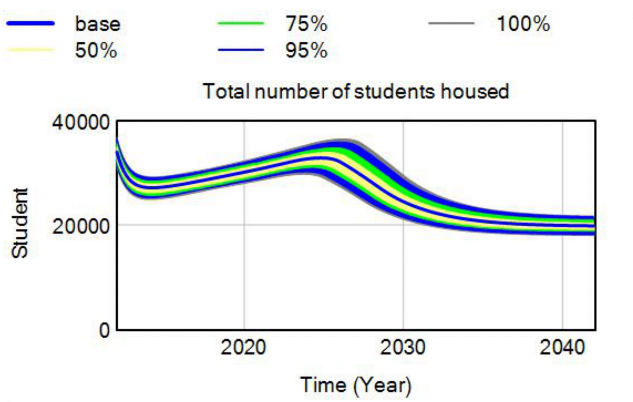
Preference Factor +- 10%

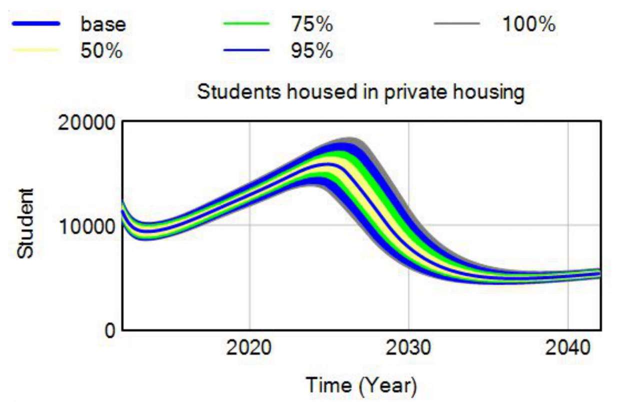
C. Numerical Uncertainties - Multivariate Sensitivity Analysis

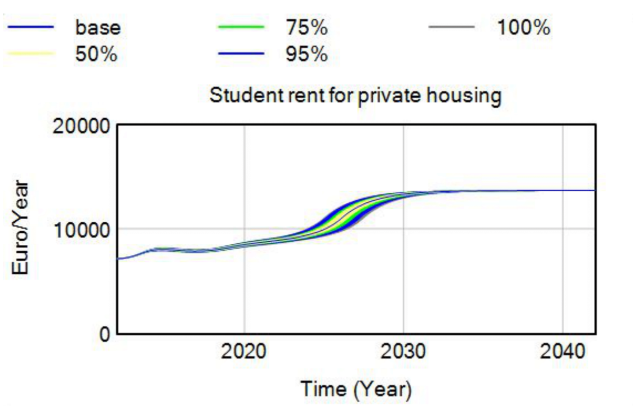
To assess the parametric uncertainty, a multivariate sensitivity analysis including all the initial values for the stocks was conducted. 200 runs with a ± 10 % variation on these variables. The results show some numerical sensitivity, particularly for the mid-term and convergence towards the long-term. The overall behaviour of these key output variables remains unchanged showing low behavioural sensitivity.







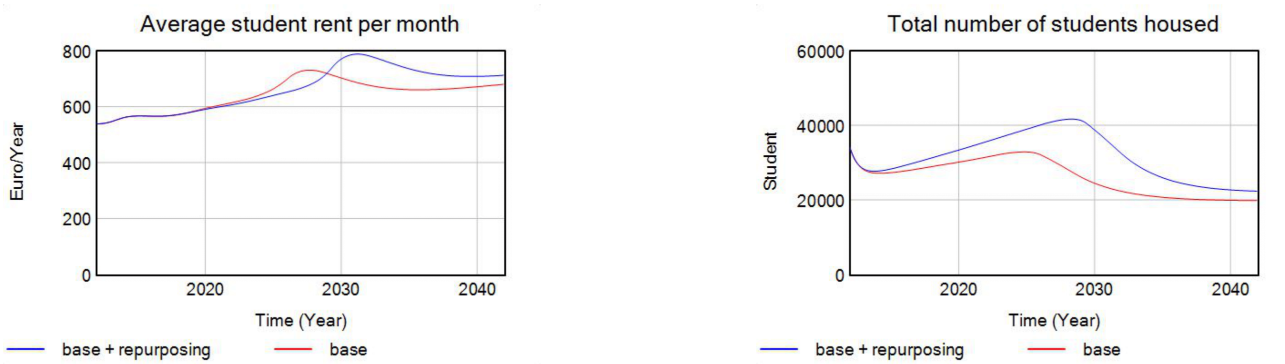




D. Structural Uncertainties - Boundary Adequacy Test

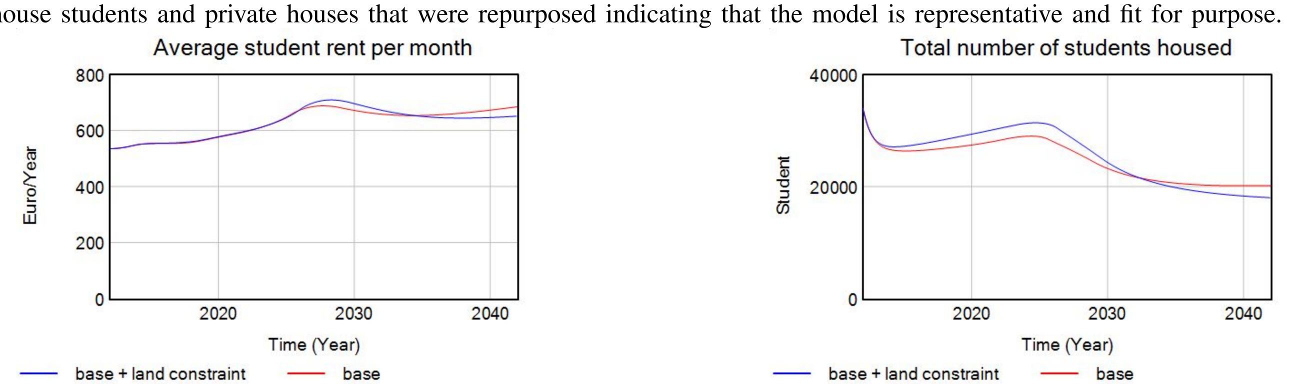
Land Scarcity: The introduction of land scarcity to the model caused an oscillating accumulation of student and private housing stocks. This can be attributed to the dependence of new house construction on the availability of land. The construction output decreases when no land is available, decreasing the two housing stocks. At the same time, demolishing old houses makes land available for housing. Since we defined land scarcity through the interaction of construction and demolition, a decreased construction output increases available land; hence, a decreased housing construction is followed by an increase. This feedback relation is responsible for the oscillating accumulation of housing stocks.

However, it was found that the problem behaviour of the model does not change significantly when including the structural relations between material resources and the construction output (Appendix Y). This is because the supply subsystem is primarily centred on the decision-making process of constructing private versus student housing. As such, the model is principally designed to depict the dynamic interplay between construction preferences and the rental subsystem, with less emphasis on the impact of physical constraints such as land scarcity on construction volume. Therefore, the structural uncertainty arises from an interest in comprehending the relationship between land scarcity and construction volume rather than how rent prices affect construction companies' decision-making process; and thus can be neglected.



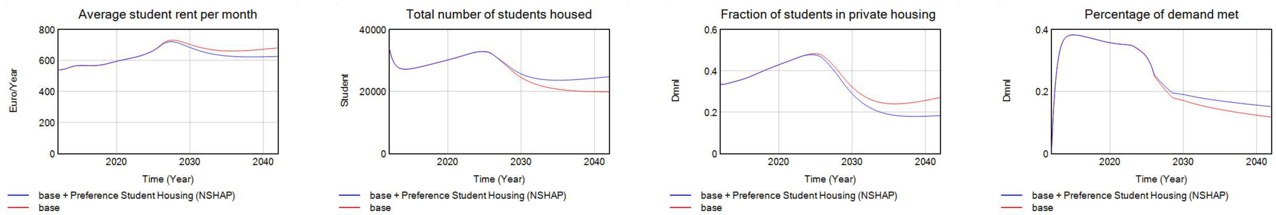
Repurposing Private Housing: The supply of private houses available for students in the model is driven by the construction and demolition of student houses for students. This simplification in the supply could represent a major source of structural uncertainty. To assess this uncertainty, repurposing private houses into private houses available for students was enabled. This phenomenon represents the choice by private landlords to start offering their properties to students in light of the high rents that students are paying. This choice was modelled using a sigmoid function that depends on *Average private rent* and is centred on the average rate of repurposing between 2012 and 2020 calculated with CBS data on Amsterdam housing and data on student housing.

This modified private housing supply subsystem structure generated little to no impact on short-term behaviour (Appendix Y). In the mid-term, the repurposing rate also increases as the *Average private rent* increases due to increased shortage. In the long-term, this effect is balanced by a reduction in the rent growth due to the increased supply of private houses for students making the value of rent and the total number of students housed converge towards the values of the unmodified model. Effectively, the model's behaviour is delayed but not profoundly modified validating the structure of the private housing supply subsystem. Furthermore, policy tests don't distinguish between private housing that was initially built to house students and private houses that were repurposed indicating that the model is representative and fit for purpose.

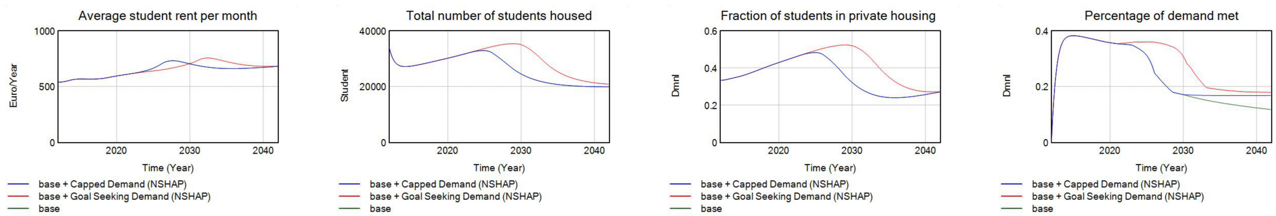


E. Policy Analysis

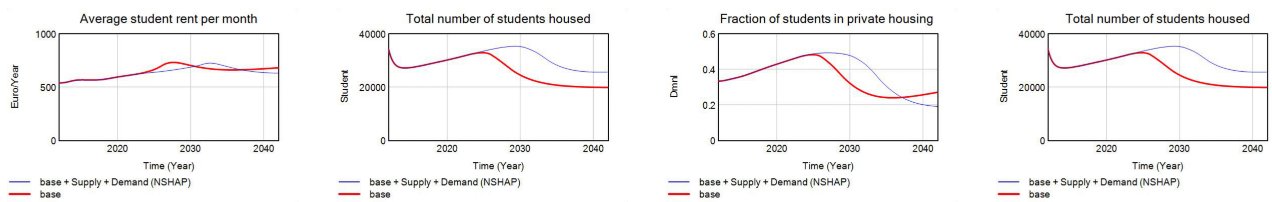
[NSHAP] Supply



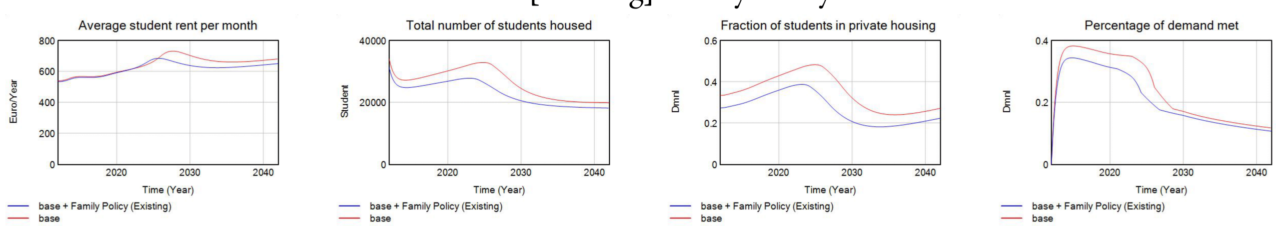
[NSHAP] Demand



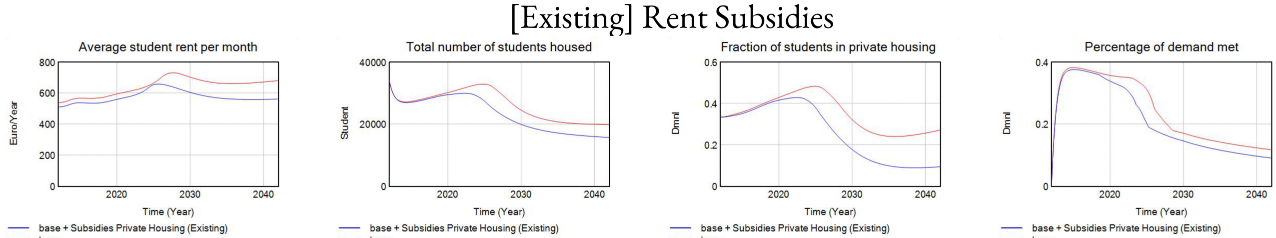
[NSHAP] Supply + Demand



[Existing] Family Policy



[Existing] Rent Subsidies



F. Model Data - Model Documentation

TABLE I: Model Documentation - Demand Subsystem

Name of Variable	Equation	Source	Description
Students looking for houses (shortage) Unit: Student	Student demand for housing - Withdraw demand for housing -"Shifting in (p)"-"Shifting in (s)" Init: 8,700	Derived from the estimated total amount of Student Shortage reported by NSHAP(2022), and the proportion of total students living in Amsterdam from Nuffic (2021)	Conceptualized as several students that don't find student house or can't afford private housing. Additional outflow stock represents unhoused students no longer looking for housing.
Students housed in private housing Unit: Student	Shifting in (p) - Shifting out (p) Init: 11,330	Derived from data of Nuffic (2021) and student housing data from the Student Housing Monitor 2022	This stock represents a fraction of the private housing available for students.
Students housed in student housing Unit: Student	"Shifting in (s)"-"Shifting out (s)" Init: 22,660	Derived from data of Nuffic (2021) and student housing data from the Student Housing Monitor 2022	The model assumes that all spaces in student housing are used by students.
Fraction of available private housing afforded by students Unit: Dmnl	Lookup with student rent for private housing. Graphs are shown in Figure 8 at the end of the table.	Basic sigmoidal behavior was approximated to a sigmoid curve representing discrete choice, as stated by Kubli et. al (2021), and constructed using current average rents and model calibration.	The fraction of students that move into private housing is assumed to depend on the private rent. This relation was approximated with a sigmoid curve where the higher the rent, the lower the proportion of students who can move in. To further assess the deep uncertainty related to this relation, a discrete sensitivity analysis was conducted.
Average accommodation time Unit: Year	3.1	Calculated with a ratio of Masters vs bachelors student ratio in Amsterdam with data of 2012 to 2021 from Nuffic (2021)	Was approximated, assuming (Master on average 2 years, Bachelors 4 years, 37% students living in AMS are doing a Masters, calculated average of 3.1 years.
Student demand Unit: Student/Year	Lookup with time between 2012 and 2052. Graphs shown in Figure 9 at the end of the table.	Data on international students in Amsterdam between 2006 and 2021 is taken from the Student Monitor; the expected amount of students living far from home is obtained from NSHAP.	Student demand in Amsterdam.
Withdraw demand for housing Unit: Student/Year	DELAY3("Students looking for houses (shortage)" /Withdrawal delay time, Withdrawal delay time)	N/A	Withdraw demand for housing is an outflow from Students looking for houses.
Shifting in (p) Unit: Student/Year	MIN(MAX((Private housing for students* "Spaces to housing ratio (p)") - Students housed in private housing,0) * MIN(Fraction of available private housing afforded by students, 1) / Shifting delay time, "Students looking for houses (shortage)" /Shifting delay time)	N/A	This flow is defined by the fraction of students that can afford the current average rent of private housing.
Shifting in (s) Unit: Student/Year	MIN(MAX((Student housing * "Spaces to housing ratio (s)") - Students housed in student housing,0)/ Shifting delay time, "Students looking for houses (shortage)" /Shifting delay time)	N/A	This flow is assumed only to be defined by the availability as it is assumed that students will first look for this type of housing before assessing the private market.
Shifting out (p) Unit: Student/Year	MIN(Students housed in private housing/ Average accommodation time, Students housed in private housing/TIME STEP)		Outflow of Students housed in private housing controlled by a material delay
Shifting out (s) Unit: Student/Year	Students housed in student housing /Average accommodation time		Outflow of Students housed in student housing controlled by a material delay
Student demand for housing	Student demand		Inflow increases Students looking for houses (shortage) and is extrapolated from NSHAP data and modified in policy scenarios.

Total number of students housed Unit: Student	Students Housed in Private Housing + Students Housed in Student Housing		The total number of students housed in both stocks
Shifting delay time Unit: Year	1	N/A	Shifting from student housing to private housing delay time.
Withdrawal delay time Unit: Year	1	N/A	Delay time for students to leave Amsterdam if they cannot find an accommodation
Shifting delay time	1	N/A	Delay time for the shift between student and private housing
Fraction of students in private housing Unit: Dmnl	Students housed in private housing / (Students housed in student housing + Students housed in private housing)		Ratio of students in private housing
Percentage of demand met Unit: Dmnl	(”Shifting in (p)”+”Shifting in (s)”)/Student demand		Percentage of students demand met

TABLE II: Model Documentation - Rent Subsystem

Name of Variable	Equation	Source	Description
Average student rent per month Unit: Euro/Year	(((Student rent for private housing - "Subsidies for students (0)") * Students housed in private housing +Student rent for student housing * Students housed in student housing)/ (Students housed in private housing+ Students housed in student housing))/12		Average student rent per month in Amsterdam.
Base private housing rent Unit: Euro/Year	6840	Taken from Monitor studentenhuisvesting, 2013	Base private housing rent for students in Amsterdam
Percentage change in rent based on shortage Unit: Dmnl	Lookup with "Students looking for houses (shortage)". Graphs are shown in Figure 10 at the end of the table.	Approximated with data from Monitor studentenhuisvesting, 2013-2022	From basic economic behaviour, a higher supply shortage and a price increase are expected. The function describing this behavior was based on the literature on price elasticity, further refined by a calibration process. Deep uncertainty arises from this relation that was assessed with a sensitivity analysis.
Student rent for private housing Unit: Euro/Year	MAX(SMOOTH(Base private housing rent * Percentage change in rent based on shortage, Rent information delay),0)		Student rent for private housing in Amsterdam.
Student rent for student housing Unit: Euro/Year	6120	Taken from Monitor studentenhuisvesting, 2013	Student rent for student housing. Assumed to be constant through the years.
Rent information delay Unit: Year	2	N/A	Delay time for house suppliers to update their rent prices based on shortage
Change in rent Unit: Euro/Year	SMOOTH(Student rent for private housing, Change delay time)		
Rent cap Unit : Euro/Year	Base No Rent(1): 999999 Rent cap policy(2): IF THEN ELSE(Time >2022, Cap value, 99999) where Cap value=11000	N/A	Rent cap after 2022. Used in the recommended policy.

TABLE III: Model Documentation - Supply Subsystem

Name of Variable	Equation	Source	Description
Percentage change in construction volume Unit: Dmnl	Lookup with time, extending from 2011 to 2044 with values between 0 to 3. Graphs are shown in Figure 11 at the end of the table.	Interpolated from Statista ”Percentage change on previous year of construction sector volume in the Netherlands” to adjust to the scale of the model	Change in construction volume over time in relation to the base value in 2011.
Preference ratio private to student housing Unit: Dmnl	(Student rent for private housing/ (Student rent for private housing + Student rent for student housing)) *Preference factor		Preference ratio of private to student housing from a construction perspective.
Preference factor Unit: Dmnl	Base Preference (0): 1.35 NSHAP increase preference (1): 1.35 - STEP(0.35 , 2022)		Calibration value that reflects the extent to which the difference of rent values affects the ratio of construction between private and student housing. This value was assumed uniform in time and for all the rent values due to limitations of economic choice modeling for this case. The source of deep uncertainty was assessed with a sensitivity analysis.
Initial construction volume for potential student spaces Unit: House/Year	1,000	Approximated with data from CBS ”Average Construction Volume for the Netherlands” (2012-2022)	Average construction volume for Amsterdam (2012 - 2022)
Maximum change in land Unit: House/Year	500		Restriction on the base construction volume defined for the boundary adequacy test.
Changes in land usage	(”Construction (p)”+” Construction (s)” -”Demolishment (p)”-”Demolishment (s)”) / Maximum change in land		Land availability in relation to the maximum change in land used for the boundary adequacy test.
Effect of land constraints (0) BoundAdeqTest	MAX(1-Changes in land usage,0)		Switch variable, used only for boundary adequacy test.

TABLE IV: Model Documentation - Supply (p) Subsystem

Name of Variable	Equation	Source	Description
Planned private housing Unit: House	Planning (p)"-"Construction (p)" Init: 1,740	CBS Statline "Dwellings and non-residential stock; changes, utility function, regions", 2023	The amount of planned private housing is a fraction of the base construction volume dependent on the rent ration between private and student housing.
Private housing for students Unit: House	"Construction (p)"+Offer houses to students -"Demolishment (p)"-Decline houses to students Init: 11,330	Taken from CBS Statline "Dwellings and non-residential stock; changes, utility function, regions", 2023 and adjusted to the model scope.	Private housing for students stock.
Construction volume of private housing Unit: House/Year	Initial construction volume for potential student spaces *Preference ratio private to student housing *Percentage change in construction volume		Construction volume of private housing which is affected by initial volume, change in volume and preference factor of construction companies.
Construction (p) Unit: House/Year	DELAY3I("Planning (p)" , "Construction (p) delay time" , Planned private housing/"Construction (p) delay time")	Construction in the Netherlands (Loyens & Loeff, 2019)	Construction is defined as a material delay of the Planning stock.
Construction (p) delay time Unit: Year	1.5	Eskinasi, 2014	A fixed delay time for construction of both housing types was defined based on literature values.
Demolishment (p) Unit: House/Year	Private housing for students/ "Demolishment (p) delay time"		Demolishment is defined as a material delay of the housing stock.
Demolishment (p) delay time Unit: Year	75	Value estimated according to Pacheco, 2022.	A fixed delay time for demolishment for both housing types was defined based on literature values.
Planning (p) Unit: House/Year	Construction volume of private housing		Assumed to be dependent on the ratio of private and student rent that landlords can receive from each type of housing and on the base construction volume for Amsterdam.
Spaces to housing ratio (p) Unit: Student/House	Base Ratio(0): 1 Family Policy Ratio(1): 0.75		The ratio represents the spaces occupied per unit of private house. It is initially defined as 1 but is modified in policy scenarios representing the change in the minimum area of student rooms.
Decline houses to students Unit: House/Year	IF THEN ELSE(Fraction of repurposed housing * Total private housing stock <0 , -Fraction of repurposed housing * Total private housing stock, 0)		The number of private homes that will no longer be available to students. Used only for Boundary Adequacy test.
Total private housing stock Unit: House	Decline houses to students-Offer houses to students		Total private housing stock (including the ones rented by students and all others). Used only for Boundary Adequacy test.
Fraction of repurposed housing Unit: 1/Year			Fraction of total private housing stock used as private housing for students per year. Used only for Boundary Adequacy tests.
Offer houses to students Unit: House/Year	IF THEN ELSE(Fraction of repurposed housing * Total private housing stock >0 , Fraction of repurposed housing * Total private housing stock , 0)		The number of repurposed private houses offered to students. Used only for Boundary Adequacy test.

TABLE V: Model Documentation - Supply (s) Subsystem

Name of Variable	Equation	Source	Description
Planned student housing Unit: House/Year	”Planning (s)”-”Construction (s)” Init: 1,740	Approximated with data from ASVA studententenuie (2012)	The amount of planned private housing is a fraction of the base construction volume dependent on the rent ration between private and student housing.
Planning (s) Unit: House/Year	Construction volume of student housing Init: 1,740	Taken from Amsterdam municipality’s Woningbouwplan (2018)	Assumed to be dependent on the ratio of private and student rent that landlords can receive from each type of housing and on the base construction volume for Amsterdam.
Student housing Unit: House	”Construction (s)”-”Demolishment (s)” Init: 22,660	Interpolated from the percentage of students living in Amsterdam from Nuffic (2021) and the Student Housing Monitor.	Student housing stock.
Construction volume of student housing Unit: House/Year	Initial construction volume for potential student spaces *(1-Preference ratio private to student housing) *Percentage change in construction volume		Construction volume of student housing which is determined by initial volume, change in construction volume, and preference of construction companies.
Construction (s) Unit: House/Year	DELAY3I(”Planning (s)”, ”Construction (s) delay time” , Planned student housing /”Construction (s) delay time”)	Value estimated by Eskinasi, 2014	Construction stock for student housing in Amsterdam.
Construction (s) delay time Unit: House/Year	2.33	Projectinformatie - Stichting DUWO, 2023	Construction delay time for student housing. Assumed to be constant over time and equal for both student housing and private housing.
Demolishment (s) Unit: House/Year	DELAY N(”Construction (s)”, ”Demolishment (s) delay time”, Student housing/”Demolishment (s) delay time”, 2)	Value estimated by Eskinasi, 2014	Outflow of Student housing stock.
Demolishment (s) delay time Unit: Year	50	Approximated according to Pacheco, 2022.	Delay time of student housing demolishment. Assumed to be constant over time and equal for both student housing and private housing.
Spaces to housing ratio (s) Unit: Student/House	1	N/A	The ratio represents the spaces occupied per unit of the student house. It is initially defined as 1 but is modified in policy scenarios representing the change in the minimum area of student rooms.

G. Lookup Graphs

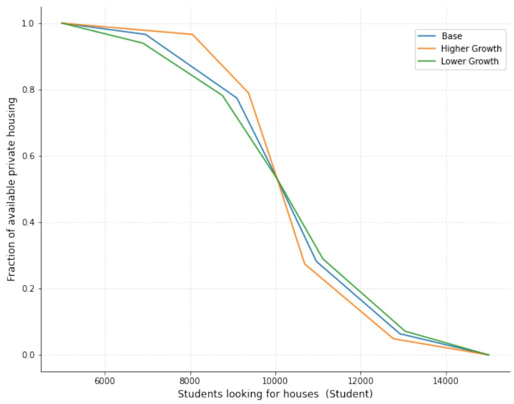


Fig. 8: Fraction of available private housing afforded by students

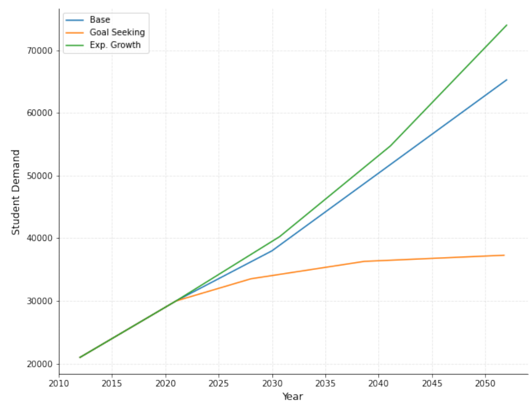


Fig. 9: Student Demand

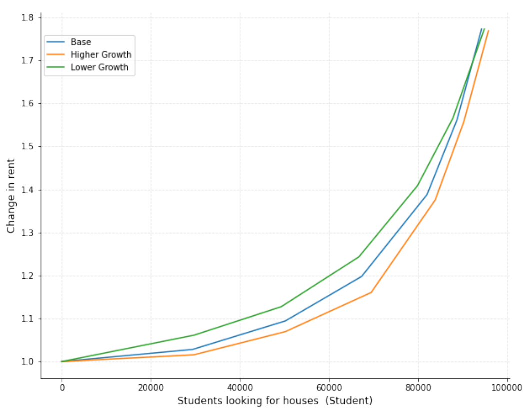


Fig. 10: Percentage change in rent based on shortage

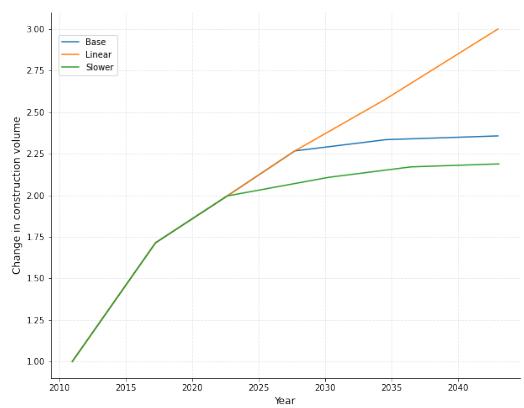


Fig. 11: Percentage change in construction volume

H. Limitations

Data Availability
One significant limitation of our study is the lack of available data or information on certain key variables. The difficulty in data availability lies in our unorthodox system boundary - in which we only analyze supply, demand, and rent for the ”students residing away from home”. The uncertainty arising from approximating this data causes slight behavioural sensitivity in our various validation tests, such as the multivariate sensitivity analyses. However, all behavioural sensitivities are limited to changes in time lags, for instance, the time of the collapse. The general shape of the behaviours still holds up to a level of integrity. It is argued that this uncertainty does not compromise the validity of our policy recommendation, but it will be difficult to pinpoint the exact time frames the policy should be enacted as well as the specific goal values for the rent cap.

Tests on Shocks
Additionally, we lack an extensive assessment of robustness. In our paper, we discuss the idea of robustness with a focus on the social drivers of change, which is represented by varying the effect of endogenous variables. However, we did not test exogenous shocks, which arguably are extremely likely in light of the recent COVID-19 occurrences and the nitrogen crisis. As such, it can be assumed that our model only addresses *prima facie* conditions as we believe that solutions will benefit more greatly from explaining the existing systemic structure than testing future uncertainties extensively.

Future Improvements to data
Given the lack of data availability, future work can focus on better means to obtain more accurate data - such as gathering data specifically for Amsterdam or conducting choice experiments to model housing construction preferences or affordability better, which could further reduce uncertainty by improving model reliance if a detailed assessment of specific threshold values or adaptation signals is needed. Likely, there would not be a convenient way for this, and it involves much time and financial investment. It can be advocated that this would be worth it to work towards greater specifics of our policy recommendations.

Future expansion of the model
Finally, there could be a need to expand the structure of our model in the future. Through the modelling process, there is a constant awareness that the interactions between the supply, demand, and rent subsystems are crucial points of understanding. However, there is not much available specific literature to understand these complex interactions; we approximate general economic theories to model this relationship. We recommend that future models look further into them and that adding these structural linkages could potentially uncover more areas to leverage policies.

I. Hour-Log

TABLE VI: Log of worked hours divided by weeks for all team members

Week	**Canan**	**Ariel**	**Ludwig**	**Ryan**	**Alex**
1	7,5	7,5	6	6	6
2	8	8	8	8	5
3	6,5	6	6	6	8
4	9	6	9	9	9
5	6	9	5	5	7
6	7	7	7	7	5
7	8	10	8	8	10
8	9	7	9	9	9
9	12	13	14	15	12
Sum	73	73,5	72	73	71