A Heterogeneous Boundedly Rational Agent Model Simulating Real-Estate Price Dynamics

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Abstract

This dissertation investigates real-estate price dynamics by constructing a heterogeneous agent-based model of boundedly rational agents. The model accounts for pricing strategies based on past market fundamentals and past price development with agents altering behaviour according to a social dynamic. The behaviour of the model is examined with respect to various parameters and reveal that real-estate price instability depends crucially on features that characterize different types of real-estate. In addition, the effectiveness and limitations of several price reduction policies are assessed through simulations. The results suggest that policies which increase the elasticity of supply result in desirable market fundamentals and a trade-off in terms of increased real-estate price volatility. In contrast, policies increasing the elasticity of demand and interest rate yield a more stable real-estate market, although with less desirable market fundamental outcomes. These insights inform policymakers of critical features and tradeoffs to account for when addressing the real-estate market's price volatility.

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1 Introduction

This dissertation investigates real-estate price formation dynamics through a heterogeneous agent-based model and is based on a prominent neoclassical real-estate market model. The real-estate market plays a crucial role within a nation's economy and brings together various stakeholders such as homeowners, renters, contractors and renovators. Real-estate volatility and market crashes manifest into negative social consequences such as higher risk of mortgage delinquencies, systemic economic damage from defaulted loans, and direct fallout in wealth and consumer sentiment from falling house prices. One does not need to look further than the aftermath of the U.S housing market bubble and the following financial crisis of 2007-2008 to understand the severe consequences of an unstable real-estate market. Understanding the dynamics of house price formation is becoming increasingly relevant due to booming real-estate market developments across the world, such as the Chinese housing market, in which house prices have on average grown nearly twice as fast as national income over the decade (Chen and Wen 2017).

The real-estate market, much like many durable goods markets, is often modelled within a stock-flow framework with a specific functional form. Such a market often exhibits characteristics of a cobweb or corn-hog cycle due to construction lags leading to periodic over and under building (Grebler and Winnick 1956, Wheaton 1987). Previously, such cycles have been dismissed as being the product of uninformed agents making systematic errors about future market conditions (Wheaton 1999). However, further studies have demonstrated sustained irrationality and heterogeneity in agents within the real-estate sector in regards to price development (Shiller 2007). Against this backdrop, a nascent literature of Heterogeneous Agent Models (HAM) developed in pursuit to describe the real-estate market more effectively (Burnside et al. 2011, Dieci and Westerhoff 2012, Bolt et al. 2014, Eichholtz and Huisman 2015, Ozbakan and Dikmen 2019) with many models originating from the HAM literature exploring dynamics within the financial markets.

The HAM presented in this dissertation introduces a novel social dynamic of agent interaction inspired by empirical observations of real-estate investor behaviour. Furthermore, this dissertation not only evaluates the behaviour of the model with respect to the new parameters introduced, but contrasts three different policies controlling real-estate price level and volatility. The presented model builds upon a well known neoclassical stock-flow model which is extended to incorporate boundedly rational agents and a social dynamic of agent interaction. Heterogeneous agents consist of two types of real-estate market investors; *fundamentalists* who base their real-estate price valuation on market fundamentals and *momentum traders* who price real-estate assets depending on past price development. Inspired by the approach of Ozbakan and Dikmen 2019, agents switch their investment strategy according to a recruitment model (Kirman 1993) in which the probability of an agent converting to a specific strategy is increasing in the relative proportion of agents holding the respective strategy. This approach is augmented by allowing parameters of the recruitment model to be endogenously determined by relative past performance of an investment strategy against the alternative strategy, which is determined by a fitness model (Eichholtz and Huisman 2015).

In the remainder of the thesis, I first review the relevant literature and focus on its development from rational expectations to HAMs incorporating bounded rationality. Subsequently, I review the literature on investment strategy heterogeneity and the social dynamics of investors, which motivate the specific characteristics of the model presented. I then present the theoretical foundation and the system of equations of the benchmark neoclassical model and the extended model before presenting the computational representation of the HAM. Various experiments are then tested with the benchmark and extended model, such as negative exogenous demand shocks with certain policies. The results are assessed both quantitatively and qualitatively. Finally, I discuss possible policy relevant insights in further detail before addressing the inherent limitations of the presented model.

2 Literature Review

HAMs were initially conceptualized for financial markets and have been recently applied within the context of the real-estate market (Ozbakan and Dikmen 2019). The two fields have developed in parallel with the modification of financial market models to explain behaviour of the real-estate market. The feasibility of modifying financial market models to a real-estate context is possible due to the increased similarity in the nature of the assets in terms of cash flows yields, possibility of capital appreciation and being subject to speculation. This is contrary to the previous conventional views on the real-estate market, which dictated that real-estate prices are determined by construction costs (Grebler and Winnick 1956), much like manufactured goods. Therefore, there was thought to be no prospect in profiting from real-estate speculation since if the price rose enough, more units could be easily built. However real-estate trends in the past decades have changed this. Davis and Heathcote 2007 reveal that the percent of home value accounted for by land in the United states rose from 15% in 1930 to 47% in 2006 and that land prices account for a major share of house price fluctuation. This increased similarity of being subject to speculation between real-estate and other financial assets suggest that when evaluating the nascent literature of HAMs within the context of the real-estate markets, it is appropriate to review the corresponding literature within financial markets. I next discuss the development of the literature from assuming rational expectations to boundedly rational agents.

2.1 Development from rational expectations to bounded rationality

Before HAMs and bounded rationality were conceptualized for the study of financial markets, the rational expectations hypothesis had dominated the expectation formation paradigm in economics since its introduction in the sixties by Muth 1961. Rational expectations is characterised by two aspects: a rational decision rule that has some micro-economic foundation and is derived from optimization principles, such as expected utility or profit and rational expectations concerning future events so as to not make systematic forecasting errors (Hommes 2005). In the seventies and eighties, representative agents, the efficient market hypothesis and rational expectations continued to dominate the paradigm in economics and finance.

However, inspired by inconsistencies between the rational expectations paradigm predictions and observed behaviour, in the late eighties and nineties heterogenous agent models and bounded rationality became increasingly popular. For instance, Shiller 1981 and Leroy and Porter 1981 claim that stock price movement display excess volatility that may not be attributed to market fundamentals alone. Furthermore, observations such as the stock market crash of October 1987 and the strong appreciation followed by a strong depreciation of the U.S. dollar in the mid-eighties, which seemed to be unrelated to economic fundamentals, were hard to explain by a representative rational agent model (Hommes 2005). Moreover, Cutler and Summers 1989 conduct several tests to examine the fraction of variation in aggregate stock returns that can be attributed to news concerning macroeconomic fundamentals and show that these only account for a third of the variance of stock returns, thus challenging the representative agent rational expectations model further. As emphasized by Arthur 1995 and Hommes 2001, the unrealistic assumption concerning perfect information about the surrounding environment and unlimited computing power is implausible. These observations prompted the development of boundedly rational HAMs which aspire to capture reality more accurately.

2.2 Review of investment strategy heterogeneity and the social dynamic

I turn to discuss the literature on investment strategy heterogeneity and the dynamic dictating how investors change strategy, which will contribute towards the specifications chosen for our model.

With the evolution of financial markets simulations from representative agent rational expectations models towards heterogeneous rationally bounded models, the natural question remaining is what is the type of heterogeneity one should introduce? Although, as noted in Clayton and Naranjo 2009, fundamentals do not completely explain the dynamics of price movements of real-estate, they still do explain a considerable proportion. Therefore, this suggests that any heterogeneity in a model describing real-estate price dynamics should have a portion capturing the fundamentals of the environment.

Additionally, Eichholtz and Huisman 2015 find the presence of a first-order moving process and there is substantial further empirical evidence that real-estate prices display strong positive serial correlation in the short term (Capozza and Mack 2004, Gao and Na 2009, Eichholtz and Huisman 2015). Multiple surveys conducted by Case and Shiller 2007, in which homebuyers were asked how much of a change do they expect there to be in the value of their home over the next 12 months, reveal that times and places with high home price increases have high expectations of future home price increases, and when the rate of price increases changes, so too do expectations of future price increases, in the same direction. Home buyers expected past price developments to extrapolate forward and this behaviour has been often included in HAMs describing real-estate price formation (Dieci and Westerhoff 2012, Eichholtz and Huisman 2015, Ozbakan and Dikmen 2019). These observations suggest that models describing price dynamics ought to also account for moving averages. Since these two strategies of investment, one based on fundamentals and the other on past performance, are known to influence investment decision making, I represent these in the model with heterogeneous agents implementing the respective strategies.

Next, I discuss the literature on the social dynamic between agents within the real-estate market to inform of an appropriate method of conceptualizing this into our model. I first discuss the implied presence of dynamic shifting amongst investment strategies in the real-estate market. Then, I discuss the literature on plausible factors affecting the dynamic.

Past studies have concluded that observed real-estate price behaviour supports the hypothesis of agents switching valuation strategies of real-estate over time. Eichholtz and Huisman 2015 examine whether fundamental factors or a momentum trend explains real-estate price dynamics. They find that the importance of each investment strategy driving real-estate prices varies over time and that during slowdowns expectations are more shaped by economic fundamentals, whilst during booms they are shaped more by past momentum. The study is unique due to the extremely long time series data used, which is particularly relevant for studying the real-estate market since investment horizons and cycles may prolong for many decades. Similarly, Ozbakan and Dikmen 2019 show that allowing for time varying weights of fundamental and momentum trading investors based on past performance of an investment strategy brings about a significant improvement to the benchmark neoclassical model, when validating against data on Istanbul's housing market. Likewise, Bolt et al. 2014 publish a real-estate market model with heterogeneous expectations that links rental levels to prices via imputed rents and find that the data supports heterogeneity in expectations, with temporary switching between trend extrapolation and mean-reversion strategy. These observations demonstrate that the relative prevelance and importance of an investment strategy in explaining market behaviour is fluctuating over time thus suggesting that it is appropriate to include a dynamic of switching investment strategies. Next, I draw upon past literature examining the factors affecting the investment strategy switching dynamic amongst investors within markets.

It is reasonable to assume that the relative past performance of an investment strategy is a driving factor of the switching of investment strategies, since investors are profit maximisers and thus seek to follow strategies offering the highest profits. This is consistent with the evolutionary approach, advocated by Nelson and Winter 1973, in which agents select a class of behavioural strategies according to their relative performance (Hommes 2005). Consequently, such a dynamic is often used in financial market simulations (Brock and Hommes 1997, Kouwenberg and Zwinkels 2014), however an alternative dynamic may be offered from behavioural economics. Herd behaviour and social contagion has been observed to contribute towards the switching of investment strategies within a market and thus is a source of endogenous fluctuation of the price levels of assets (Shiller 2007). Shiller 2007 argues that the feedback that creates bubbles has the primary effect of amplifying stories that justify the bubble initially, which he coins as "new era" stories. He recounts occasions in which vivid alarmist narratives of the future where present during unusual booms. For instance, he attributes the Club of Rome's study "Limits on Growth", which predicted expanding population growth rates causing exhaustion of resources and mass starvation, as a driver of the "great population scare" leading the boom of U.S. farmland prices. The boom had coincided with a common concern that farmland was diminishing as it was being converted to suburban areas, shopping centres and parking lots, and thereafter never able to return to agricultural use. Shiller notes that such stories are promulgated by word of mouth or via news media. For this reason, namely that the contagion properties of convincing an agent to prescribe to an investment strategy increases with the popularity of it, the recruitment model explaining "heard" behaviour within financial markets developed by Kirman 1993 seems appropriate to adopt.

Following Ozbakan and Dikmen 2019, Eichholtz and Huisman 2015, Bolt et al. 2014, Burnside et al. 2011, Dieci and Westerhoff 2012 and accounting for the developments made in the literature of real-estate and financial markets simulations, I incorporate dynamic shifting of investment strategies in our heterogeneous rationally bounded agent model. To account for the social contagion observed in markets, I adopt an extended version of Kirman 1993 recruitment model in which parameter values are determined by a simplified fitness measure proposed by Eichholtz and Huisman 2015. Arranging the models in this order is intended to mimic the circumstance in which past predictive performance of a strategy influences the probability of contagion of that respective strategy, as opposed to converse.

3 Model

Our model's foundation is built upon a prominent analytical neoclassic real-estate model developed by Wheaton 1999, which is a stock flow model taking a specific functional form. Price movements of homogeneous pieces of real-estate are determined by market fundamentals such as elasticity of demand, elasticity of supply, the depreciation rate, the discount rate and the supply lag. The model incorporates backward looking behaviour by allowing agents to evaluate future prices based on current rents and interest rate.

3.1 Benchmark model

In the benchmark model, demand for rental property is a dynamic function of a demand constant (α_1), current exogenous demand of real estate (E_t), current rental level (R_t) and the demand elasticity (ε) described by Equation 1:

$$D_t = \alpha_1 E_t R_t^{-\varepsilon} \tag{1}$$

It is assumed that the market clears by rents adjusting until demand of rental property equals supply ($D_t = S_t$). Hence, this leads to the following relationship:

$$R_t = \left(\frac{S_t}{\alpha_1 E_t} \right)^{\frac{1}{-\varepsilon}} \tag{2}$$

Naturally, the rent level is increasing in the exogenous demand variable and decreasing in the stock of real-estate. The stock of space evolves according to the difference equation below. Depreciation occurs at a constant rate (δ) and the flow of new real-estate (C_{t-n}) is the level of construction initiated n periods ago, where n is the construction supply lag characterising time required for construction and project planning.

$$\frac{S_t}{S_{t-1}} = 1 - \delta + \frac{C_{t-n}}{S_{t-1}} \tag{3}$$

Therefore, the ratio of the current stock of real-estate to the last period is decreasing in the depreciation rate and increasing in the new realized flow of construction relative to last period's stock of property. The latter ratio is determined by the forecasted real-estate price for the time period when construction would be completed (P_t), a supply constant (α_2) and the price elasticity of supply (η):

$$\frac{C_{t-n}}{S_{t-1}} = \alpha_2 P_t^{\eta} \tag{4}$$

The ratio of new construction is increasing in the forecasted real-estate price. One of the simplest forms of myopic fundamental valuation behaviour is to assume that forecasts of asset prices n periods ahead is a constant capitalization of current rents at the time of the pricing decision (Wheaton 1999, Hendershott and Kane 1995):

$$P_{t+n} = \frac{V_t}{r} \tag{5}$$

This strategy of real-estate pricing will be referred to as "fundamentalist" henceforth. Such pricing strategy is myopic as it is backward looking and is a classical mistake which generates cobweb cycles (Wheaton 1999).

3.2 First extension: heterogeneity

I first extend the baseline model by allowing for naïve momentum traders, who value real-estate by projecting the moving average growth rates of the past m periods on the last period's price. In each period t, momentum traders determine a valuation for that period ($P_{m,t}$) using a moving average growth rate and project prices up until $t+n$:

$$P_{m,t} = \left(\frac{1}{m-1} \sum_{i=1}^{m-1} \frac{P_{t-i}}{P_{t-i-1}} \right) P_{t-1} \tag{6}$$

Simultaneously, fundamentalists continue to value real-estate for the current period by capitalizing current rents to the current interest rate. At time t, fundamentalist compute a valuation for that period ($P_{f,t}$) and project this price up until $t+n$.

$$P_{f,t} = \frac{V_t}{r} \tag{7}$$

Having extended the baseline model to incorporate heterogeneity in investment strategy, the realized market price of real-estate at time t is now defined to be the sum of the fundamentalist's valuation and momentum trader's valuation weighted by their respective representation in the investor population:

$$P_t = \frac{M}{N} P_{m,t} + \frac{N-M}{N} P_{f,t} \tag{8}$$

Where M is the number of momentum traders in the economy and N is the total number of agents.

3.3 Second extension: social dynamic

Next, I introduce the social dynamic through which agents interact and may switch their investment strategy from fundamentalist to momentum trader, or the opposite.

The behaviour switching regime follows an extended version of a stochastic recruitment model which explains the contagion behaviour described in financial markets literature as corresponding to the equilibrium distribution of a stochastic process rather than switching between two multiple equilibria (Kirman 1993). The state of the system is defined as the number momentum trader agents, M, amongst a total of N agents, i.e:

$$M \in (0, 1, ..., N) \tag{9}$$

The system evolves as investors interact in random. If a momentum trader interacts with a fundamentalist, then the probability of converting the fundamentalist to be a momentum trader at time t is $\rho_{m,t}$ and conversely the probability of converting a momentum trader to become a fundamentalist is $\rho_{f,t}$. There is a probability, θ, that an investor changes their strategy independently before interacting with anyone, which connotes random self-conversion for instance due to the replacement of an existing trader by a new one who may not share necessarily the same view (Kirman 1993). Dynamic development of the process is then given by the two probabilities below where $P(M, M+1)$ is the probability of an increment of M in a discrete time step and $P(M, M-1)$ is the probability of a decrement.

$$P(M, M+1) = \left(1 - \frac{M}{N}\right)\left(\theta + \rho_{m,t}\frac{M}{N-1}\right) \tag{10}$$

$$P(M, M-1) = \left(\frac{M}{N}\right)\left(\theta + \rho_{f,t}\frac{N-M}{N-1}\right) \tag{11}$$

I choose θ to be a small and positive and define $\rho_{f,t} + \rho_{m,t} = a$ where a is a positive constant, as this allows for an increasingly "persuasive" investment strategy to increase the relative probability of converting opposite agents to the respective strategy. For example, in the case that the momentum trading strategy becomes more "persuasive" (indicated by a higher $\rho_{m,t}$), this results in a higher probability of recruiting others to this strategy (increase in $P(M, M+1)$) and a lower probability of losing an agent from the momentum trading strategy to the fundamentalist (decrease in $P(M, M-1)$), since the the sum of $\rho_{m,t}$ and $\rho_{f,t}$ is the constant a. I allow for a positive θ so as not to get "stuck" at $M = 0$ or $M = N$.

To account for a learning process of investors in regards to the past performances of each investment strategy, I use a simplified version of the fitness model suggested by Eichholtz and Huisman 2015. This fitness model yields a relative performance measure ($w_{m,t} \in (0,1)$) which alters the probability of converting a fundamentalist to a momentum trader in an interaction ($\rho_{m,t}$) by the equation:

$$\rho_{m,t} = a w_{m,t} \tag{12}$$

The following multinomial logit probability determines the relative performance measure of the momentum trading strategy to the fundamentalist strategy ($w_{m,t}$) at time t. It includes a sensitivity parameter, $\gamma > 0$, and the potential realized gains or losses that an agent would have realized with either strategy at time t ($u_{m,t}$ for the momentum trader and $u_{f,t}$ for the fundamentalist):

$$w_{m,t} = \frac{e^{\gamma u_{m,t}}}{e^{\gamma u_{m,t}} + e^{\gamma u_{f,t}}} \tag{13}$$

The variable γ measures how sensitive the relative performance measure is to differences in realized profits between the two investment strategies. The case $\gamma = 0$ corresponds to the situation in which agents do not care about past performances of the strategies, hence these will not change the probabilities of "convincing" others to the respective strategy described earlier in the recruitment model. Conversely, if $\gamma = \infty$, this corresponds to the case in which agents weigh any difference in past performance heavily. Realized gains or losses of a strategy at time t is calculated as the profit or loss that an agent would have obtained over the past q periods having implemented the respective strategy, where q is a memory parameter. Specifically, the realized gain or loss from the momentum trading strategy ($u_{m,t}$) and the fundamentalist strategy ($u_{f,t}$) is given by:

$$u_{m,t} = \frac{1}{q-1} \sum_{i=1}^{q-1} \Delta P_{t-i} sgn(\Delta P_{m,t-i}) \tag{14}$$

$$u_{f,t} = \frac{1}{q-1} \sum_{i=1}^{q-1} \Delta P_{t-i} sgn(\Delta P_{f,t-i}) \tag{15}$$

Where $\Delta P_{m,t}$ and $\Delta P_{f,t}$ are the price change forecasts between time t and $t-1$ of the momentum trading strategy and fundamentalist strategy respectively.
The social dynamic thus encourages a larger fraction of the population to subscribe to the more effective investment strategy through the fitness model and, subsequently, through the

recruitment model. For example, consider the case that the momentum trading strategy would have yielded superior profits during past q periods. Assuming $\gamma > 0$, this would in turn result in the relative performance measure to be greater than 0.5. Thus, the probability of converting an agent to become a momentum trader ($\rho_{m,t}$) is larger than the probability of converting an agent to become a fundamentalist ($\rho_{f,t}$) by Equation 12 and 13. The converse is true, if the fundamentalist strategy had outperformed during the relevant memory period.

It is important to note that even if the model encourages agents to shift to the superior strategy, the recruitment model still allows for a contagion affect to take place and price bubbles to form. For instance, the momentum trader strategy valuation may deviate substantially from the fundamentalist's valuation, but if momentum traders are heavily represented in the population then the realized market price would be closer to the momentum trader's valuation and strengthen their probability of recruiting others. Therefore, the model allows for "self-fulfilling prophecies" to take place creating drastic deviation from market fundamentals.

3.4 Computational representation

To test the benchmark model I use parameter values which are used to scale the model's constants α_1 and α_2 to yield the steady state solution of $E = 10, S = 2,500$ million square feet, $R = \$20.00$ per square foot, $r = 0.05$ and $P = \$400.00$ per square foot through Equations 2-5. Such values mirrored the aggregate office market of the largest 54 U.S. metropolitan areas and elasticities in this range have been found for office space (Wheaton, Torto, and Evans 1997) and hotel space (Wheaton and Rossoff 1998). Although the time variable (t) is arbitrary, it may be interpreted as yearly, since all other variables and parameters values are in a yearly basis. See Table 1 for a list of the default values of the remaining parameters used in the simulations.

Similar to as observed in Ozbakan and Dikmen 2019, Figure 1 and 2 depict the steps in each discrete time period. Each run of the simulation iterates through a specified number of time steps during which market fundamentals, price forecasts and the distribution of the in-

Parameter	Symbol	Value
Elasticity of demand	ε	0.4
Elasticity of supply	η	2.0
Depreciation rate	δ	0.05
Lag period for construction	n	5
Interest rate	r	0.05
Moving average memory parameter	m	5
Fitness model memory parameter	q	5
Intensity of choice parameter	γ	0.1
Sensitivity parameter of recruitment model	a	0.1
Total number of investors	N	100

Table 1: Parameter values

vestment population evolve. The activity diagram of the baseline simulation can be observed in Figure 1. Initially, at $t = 0$ stock, rent and price are set to initial values, whilst initial construction activity is calculated according to Equation 4 and the initial delivered flow of real-estate is set to this. At later periods, the stock, rent, price and construction activity of real-estate are determined by Equations 2-5. Through subsequent iterations, the delivered flow of real-estate is set depending on whether the construction lag parameter (n) has lapsed.

While Figure 1 displays the benchmark model, the proposed extension differs by allowing for heterogeneous agents and dynamic agent behaviour in the box shaded grey, which represents the step where price is determined. This part is further explained in Figure 2.

As show in Figure 2, in the proposed extension of the model, the fundamental valuation from t to $t+n$ is first calculated followed by the calculation of the corresponding momentum trader's valuation, given at least m periods have passed. Thereafter, if q periods have lapsed, the fitness model calculates the relative performance measure of the investment strategies according to Equations 13-15 which subsequently determines the conversion probabilities for the recruitment model (Equation 12). Through the stochastic recruitment process, given by Equations 10-11, the new distribution of momentum traders and fundamentalists are determined. Using the newly formed composition of investors the price at time t and new forecasts up until $t + n$ are calculated by Equation 8. Initially, each investor is assigned randomly to either be a fundamentalist or momentum trader with a 50% chance and the distribution of investor types evolves continuously thereafter.

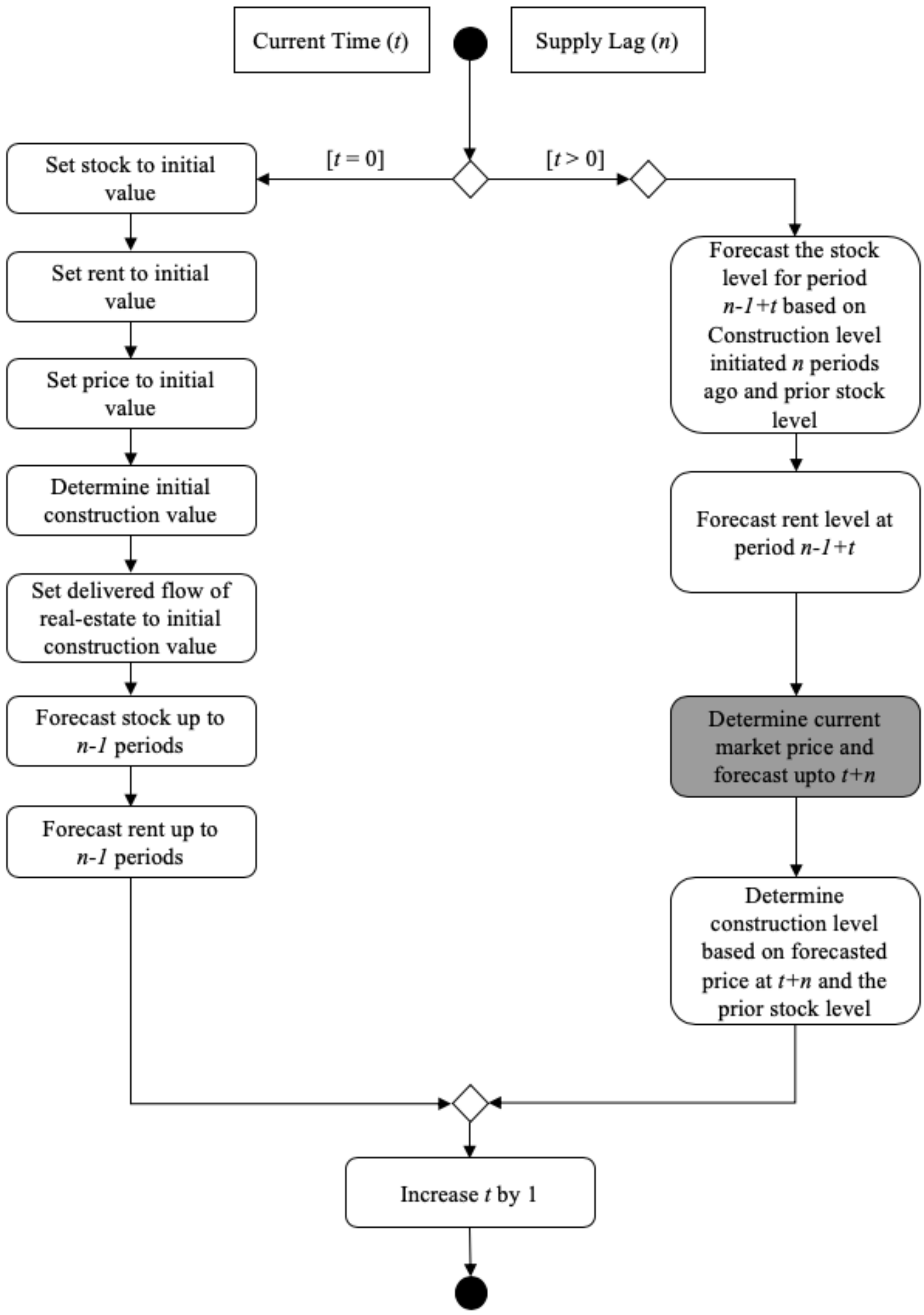

Figure 1: Baseline model activity diagram

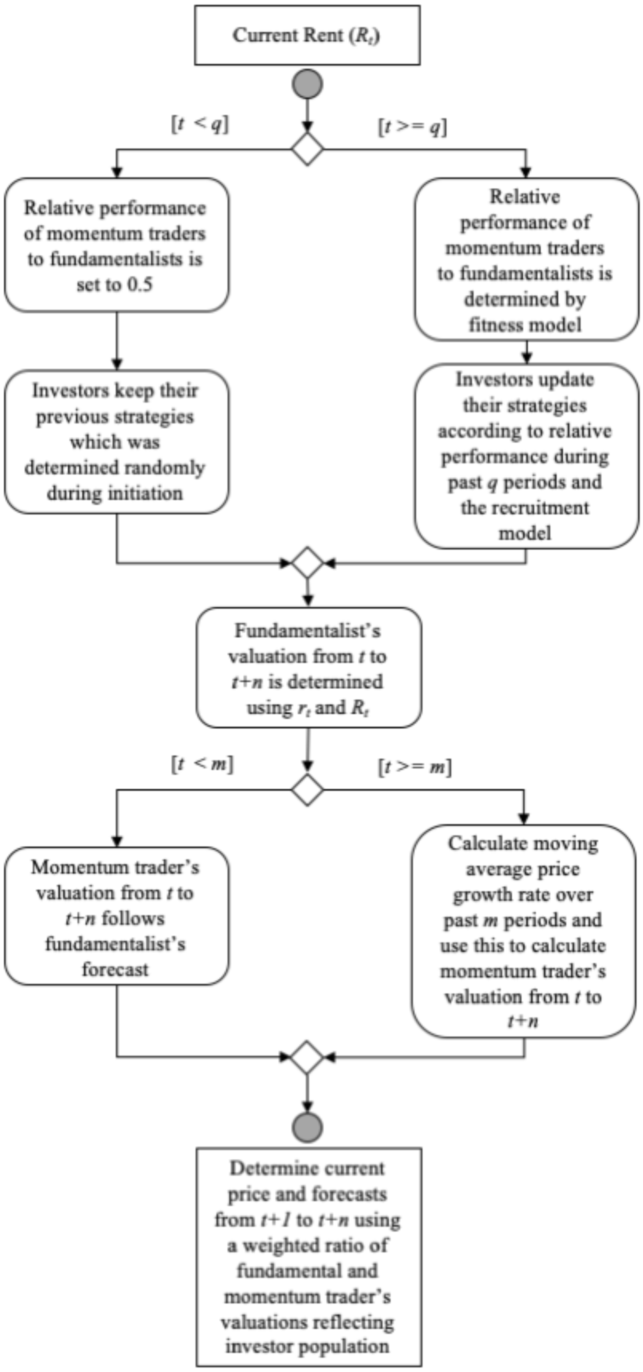

Figure 2: Extension activity diagram

The simulation in this dissertation was built with the programming language Python utilizing various imported libraries. The programme encapsulates the underlying logic of the model in the class “RealEstate”, which is initiated with the model parameters and contains methods to implement the aforementioned equations. In particular, the method “Iteration” calls for all the required steps in the simulation in the respective order as shown in Figure 1.

4 Experimentation

In this section I examine the previously described model through numerous simulations. I first test the model without the proposed extensions and, following Wheaton (1999), I simulate a negative demand shock in order to establish that the model is operating as intended. Next, I investigate the behaviour of the extended model with a negative exogenous demand shock. Finally, I examine the effect of various policies intended to decrease real-estate prices on the price volatility resulting from an exogenous negative demand shock.

4.1 Experimentation with the benchmark model

To validate the model is operating as intended, I construct a simulation similar to Wheaton 1999 and compare the results. I impose a -10% permanent decrease in the exogenous demand variable from $E = 10$ to $E = 9$ at $t = 1$ and plot the ratio of stock to exogenous demand and price level.

The results in Figure 3 show how the inelastic demand results in a sharp decrease in price, which persists until new flows of decreased construction levels are released into the market, thus decreasing supply. The results demonstrate a clear over and under building of the market with the ratio of stock to exogenous demand surpassing the analytical steady state level and oscillating around the steady state. Oscillations occur in both indicators and decrease in amplitude before finally converging to their steady state. Increasing the difference between the elasticity of demand and elasticity of supply, for instance changing them to 0.2 and 2.4 respectively, results in more drastic oscillations with low convergence. Likewise, increasing the construction lag parameter n yields a higher amplitude in the oscillations of prices, however with decreased frequency.

From Figure 4, which plots values of market fundamentals (S_t, R_t, P_t, C_t) at each discrete time step, we naturally see relationships emerging in line with expectations of the implemented equations. The figure reveals predictable and stable negative relationships between the stock of real-estate and rents as well as between construction levels and stock of real-

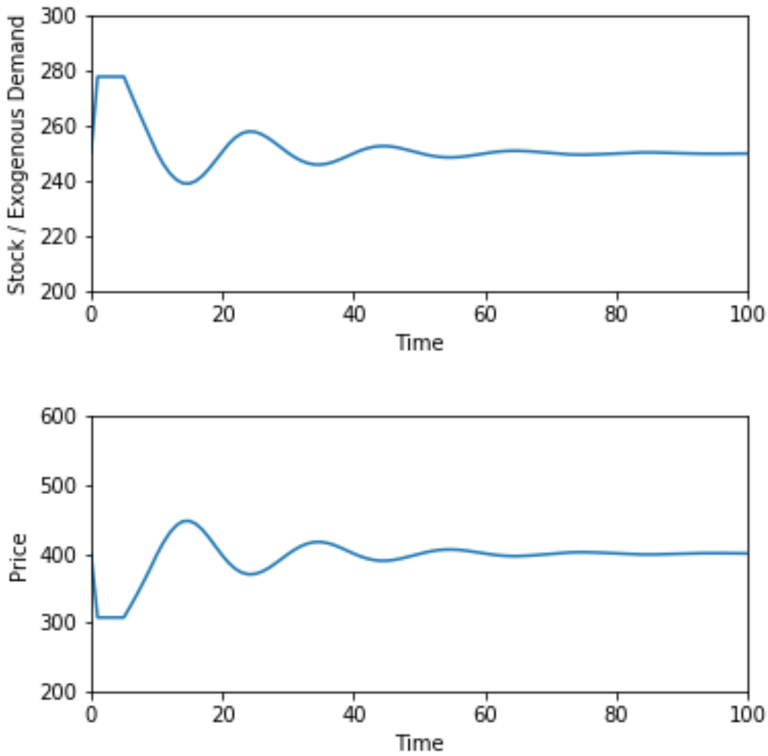

Figure 3: Baseline model experiment results

estate. In addition, fairly steady positive relationships occur between the rent and price of real-estate as well as between price and construction levels. The described relationships appear to be linear, although with greater variation in the magnitudes of the variables, more distinct forms emerge.

These results are alike to Wheaton's observations (Wheaton 1999, Figure 3), except flipped in the horizontal axis, as Wheaton uses a positive exogenous demand shock. Hence, this allows us to contrast the behaviour observed from the extended model incorporating the proposed modifications to the known behaviour of the Wheaton baseline model. Next, I introduce a similar exogenous negative demand shock to the model including the proposed extensions.

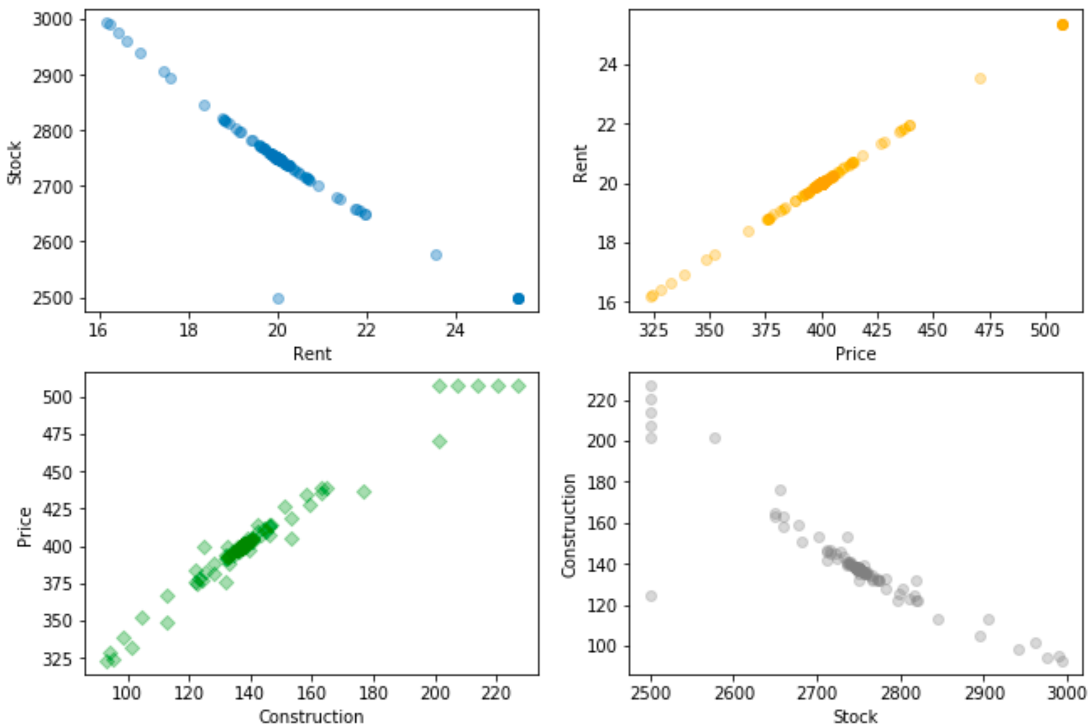

Figure 4: Baseline model market fundamentals quadrants

4.2 Experimentation with the extended model

Using the prior mentioned parameter values, I simulate a similar -10% decrease in the exogenous demand at $t = 99$ and observe the simulation behaviour up until $t = 300$.

Unlike the restricted model, which eventually converged to a steady state, the extended model demonstrates endogenous fluctuations attributable to the new momentum trader investor type and the stochasticity introduced through the social dynamic (See Figure 5). The price remains stable before the exogenous shock at $t = 99$, after which a cascade of oscillations of the price level occur, mostly between $P_t = 200$ and $P_t = 500$.

Concerning the new parameter values introduce by the extension, the model seems to behave in intuitive ways to parameter changes. Similar to as observed in the baseline model, increasing the difference between the elasticity of demand and supply increases the volatility

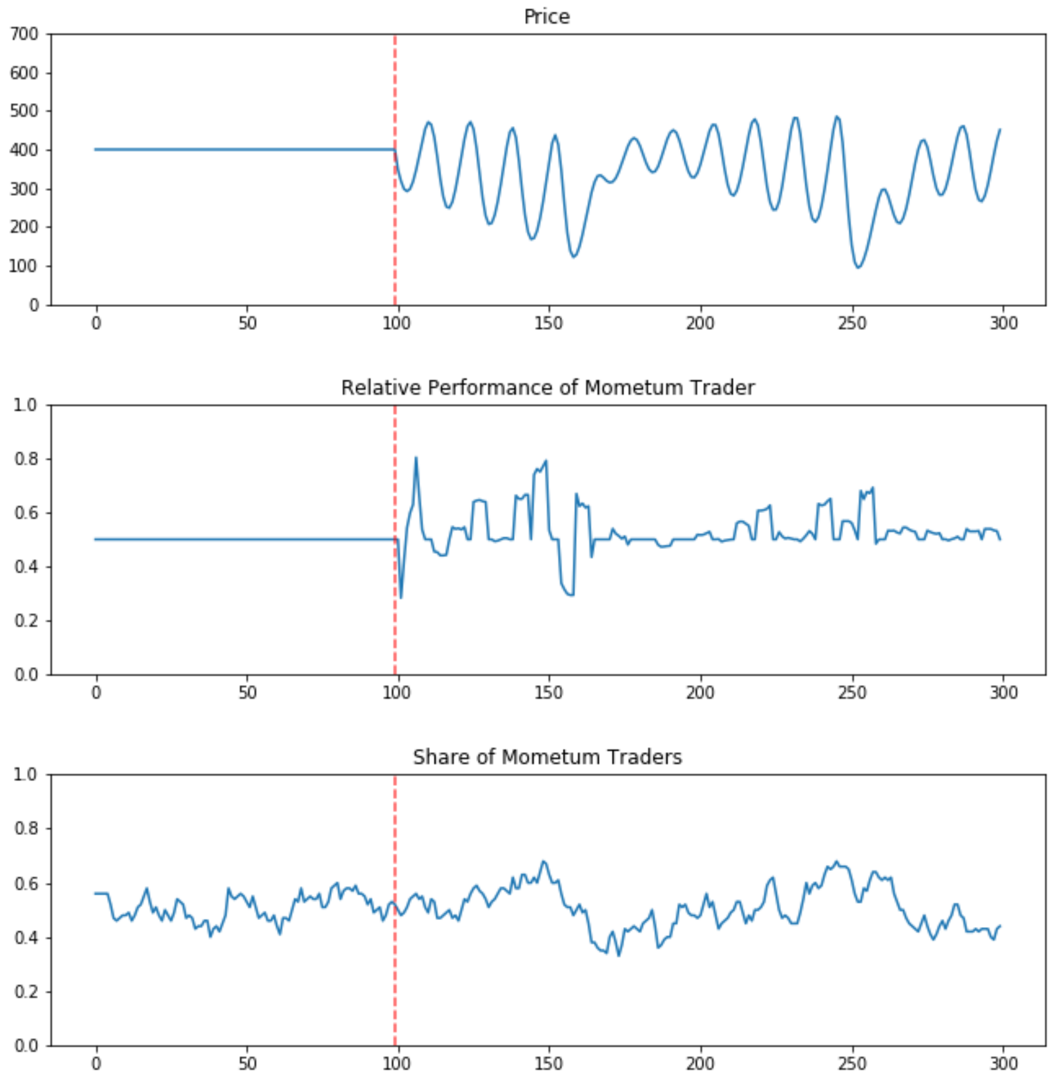

Figure 5: Extended model experiment results

of price swings (See Appendix Table 3 for statistical test and Figures 14-16). A large difference in the elasticities also results in price crashes with the price remaining near zero for a prolonged period (See Appendix Figure 16). Also, increasing the construction lag parameter n contributes towards increased price oscillations. An increase in the intensity of choice parameter (γ) and the sensitivity of the fitness model (a), which analogously represent an

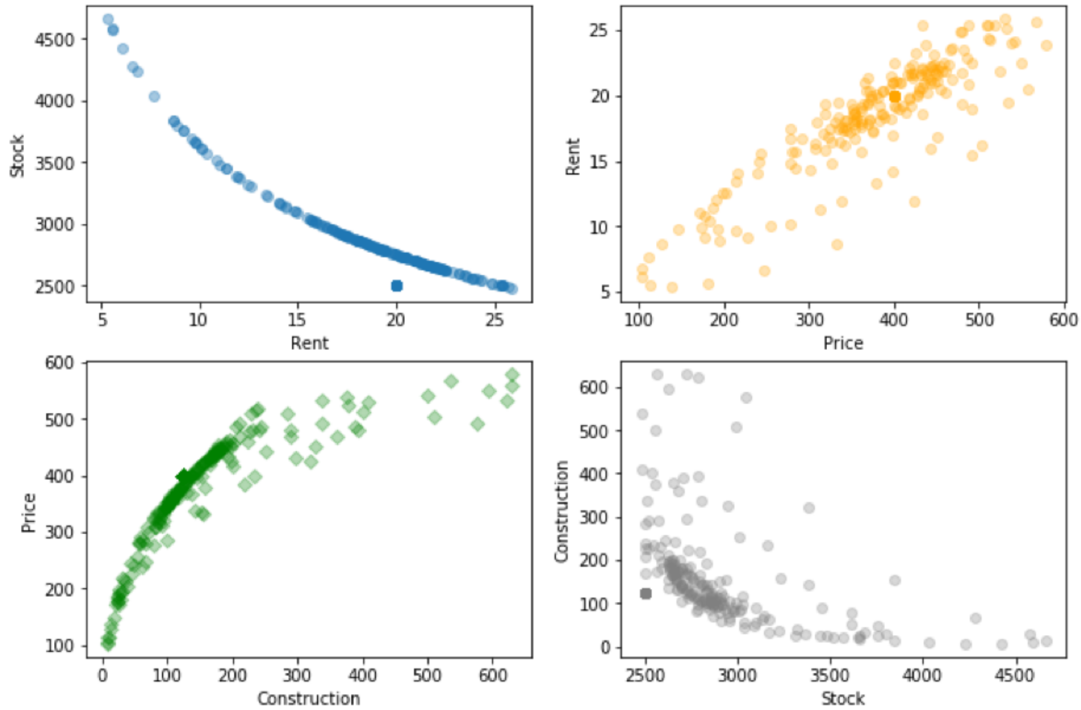

Figure 6: Extended model market fundamentals quadrants

investors "attentiveness" as to which strategy has performed better recently and the overall influence this has on decision making, results in larger oscillations with frequent crashes (See Appendix Figure 13).

It is evident that a smaller memory parameter of momentum traders (e.g. $m = 2$) results in more frequent and lower amplitude oscillations. As m increases, the oscillation amplitudes increases, albeit without price crashes. With a high momentum trader memory parameter, $m = 15$, the price level interestingly is more stable. A small ($m = 2$) or large ($m = 15$) memory parameter has a stabilising effect of real-estate price volatility with high volatility observed near $m = 8$ (See Appendix Table 4 for statistical test and Figures 17-19).

Right after the exogenous shock, the relative performance of fundamentalists increases because only the fundamentalist strategy is able to take information of changing exogenous demand into account. Afterwards, in the absence of further shocks to the system, the relative performance of the momentum trading strategy is more often superior.

From Figure 6 we see underlying relationships similar to that of Figure 4, with some deviation. The plots in Figure 6 display greater variability around the relationships in Figure 4, as well as different forms. For instance, in contrast to Figure 4, the stock to rent quadrant reveals a predictable and stable strictly convex relationship which is determined by Equation 2. The behaviour of the remaining quadrants' relationships are less orderly. For example, the rent to price ratio displays a negative relationship of elliptical cycles of discrete plots around the stable state at $P_t = 400$, $R_t = 20$ reflecting the market price oscillations, with greater amplitude oscillations expressed as larger ellipses. In addition, the price to construction level and construction level to stock of real-estate quadrants illustrate a strictly concave positive relationship and a less clear strictly convex relationship respectively. Figure 6 indicates that the volatility in price, further contributed by the heterogeneous agents and social dynamic, is linked to greater volatility in other market fundamentals such as stock of real-estate, construction levels and rent, which may, in addition to excess price volatility, have negative welfare consequences.

The simulations of the extended model demonstrate how the interaction between myopic fundamental investors and momentum traders may lead to a market with an endogenously fluctuating price level, initiated by an exogenous shock. This is exacerbated by a high presence of momentum traders, whilst a high presence of fundamentalist is often accompanied by relatively stable prices. Furthermore, it illustrates that periods with highest volatility need not be during an exogenous shock, but during the following unstable period and that the increased instability in price levels in turn generates increased volatility in other market fundamentals. Having contrasted the characteristics of various parameters of the model against the baseline, in the next set of experiments I investigate various policies targeted to decrease the price of real-estate.

4.3 Experimentation with various price reduction policies

Next, I consider the effect of three policies intended to decrease the price level on the vulnerability of the system in terms of real-estate price volatility and other market fundamentals. I implement each respective policy and introduce an identical unexpected negative demand shock. The three policies are:

1. Increasing the elasticity of supply

2. Increasing the elasticity of demand

3. Increasing the interest rate

The set of experiments are analogous to a policy maker relying on the neoclassical framework seeking to reduce real-estate prices from the market steady state with an unexpected negative demand shock occurring at a later date. Policy makers may choose to do so, for instance, in an economy in which the real-estate construction industry is dominated by an oligopoly and the resulting real-estate prices are accordingly at an undesirably high steady state level. Or, if in a low interest rate environment, real-estate price inflation is leading to excessive inequality between real-estate owners and renters. The exogenous shock implemented is used to assess the vulnerability of the system left by each policy in terms of exposure to unexpected future demand shocks. This may inform policy makers to choose policies that are appropriate and do not result in a vulnerable system that are prone to excessive price volatility in the case of an unexpected demand shock. It is important to note that the policies simulated are not intended to correct a current speculative market bubble. Although, despite this not being the aim of the policy maker in our simulation, this does not prevent such a bubble ensuing due to shifting fundamentals caused by the policy.

Each of the three policies proxy various real-life policies which are discussed later. The experimental framework is kept identical across policies. Each variable is altered so as to yield a 10% reduction in real-estate prices within a 10 year period in the baseline model ($P_0 = 400$ to $P_{10} = 360$). After this, at $t = 11$, a 10% permanent negative demand shock is introduced. Henceforth, the variables are not altered further allowing us to compare the state of the system after the respective policies had been implemented. I initially implement the experiments using the baseline model and then proceed to replicate them with the extended model. This allows us to contrast the conclusions regarding the policy drawn between the neoclassic model and the extended one incorporating heterogeneity and a social dynamic.

4.3.1 Policy 1: Increasing price elasticity of supply

First, I simulate the policy of increasing the price elasticity of supply of real-estate with the purpose to decrease price levels in the baseline model and consequently in the extended model. Real-life policies achieving this could for instance include liberalizing land controls or zoning schemes for real-estate development. This would increase the ability of developers to respond to changes in demand, since there is increased flexibility in construction levels delivered. Alternatively, polices aimed to increase competition in the real-estate development industry by decreasing barriers to entry result in an increased elasticity of supply. Such policies may include improving access to financing for new entrants or number of units available to bid for in a new site granted for development. With more market participants, if one supplier cannot meet the required quantity demanded, the others may fill in the gap leading to a more responsive, thus elastic, supply.

I investigate the effect of the policy by continuously incrementing the elasticity of supply by a constant in order to reach a price level of $P_t = 360$ by $t = 10$. Since the price level is monotonically decreasing in the elasticity of supply in the neoclassic model, I implemented a binary search algorithm in Python to find the constant by which to increment in each period. This process is described further in the code.

From Figure 7 we see how incrementally increasing the elasticity of supply by a constant results in the price decreasing to the desired price level of $P_{10} = 360$ with the baseline model. The price and rent levels display a similar behaviour to that of the exogenous shock experiment depicted in Figure 3. Construction and stock levels are also increasing whilst the policy is implemented and after oscillations, they settle at steady states noticeably higher than initial values.

Subsequently, I implement the same policy to the extended model (Figure 8) incorporat-

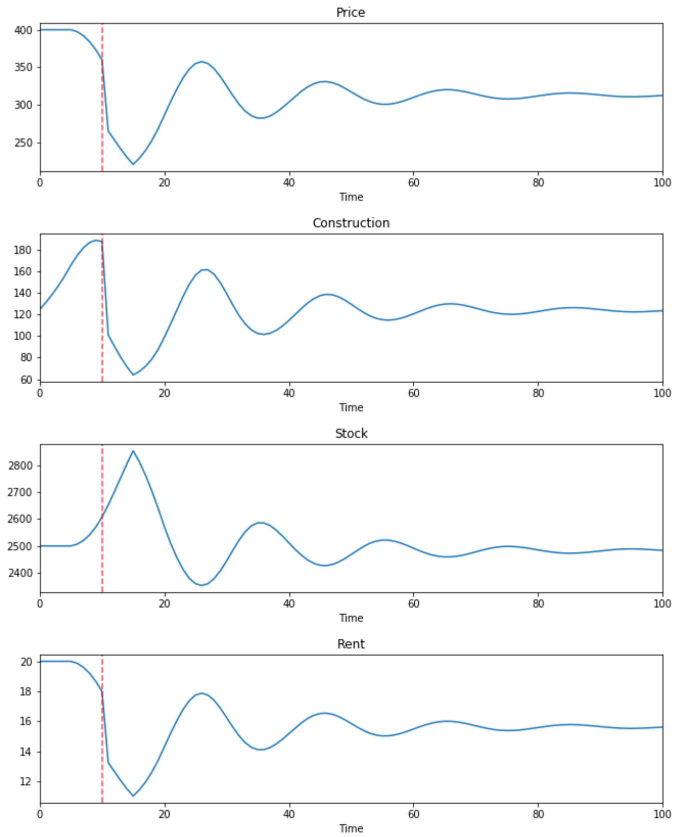

Figure 7: Baseline model: increasing elasticity of supply policy

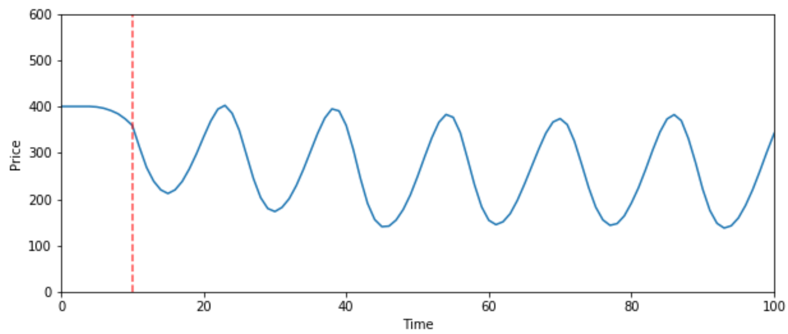

Figure 8: Extended model: increasing elasticity of supply policy

ing heterogeneous agents and a social dynamic. Similar to the results of implementing the policy using the baseline model, prices are generally decreasing during the implementation of the policy. Price volatility is as expected much higher when heterogeneous agents and a social dynamic is introduced.

4.3.2 Policy 2: Increasing price elasticity of demand

Secondly, I simulate the policy of increasing price elasticity of demand of real-estate in order to decrease price levels. Such policies may consist of government actions to encourage the development of an underdeveloped rental real-estate market. Since a sizeable portion of potential real-estate investors would be owner occupiers, promoting the market for renting, which is a substitute for owner occupancy, would increase the elasticity of demand for real-estate and may result in decreased real-estate prices. Recently such a policy has been implemented for instance in China where some first-tier cities require developers to develop rental communities for lower- and middle-income families in a pursuit to manage house prices (Koss and Shi 2018). Or, alternatively, for real-estate investors solely interested in the return on investment, other asset classes are substitutes. Thus, a government could promote investments in other assets to alleviate real-estate prices, such as the Qualified Domestic Institutional Investor scheme in China, which allows investors to directly invest in offshore securities. In addition, local financial markets could be developed to offer alternative investment instruments as a store of value (Koss and Shi 2018).

Keeping consistent with the experiment methodology, I continually increment the elasticity of demand by a constant to reach a price level of $P_{10} = 360$. To solve for an appropriate constant, I implemented a binary search algorithm as before.

The results in Figure 9 demonstrate that using the baseline model, a continual increase of the elasticity of demand leads to the price and rent to decrease. Throughout the implementation of the policy, construction and stock levels decline. I subsequently simulate the policy with the extended model.

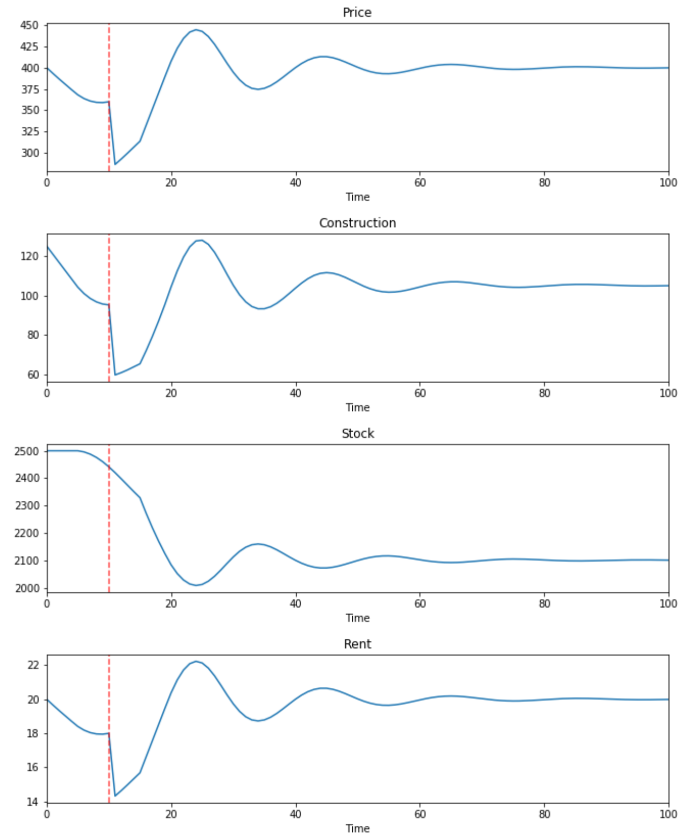

Figure 9: Baseline model: increasing elasticity of demand policy

Simulations of implementing the increasing demand elasticity policy using the extended

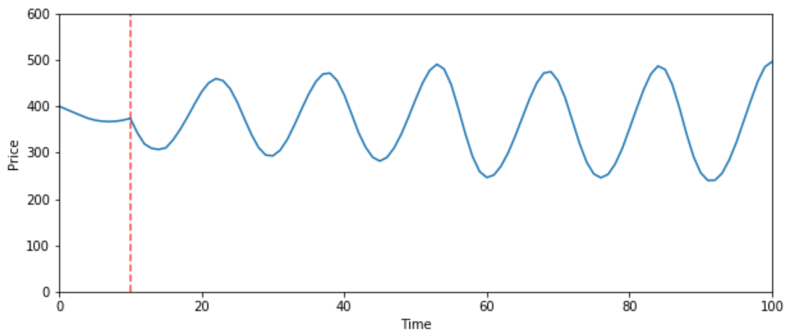

Figure 10: Extended model: increasing elasticity of demand policy

model (Figure 10) reveal that price oscillations of various time length persist, but are lower in amplitude than those resulting from the previous policy.

4.3.3 Policy 3: Increasing interest rate

Thirdly, I investigate real-life policies targeted to increase the discount rate used to value real-estate, which is proxied by the policy of increasing the interest rate in our simulation. An increase in the discount rate would decrease prices, as future cash flows are discounted more heavily when determining the valuation of real-estate (Equation 5 and 7). Since a large share of real-estate investment is partly debt financed, the mortgage rate plays a crucial role in determining discount rates. As mortgage rates are influenced by short-term interbank overnight rates, such as the effective federal funds rate, central banks may utilise various monetary policy tools to achieve an increased discount rate. For instance, the central bank may increase the discount rate that banks pay on short-term loans from the central bank, therefore decreasing the money supply, hence increasing discount rates. Likewise, by increasing reserve requirements held by banks against deposits, banks will be able to loan less leading to a decreased money supply and increased discount rate. In addition, central banks may participate in open market operations of selling government securities, decreasing the securities' price level and increasing their interest rates. This leads to an increase in overall interest rates, including the federal funds rate, and consequently the discount rate used by real-estate investors.

I continue experimentation in an equivalent manner and implement the policy by compounding the interest rate by a certain constant every year. As before, I use a binary search algorithm to search for an appropriate constant.

Unlike either of the previous policies, rent is increasing in a convex manner (Figure 11). Following the exogenous shock and discontinued policy, price levels oscillate and revert back to the initial steady state level, while rents remain at a higher level. Much like the increasing elasticity of demand policy, and unlike the increasing elasticity of supply policy, the construction and stock levels stabilise at a lower than in initiation.

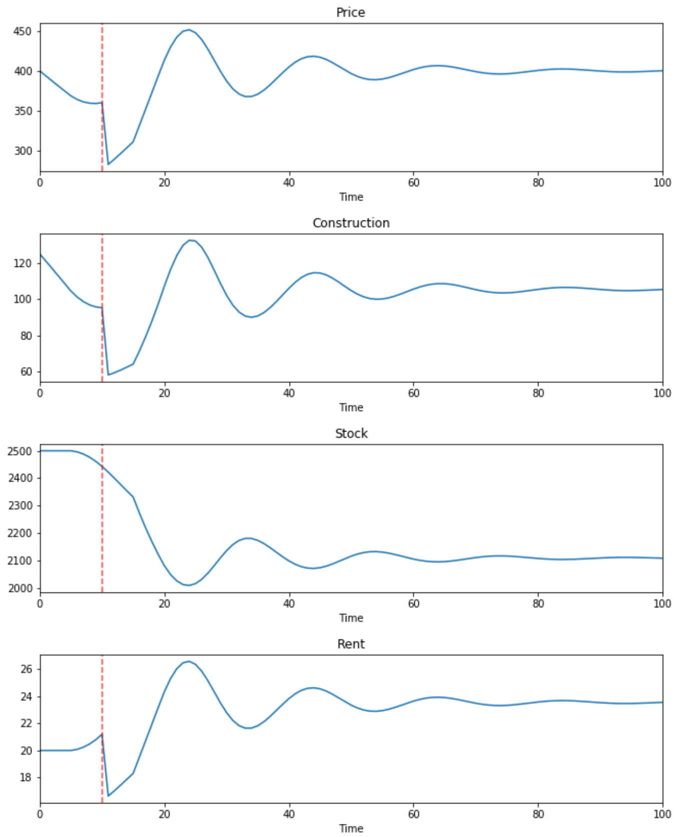

Figure 11: Baseline model: increasing interest rate policy

Using the extend model (Figure 12), we see that heterogeneous agents and the social dynamic contribute to an oscillating price level after the exogenous demand shock. In the following section I investigate the relative price instability after each policy had been implemented.

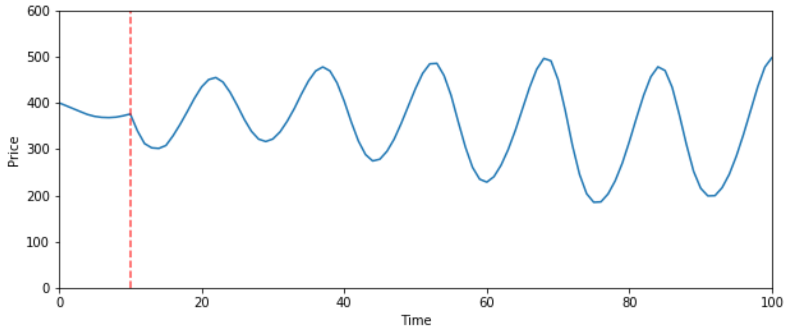

Figure 12: Extended model: increasing interest rate policy

4.3.4 Comparing price instability resulting from policies

To quantitatively assess how the different policies affect price instability, I regress the standard deviation of the normalized prices on dummy variables representing policies used in each respective simulation and a constant representing no policy. Here I discuss the data manipulation conducted and the method utilized.

First, I simulate for 1000 iterations the exogenous negative demand shock scenario with each of the previously mentioned three policies. As a baseline reference, I also simulate the demand shock without any policy. The price level time series data generated is sliced to obtain price levels from $t = 11$ to $t = 100$. These time series are then normalized in scale by dividing each observation of the price by the mean price level throughout the respective period. I then compute the standard deviation for each of the normalized price time series data.

The price level time series data is normalized so that the standard deviation is not sensitive to scale. This is performed since even though the units amongst the generated data is the same, the scale may differ. This is evident from previous simulations where price swings will oscillate at differing levels depending on the where the price converged in the baseline models of the policies.

It is unrealistic to assume that policy makers would not react to a drastic exogenous shock, however the purpose of the simulations is not to mimic the events after an exogenous demand shock, but to assess the vulnerability of the system to price oscillations after a policy aimed to control real-estate prices had historically been implemented.

Table 2 demonstrates that the standard deviation of normalized prices without any policy

Variable	Coefficient	t-ratio	p-value
Constant	0.3309	245.959	0.000
Supply elasticity policy	0.0271	14.263	0.000
Demand elasticity policy	-0.0585	-30.762	0.000
Interest rate policy	-0.0128	-6.752	0.000
R^2	0.347		
Number of observations	4000		

Table 2: Regression of normalized standard deviation of price level on policy dummies

previously implemented was on average 0.3309. Having implemented a policy of linearly increasing the elasticity of supply the average standard deviation of the normalized prices increased by over 8% from the baseline. The policy of linearly increasing elasticity of demand decreased the standard deviation of normalized price levels by over 17% of the baseline. Furthermore, the policy of increasing interest rates resulted in a standard deviation of normalized price levels slightly lower than that of the baseline. All coefficients are statistically significant at the 1% significance level.

5 Discussion

Here I discuss the results obtained from the prior experiments. I first examine the influence of parameters within the baseline and extended model. Then, I turn to compare the effect of the various price reduction policies implemented on the system generated. Lastly, I discuss various limitations of the mode and possible areas of improvement.

5.1 Model evaluation

In this section, I analyse how parameter values of the baseline and extended model influence the outcomes in the respective models.

I find results consistent to Wheaton 1999, who found that a necessary condition for market oscillation is that supply is more elastic than demand. Furthermore, as discussed in the results, an increased lag of supply (n) contributes towards increased oscillations. These observations suggest that the model shares characteristics to that of a cobweb model, resulting in prices subject to periodic fluctuation. In the model, developers' expectations of future prices are based on the market consensus composed of fundamentalists' and momentum traders' valuations, thus decisions of new construction volumes are fundamentally based on past realizations of prices. This leads to a constant disaccord between the demand and supply side, since the latter is responding to an outdated signal. An increased difference between the elasticity of demand and supply reinforces this dissonance, since with a relatively larger elasticity of supply, decisions of new construction volumes are sensitive to outdated price signals. Once the new construction volumes are released into the market, sharp changes in price ensue due to the relatively inelastic demand, hence exacerbating the dissonance further, as the new realized price will inform construction decisions in the future. These results inform that in real-estate markets suffering from volatile endogenous price oscillations, policies attempting to decrease the gap between the elasticity of supply and elasticity of demand will subdue the oscillations. Or alternatively, policies targeting to shorten the supply lag, such as faster government approval of development proposals, will attenuate price volatility.

A larger sensitivity parameter determining the influence of the Fitness and Recruitment model (a) and a larger intensity of choice parameter (γ) lead to instability of the house price. This is in accordance of Ozbakan and Dikmen 2019, who found that large γ values caused price fluctuations with higher magnitudes and price instability persisted longer for later periods after a shock. A high γ and a promote self-fulfilling valuations and instability, since if in a given time the best performing strategy has been the momentum trading strategy, then a plethora of investor will subscribe to this and the resulting realized future price will disproportionally reflect the momentum trader valuation. Therefore increasing the success of this valuation strategy in forecasting prices further and attracting a larger share of the investor universe. The combination of high a and γ are analogous to the investor population being particularly susceptible to "fads" in investment decision making and informs policy makers to address this issue by perhaps preventing fire sales of assets with a trading curb.

From the previously discussed observations of different parameter settings of the extended model, it is evident that some combinations of parameter values yield endogenous price fluctuations. In accordance with results found by Ozbakan and Dikmen 2019, I find that even with stable parameter settings for the underlying benchmark model instability in the market may ensue with the extended model.

In agreement with Ozbakan and Dikmen 2019, I find that an investor universe populated with a skew towards more momentum traders than fundamentalists is the most destabilising than a population of all fundamentalist or mostly fundamentalists. This suggests that the disaccord between the valuation methodologies and their interaction to the common price faced is another source of volatility. Contrary to Eichholtz and Huisman 2015, who discovered using a HAM that market boom periods are associated with a higher share of momentum traders whilst bust periods are associated with a higher share of fundamental traders, I find that both booms and busts are associated with a larger share of momentum traders. The difference in findings may be attributed to the different valuation methodologies installed within the fundamentalist agents, that is, in Eichholtz and Huisman's model the fundamentalists were mean reverting, whilst in my specification the fundamentalists are cashflow discounting. Therefore, in their model the fundamentalists were directly pulling prices back down or up to the fundamental value, whilst in the presented extended model the fundamentalists are indirectly inducing the same outcome, but in a weaker manner, as they are reacting to rent levels which may themselves be drastically out of stable state.

Similar to the benchmark model, the occurrence of oscillations in the extended model depends crucially on the features that characterize different types of real-estate: demand and supply elasticity and constructing lag. This indicates that cyclical behaviour of real-estate could be intrinsically different across property types, which is in line with empirical observations (Wheaton 1999). Therefore, policy implementations aimed to affect a property market should be drafted with the respective property market's idiosyncrasies in mind.

5.2 Policy treatment

I now discuss the three policies explored and their effects on market fundamentals and price behaviour following an exogenous shock within the context of the benchmark and extended model. Welfare consequences are not merely bounded to behaviour of the price level, however I focus on this due to the direct link to the behaviour of other market fundamentals, which may in turn affect stake holders.

The policy of increasing elasticity of supply yielded desirable results in terms of levels of market fundamentals, however further exploration with the extended model revealed a trade-off in terms of stability. Figure 7 demonstrates how an increase in the elasticity of supply in the benchmark model leads to a lower price and rent level with increased stock of property, which are all desirable outcomes since this results in more affordable real-estate and increase in employment in the construction sector. However, Figure 8 and Table 2, which shows a statistically significant positive coefficient of the "Supply elasticity policy" dummy variable, reveals that this type of policy yields a system that is the most vulnerable in term of price volatility in the event of an exogenous shock. This result can be explained by the fact that an increasing elasticity of supply increases the responsiveness of new construction activity to price levels, but due to the delay in construction delivery the new flow of real-estate will be introduced to the market too late, therefore exacerbating the cobweb cycle. From a policy perspective, this insight indicates that before commencing on policies to increase the supply elasticity for a particular objective the corresponding welfare trade-off stemming from increased price instability should be assessed.

In contrast to the previous policy discussed, the policy of increasing the elasticity of demand yields opposite outcomes of market fundamental, however with substantially lower volatility in price levels in the extended model. It is interesting to note from Figure 9 that post shock and discontinued policy, the price and rent adjust back to the initial levels, indicating that policies increasing the elasticity of demand for real-estate must be continually implemented to sustain desired price levels, unlike the policies increasing the elasticity of supply. This suggests that policies influencing the demand elasticity to abate real-estate prices are only feasible temporarily, as continued implementation will decrease stock and construction levels continually. Moreover, it is unclear how policy makers could sustain an increase in demand elasticity practically after a certain point. Table 2 illustrates how the resulting system is the most robust, with a large negative statistically significant coefficient of the dummy variable "Demand elasticity policy". With an increased elasticity of demand, the quantity demanded shows increased responsiveness leading to reduced price volatility. Therefore, this policy demonstrates a trade-off between reduced volatility and desirable construction and stock levels. Hence, such policies to reduce real-estate prices may be appropriate when the consequence of high price volatility is deemed to be too high.

Much like increasing the elasticity of demand, the policy of increasing the interest rate yields similar behaviour in terms of market fundamentals of the baseline model, except that the rent levels do not converge back to initial values as in the prior policy, but remain indefinitely higher. This suggests that a policy of increasing interest rates to provide affordable housing may be counterproductive, as the decreased real-estate prices through this policy result simultaneously in increased rents. However, such a policy may be more suitable in combatting a real-estate price speculative bubble. Price volatility in the extended model resulting from the increased interest rate policy is also lower than without any policy (See negative coefficient of "Interest rate policy" of Table 2), although the relative stability generated pales in comparison to that generated by the policy of increasing elasticity of demand. Ostensibly, the policy of increased demand elasticity yields preferable outcomes of market fundamentals and price stability, thus leaving little reason to choose the policy of increasing interest rates to achieve various policy goals, such as to reduce price volatility. However, it should be noted that in practice, policies increasing the interest rate are more readily applied than policies resulting in increased elasticity of demand, which often are merely alleviating previous restrictions on markets or alternative options and as such are transient in nature.

5.3 Limitations

As expected from a heterogeneous agent-based model simulating real-estate price dynamics, I encounter a number of limitations to external validity of the findings.

The first predicament is to identify and incorporate all relevant factors of the real-estate market which affect real-estate price dynamics into the model. For instance, in the current model there is no recognition of debt financing of real-estate. Real-estate financing is often done with debt and securing a loan takes time. Incorporating this in the model creates backward historical linkages that may be strong enough to create market oscillations (Wheaton 1999). Moreover, in Equation 2, I implicitly assumed that vacancy is ignored and that the market clears in each period, since supply of rental real-estate always equals demand. This assumption could be challenged and vacancy could be added to produce a more granular model encapsulating reality.

Another predicament is the refinement of the chosen parameter values. In my simulations I have assumed parameter values similar to that of Wheaton 1999, which mirror the aggregate office market of the largest 54 U.S. metropolitan areas and elasticities for office space. Further empirical and statistical studies, for instance through method of moments estimation, are required to determine realistic values for parameters associated with the social dynamic, such as a, γ, θ, m, q, which, for now have, been chosen arbitrarily. It is also important to note that the parameter values may alter over time giving a time dependant influence, thus yet another aspect that the current model does not capture.

The assumed type of heterogeneity and valuation strategy is another source of limitations of the model. Namely, I assume heterogeneity is discrete and binary. This characterisation is an over simplification and in reality investors may have a weighted mix of strategies. In addition, the fundamental valuation methodology (Equation 7), might be enhanced to account for past and future rents, since real-estate assets are often leased to multiple tenants at differing time periods at differing lengths of tenancy. This blending of leases with different maturities creates a well-known lag between movements in market rent and real-estate property income (Wheaton 1999). Another limitation concerning the agent's valuation strategy is assuming a single momentum-based methodology is employed when perhaps alternative momentum-based valuations are utilised in addition to the one proposed in Equation 6, such as an extrapolation of past m years average obtained profits or losses. Moreover, the current model could be extended to incorporate the cost of investors employing a relatively sophisticated fundamentals-based valuation methodology. This would discourage investors to employ this strategy and, in the absence of exogenous random shocks, the investor population would converge to represent the cheaper strategy to economised on operational costs, as noted in Sethi and Franke 1995.

It should be acknowledged that the model suffers from a common fundamental problem of HAMs attempting to resemble reality, which is the excessive degrees of freedom generated. Any heterogeneous agent-based model describing real-estate price dynamics must provide a plausible story justifying the particular characteristics of agents and the method of how they evolve in the system without containing irrelevant additions. Whilst conducting the necessary research, it was evident that remarkably little work in survey data analysis has focused on the dynamic of the selection of expectation strategies. Such work is required to guide future attempts of constructing heterogeneous agent-based models to integrate only relevant dynamics.

6 Conclusion

The presented model reveals insights in a sparsely-explored area within economics of heterogeneous agent models (HAMs) that are utilised to simulate the dynamics of investors within the context of the real-estate market. The proposed model offers an improvement of the baseline neoclassical model and past heterogeneous agent models as it incorporates an extended social dynamic through which investors interact based on a Recruitment Model (Kirman 1993) and Fitness Model (Eichholtz and Huisman 2015) capturing past market observations.

Examining the model's behaviour quantitatively and qualitatively with respect to various parameters inform policy makers to address certain features of a real-estate market characterised by heterogeneous agents. The results suggest for instance that an increased difference between the elasticity of supply and demand result in greater price instability since the cobweb nature of the real-estate market is exacerbated. Furthermore, an investor universe populated with a skew towards momentum traders is the most destabilising composition. In addition, real-estate price instability depends crucially on features that characterise different types of real-estate, hence suggesting that a tailored policy for different classes of real estate is prudent, as oppose to a ”one size fits all” approach.

Several specific policies aimed at reducing real-estate prices are tested to assess the limitations and outcomes of these with respect to market stability measured by the volatility of price levels. The simulations suggest that policies which increase the elasticity of supply result in desirable market fundamentals and a trade-off in terms of increased real-estate price volatility. In contrast, policies increasing the elasticity of demand and interest rate yield a more stable real-estate market, although with less desirable market fundamental outcomes. These insights inform policymakers of critical outcomes and tradeoffs to account for when addressing the real-estate market's price level.

As expected from a heterogeneous agent-based model simulating real-estate price dynamics, a number of limitations to external validity are encountered. The model may be extended by accounting for other relevant factors of the real-estate market such as vacancies and debt-financing. The chosen parameter values of the model which are based on past empirical studies could be refined further by method of moments estimation. Finally, whilst conducting the necessary research, it was evident that little work in survey data analysis has focused on the dynamic selection of expectation strategies within the real-estate market. Such work is required to guide future attempts of constructing heterogeneous agent-based models and remains an area requring further research.

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A Appendix

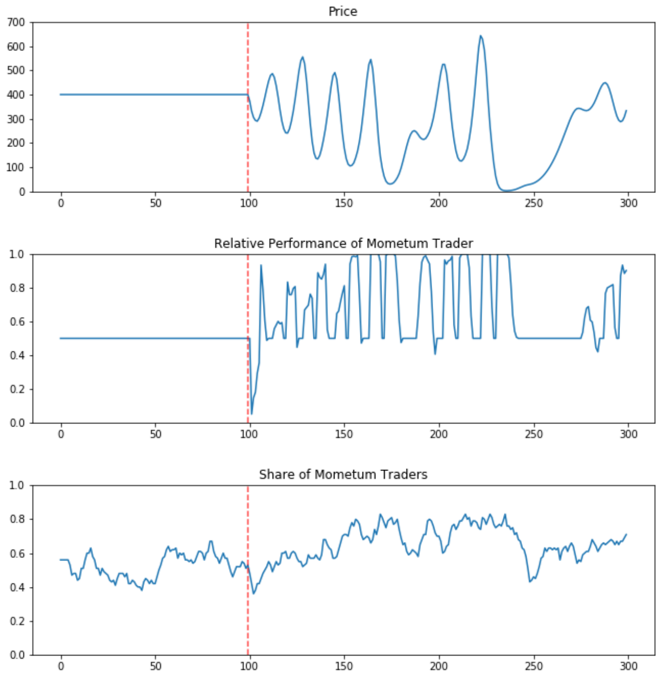

Figure 13: Market crash with $\gamma = 0.3$ and $a = 0.2$

Variable	Coefficient	t-ratio	p-value
Constant	0.3314	75.705	0.000
E.o.D = 1.0, E.o.S = 1.0	-0.3017	-48.734	0.000
E.o.D = 0.2, E.o.S = 2.2	1.0744	173.554	0.000
R^2	0.948		
Number of observations	3000		

Table 3: Results of regressing normalized standard deviation of price level on dummies representing different elasticity specifications. Constant represents E.o.D $= 0.4$ and E.o.S $= 2.0$

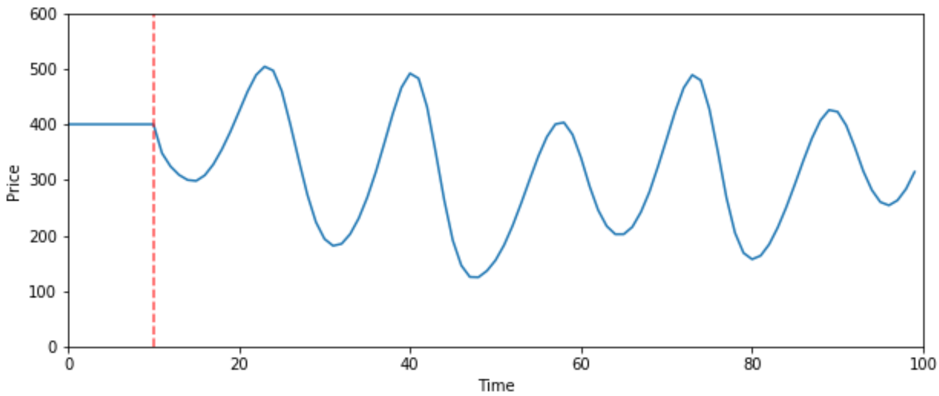

Figure 14: Extended model: negative exogenous demand shock with $\varepsilon = 0.2, \eta = 2.2$

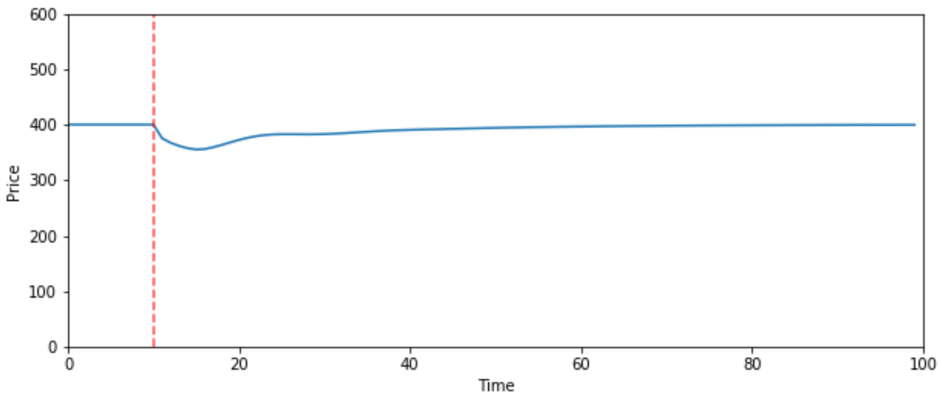

Figure 15: Extended model: negative exogenous demand shock with $\varepsilon = 1.0, \eta = 1.0$

Variable	**Coefficient**	**t-ratio**	**p-value**
Constant	0.1949	166.633	0.000
$m = 8$	0.1434	86.665	0.000
$m = 15$	-0.1061	-64.151	0.000
R^2	0.884		
Number of observations	3000		

Table 4: Results of regressing normalized standard deviation of price level on dummies representing different m. Constant represents $m = 2$

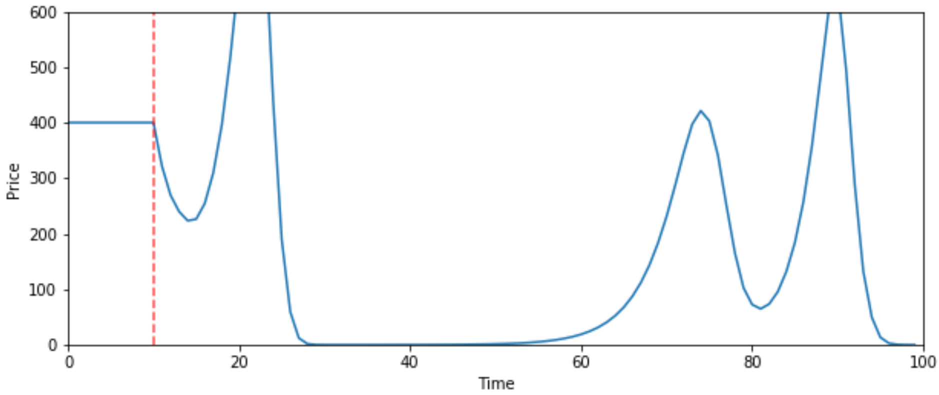

Figure 16: Extended model: negative exogenous demand shock with $\varepsilon = 0.2, \eta = 2.2$

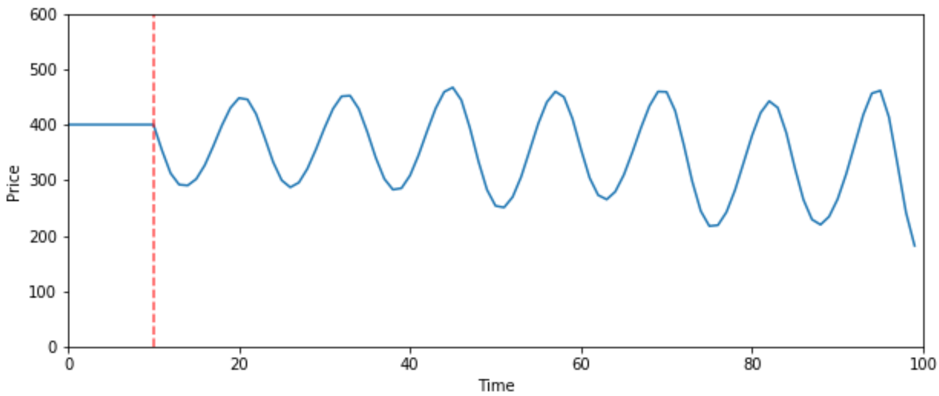

Figure 17: Extended model: negative exogenous demand shock with $m = 2$

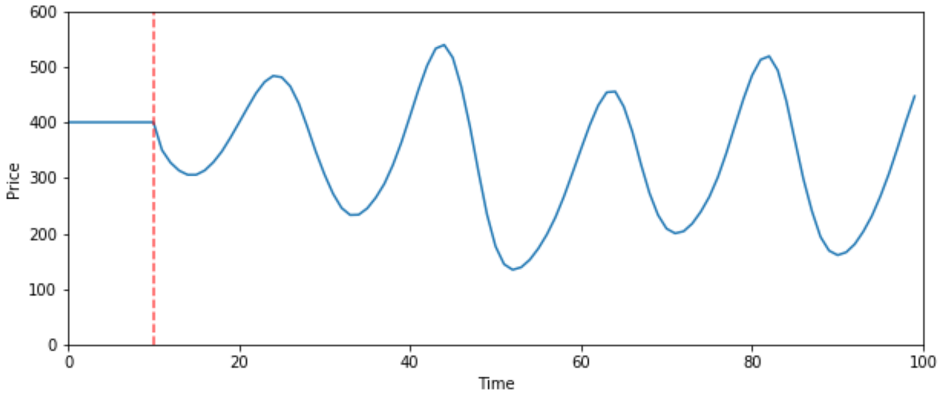

Figure 18: Extended model: negative exogenous demand shock with $m = 8$

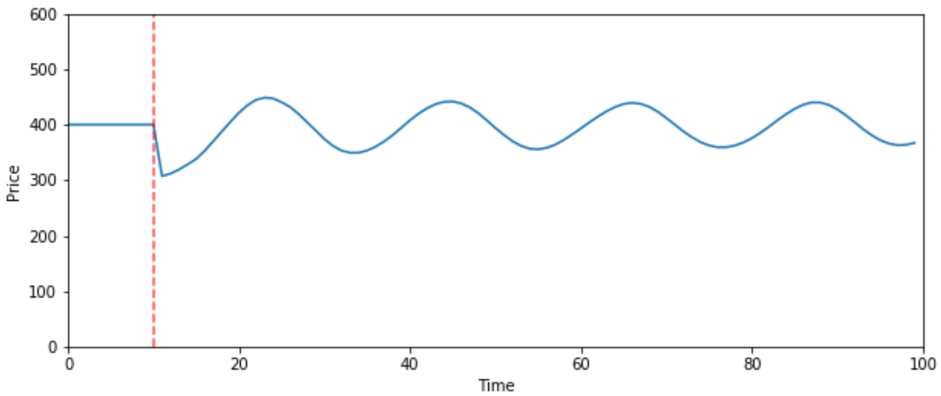

Figure 19: Extended model: negative exogenous demand shock with $m = 15$