System Dynamics, Market Microstructure and Asset Pricing

By

Mindaugas Leika

M.Sc. Economics.
Vilnius University, Vilnius 2004

SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF BUSINESS ADMINISTRATION
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2013

© 2013 Mindaugas Leika All Rights Reserved.

The author hereby grants to MIT permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part in any medium now known or hereafter created.

Signature of Author:

MIT Sloan School of Management
May 10, 2013

Certified By:

Andrew W. Lo
Charles E. and Susan T. Harris Professor
Director, Laboratory for Financial Engineering, MIT Sloan School of Management

Accepted By:

Stephen Sacca
Director, MIT Sloan Fellows Program in Innovation and Global Leadership
MIT Sloan School of Management
System Dynamics, Market Microstructure and Asset Pricing

By

Mindaugas Leika

Submitted to the MIT Sloan School of Management on May 10, 2013 in partial fulfillment of the requirements for the degree of Master of Business Administration

ABSTRACT

Traditional asset pricing approaches are not able to explain extreme volatility and tail events that characterized financial markets in the past decade. System Dynamics theory, which is still underutilized in financial modeling, could help researchers to model stock market dynamics, explain and simulate extreme events.

This paper proposes an artificial stock market model, which can be used to simulate stock market behavior, incorporate various assumptions about interactions among market participants: fundamental, noise and technical traders. The model includes multiple feedback loops, namely, positive feedback, ratings, debt and leverage. Dynamic interactions among loops stabilize markets and limit bubble formation. Model simulation results show, that not only the numerical limit of leverage, but also regulatory definition of leverage matters. Market stability can be achieved faster with lower system-wide and narrow definition of leverage. To increase stability, Central banks and regulators might consider targeting leverage in a financial system.

Thesis Supervisor: Andrew W. Lo
Title: Charles E.and Susan T.Harris Professor, Professor of Finance
[Page intentionally left blank]
# TABLE OF CONTENTS

LIST OF TABLES AND FIGURES ........................................................................................................ 6

1. INTRODUCTION .................................................................................................................... 7

2. LITERATURE REVIEW ......................................................................................................... 11

3. MODELING ARTIFICIAL STOCK MARKETS: SYSTEM DYNAMICS APPROACH 14
   3.1 Four approaches to asset pricing ...................................................................................... 14
   3.2 What are features of systems? .......................................................................................... 19
   3.3 How can system dynamic models incorporate the four approaches? ............................ 25
   3.4 Stability conditions ......................................................................................................... 31
   3.5 Modeling limitations ....................................................................................................... 35
   3.6 Conclusion ...................................................................................................................... 37

4. AN ARTIFICIAL STOCK MARKET MODEL ........................................................................ 40
   4.1 Model boundaries .......................................................................................................... 40
   4.2 Traders ............................................................................................................................ 42
   4.3 Trades ............................................................................................................................. 47
   4.4 Simulation results ........................................................................................................... 48
   4.5 Possible expansion ......................................................................................................... 53

5. SUMMARY AND CONCLUSIONS .................................................................................. 55

REFERENCES ............................................................................................................................. 57

ANNEX I. MODEL DOCUMENTATION .................................................................................. 60

ANNEX II. MODEL DIAGRAMS ............................................................................................ 111
LIST OF TABLES AND FIGURES

FIGURE 1 Market types ................................................................................................................................. 18
FIGURE 2 Simple Stock Market .......................................................................................................................... 25
FIGURE 3 Basic structure of an artificial trading market .............................................................................. 27
FIGURE 4 Market hierarchy ............................................................................................................................... 28
FIGURE 5 Structure and stability of market .................................................................................................... 29
FIGURE 6 Stock and flow components of asset pricing .................................................................................. 30
FIGURE 7 Leverage loop .................................................................................................................................. 31
FIGURE 8 Maximum leverage and asset prices .............................................................................................. 34
FIGURE 9 Linkages among various asset-pricing approaches ....................................................................... 39
FIGURE 10 Two main loops ............................................................................................................................. 40
FIGURE 11 Fundamental traders' trading loops ........................................................................................... 43
FIGURE 12 Technical traders' trading loops .................................................................................................... 45
FIGURE 13 Noise traders' trade loops .............................................................................................................. 46
FIGURE 14 Pricing loops .................................................................................................................................. 47
FIGURE 15 Simulated earnings shock .............................................................................................................. 49
FIGURE 16 Stock price: narrow leverage ......................................................................................................... 50
FIGURE 17 Stock price: only FTs use leverage ............................................................................................... 50
FIGURE 18 Stock price: broad vs. narrow leverage ....................................................................................... 51
FIGURE 19 Dividend payments and stock price ............................................................................................. 52

TABLE 1 Types of delays in the model ........................................................................................................... 41
1. INTRODUCTION

The past ten years can be characterized as years of extreme volatility and tail events in financial markets: since the “black Monday” of October 19, 1987, out of 11 observations of daily S&P 500 index drops by more than 5 percent, 7 happened in 2008. In addition to this, the “Flash Crash” on May 6, 2010 wiped out almost 9 percent of S&P 500, although losses were partially recovered within 20 minutes\(^1\). Burst of housing price bubble in Japan in early nineties, “dot-com” and housing price bubbles in US or commodity price bubble worldwide wiped out substantial amount of wealth and caused recessions. All these market events cannot be explained by simple traditional approaches, which trace back their roots to efficient market hypothesis. It is easy to blame someone else for the crisis: bad programs, bad behavior (greed), and bad weather, or just bad luck as the last argument. But in the end we have to answer the question, why these “bad” events happen, whether they are purely random and thus unexpected, or contrary to this – embedded in the design of current financial system and thus can be anticipated and/or managed \textit{ex ante}. In the former case we are dealing with a true “knightian” uncertainty, in the latter – with risk.

To answer the question whether we are dealing with truly external disturbances or just internal ones, we have to build model, which mimics financial system’s behavior. With the help of the model one can make various simulations and adjust parameters (like capital adequacy requirements for banks, leverage requirements for other institutions etc.). But financial system is a very complex structure: thousands of participants, multiple layers (households (primary investors),

\(^1\) Findings Regarding Market Events of May 6, 2010.  
intermediaries (banks, funds etc.), multiple markets (equity, debt, derivatives etc.), and multiple countries. It is barely possible to build a model, which includes all interactions, derives demand and supply equations, equilibrium prices under a predefined set of parameters. This paper uses simplified system approach, i.e. models behavior of purely artificial asset market with just one single type of stock and three types of players: fundamental traders (or sophisticated investors, e.g. banks, funds), noise traders (small investors, households, "mom and pop traders") and technical traders (technical analysts who follow short-term trends). The aim of the paper is to show, how positive feedback investment strategy (see Schleifer (2000)), heterogeneous believes of traders, and ability to use leverage affects behavior of asset prices. The model relies on System Dynamics (SD) methodology developed by (Sterman (2000)), and its applications for financial markets (Weitert (2007), Provenzano (2002), Lo and Getmansky (2005)) and Vensim software. This model can be used to simulate impact of various external parameters set by regulators (interest rates, maximum leverage ratios) on behavior of traders and asset prices. Proposed model differs from existing models because it includes leverage, i.e. negative feedback loop that in theory should stabilize the markets and prevent excessive price fluctuations. Contrary to assumptions developed by Weitert (2007), this model assumes heterogeneity among fundamental investors, i.e. their leverage and expectations about fundamental price.

System dynamics approach employed in the model is not a new pricing paradigm per se, it is rather a technology to incorporate various assumptions and theories about asset pricing and behavior of investors into one single framework.
Artificial financial market models incorporate various agents, like hedge funds, banks, insurance companies, depositors etc. Dynamics of asset prices can be calibrated using various macro data, inputs from structural macroeconomic models. Further development of dynamic artificial stock market models could incorporate many other assumptions from behavioral finance theory: anchoring, recency effect, overconfidence, and prospect theory. All in all, such models reveal and help to explain complexity of decision making processes, bounded rationality of market players, copying activities (herding behavior), adaptive learning and expectations.

As LeBaron (2005) points out, financial markets are very well suited for experiments: it is much easier to simulate short time period rather than entire life cycle of an individual; secondly, there are multiple sources of high frequency data. SD approach thus provides good simulation platform to design and implement various artificial experiments to validate real life behavior.

In this thesis, I broadly seek two objectives: first, to describe and present system dynamics approach to asset pricing, basically addressing shortage of literature on this topics, and secondly, propose an extended artificial market model, which incorporates leverage or debt loop. While fundamental asset pricing theories are to narrow, i.e. focus on one or several features of the asset pricing equation, and do not incorporate dynamic interaction among traders and feedback effects, system dynamics approach to modeling could substantially extend our understanding about complex financial systems and benefit decision making process. Dynamic models can be used to simulate market reactions to various policy proposals, used as stress testing tools and for trading simulations.
The thesis is organized as follows: the second part provides short literature review on system dynamics approach to financial modeling, the third part – presents and explains how SD methodology could enhance asset pricing theory, and finally the last part provides example of such a model and gives a summary of simulation results. Thesis annexes include model code and structural diagrams.
2. LITERATURE REVIEW

Although System Dynamics (SD) is not a new phenomenon in academic research\(^2\), surprisingly little analysis is made so far by applying SD methodology in finance. It is also surprising, that no paper about SD application to financial markets in general or asset pricing in particular was published in academic journals before 2013. Almost all models cited below exist in the form of either conference proceedings or working paper. It is easy to count inventory: there are a couple of models (Weitert 2007), Provenzano (2002), and papers on hedge funds (Getmansky and Lo 2005), one on stress testing (Anderson, Long et al. 2011) and banking crisis (Pruyt 2009). At MIT, the birthplace of System Dynamics approach, most SD papers focused on manufacturing, quality management, and supply chain processes. This is especially evident from simply looking into MIT Sloan theses database: most of the theses apply system dynamic methodology for the above-mentioned topics. Simple search in academic databases reveals no article on application of system dynamic approach in asset pricing. Moreover, database of System Dynamic Review, an academic journal, lists no article on asset pricing or financial markets. There might be several reasons why SD approach was and still is not very popular among financial researchers: complexity of financial markets and the need to build very complex models of interaction that include many behavioral assumptions; bias towards purely theoretical, mathematical concepts and predominance of efficient markets theory, and finally fragmentation of behavioral finance theory. That being said, System Dynamic approach

---

\(1\) First developed by MIT professor J. Forrester in 1950s
can greatly benefit our understanding and modeling of financial markets, especially interactions among traders, trading volumes, market liquidity and prices.

Provenzano (2002) was one of the first to incorporate Dynamic behavior of market participants (traders) into an existing asset-pricing theory. He simulated behavior of two different types of traders: professional and positive feedback traders. He finds that, existence of professional traders stabilizes the market, and existence of trend followers creates instability and causes speculative dynamics. Weitert (2007) attempted to extend Provenzano (2002) model and incorporate behavior of three different types of investors: fundamental analysts, technical analysts and noise traders. He concludes, that, SD based model revealed importance of technical analysts in bubble formation as well as herding behavior among noise traders. Further incorporation of various behavioral phenomena could extend structural flexibility of such models.

Anderson, Long et al. (2011) focus on stress testing of financial system: they model banks’ balance sheet, include six type of assets, all have risk weight assigned to calculate CAR: Highly Liquid Assets (Cash and Due from Central Bank), Domestic Interbank Loans and Placements, Foreign Interbank Loans and Placements, Investments and Securities, Loans, Other Assets (including fixed).

Pruyt (2009) created a system dynamics models to explain the crisis of Fortis Bank. He modeled behavior of bank’s stock, assets and liabilities, namely fear in the market, quality of loans and stock market value.

Finally, Getmansky and Lo (2005) apply SD theory to explain behavior of hedge funds, namely collapse of LTCM in 1998. Their model includes various relationships
between hedge fund, dealer and investors: securities, loans, collateral, margin calls, and stock market. They conclude, that although leverage alone does not lead to a collapse of hedge fund, however high leverage coupled with highly correlated positions could lead to a failure.
3. MODELING ARTIFICIAL STOCK MARKETS: SYSTEM DYNAMICS

APPROACH

3.1 Four approaches to asset pricing

From the first look it might seem that the SD approach just confirms what behavioral economists tried to prove for many years: traders are heterogeneous and might be irrational in their behavior. However, deeper look reveals that SD approach to asset pricing is different; it is rather a new modeling tool than a completely new type of scientific paradigm. SD tries to explain not the equilibrium, but dynamics, i.e. how equilibrium can be reached. In contrast to application of System Dynamics in finance, there is enormous amount of research devoted to asset pricing, market microstructure and liquidity. What traditional theoretical assumptions SD approach can incorporate? I grouped these into four categories, namely asset pricing theory, market liquidity, market microstructure and behavioral finance.

**Fundamental asset pricing** theory relies on two basic assumptions: Efficient Market Hypothesis (EFH) (Fama, 1965) and Arbitrage pricing theory (APT) (Ross, 1976). The first principle means, that asset prices incorporate all available information, and the second – there are no two similar securities that could have different prices, as risk-free arbitrage strategy employed by informed investors eliminates price differences immediately. Hence in efficient markets, prices should reflect fundamentals and follow random walk. In such a market, prices are formed by informed, long-term investors that are not constrained by liquidity requirements or holding period. Moreover, efficient markets also assume, that trading is done by small,
almost atomistic "investors", as no one of them has market power and is able to make an impact on prices by trading. Traders are fully rational, markets are integrated, and liquidity is not an issue.

This idealized world however sharply contrasts with reality: large institutional investors dominate markets, and many small traders are not fully rational and fully informed. Thus arbitrage is a possibility, although usually it is not without a risk, hence called risk arbitrage as it employs price guessing, i.e. assumptions that prices will converge over time. Arbitrageur in this case needs to post a collateral, and if, within a certain period of time, prices do not converge, arbitrageur looses money (collateral).

**Liquidity theory** is one of the most challenging concepts in asset pricing: liquidity risk premium is not constant, and in most extreme situations, liquidity of assets can disappear altogether. There are several theoretical approaches towards liquidity: static, which basically tries to explain and measure additional return required for investors to hold less liquid assets, and dynamic approach, which analyses balance sheet restrictions that market participants face. The first, static approach (Acharya and Pedersen (2005) and Amihud, Mendelson and Pedersen (2006)) endogenizes liquidity by incorporating it into Capital Asset Pricing Model (CAPM) equation via trading costs. Asset illiquidity is dependent on its correlations with market illiquidity. Investors require compensation for holding assets that are positively correlated with the market liquidity (i.e. assets are illiquid when markets tend to be illiquid) and require lower returns on assets that are negatively correlated with market liquidity, i.e. are liquid when markets in general tend to be illiquid. Chen, Liu, Shin et al (2012) develop dynamic approach: separate asset and liability side measures...
of liquidity. While asset side measures amount of credit available to the private sector, the liability side reflects leverage constraints of financial institutions.

**Market microstructure theory** rejects hypothesis that market structure has no effect on prices. Markets are places where actual pricing happens, i.e. equilibrium price is calculated based on moment prevailing supply and demand conditions. The asset price is determined by interaction of fundamental factors (cash flows, discount rates, expectations, risk premium etc.) and market structures (types of traders, order processing system, information efficiency)\(^3\). Early asset pricing models tend to ignore market microstructure, although it makes an impact on price dynamics. Francioni et al. (2008) associate this with friction and trading costs. Information is not instantly incorporated into prices, there are traders who learn first (although now it might take a few milliseconds) and execute trades first, so speed is a crucial factor for profits: informed and faster traders benefit at the expense of uninformed and slow ones. Therefore market microstructure theory focuses on different types of traders (noise, liquidity, fundamental, informed, uninformed etc.), information transmission (some traders get information before the others), information processing (some are better at understanding it and interpreting), market types (dealer market with intermediaries vs. limit order market without intermediaries providing liquidity). All in all, the central piece of market microstructure theory is based around trading: why and when trading occurs and who is trading.

Trading systems are getting more complex and complicated: more than several decades ago, trading was dominated by manual input of information, floor trading and

---
\(^3\) Liquidity theories complement this approach by adding both, liquidity risk premium to an asset price and quantifying traders' balance sheet constraints as signals to trade.
relatively simple structure of the system, with relatively few interconnections among exchanges and market participants. Today, trading is dominated by electronic systems; there exists many interlinkages among exchanges, market makers and financial institutions. According to the SEC report [2010], “the current market structure can be described as dispersed and complex”. More dispersed trading among various trading centers (exchanges, platforms) has an impact on system stability and efficiency. Dispersed markets are potentially more stable and less prone to systemic risks, and competition among exchanges and various service providers (trading platforms) lowers margins and bid-ask spreads. Moreover, electronic trading reduces transaction costs, increases liquidity and allows many more participants (traders) to join the market directly. By this I mean, on-line platforms reduced “shoe leather” costs, so many mom-and-pop, small unsophisticated and uninformed traders joined the market and can do transactions more frequently. Electronic trading also made possible strategy to cut large (parent) orders into small ones (child) and execute (route) them on different trading centers.

But all these structural changes also have a negative impact on the markets: shock transmission time went down, and high frequency traders, that currently dominate the market, can create systemic shocks due to errors in their algorithms. There is also a possibility that a fraudulent attack on a particular stock can be created, e.g. momentum ignition strategy (e.g. the most recent Twitter crisis, when hackers transmitted fraudulent message on the market). Market has a lot of noisy trades, that happens just because some market participants are compensated for trading rather than taking on asset price risks (fundamental risks), so it might be more difficult to
observe whether one or the other asset price reflects fundamental value or not. This can be attributed to the so-called “maker-taker” pricing model, under which traders receive transaction rebate for providing liquidity in the markets.

**Figure 1 Market types**

**Old system: Dealer Market**

- Spread
- Dealer
- Bid Price
- Ask Price
- Buyer
- Seller

**New system: Limit Order Market**

- Commission fees
- Exchange: ordering and matching
- Buy orders
- Sell orders
- Buyer
- Seller

**Behavioral finance theory** explains traders' motivation to trade: individuals' risk profiles are different and do depend on formulation of problem, framing (Kahneman and Tversky, 1981), traders' emotional reactivity, mood and personality (Lo, Repin and Steenbarger, 2005) or even impact of Seasonal Activity Disorder (Kamstra, Kramer, Levi, 2003). Behavioral finance theory explains why asset price bubbles emerge, phenomena, which could not be explained by applying conventional models of fundamental asset pricing to market data. There is considerable evidence, that investors willingness to take on risk depends on various psychological, environmental and personal characteristics, that shapes how traders react to market
information. For example, noise traders who believe, that they know, but indeed they do not have any insider information (information advantage), base their trades on price changes in the past. The higher price changes, the more noise traders will buy an asset and vice-versa. Their strategy (buy high, sell low) is contrary to what other, sophisticated investors do (buy low, sell high). This Positive feedback trading leads to formation of asset price bubbles (Schleifer, 2000).

3.2 What are features of systems?

System dynamics models interpret each market as system. Such models include factors, which to a large extent are excluded from traditional asset pricing models, focused on returns, errors and correlations. Asset prices are outcomes of demand and supply, expectations, flows of money and information. Market place is a system that involves many complex actions and interactions among system participants. Following Meadows (2008), systems have the following properties:

1. System resilience;
2. Market self-organization;
3. Market hierarchy;
4. Information flows, delays and non-linearity (adaptive expectations);
5. Distinction between stocks and flows;

Resilience of a financial market is its ability to get back to equilibrium after disruptions. As market participants adapt to an external or internal shock, market structure might change. Efficient market theory assumes, that market prices at...
Equilibrium reflect fundamentals and are not affected by individual market traders, i.e. number of traders exiting and leaving market or amount of stocks bought or sold. Even if some institutions (traders) fail (traders leave the market due to bankruptcy), the whole market system survives and performs its vital functions to the society, i.e. a) transfers scarce financial resources through the time and space; b) provides reliable signals to the real economy about prices of resources. Hence, market resilience is its ability to move back to equilibrium price after disruptions. Empirical evidence, gives us, however a different picture: markets have memory and it takes time to move back to equilibrium. In many cases financial system is not able to get back to its least costly state (or in terms of physics, maximum entropy) of transferring resources across time and space without external intervention. Without the lender of the last resort the system would have collapsed many times before it was able to fix it itself. For example, the FED, an external institution, was established with the aim to safeguard US financial system against the sudden loss in confidence and subsequent financial panics.

**Self-organization** is another interesting feature of systems. Learning, diversifying, complexifying and evolving characterize how systems self-organize. Self-organization in many cases is a market reaction to various regulatory constraints. Regulators usually want to encourage lower risk taking, so strengthen capital regulations. Financial institutions start looking for creative ways on how to minimize their impact. This is similar to any biological or physical system: it tries to get back to equilibrium. Financial engineering is a response we typically observe in markets.

For example, many regulators set minimum standards for pension funds and insurance companies, which bans their outright investments into risky corporate
bonds. However search for yield led to innovations called Credit-Linked Notes. Under this contract, bank or other highly rated financial institution issues notes to an investor, but return on these notes is linked to return on a reference portfolio. This portfolio has nothing to do with the issuer. Total return swaps are similar instruments. This is a contract that enables investor receive cash payments generated by risky corporate bonds without buying bonds themselves. If bonds default, the investor has to make a corresponding payment to the counterparty. Because of Basel rules, banks were very active users of such credit derivatives: insured contract carried less risk, and lower capital requirement. However, there is a fundamental issue: insurance is placed within the system, and if it is concentrated, it will not work. The most illustrative example was the AIG case. And there are many more examples of such behavior, one German bank, for example, insured credit contracts within its own group. All these instruments replaced credit risk with counterparty risk. So instead of dealing with just credit risk in the system, we are dealing with multiple sources of risk. One more recent example of self-organization of financial system comes from financial crisis in Cyprus (2012): public did not trust banks and the system moved back to cash operations and barter deals. Hence system tried to restore itself but at slow pace and with huge loss of efficiency.

Self-organization creates another phenomenon: policy resistance. This is the situation when goals of supervisor and supervised diverge. Even if they converge in the long term, it is impossible to achieve goals in the short term. For example, banks' capital adequacy regulations: they are very complicated and markets like these complications, because it is much more easier to downplay regulation's impact. Many
policy resistance examples came from conventional economic theory: policy makers want to increase job creation, however unemployment rate is stable or rising. They want more investment into disruptive innovations, but markets invest more into efficient ones. We want to collect more taxes, but once we increase tax rate, business finds ways how to minimize tax payments. We can go on and on, there are many examples when regulator optimizes, but business optimize as a result. The dynamics of this game, shows, that a regulator almost always plays reactive rather than proactive role. The result of these activities is growing complexity of financial markets, and as a response- growing complexity of regulation. Structured products for example emerged in a recent decade; Basel III now includes regulation on liquidity, like liquidity coverage ratio and net stable funding ratio etc. Disintermediation is another trend, i.e. we do observe emergence of various non-bank financial institutions, especially the ones utilizing Internet technologies.

**Market hierarchy.** Financial systems are organized under principle of hierarchy: at the bottom are retail investors, households, mom and dad traders. They are to a large extent unsophisticated and fell under the category of noise traders. Institutional investors, like mutual and hedge funds, private equity groups are first aggregators. Funds of funds play intermediary role. Finally at the top are exchanges, where transactions take place and market prices are calculated. Principle of hierarchy says, that top layers in this financial “food chain” serve for the interests of lower layers.

**Information flows, delays and non-linearity (adaptive expectations).** Systems are also characterized by the flows of information. Delays in information flows extend price adjustment process and are the primary reason for oscillations. In many
situations, especially financial crises, markets exhibit non-linear behavior. Real estate market is a good illustration: it takes time to build houses or commercial property. Once a demand increases, supply reacts, but with a delay. This delay is caused by construction time, zoning requirements, decision-making process etc. Because of the gap between supply and demand, prices rise. Once supply increases, demand already goes down. Prices go down, and many unsold inventories remain. The same principles can be applied to stock market pricing process, albeit stocks are financial, not real assets, hence demand and supply can adjust momentarily. Similarities lie not in supply or demand process (definitely, there is no need to print and transfer physical stock), but in a way human traders gather, interpret information and make decisions. Market traders have different ability to gather information, have different expectations and make different conclusions while observing the same trends. Whereas one group of traders makes decisions immediately (or base their decisions on algorithms), others need time to digest it. They act slow or act too fast and engage in herding behavior. These delays in action cause market price fluctuations beyond unpredictable “random-walk” scenario. Masulis and Shivakumar (2002) find that on the NASDAQ trading system, price adjustments to seasoned equity offerings were by about an hour faster than on NYSE/AMEX system. They attributed these findings to greater risk taking opportunities, more rapid order execution and better informed trading at NASDAQ. Lo (2004) proposed Adaptive Markets hypothesis, which inter alia explains the need to incorporate adaptive expectation hypothesis into financial models.
**Stocks and flows.** The most common way to find fundamental price of a given stock is to concentrate on flow of dividends:

\[ p_t = E_t \left[ \sum_{t=1}^{T} \frac{d_{t+T}}{(1+r)^T} \right] + E_t \left[ \frac{p_T}{(1+r)^T} \right] \]  

(1)

Where \( p_t \) is market price today, \( d_{o,T} \) – dividend flow up to period T, \( r \) – market discount rate, \( p_T \) – expected market price at date T and \( E_t \) – expectations operator. If there are no bubbles in market, expectation component about future increase in price \( p_T \) is equal to zero, as all price changes should be immediately reflected in the first component of the pricing equation, i.e. discounted flow of dividends. If this condition does not hold, bubbles emerge: the pricing reflects expected changes in price (stock component) because of changes in price. This is unsustainable, however it creates powerful incentives for noise trading (see De Long, Schleifer, Summers et al. 1990 and Schleifer 2000).

**Behavioral phenomena.** Behavioral finance and psychology literature provides a long list of various psychological biases and factors that affect decision-making. I will mention just a couple of them. Bounded rationality is a phenomenon when we do not have enough information or it takes long time to get this information and process it (Simon 1957). Traders might not know how much capital entrepreneurs invest into real estate markets or speculators into a particular stock. They might also have short-term incentives to ignore this information even if it is available in the market. Banks might be reluctant to lend to each other during crises times because they do not trust their counterparts. There are many other examples of bounded rationality in the markets, like focus on current events rather than long-term behavior of markets.
3.3 How can system dynamic models incorporate the four approaches?

System dynamics models can incorporate liquidity, behavioral finance, and fundamental asset pricing theories into one coherent framework. Although, there are only a couple of publicly available SD models that model stock market, they all incorporate not only different types of traders, but also inter-linkages among them. I construct model, which adds mechanisms through which leverage, profit or loss affect capital, trading and stock prices. Modeling starts by identifying model boundaries, i.e. exogenously and endogenously determined variables. Stock market is an open system, i.e. there are variables which are determined exogenously: initial stock price, interest rates, quantity of stocks traded, number of traders, capital, earnings (dividends) etc. Other variables are determined within the system, i.e. quantities of stock bought/sold by each trader, current: stock price, debt, leverage, capital, profit/loss etc. The model has inputs (arrows pointing inwards), output (arrows pointing outwards) and internal flows (arrows connecting elements).

**Figure 2 Simple Stock Market**
Figure 2 however does not provide any insights about control mechanisms inside the model, i.e. how particular system produces outputs, i.e. what is the transfer function and what is the control mechanism. Following Doyle, Francis et al. (1992) a general model can be described as an equation:

$$ y = (P + \Delta)u + n \quad (2) $$

Where $y$ is output, $u$ is input, $P$ – transfer function, $\Delta$ – unknown perturbation and $n$ – disturbance. If we apply this to stock markets, $y$ would be market price, $P$ – pricing function that determines fundamental price, $\Delta$ – external shock, and $n$ – white noise. However models described in Equation 2, are simply static models, i.e. based on historical data, estimated parameters. They do not incorporate feedback loops, i.e. processes that control systems. The simplest loop that restores equilibrium in simple stock market is price (leverage effect): the higher the price of the stock above its equilibrium (fundamental) value, the more incentives traders have to sell stock and vice versa. Figure 3 gives a rough overview of basic structure of a simple system dynamic model that has tree types of traders: fundamental, noise and technical. It has two types of flows: supply/demand (stocks) and information (prices/leverage), and one feedback loop: price effect.
Contrary to physical and mathematical models where system parameters are determined, economic models have many fuzzy elements, for example, what is a fundamental stock price and when it is overvalued and when it is undervalued? Do all traders get this information immediately, do they interpret it in the same way and at the same time, do they have the same or different expectations? Because humans make decisions, modeling of stock market involves many more feedback mechanisms and uncertainty parameter $\Delta$ plays greater role.

Market hierarchy, i.e. links of upward and downward trade subordination, creates further modeling complications. Hierarchy (Figure 3) can be modeled by adding interactions among various layers and sub-systems within the system. For example, buy/sell order flows from retail investors are aggregated by intermediaries (mutual funds, banks etc.) and then transmitted to exchanges. At the intermediate level, institutional investors trade among themselves. They create their own networks.
to bypass exchanges. These parallel networks can help to strengthen system's resilience, however might make price discovery less transparent.

**Figure 4 Market hierarchy**

Explicit modeling of interactions among multiple players is a challenging task. Many studies collected information on market topology (i.e. connections among traders, various institutions), visualized flows, identified behavioral patterns or performed various statistical tests to identify and quantify connections (for example, Bech, Atalay 2008; Billio, Getmansky, Lo et al. 2010). However most of the academic work usually focuses on identifying past behavior, but not on modeling future, i.e. applying obtained results in a dynamic model.
Studies focused on contagion also provide important insights about behavior of financial institutions before and during systemic events (for example, Nier E., Yang J. et al. 2007). If market structure is more complete, it is more stable and less prone to sudden crashes. This has direct effect on pricing: existence of parallel networks should minimize risk of network malfunction, maximize spread of information and make pricing process more efficient.

**Figure 5 Structure and stability of market**

![Figure 5 Structure and stability of market](image)

Network effects can be simulated in SD models via various threshold functions that describe how institutions behaved in the past. For example, if Trader A traded with Trader B only if A's rating was above BB+ (investment grade), rating downgrade simulation automatically breaks this connection. Amount of trade can be constructed in a similar way: it can depend on ratings, counterparty's leverage, size etc.

The next step in SD models is to define pricing equation, i.e. how market price is obtained. We can observe two components of stock price: flow based (dividends) and
stock based (market prices) (Figure 6). While dividends and discount rate are fundamental components that should change stock price, there is a behavioral positive (or negative) feedback effect related to value of price itself. If this component is not zero, price will go up or down just because traders expect it to behave. In practice it is however difficult to disentangle both components and quantify what share of price increase was due to expectations about change in future dividends (decline in discount rate), and what due to expectations about increase in price itself. Studies that focus on bubbles in markets suggests using various unit root and cointegration tests (see Campbell and Schiller 1987, Siegel 2003).

**Figure 6 Stock and flow components of asset pricing**

![Diagram showing stock and flow components of asset pricing](image)

 Asset prices do depend on the amount of money circulating in market, i.e. ability to trade with leverage. Adrian and Shin (2010) propose a simple model how leveraging and deleveraging processes cause fluctuations in asset prices. While it is not easy to include leverage proxy into conventional stock pricing models, SD models are well suited for this task: leverage is a stock variable, and by controlling it, one can simulate various outcomes in stock market prices. Increase in debt increases leverage,
and debt-servicing costs go up. As debt increases, debt-servicing capacity goes down. This limits amount of money (capital) flowing into stock market.

**Figure 7 Leverage loop**

![Leverage loop diagram]

3.4 Stability conditions

It is hard to find any system, which is perfectly stable. Majority of the systems do exhibit cyclical behavior. It is caused by delays in adjustment loops (negative loop). Contrary, if positive feedback loop dominates, a system shows exponential growth. If negative feedback dominates, we observe a goal seeking behavior in the system, i.e. it approaches some limit (see Sterman 2010).

In financial world, positive feedback loop leads to an increase in stock demand. If supply is limited (and usually it is, as public companies do not issue unlimited amount of shares immediately), mismatch between supply and demand lifts stock price further up. As price increases, negative feedback loop should come into play and limit trading activity by increasing trading costs (higher leverage, borrowing, interest rates etc.). If both loops cancel each other we obtain stable stock market model, i.e. based on disturbance, prices get back to an old or new fundamental level. System control theory states that internally stable systems should have strictly proper transfer functions, i.e. degree of the numerator is less than the degree of the denominator.
Equation 3 satisfies this condition. In the time domain, equation can be written as:

\[ p(T) = P_0 x(T) + \int_{-\infty}^{\infty} P_1(T + t) x(t) dt \quad (3) \]

where \( P(T) \) is market price, \( P_0 \) - initial price based on current level of dividends \( x \) (alternatively it is value of transfer function \( P \) at time period \( T \)). \( P_1 \) is transfer function, \( t \) - time period and \( x \) - flow of dividends. If flow of dividends \( x \) is finite number, i.e.:

\[ |x(T)| \leq c, \text{ for all } T, \text{ then we can rewrite Equation 3:} \]

\[ P(T) \leq P_0 c + \int_{-\infty}^{\infty} P_1(t) dt c \quad (4) \]

This gives us an interpretation of internal stability: since inputs (dividends) are finite, right hand side should be finite as well. Stock price should not grow exponentially. This assumption is valid, if valuation is based on assumption that stock value, similar to company's value, has terminal value, which might be expressed using perpetuity formula:

\[ P_T = \frac{X_T}{r} \quad (5) \]

where \( r \) - discount rate.

However this is just one of the two major loops that characterize the system, the other one is leverage. Leverage \( L \) for trader \( i \) can be expressed as ratio of debt \( D_i \) to capital \( C_i \):

\[ L_i = \frac{D_i}{C_i} \quad (6) \]

This measure is stable, if both, \( D_i \) and \( C_i \), are finite. While technically \( D \) is finite, capital might growth if value of assets grows (unrealized profit), because stock portfolio value
increases once market price goes up. As a result, leverage goes down, and traders can take on more debt, buy more stocks and drive market price even higher. Only two players in the system can inflate stock price indefinitely if they constantly borrow money and trade with each other. With this definition of leverage (equation 6) system is unstable. More narrow definition of leverage \( L_i^n \) assumes that it is equal to debt \( D \) over cash \( S \) and initial capital \( C_0 \):

\[
L_i^n = \frac{D_i}{c_i s_i} \quad (7)
\]

This definition brakes reinforcing feedback loop, i.e. increase in market valuation does not affect capital unless stocks are sold (realized profit) and cash is held.

Again, the same argument about finite leverage numbers applies to this loop as well: leverage is not indefinite, if there are constraints in place as shown in equation 7. Although, High Frequency Traders (HFTs) technically might be extremely highly leveraged during the trade period (intraday), they buy and sell almost instantly; hence their impact on pricing is minimal. Finally, our small trading system is stable if transfer functions are proper and stable for all loops and all traders. If leverage and other possible loops are not stable, system is unstable and can exhibit exploding behavior (bubbles). Even relatively small SD models might have hundreds of loops, thus stability testing can be a tedious task. Doyle, Francis et al. (1990) gives detailed explanation of efficient stability testing algorithms.

System stability conditions have very practical meaning: policy makers could use simulations to determine at what minimum leverage levels asset prices tend to increase beyond prudential limits.
Figure 8 Maximum leverage and asset prices

Figure 8 illustrates this point: if traders are able to increase leverage from $L_0$ to $L_1$, asset prices might grow for a longer time and be less volatile than with the lower leverage $L_0$. Global Financial Crisis provides an empirical illustration: Basel II capital standard allowed banks to decrease capital requirements on many balance sheet items, as a result their leverage went much beyond initial levels, envisaged in Basel I capital regulations. World enjoyed almost a decade of low volatility (so called The Great Moderation period). Once many financial institutions reached leverage limits, positive feedback component of the first pricing loop stopped working, as prices should adjust to the level of dividends (fundamental factors). This adjustment caused decline in prices and increase in leverage. As capital declined, negative leverage loop came into play: it amplified further decline in asset prices.

In many situations we don't have any luxury to test various propositions about optimal amount of leverage in real markets: it might take too much time to conduct those “natural” experiments, hence SD is a natural platform to simulate stability conditions. I want to emphasize importance of seeking correct goal: policy makers love
to stick to certain targets, like 8 or 10 percent of capital, 60 percent of debt to GDP ratio or any other political target. But from a system’s point of view, not the capital ratio, or debt ratio for a given state is of utmost importance: system's stability or in other words, sustainability, is what matters much more.

3.5 Modeling limitations

The highest complexity of SD models would be an ability to model market self-organization. This is a big challenge for System Dynamic models, as this involves modeling of changes in the market structure itself. Although presence of feedback loops helps SD models avoid fallacy of simple macroeconomic models described by famous Lucas critique (Lucas, 1976), SD models are still not able to reflect changes in self-organization, i.e. how structure of the system changes as a result of policy changes, external and internal shocks. This is because these changes are hardly predictable, and there are many ways how systems can change themselves.

While SD models can potentially incorporate behavioral phenomena (like delays in action, various strategic outcomes, like tit-for-tat, cooperation or non-cooperation, biases, prospect theory), to a broad extent this represents another modeling challenge: it is impossible to represent enormous array of irrational choices by a model with fixed number of possible outcomes (choices). Humans, who run companies, make decisions to trade, engage in opportunistic behavior, and seek opportunistic deals. These deals might be risky, but have huge potential upside for management and very limited downside due to limited liability. A good example of such situations is rogue traders, who make irrational bets from a risk management or
company's perspective, but might behave fully rational from their own understanding about limited liability they have. The most recent "London Whale" example is a good illustration, when just one large institutional trader alone can create bubble in a specific market.

Another phenomenon that is hardly modeled is so called Dark pools and high frequency traders (HFTs). Dark pools were established mainly to let large institutional investors to execute large orders without making significant impact on prevailing market prices. This is one of the differences between old and new systems: fundamental investors could benefit from this advantage if they want to sell large number of shares. Theoretically this should lower price volatility, however this is a source of potential instability if the size of the trade is discovered. In other words, the current system allows gaming against the market and expects increased returns by hiding the amount of actual trade. On the other hand, one can argue, that this split indeed improves market efficiency, as one large trade is split into a number of small trades. So HFTs or "front runners" can be seen as traders chasing for fundamental information, and thus increasing market efficiency. Although computers using sophisticated algorithms do more and more trading, there is some empirical evidence, that except rare disruptive events, HFTs provide liquidity to the market, lower transaction costs (see for example Jones 2013). Brogaard, Hendershott et al. 2013 provide further evidence that HFTs facilitate market price discovery process "by trading in the direction of permanent price changes and in the opposite direction of transitory pricing errors".
While HFTs do not play major a role in fundamental asset pricing process (their activity is not meant to move prices out of their long-term equilibrium) and their activities might not necessarily be seen by fundamental, noise or other regular “low-frequency” traders, their inclusion could benefit the model. In this case it would be possible to model HF trading related risks.

3.6 Conclusion

Figure 8 provides an overview how various theories are related together and how major asset pricing loops are incorporated. While fundamental theory gives an input into asset pricing formula (dividends, random movements, discount rate (pricing kernel), system dynamics approach incorporates other three groups of theories, namely behavioral, market microstructure and liquidity. The first positive feedback loop has nothing to do with fundamentals; it is based solely on internal microstructure of market and behavioral biases of traders. The second, negative feedback loop, stabilizes our artificial market by increasing trading costs, limiting leverage and changing expectations among traders about under/overvaluation of assets.

Claiming that there are just two major loops in asset pricing is a major oversimplification. Market price is a result of interaction of many feedback loops in the system. Proposed pricing model (Chapter 4) contains hundreds of loops. The reality is even much more complicated, and of course, model is not reality, it is a simplification. System dynamics approach is simplification of reality, but at the same time it is also an extension of very simple asset pricing models. It does not tell us what price is
fundamental, however it gives us better explanations on why and how prices fluctuate as well as what to do to limit those fluctuations.
Figure 9 Linkages among various asset-pricing approaches

Source: author.
4. AN ARTIFICIAL STOCK MARKET MODEL

4.1 Model boundaries

Market consists of 6 traders: three fundamental (FT), two noise (NT) and one technical (TT). Fundamental part of asset price is an input into the model, and market price and trade volumes are main outputs. Of course, model generates many internal outputs, like cash, profit, leverage, rating, capital, stock inventory etc. for each trader. There are several primary inputs: initial cash, initial capital, initial stock inventory, initial market price, initial individual prices for each trader. The model's limits portrayed in Figures 2 and 9. Model code is provided in Annex I and schematic diagrams - on Annex II.

The model has two major loops: positive feedback (reinforcing) and debt (balancing).

Figure 10 Two main loops
The fundamental part of asset pricing formula (1) is an exogenous variable. There are two numbers generated by software random number generator: earnings and random movements (random number generator is taken from Sterman 2000). The model itself does not explain or determine how earnings are generated. Dividends emerge randomly and follow random noise approach. This is, of course, a simplification, as dividends depend on corporate income, interest rates, GDP, various demand conditions, inflation, innovations, and many other market and macroeconomic variables. The model however allows incorporating various assumptions about earnings autocorrelation, similar to one observed in reality. It is also possible to expand the model by incorporating various models that link macro variables with dividends to forecast dividend payments.

When it comes to the balance sheet of traders, again, many simplifying limitations are at play. The model combines just several important items: debt, cash, stock inventories (assets at market prices). In systems, sources of oscillations are delays, price fluctuations happen not just because of changes in fundamentals, but also because of changes in the way and speed under which traders are able to acquire information, interpret it, and make decisions. It does not happen instantaneously, but with a delay. The model incorporates three delays; they are listed in Table 1 below.

**Table 1 Types of delays in the model**

<table>
<thead>
<tr>
<th>Delay</th>
<th>Explanation</th>
<th>Default value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustment time</td>
<td>Time for a stock price to adjust to changes in demand/supply</td>
<td>0. It is assumed that stock price react to changes (market order ratio, difference between sell and buy orders etc.) instantaneously. In less efficient, less liquid markets this parameter can be higher than</td>
</tr>
</tbody>
</table>
Adjustment time (individual for each trader or group of traders) | Adjustment time is the first order information delay or the gap between the current belief about the price and actual price. | Default value needs to be calibrated individually, however in more efficient markets for more efficient institutions this delay is very low. For HFTs this delay should be 0. For noise traders this delay should be the highest one (even several days, in most extreme case, if NTs don’t care about their portfolio very frequently). All in all, individual delay should also reflect situations when traders are not able or willing to obtain information (e.g. confirmation bias).

Rating adjustment time | This parameter is default for all traders. Parameter is based on assumption, that ratings or market's understanding about trader's leverage do not change immediately, even then leverage changes. If trader is not rated, then it's rating is just an approximation of its borrowing costs as a function of leverage. | Default value for this parameter is one day. The motivation is as follows: trader releases data about its leverage at day 1. Markets will most likely react at day 2. If markets react immediately to change in trader's leverage, delay should be almost 0. If rating is based on Rating agency's rating, time to adjust might be even longer, as agencies do careful examination and only then assign/change rating.

Combination of information delays gives us framework for price oscillations in stock markets, moreover, as Sterman (2000) notices, it has another nice property: smoothing out short-term noise.

4.2 Traders

Fundamental traders. These are large institutional investors, like commercial and investment banks, mutual, hedge funds etc. These traders have superior (not necessarily insider) information about market; they monitor their portfolios constantly and are less susceptible to various behavioral biases. Fundamental traders
trades are based on their expectation whether market price is above fundamental price or not. If market price is above, FTs sell stocks and vice-versa. If market value is below fundamental value, FTs evaluate profit opportunities: whether they can buy stocks from existing cash only, or borrow (use leverage). Leverage pressure is the ratio of target leverage and existing one. If target leverage is above existing, FTs borrow. Price of debt is market interest rate, however adjusted for FTs leverage, i.e. highly leveraged traders pay risk premium. Once FTs reach their target leverage, they do not buy additional stocks. This is model's constrain. However, if stock price is rising further, portfolio market valuation goes up. In this case, model has two options: market valuation of current portfolio, and thus increases in capital, or alternatively, more strict measure of leverage, namely cash and initial capital. In this case, leverage is a binding constraint, while in the former case it might be not – leverage goes down once market valuation of portfolio (subsequently capital) goes up (see equations 6 and 7).

**Figure 11 Fundamental Traders' trading loops**
If fundamental traders dominate market, market price reaches equilibrium value, i.e. its fundamental value. This is consistent with SD theory: if balancing loops dominant, system exhibits goal-seeking behavior, i.e. moves towards fundamental price. The price itself changes only when some external constraints are relaxed, i.e. interest rate (discount factor) or earnings change.

**Technical traders' (TTs)** trades are based on their perception about market trends: once prices go up, TTs buy, and once prices goes down – they sell. Technical traders, or technical analysts trading motivation and algorithms are more complicated than FTs. Lo, Mamaysky et al. (2000) provide evaluation of effectiveness of some TTs strategies (based on recognized technical patterns), and find that several technical indicators have value, as patterns tend to repeat over time.

My model incorporates very simple positive feedback strategy: TTs buy once prices go up, and sell once prices go down. In this regard, their strategy is based on trend only, while more sophisticated algorithms can incorporate various patterns, as described by Lo, Mamaysky et al. (2000).

Existence of technical traders moves system out of equilibrium, i.e. market price moves above fundamental value if market demand increases, and below fundamental value if market demand goes down. TTs strategies create reinforcing loop, but once price moves above its fundamental value, FTs have to sell. If this does not happen immediately, as there are delays. FTs might be willing to hold assets and hope that they can sell them once price increases even more. So FTs can also engage in positive feedback trading strategy, i.e. fundamental investors are not fundamental any more but rather TTs.
Noise traders have misperceptions about the markets, i.e. they think they know what a fundamental price is, but indeed they don’t know. In other words, there are investors who know that they don’t know (they are risk averse and tend to not invest into risky securities, and investors who don’t know that they don’t know (risk lovers). Noise traders in the model are the latter type, i.e. the ones who don’t know what is the fundamental price, don’t have superior information (analytics), and thus base their trading decisions on short-term trends in the market or their own believes about the value of stock. Schleifer (2000) makes assumption that noise traders are the ones who have erroneous believes about future returns on a risky asset. Behavior of noise traders is best characterized by so called Friedman effect: “buy high, sell low” (Friedman (1953), De Long, Schleifer et al (1990)). Noise traders are different from other types of traders: their ability to use leverage is much more limited than in the
case of fundamental or technical traders (professional investors), their expected price formation mechanism does not incorporate fundamental price or calculations about future distribution of stock returns (dividends). They can follow trend and have subjective believes about market.

**Figure 13 Noise traders’ trade loops**

![Diagram](image)

Existence of Noise traders should not move the system out of equilibrium, if their strategies are purely random, i.e. if some of them believe that price will go up, and some that price will go down, their erratic and random trading behavior can cancel each other. However NTs usually need more time to interpret information, so their subjective price is based on delayed market price and random movements. Weitert (2007) adds another loop in NTs pricing process: herding behavior, i.e. NTs reaction to observed trades in the market. While this is a valid assumption, it is difficult to analytically distinguish between TTs and NTs. TTs do exhibit some herding behavior as they observe market trends directly and follow trend. Trend is a signal for trade. If NTs jump into bandwagon, they follow the same strategy as TTs.

Figure 14 shows how trading strategies of all types of traders interrelate.
4.3 Trades

Markets represent complicated network of buyers and sellers, either individual ones or institutional investors. The network is not only technical network (i.e. used for transactions), it is also a social network as it sends information about demand and supply of individual stocks. Information asymmetry is critical, as trading counterpart might not know for what reasons stockholders wants to sell/buy his stock. In the model there are two fundamental types of trades:

a) Information trades driven by expectations;

b) Liquidity trades, driven by excessive leverage and asset fire sale (zero or negative capital).
Information trades are driven by either change in fundamental value (FTs), trend (TTs) or random effects (NTs). Positive feedback trading strategy is based on positive feedback loop, which is created by market expectations (news, reports, profits) or observations of trades. Fundamental price is not observable due to heterogeneous opinions: each fundamental investor FT has different view on fundamental value (fundamental price is observed only, and only if market expectations are homogenous).

Liquidity trades are not related to any of the information about fundamental value of security (i.e. insider information, beliefs etc.). They are based on traders liquidity needs. In general, trading liquidity needs might arise because: a) consumption (dividend payout), b) opportunistic investment opportunities or c) excessive leverage.

Model assumes that trading means either increase or decrease in inventory (stock) of assets.

4.4 Simulation results

Model simulation tests leveraging/deleveraging phenomenon and what impact it makes on market prices. Amount of stocks in a market is fixed; moreover, demand has to meet supply, i.e. if no one trader is selling, no one else can buy. To simplify modeling process, this version does not allow short selling. Supply emerges only when one or more traders think, that stock is overvalued (information trading) or needs to sell because of liquidity needs (liquidity trades). To test how market reacts to unexpected events, random increase in earnings is simulated (see Figure 15).
For initial simulations, the narrow measure of leverage is applied (equation 7). Increase in earnings is unexpected, and traders do not know *ex ante*, whether it is temporary or permanent. Figure 16 provides illustration with leverage levels 1, 5 and 10. Initial market price is 10, and asset price moves according to changes in expected dividends (fundamental pricing) and some random variable. Initial leverage is 1, but once leverage constrains are relaxed, demand for assets increases and market price goes up. Increase in leverage leads to oscillations in the market. Duration of stock price bubble is longer and market needs more time to get back to equilibrium. Exact form of market reaction, of course, depends on many parameters, including delays, behavioral patterns of traders (expectations about fundamental prices), shapes of demand and supply functions. Why price moves back to a new elevated equilibrium level? This is the result of debt repayment loop (only cash can be used to repay debt, hence traders have to sell some stock) and behavior of FTs. After some time traders realize, that earnings shock is temporary, not permanent, and adjust their expectations. Once price
increases above fundamental value, FTs sell. TTs follow immediately, and NTs follow with delay.

**Figure 16 Stock price: narrow leverage**

If only FTs can use leverage, (Figure 16) asset price dynamics is similar, however magnitude of bubble is lower, and adjustments happen faster.

**Figure 17 Stock price: only FTs use leverage**
Figure 18 gives an illustration what happens in a system, when leverage constraint is further relaxed, i.e. broad leverage measure is applied (equation 6). Once a one-time increase in dividends is simulated, leverage goes down when prices rise. NTs and TTs change expectations about price: demand jumps, asset price increases further; debt goes up as traders increase their leverage. FTs buy, until their actual leverage is equal to target. Once leverage goes up, demand increases further, asset price moves to new heights. Leverage goes down, borrowing goes further up and so on. Once system rises to a new equilibrium price, it exhibits oscillating behavior. Serrate line displays dynamic adjustment of rating, i.e. rating adjustment delay. The price does not go up indefinitely, because there are balancing loops that come into play: liquidity trade (debt servicing) and FTs expectations about fundamental price.

**Figure 18 Stock price: broad vs. narrow leverage**

Simulation results support hypothesis proposed by Adrian and Shin (2010), as well as results from an experiment conducted by Cipriani, Fostel and Houser (2012): when an asset can be used as a collateral, its price goes up. Increase in leverage coupled with some random increase in earnings, creates bubble due to false
expectations that this increase is permanent. NTs and TTs jump into the trading, and FTs also adjust their price expectations upwards. With leverage 1, bubble is very small, however with leverage 5, price oscillations are much bigger and last longer. Figure 18 illustrates, that not only the maximum leverage ratio matters, but also its definition as well. Narrow definition controls positive, reinforcing feedback loop much better than broad definition. System is more stable and moves back to initial equilibrium faster.

While maximum leverage and its definition is one set of parameters, which can be controlled, another one is dividends. Regulators do not control dividends explicitly, however results of stress testing (also capital assessment programs in the US) might prohibit banks (traders) from paying dividends to shareholders. What impact this dividend payment policy has on stock prices? In theory, dividend payments, inter alia, should increase leverage (capital is paid out) and decrease demand for assets. In my simple model, traders pay out 50% of their trading profits as dividends. Figure 19 illustrates this situation.

**Figure 19 Dividend payments and stock price**
While dividend payout indeed reduces bubble size, its effect is not very significant. Dividend payments require cash; hence traders need to sell part of stock inventory. Dividends also reduce cash holdings, and hence lower capital, increase leverage, lower rating, increase cost of debt, and ultimately depress expected profits. Once the bubble bursts, and artificial market moves closer to equilibrium, no trading profit is made: very little trading occurs, as traders do not have divergent expectations about fundamental price.

4.5 Possible expansion

Although my model expands SD models developed earlier by Provenzano (2002) and Weitert (2007), it is still has many limitations, including short selling rule, information transmission and expectations channels. Unlike reality, model results show, that once market is in equilibrium, very little trade occurs: only to satisfy liquidity needs. However in real life, much of trading occurs due to diverging expectations. In my model expectations might diverge among fundamental and noise traders, but converge among technical traders (that is why I included only one TT). The first ones exhibit random behavior, the latter ones tend to follow established patterns of technical analysis. Traders' choice does depend on market mood, i.e. optimistic or pessimistic expectations. This mood can be extracted from market itself, e.g. social networks: Facebook, Twitter, search sites like Google, Bing etc.  

^ For example see: http://www.peoplebrowsr.com/Datamine
Another way to change and expand the model is to use Limit order market mechanism. This involves order matching and price competition, i.e. the way in which most of electronic markets work.

And finally, dividend or fundamental pricing module can be added. This part of model could be used to test dynamically numerous assumptions about macroeconomic developments and asset prices.

There is also a possible regulatory implication: to maintain financial stability, central banks and regulators should think about targeting a leverage ratio in a financial system, i.e. the current rigid leverage ratio defined by Basel II/III regulations and capital adequacy rules could be made more flexible and countercyclical.
5. SUMMARY AND CONCLUSIONS

This thesis adopts System Dynamic theory to asset pricing and presents artificial stock market model, which includes debt and leverage feedback loops.

The model presented in this thesis, incorporates dependency between market microstructure, its stability and price formation mechanism. Novelty of this approach lies in dynamic modeling of interactions between various market participants, their impact on asset prices and system stability.

Each model needs to have its purpose, and the purpose of SD based model is not to find the holy grail of equilibrium price, which reflects countless fundamentals, but to explain how systems move to equilibrium. Hence, the aim of this model is to address the following issues:

a) How market microstructure impacts asset pricing?

b) How to increase market stability?

I show, that asset prices do depend on behavior of three types of investors, namely Fundamental Traders, Noise Traders and Technical traders. Once all there types of investors have different expectations about price, trading in an artificial market occurs normally and price fluctuates around equilibrium. Unexpected temporary increase in earnings causes asset price bubble, as investors speculate and do not know, whether this increase in dividends is permanent or temporary. This bubble is small, if traders are not allowed to leverage their positions. Leverage increases bubble size and period. Moreover, if regulatory or market definition of leverage (used for rating purposes) is broad, this creates a second reinforcing feedback loop, which increases price further.
Simulation results suggest that leverage loop is an important feedback mechanism, which affects asset price fluctuations and causes instability. This has essential regulatory implications: leverage definition and maximum numbers should be defined with less ambiguity and do not allow broad interpretation to avoid self-reinforcing feedback loop and unsustainable increase in prices.

The idea behind leverage and rating mechanism is to control the system, avoid excessive fluctuations. Similar to physical systems, internal instability can destroy it (or in nuclear physics terms, create "uncontrollable chain reaction"). This type of financial explosion we observed in 2008-9, at the peak of Global Financial Crisis. This was a clear indication, that internal control mechanisms in our financial system are broken. Positive feedback loop, observed in early 2000s as the "dot-com bubble", repeated again in 2008, but this time as housing bubble. While it is difficult to identify bubbles in advance, it is possible to control their magnitude by making sure, that balancing loops (leverage) work well.

System Dynamics methodology is still rarely used in finance modeling. However it is a natural platform of choice to build a dynamic artificial stock market model. It can incorporate most recent advances in financial economics, psychology and neurosciences. Of course, every model is not a reality; it is just a simplified reflection of it. We should understand those limitations while incorporating various rules and functions into models. Any model is based on rules, either internally computed or external parameter driven. It is thus far less complex than human behavior and real market, nevertheless I hope that such models would give us better understanding and provide guidance on how to design strategies for traders, investors and policymakers.
REFERENCES


Jones, Ch. (2013) "What do we know about high-frequency trading?" Mimeo, Columbia Business School.


ANNEX I. MODEL DOCUMENTATION

(001) Adjustment time = 0.0005
Units: Day
Time to adjust market price to changes in demand and supply conditions. As trading is done instantly, this time is very short by default.

(002) Adjustment time FT1 = 0.01
Units: Day
Adjustment time in days

(003) Adjustment time FT2 = 0.05
Units: Day
Time to adjust price expectations

(004) Adjustment time FT3 = 0.05
Units: Day
Time to adjust expected fundamental price

(005) Adjustment time NT1 = 2
Units: Day

(006) Adjustment time NT2 = 0.5
Units: Day
Amount of time noise trader reacts to changes in market price

(007) Adjustment time TT1 = 0.125
Units: Day
Time delay in days that TT needs to realize trend prevailing in the market.

(008) Allow noise trader own prices = 0
Units: Dimensionless
If =1, noise traders start trading by having their own price (initial price NTx). If =0, noise traders initial price is market price delayed by 1 day.

60
Borrowing amount FT1 = 
IF THEN ELSE( Expected profit FT1>0:AND:Leverage pressure 
FT1<1:AND:Borrowing FT1 
=1, (Capital FT1*Target leverage FT1- 
Capital FT1*Leverage FT1) 
, 0 )
Units: USD/Day
Borrowing equals to the current market price times buy order.
Borrowing is equal to 0 if leverage pressure is below 1 and/or
expected profit is negative.

Borrowing amount FT2 = 
IF THEN ELSE( Expected profit FT2>0:AND:Leverage pressure 
FT2<1:AND:Borrowing FT2 
=1, Capital FT2*Target leverage FT2-Capital FT2*Leverage FT2 
, 0 )
Units: USD/Day
Borrowing equals to the current market price times buy order.
Borrowing is equal to 0 if leverage pressure is below 1 and/or
expected profit is negative.

Borrowing amount FT3 = 
IF THEN ELSE( Expected profit FT3>0:AND:Leverage pressure 
FT3<1:AND:Borrowing FT3 
=1, Capital FT3*Target leverage FT3-Capital FT3 
*Leverage FT3 
, 0 )
Units: USD/Day
Borrowing equals to the current market price times buy order.
Borrowing is equal to 0 if leverage pressure is below 1 and/or
expected profit is negative.

Borrowing amount NT1 = 
IF THEN ELSE( Expected profit NT1>0:AND:Leverage pressure 
NT1<1:AND:Borrowing NT1 
=1, Capital NT1*Target leverage NT1-Capital NT1 
*Leverage NT1 
, 0 )
Units: USD/Day
Borrowing equals to the current market price times buy order.
Borrowing is equal to 0 if leverage pressure is below 1 and/or
expected profit is negative.

Borrowing amount NT2 =
IF THEN ELSE( Expected profit NT2>0:AND:Leverage pressure NT2<1:AND:Borrowing NT2 =1, Capital NT2*Target leverage NT2-Capital NT2 *Leverage NT2, 0 )
Units: USD/Day
Borrowing equals to the current market price times buy order.
Borrowing is equal to 0 if leverage pressure is below 1 and/or expected profit is negative.

(014) Borrowing amount TT1=
IF THEN ELSE( Expected profit TT1>0:AND:Leverage pressure TT1<1:AND:Borrowing TT1 =1, Capital TT1*Target leverage TT1-Capital TT1 *Leverage TT1, 0 )
Units: USD/Day
Borrowing equals to the current market price times buy order.
Borrowing is equal to 0 if leverage pressure is below 1 and/or expected profit is negative.

(015) Borrowing FT1=
1
Units: Dimensionless

(016) Borrowing FT2=
1
Units: Dimensionless

(017) Borrowing FT3=
1
Units: Dimensionless
Discrete variable: if 0 - no borrowing allowed, 1 - borrowing allowed.

(018) Borrowing NT1=
1
Units: Dimensionless

(019) Borrowing NT2=
1
Units: Dimensionless
1- borrowing allowed; 0 - borrowing not allowed.

(020) Borrowing TT1=
1
Units: Dimensionless

(021) Buy FT1=
   IF THEN ELSE( Demand FT1>0 , IF THEN ELSE( Supply FT2+Supply FT3+Supply NT1
   +Supply TT1+Supply NT2>=Demand FT1 , Demand FT1 , Supply FT2
   +Supply FT3
   +Supply NT1+Supply TT1+Supply NT2 ) , 0
tel) Units: Stocks/Day
Amount of stocks bought depends on market supply: if supply is
greater than demand, demand, otherwise - supply. If no stocks
are offered for sale, 0.

(022) Buy FT2=
   IF THEN ELSE( Demand FT2>0 , IF THEN ELSE( Supply FT1+Supply FT3+Supply NT1
   +Supply TT1+Supply NT2>=Demand FT2 , Demand FT2 , Supply FT1
   +Supply FT3
   +Supply NT1+Supply TT1+Supply NT2 ) , 0
tel) Units: Stocks/Day
Buy orders executed

(023) Buy FT3=
   IF THEN ELSE( Demand FT3>0 , IF THEN ELSE( Supply FT1+Supply FT2+Supply NT1
   +Supply TT1+Supply NT2>=Demand FT3 , Demand FT3 , Supply FT1
   +Supply FT2
   +Supply NT1+Supply TT1+Supply NT2 ) , 0
tel) Units: Stocks/Day
Buy orders executed

(024) Buy NT1=
   IF THEN ELSE( Demand NT1>0 , IF THEN ELSE( Supply FT1+Supply FT2+Supply FT3
   +Supply TT1+Supply NT2>=Demand NT1 , Demand NT1 , Supply FT1
   +Supply FT2
   +Supply FT3+Supply TT1+Supply NT2 ) , 0
tel) Units: Stocks/Day
Buy orders executed

(025) Buy NT2=
IF THEN ELSE( Demand NT2 > 0, IF THEN ELSE( Supply FT1 + Supply FT2 + Supply FT3 + Supply TT1 + Supply NT1 >= Demand NT2, Demand NT2, Supply FT1 + Supply FT2 + Supply TT1 + Supply NT1 ), 0 )

Units: Stocks/Day
Buy orders executed

(026) Buy orders = Fundamental Traders Buy + Noise traders Buy + Technical traders Buy
Units: Stocks/Day
Sum of all buy orders

(027) Buy TT1 = IF THEN ELSE( Demand TT1 > 0, IF THEN ELSE( Supply FT1 + Supply FT2 + Supply NT1 + Supply NT2 >= Demand TT1, Demand TT1, Supply FT1 + Supply FT2 + Supply FT3 + Supply NT1 + Supply NT2 ), 0 )

Units: Stocks/Day
Buy orders executed

(028) Capital FT1 = INTEG ( Profitability FT1 * Capital FT1 - Capital outflows FT1 + Profitability from trading FT1, Initial capital FT1)
Units: USD
Capital of the first Fundamental trader. It is equal to total capital plus profit minus outflows. Initial value is equal to 100.

(029) Capital FT2 = INTEG ( Profitability FT2 * Capital FT2 - Capital outflows FT2 + Profitability from trading FT2, Initial capital FT2)
Units: USD
Capital of the first Fundamental trader. It is equal to total capital plus profit minus outflows. Initial value is equal to 100.

(030) Capital FT3 = INTEG ( Profitability FT3 * Capital FT3 - Capital outflows FT3 + Profitability from trading FT3,
Initial capital FT3)

Units: USD
Capital of the first Fundamental trader. It is equal to total capital plus profit minus outflows. Initial value is equal to 100.

(031) Capital NT1= INTEG (Profitability NT1*Capital NT1-Capital outflows NT1+Profit from trading NT1)

Initial capital NT1)

Units: USD
Capital of the first Fundamental trader. It is equal to total capital plus profit minus outflows. Initial value is equal to 100.

(032) Capital NT2= INTEG (Profitability NT2*Capital NT2-Capital outflows NT2+Profitability from trading NT2)

Initial capital NT2)

Units: USD
Capital of the first Fundamental trader. It is equal to total capital plus profit minus outflows. Initial value is equal to 100.

(033) Capital outflows FT1=
IF THEN ELSE( Capital FT1>0:AND:Profit from trading FT1>0:AND:Cash FT1>0
, Dividend payments FT1*Profit from trading FT1 +Debt amortization constant*Debt FT1,
, IF THEN ELSE( Capital FT1>0:AND:Profitability FT1<=0:AND:Cash FT1>=Debt amortization constant
*Debt FT1:AND:Debt FT1>0 , Debt amortization constant
*Debt FT1 , IF THEN ELSE( Capital FT1>0:AND:Debt FT1>=0:AND:Debt amortization constant
*Debt FT1>Cash FT1 , Cash FT1 , 0)
)
)
Units: USD/Day
If profit is above 0, dividends are paid. If capital is zero, neither dividends are paid, nor debt is serviced.

(034) Capital outflows FT2=
IF THEN ELSE( Capital FT2>0:AND:Profit from trading FT2>0:AND:Cash FT2>0
, Dividend payments FT2*Profit from trading FT2 +Debt amortization constant*Debt FT2 , IF THEN ELSE
( Capital FT2>0:AND:Profitability FT2<=0:AND:Cash FT2>=Debt amortization constant *Debt FT2:AND:Debt FT2>0 , Debt amortization constant *Debt FT2 , IF THEN ELSE( Capital FT2>0:AND:Debt FT2>=0:AND:Debt amortization constant *Debt FT2>Cash FT2 , Cash FT2 , 0
) ))
Units: USD/Day
If profit is above 0, dividends are paid. If capital is zero, neither dividends are paid, nor debt is serviced.

(035) Capital outflows FT3=
IF THEN ELSE( Capital FT3>0:AND:Profit from trading FT3>0:AND:Cash FT3>0
, Dividend payments FT3*Profit from trading FT3 +Debt amortization constant*Debt FT3 , IF THEN ELSE
( Capital FT3>0:AND:Profitability FT3<=0:AND:Cash FT3>=Debt amortization constant *Debt FT3:AND:Debt FT3>0 , Debt amortization constant *Debt FT3 , IF THEN ELSE( Capital FT3>0:AND:Debt FT3>=0:AND:Debt amortization constant *Debt FT3>Cash FT3 , Cash FT3 , 0
) ))
Units: USD/Day
If profit is above 0, dividends are paid. If capital is zero, neither dividends are paid, nor debt is serviced.

(036) Capital outflows NT1=
IF THEN ELSE( Capital NT1>0:AND:Profit from trading NT1>0:AND:Cash NT1>0
, Dividend payments NT1*Profit from trading NT1 +Debt amortization constant*Debt NT1 , IF THEN ELSE
( Capital NT1>0:AND:Profitability NT1<=0:AND:Cash NT1>=Debt amortization constant *Debt NT1:AND:Debt NT1>0 , Debt amortization constant *Debt NT1 , IF THEN ELSE( Capital NT1>0:AND:Debt NT1>=0:AND:Debt amortization constant *Debt NT1>Cash NT1 , Cash NT1 , 0
) )
*Debt NT1>Cash NT1, Cash NT1, 0

)}
Units: USD/Day
If profit is above 0, dividends are paid. If capital is zero, neither dividends are paid, nor debt is serviced.

(037) Capital outflows NT2=
    IF THEN ELSE( Capital NT2>0:AND:Profit from trading NT2>0:AND:Cash NT2>0
    , Dividend payments NT2*Profit from trading NT2
    +Debt amortization constant*Debt NT2
    , IF THEN ELSE
    ( Capital NT2>0:AND:Profitability NT2<=0:AND:Cash NT2>=Debt amortization constant
    *Debt NT2:AND:Debt NT2>0 , Debt amortization constant
    *Debt NT2 , IF THEN ELSE( Capital NT2>0:AND:Debt NT2>=0:AND:Debt amortization constant
    *Debt NT2>Cash NT2 , Cash NT2 , 0

) )
Units: USD/Day
If profit is above 0, dividends are paid. If capital is zero, neither dividends are paid, nor debt is serviced.

(038) Capital outflows TT1=
    IF THEN ELSE( Capital TT1>0:AND:Profit from trading TT1>0:AND:Cash TT1>0
    , Dividend payments TT1*Profit from trading TT1
    +Debt amortization constant*Debt TT1
    , IF THEN ELSE
    ( Capital TT1>0:AND:Profitability TT1<=0:AND:Cash TT1>=Debt amortization constant
    *Debt TT1:AND:Debt TT1>0 , Debt amortization constant
    *Debt TT1 , IF THEN ELSE( Capital TT1>0:AND:Debt TT1>=0:AND:Debt amortization constant
    *Debt TT1>Cash TT1 , Cash TT1 , 0

) )
Units: USD/Day
If profit is above 0, dividends are paid. If capital is zero, neither dividends are paid, nor debt is serviced.

(039) Capital TT1= INTEG ( Profitability TT1*Capital TT1-Capital outflows TT1+Profitability from trading TT1
Initial capital TT1)

Units: USD

Capital of the first Fundamental trader. It is equal to total capital plus profit minus outflows. Initial value is equal to 100.

(040) Cash FT1 = INTEG(
   Inflows FT1-Outflows FT1,
   Initial Cash FT1)

Units: USD
Cash is equal to initial cash plus inflows minus outflows.

(041) Cash FT2 = INTEG(
   Inflows FT2-Outflows FT2,
   Initial Cash FT2)

Units: USD [0,?]
Cash is equal to initial cash plus inflows minus outflows.

(042) Cash FT3 = INTEG(
   Inflows FT3-Outflows FT3,
   Initial Cash FT3)

Units: USD
Cash is equal to initial cash plus inflows minus outflows.

(043) Cash NT1 = INTEG(
   Inflows NT1-Outflows NT1,
   Initial Cash NT1)

Units: USD
Cash is equal to initial cash plus inflows and minus outflows.

(044) Cash NT2 = INTEG(
   Inflows NT2-Outflows NT2,
   Initial Cash NT2)

Units: USD
Cash is equal to initial cash plus inflows and minus outflows.

(045) Cash TT1 = INTEG(
   Inflows TT1-Outflows TT1,
   Initial Cash TT1)

Units: USD
Cash is equal to initial cash plus inflows and minus outflows.

(046) Change in expected price FT1 =
   (Initial Fundamental price FT1 + NPV( Earnings , Interest rate , 0 , 1 ) -
   Expected price FT1)
Change in expected price occurs because of changes in revenues and depends on adjustment time.

(047) Change in Expected Price FT2 =

\[ \frac{\text{Initial Fundamental price FT2} + \text{NPV}( \text{Earnings}, \text{Interest rate}, 0, 1) - \text{Expected price FT2}}{1 + \text{Adjustment time FT2}} \]

Units: USD/Stocks/Day

Change in expected price depends on initial fundamental price adjusted by NVP of earnings. Adjustment time estimates FTs reaction time to change in fundamentals.

(048) Change in expected price FT3 =

\[ \frac{\text{Initial Fundamental price FT3} + \text{NPV}( \text{Earnings}, \text{Interest rate}, 0, 1) - \text{Expected price FT3}}{1 + \text{Adjustment time FT3}} \]

Units: USD/Stocks/Day

Change in expected price occurs because of changes in revenues and depends on adjustment time.

(049) Change in expected price NT1 =

\[ \frac{\text{Price NT1} - \text{Expected price NT1} + \text{Random movements}}{1 + \text{Adjustment time NT1}} \]

Units: USD/Stocks/Day

Change in expected price occurs because of random movements delayed by adjustment time. Noise traders are subject to random changes of valuation.

(050) Change in expected price NT2 =

\[ \frac{\text{Price NT2} - \text{Expected price NT2} + \text{Random movements}}{1 + \text{Adjustment time NT2}} \]

Units: USD/Stocks/Day

Change in expected price occurs because of random movements delayed by adjustment time. Noise traders are subject to random changes of valuation.

(051) Change in expected price TT1 =

\[ \text{Trend input TT1} \]

Units: USD/Stocks/Day

Change in expected price occurs because of changes in revenues and depends on adjustment time.

(052) Change in Pink Noise = (White Noise - Pink Noise)/Noise Correlation Time

Units: 1/Day
Change in the pink noise value; Pink noise is a first order exponential smoothing delay of the white noise input.

(053) Change in Pink Noise 0 = (White Noise 0 - Pink Noise 0)/Noise Correlation Time 0
Units: 1/Day
Change in the pink noise value; Pink noise is a first order exponential smoothing delay of the white noise input.

(054) Cost of debt FT1 =
Interest rate + Table of ratings and cost of debt (Rating adjustment delay FT1)
Units: percent/Day
This is the effect of rating on cost of debt

(055) Cost of debt FT2 =
Interest rate + Table of ratings and cost of debt (Rating adjustment delay FT2)
Units: percent/Day
This is the effect of rating on cost of debt

(056) Cost of debt FT3 =
Interest rate + Table of ratings and cost of debt (Rating adjustment delay FT3)
Units: percent/Day
This is the effect of rating on cost of debt

(057) Cost of debt NT1 =
Interest rate + Table of ratings and cost of debt (Rating adjustment delay NT1)
Units: percent/Day
This is the effect of rating on cost of debt

(058) Cost of debt NT2 =
Interest rate + Table of ratings and cost of debt (Rating adjustment delay NT2)
Units: percent/Day
This is the effect of rating on cost of debt

(059) Cost of debt TT1 =
Interest rate + Table of ratings and cost of debt (Rating adjustment delay)

TT1

Units: percent/Day
This is the effect of rating on cost of debt

(060) Debt amortization constant =

0
Units: Dimensionless
Percentage of debt that has to be returned each day.

(061) Debt amortization FT1 =

IF THEN ELSE ( Cash FT1 > 0 , Debt FT1 * Debt amortization ratio
FT1 * EXP ( Cost of debt FT1
* Time ) * Debt amortization constant , 0 )
Units: USD/Day
Daily payments of debt

(062) Debt amortization FT2 =

IF THEN ELSE ( Cash FT2 > 0 , Debt FT2 * Debt amortization ratio
FT2 * EXP ( Cost of debt FT2
* Time ) * Debt amortization constant , 0 )
Units: USD/Day
Daily payments of debt. If cash is greater than daily payment
amount, debt is repaid according to schedule, if not- 0 debt is
repaid or only part of it.

(063) Debt amortization FT3 =

IF THEN ELSE ( Cash FT3 > 0 , Debt FT3 * Debt amortization ratio
FT3 * EXP ( Cost of debt FT3
* Time ) * Debt amortization constant , 0 )
Units: USD/Day
Daily payments of debt

(064) Debt amortization NT1 =

IF THEN ELSE ( Cash NT1 > 0 , Debt NT1 * Debt amortization ratio
NT1 * EXP ( Cost of debt NT1
* Time ) * Debt amortization constant , 0 )
Units: USD/Day
Daily payments of debt

(065) Debt amortization NT2 =

IF THEN ELSE ( Cash NT2 > 0 , Debt NT2 * Debt amortization ratio
NT2 * EXP ( Cost of debt NT2
* Time ) * Debt amortization constant , 0 )
Units: USD/Day
Daily payments of debt

(066) Debt amortization ratio FT1 =
    IF THEN ELSE ( Cash FT1 >= Debt FT1, 1, ZIDZ( Cash FT1, Debt FT1 ) )
Units: USD/Day
Debt amortization is proportional to available cash. If cash is higher than debt, FT pays debt as scheduled, otherwise proportional share of cash is used.

(067) Debt amortization ratio FT2 =
    IF THEN ELSE ( Cash FT2 >= Debt FT2, Debt FT2, ZIDZ( Cash FT2, Debt FT2 ) )
Units: USD/Day

(068) Debt amortization ratio FT3 =
    IF THEN ELSE ( Cash FT3 >= Debt FT3, Debt FT3, ZIDZ( Cash FT3, Debt FT3 ) )
Units: USD/Day

(069) Debt amortization ratio NT1 =
    IF THEN ELSE ( Cash NT1 >= Debt NT1, 1, ZIDZ( Cash NT1, Debt NT1 ) )
Units: USD/Day
If cash is higher than debt, all debt is covered immediately, otherwise only partially, i.e. the share of cash/debt

(070) Debt amortization ratio NT2 =
    IF THEN ELSE ( Cash NT2 >= Debt NT2, 1, ZIDZ( Cash NT2, Debt NT2 ) )
Units: USD/Day
If cash is higher than debt, all debt is covered immediately, otherwise only partially, i.e. the share of cash/debt

(071) Debt amortization ratio TT1 =
    IF THEN ELSE ( Cash TT1 >= Debt TT1, 1, ZIDZ( Cash TT1, Debt TT1 ) )
Units: USD/Day
If cash is higher than debt, all debt is covered immediately, otherwise only partially, i.e. the share of cash/debt

(072) Debt amortization ratio TT1 =
    IF THEN ELSE ( Cash TT1 > 0, Debt TT1 * Debt amortization ratio TT1 * EXP( Cost of debt TT1 * Time ) * Debt amortization constant, 0 )
Units: USD/Day
Daily payments of debt

(073) Debt FT1 = INTEG (
Borrowing amount FT1-Debt amortization FT1, 
Initial debt FT1)
Units: USD  
Initial debt level of the first fundamental trader. Initial value is equal to 0.

\(074\) Debt FT2 = INTEG ( 
Borrowing amount FT2-Debt amortization FT2, 
Initial debt FT2)
Units: USD  
Initial debt level of the first fundamental trader. Initial value is equal to 0.

\(075\) Debt FT3 = INTEG ( 
Borrowing amount FT3-Debt amortization FT3, 
Initial debt FT3)
Units: USD  
Initial debt level of the first fundamental trader. Initial value is equal to 0.

\(076\) Debt NT1 = INTEG ( 
Borrowing amount NT1-Debt amortization NT1, 
Initial debt NT1)
Units: USD  
Initial debt level of the first fundamental trader. Initial value is equal to 0.

\(077\) Debt NT2 = INTEG ( 
Borrowing amount NT2-Debt amortization NT2, 
Initial debt NT2)
Units: USD  
Initial debt level of the first fundamental trader. Initial value is equal to 0.

\(078\) Debt TT1 = INTEG ( 
Borrowing amount TT1-Debt amortization TT1, 
Initial debt TT1)
Units: USD  
Initial debt level of the first fundamental trader. Initial value is equal to 0.

\(079\) Delayed market price NT1 = 
\(\text{DELAY FIXED}(\text{Market price}, 1, \text{Market price})\)
Units: USD  
Noise trader has no information about fundamental value of stock. She forms her beliefs based on past (latest) market price.
Delayed market price \( NT2 = \) 
\[
\text{DELAY FIXED( Market price , 1 , Market price )}
\]
Units: USD
Noise trader has no information about fundamental value of stock. She forms her beliefs based on past (latest) market price.

Demand \( FT1 = \) 
\[
\text{IF THEN ELSE( Demand function FT1>0 , Demand function FT1 , 0 )}
\]
Units: Stocks/Day
Buy order is available if demand function is positive only.

Demand \( FT2 = \) 
\[
\text{IF THEN ELSE( Demand function FT2>0 , Demand function FT2 , 0 )}
\]
Units: Stocks/Day
Buy order is available if demand function is positive only.

Demand \( FT3 = \) 
\[
\text{IF THEN ELSE( Demand function FT3>0 , Demand function FT3 , 0 )}
\]
Units: Stocks/Day
Buy order is available if demand function is positive only.

Demand function \( FT1 = \) 
\[
\text{INTEGER ( IF THEN ELSE ( Capital FT1>0 , IF THEN ELSE ( Expected profit FT1 >0:AND:Leverage pressure FT1<1 , (Target leverage FT1 -Leverage FT1)*Cash FT1/Market price , IF THEN ELSE ( Expected profit FT1 =0:AND:Leverage pressure FT1=1 , 0 , IF THEN ELSE ( Expected profit FT1 >=0 :AND:Leverage pressure FT1>1 , ) , -1*(Leverage FT1-Target leverage FT1)*Cash FT1/Market price , -1*Effect of market price and supply elasticity FT1*Stock inventory FT1)) ) , -1*Stock inventory FT1 )}
\]
Units: Stocks/Day
Demand function incorporates decision making algorithms based on leverage and expected profit. If capital is equal to 0 or negative, trader sales whole portfolio (firesale of assets). If capital is >0, many alternatives emerge. If expected profit is >0 and leverage below target, trader buys stocks up to target leverage ratio. In any case, if leverage ratio is above target, trader sells stocks. If leverage ratio is equal to target and expected profit=0, trader does nothing. If expected profit is negative (below threshold defined by effect of market price and supply elasticity), trader sells part of this portfolio.
Demand function $\text{FT2}=$

\[
\text{INTEGER ( IF THEN ELSE ( Capital FT2}>0 \text{, IF THEN ELSE ( Expected profit FT2} >0:AND:Leverage pressure FT2<1 \text{, (Target leverage FT2}
\]

\[
\text{-Leverage FT2)*Cash FT2/Market price, IF THEN ELSE ( Expected profit FT2}
\]

\[
=0:AND:Leverage pressure FT2=1, 0 \text{, IF THEN ELSE ( Expected profit FT2}=0
\]

\[
:AND:Leverage pressure FT2>1, 
\]

\[
-1*(Leverage FT2-Target leverage FT2)*Cash FT2/Market price, 
\]

\[
-1*\text{Effect of market price and supply elasticity FT2*Stock Inventory FT2})
\]

), -1*Stock Inventory FT2 )

Units: Stocks/Day
Demand function incorporates decision making algorithms based on leverage and expected profit. If capital is equal to 0 or negative, trader sales whole portfolio (firesale of assets). If capital is >0, many alternatives emerge. If expected profit is >0 and leverage below target, trader buys stocks up to target leverage ratio. In any case, if leverage ratio is above target, trader sells stocks. If leverage ratio is equal to target and expected profit=0, trader does nothing. If expected profit is negative (below threshold defined by effect of market price and supply elasticity), trader sells part of this portfolio.

Demand function $\text{FT3}=$

\[
\text{INTEGER ( IF THEN ELSE ( Capital FT3}>0 \text{, IF THEN ELSE ( Expected profit FT3} >0:AND:Leverage pressure FT3<1 \text{, (Target leverage FT3}
\]

\[
\text{-Leverage FT3)*Cash FT3/Market price, IF THEN ELSE ( Expected profit FT3}
\]

\[
=0:AND:Leverage pressure FT3=1, 0 \text{, IF THEN ELSE ( Expected profit FT3}=0
\]

\[
:AND:Leverage pressure FT3>1, 
\]

\[
-1*(Leverage FT3-Target leverage FT3)*Cash FT3/Market price, 
\]

\[
-1*\text{Effect of market price and supply elasticity FT3*Stock Inventory FT3})
\]

), -1*Stock Inventory FT3 )

Units: Stocks
Demand function incorporates decision making algorithms based on leverage and expected profit. If capital is equal to 0 or negative, trader sales whole portfolio (firesale of assets). If capital is >0, many alternatives emerge. If expected profit is >0 and leverage below target, trader buys stocks up to target leverage ratio. In any case, if leverage ratio is above target, trader sells stocks. If leverage ratio is equal to target and expected profit=0, trader does nothing. If expected profit is negative (below threshold defined by effect of market price and supply elasticity), trader sells part of this portfolio.
supply elasticity), trader sells part of this portfolio.

(087) Demand function NT1=
\[
\text{INTEGER ( IF THEN ELSE ( Capital NT1>0 , IF THEN ELSE ( Expected profit NT1 >0:AND:Leverage pressure NT1<1 , (Target leverage NT1 -Leverage NT1)*Cash NT1/Market price , IF THEN ELSE ( Expected profit NT1 =0:AND:Leverage pressure NT1=1 , 0 , IF THEN ELSE ( Expected profit NT1 >=0:AND:Leverage pressure NT1>1 , -1*(Leverage NT1-Target leverage NT1)*Cash NT1/Market price , Speculative trade NT1))), -1*Stock Inventory NT1 ))}
\]

Units: Stocks/Day
Demand function incorporates decision making algorithms based on leverage and expected profit. If capital is equal to 0 or negative, trader sales whole portfolio (firesale of assets). If capital is >0, many alternatives emerge. If expected profit is >0 and leverage below target, trader buys stocks up to target leverage ratio. In any case, if leverage ratio is above target, trader sells stocks. If leverage ratio is equal to target and expected profit=0, trader does nothing. If expected profit is negative (below threshold defined by effect of market price and supply elasticity), trader sells part of this portfolio.

(088) Demand function NT2=
\[
\text{INTEGER ( IF THEN ELSE ( Capital NT2>0 , IF THEN ELSE ( Expected profit NT2 >0:AND:Leverage pressure NT2<1 , (Target leverage NT2 -Leverage NT2)*Cash NT2/Market price , IF THEN ELSE ( Expected profit NT2 =0:AND:Leverage pressure NT2=1 , 0 , IF THEN ELSE ( Expected profit NT2 >=0:AND:Leverage pressure NT2>1 , -1*(Leverage NT2-Target leverage NT2)*Cash NT2/Market price , Speculative trade NT2))), -1*Stock Inventory NT2 ))}
\]

Units: Stocks/Day
Demand function incorporates decision making algorithms based on leverage and expected profit. If capital is equal to 0 or negative, trader sales whole portfolio (firesale of assets). If capital is >0, many alternatives emerge. If expected profit is >0 and leverage below target, trader buys stocks up to target leverage ratio. In any case, if leverage ratio is above target, trader sells stocks. If leverage ratio is equal to target and expected profit=0, trader does nothing. If expected profit is negative (below threshold defined by effect of market price and supply elasticity), trader sells part of this portfolio.
Demand function TT1 =
   INTEGER ( IF THEN ELSE ( Capital TT1>0 , IF THEN ELSE ( Expected profit TT1 >0:AND:Leverage pressure TT1<1 , (Target leverage TT1 -Leverage TT1)*Cash TT1/Market price , IF THEN ELSE ( Expected profit TT1 =0:AND:Leverage pressure TT1=1 , 0 , IF THEN ELSE ( Expected profit TT1 >=0:AND:Leverage pressure TT1>1 , -1*(Leverage TT1-Target leverage TT1)*Cash TT1/Market price , Trend trade TT1)) ) , -1*Stock Inventory TT1 ))
Units: Stocks/Day
Demand function incorporates decision making algorithms based on leverage and expected profit. If capital is equal to 0 or negative, trader sales whole portfolio (firesale of assets). If capital is >0, many alternatives emerge. If expected profit is >0 and leverage below target, trader buys stocks up to target leverage ratio. In any case, if leverage ratio is above target, trader sells stocks. If leverage ratio is equal to target and expected profit=0, trader does nothing. If expected profit is negative (below threshold defined by effect of market price and supply elasticity), trader sells part of this portfolio.

Demand function NT1 =
   IF THEN ELSE ( Demand function NT1>0 , Demand function NT1 , 0 )
Units: Stocks/Day
Buy order is available if demand function is positive only.

Demand function NT2 =
   IF THEN ELSE ( Demand function NT2>0 , Demand function NT2 , 0 )
Units: Stocks/Day
Buy order is available if demand function is positive only.

Demand function TT1 =
   IF THEN ELSE ( Demand function TT1>0 , Demand function TT1 , 0 )
Units: Stocks/Day
Buy order is available if demand function is positive only.

Dividend payments FT1 =
   0.5
Units: Dimensionless
Initial value is 50% of profit

Dividend payments FT2 =
   0.5
Units: Dimensionless
Initial value is 50% of profit
(095) Dividend payments FT3 = 
0.5 
Units: Dimensionless 
Initial value is 50% of profit, if profit is >0

(096) Dividend payments NT1 = 
0.5 
Units: Dimensionless 
Initial value is 50% of profit

(097) Dividend payments NT2 = 
0.5 
Units: Dimensionless 
Initial value is 50% of profit

(098) Dividend payments TT1 = 
0.5 
Units: Dimensionless 
Initial value is 50% of profit

(099) Dividends FT1 = 
IF THEN ELSE( Capital FT1>0:AND:Profitability FT1>0:AND:Cash FT1>0 
, Dividend payments FT1 
*Profit from trading FT1 , 0 
) 
Units: USD/Day 
If capital is higher than 0, profitability also positive, 
 dividends are paid. They are paid from profit from trading, but not from change in value of assets.

(100) Dividends FT2 = 
IF THEN ELSE( Capital FT2>0:AND:Profit from trading FT2>0:AND:Cash 
FT2>0 , Dividend payments FT2*Profit from trading FT2, 0 ) 
Units: USD/Day

(101) Dividends FT3 = 
IF THEN ELSE( Capital FT3>0:AND:Profit from trading FT3>0:AND:Cash 
FT3>0 , Dividend payments FT3*Profit from trading FT3, 0 ) 
Units: USD/Day

(102) Dividends NT1 = 
IF THEN ELSE( Capital NT1>0:AND:Profit from trading NT1>0:AND:Cash 
NT1>0
Dividend payments \( NT1 \times \text{Profit from trading } NT1, 0 \)
Units: USD/Day

\[(103)\] Dividends \( NT2 = \begin{cases} \text{IF } \text{Capital } NT2 > 0 : \text{AND: Profit from trading } NT2 > 0 : \text{AND: Cash} \\ \text{Dividend payments } NT2 \times \text{Profit from trading } NT2, 0 \end{cases} \]
Units: USD/Day

\[(104)\] Dividends \( TT1 = \begin{cases} \text{IF } \text{Capital } TT1 > 0 : \text{AND: Profit from trading } TT1 > 0 : \text{AND: Cash} \\ \text{Dividend payments } TT1 \times \text{Profit from trading } TT1, 0 \end{cases} \]
Units: USD/Day

\[(105)\] Earnings = Initial earnings \times \text{Input}
Units: USD
The exogenous earnings.

\[(106)\] Effect of market price and supply elasticity \( FT1 = \begin{cases} \text{Table of supply elasticity } FT \text{(Ratio of market price and expected price } \) \\ \text{Units: Dimensionless} \\ \text{Effect of difference between expected fundamental price and} \\ \text{market price is non-linear: once this difference reaches 50%, } FT \\ \text{sells almost all of its portfolio.} \end{cases} \]

\[(107)\] Effect of market price and supply elasticity \( FT2 = \begin{cases} \text{Table of supply elasticity } FT \text{(Ratio of market price and expected price } \) \\ \text{Units: Dimensionless} \\ \text{Effect of difference between expected fundamental price and} \\ \text{market price is non-linear: once this difference reaches 50%, } FT \\ \text{sells almost all of its portfolio.} \end{cases} \]

\[(108)\] Effect of market price and supply elasticity \( FT3 = \begin{cases} \text{Table of supply elasticity } FT \text{(Ratio of market price and expected price } \) \\ \text{Units: Dimensionless} \\ \text{Effect of difference between expected fundamental price and} \\ \text{market price is non-linear: once this difference reaches 50%, } FT \\ \text{sells almost all of its portfolio.} \end{cases} \]
Effect of market price and supply elasticity NT1=

Table of supply elasticity NT(Ratio of market price and expected price
NT1)

) Units: Dimensionless
Effect of difference between expected fundamental price and
market price is non-linear: once this difference reaches 50%, FT
sells almost all of its portfolio.

Effect of market price and supply elasticity NT2=

Table of supply elasticity NT(Ratio of market price and expected price
NT2)

) Units: Dimensionless
Effect of difference between expected fundamental price and
market price is non-linear: once this difference reaches 50%, FT
sells almost all of its portfolio.

Effect of market price and supply elasticity TT1=

Table of supply elasticity NT(Ratio of market price and expected price
TT1)

) Units: Dimensionless
Effect of difference between expected fundamental price and
market price is non-linear: once this difference reaches 50%, FT
sells almost all of its portfolio.

Expected price FT1 = INTEG(
Change in expected price FT1,
Initial Fundamental price FT1)
Units: USD/Stocks
Initial Fundamental Price adjusts due to change in expected
price, however with Adjustment time lag

Expected price FT2 = INTEG(
Change in Expected Price FT2,
Initial Fundamental price FT2)
Units: USD/Stocks
Initial Fundamental Price adjusts due to change in expected
price, however with Adjustment time lag

Expected price FT3 = INTEG(
Change in expected price FT3,
Initial Fundamental price FT3)
Units: USD/Stocks
Initial Fundamental Price adjusts due to change in expected price, however with Adjustment time lag

(115) Expected price NT1= \( \text{INTEG} \left( \frac{\text{Change in expected price NT1}}{\text{Delayed market price NT1}} \right) \)
Units: USD

Initial Fundamental Price adjusts due to change in expected price, however with Adjustment time lag

(116) Expected price NT2= \( \text{INTEG} \left( \frac{\text{Change in expected price NT2}}{\text{Delayed market price NT2}} \right) \)
Units: USD

Initial Fundamental Price adjusts due to change in expected price, however with Adjustment time lag

(117) Expected price TT1= \( \text{INTEG} \left( \frac{\text{Change in expected price TT1}}{\text{Market price}} \right) \)
Units: USD

Initial Fundamental Price adjusts due to change in expected price, however with Adjustment time lag

(118) Expected profit FT1= 
\( \left( \frac{\text{Expected price FT1} - \text{Market price}}{\exp(-\text{Interest rate}\times\text{Time})} \right) - \text{Cost of debt FT1} \)
*Market price-Spread
Units: USD/Day
Expected profit of FT 1, i.e. expected price minus market price and minus cost of debt and spread

(119) Expected profit FT2= 
\( \left( \frac{\text{Expected price FT2} - \text{Market price}}{\exp(-\text{Interest rate}\times\text{Time})} \right) - \text{Cost of debt FT2} \)
*Market price-Spread
Units: USD/Day
Expected profit of FT 2, i.e. expected price minus market price and minus cost of debt and spread

(120) Expected profit FT3= 
\( \left( \frac{\text{Expected price FT3} - \text{Market price}}{\exp(-\text{Interest rate}\times\text{Time})} \right) - \text{Cost of debt FT3} \)
*Market price-Spread
Units: USD/Day
Expected profit of FT 1, i.e. expected price minus market price
and minus cost of debt and spread

(121) Expected profit NT1 =
\[(\text{Market price - Expected price NT1}) / \exp(-\text{Interest rate} \times \text{Time})\] - Cost of debt NT1

*Market price - Spread
Units: USD/Day
Expected profit of NT, i.e. market price minus expected price discounted by interest rate and minus cost of debt and spread

(122) Expected profit NT2 =
\[(\text{Market price - Expected price NT2}) / \exp(-\text{Interest rate} \times \text{Time})\] - Cost of debt NT2

*Market price - Spread
Units: USD/Day
Expected profit of NT, i.e. market price minus expected price discounted by interest rate and minus cost of debt and spread

(123) Expected profit TT1 =
\[(\text{Market price - Expected price TT1}) / \exp(-\text{Interest rate} \times \text{Time})\] - Cost of debt TT1

*Market price - Spread
Units: USD/Day
Expected profit of NT, i.e. market price minus expected price discounted by interest rate and minus cost of debt and spread

(124) FINAL TIME = 250
Units: Day
The final time for the simulation.

(125) Fundamental Traders Buy =
Demand FT1 + Demand FT2 + Demand FT3
Units: Stocks
Total buy orders from fundamental traders

(126) Fundamental traders Sell =
Supply FT1 + Supply FT2 + Supply FT3
Units: Stocks
Aggregate sell orders from fundamental traders

(127) Inflows FT1 =
Borrowing amount FT1 + Market price * Sell FT1 - Spread * Sell FT1
Units: USD/Day
Inflows are equal to borrowings and cash proceeds from stock sales. Spread is deducted as trading costs.
Inflows $\text{FT2} = \text{Borrowing amount FT2} + \text{Market price} \times \text{Sell FT2} - \text{Spread} \times \text{Sell FT2}$
Units: USD/Day
Net income from sales and borrowing. Equals to borrowing amount, income from sales minus commission fees (spread).

Inflows $\text{FT3} = \text{Borrowing amount FT3} + \text{Market price} \times \text{Sell FT3} - \text{Spread} \times \text{Sell FT3}$
Units: USD/Day
Inflows are equal to borrowings and cash proceeds from stock sales. Spread is deducted as trading costs.

Inflows $\text{NT1} = \text{Borrowing amount NT1} + \text{Market price} \times \text{Sell NT1} - \text{Spread} \times \text{Sell NT1}$
Units: USD/Day
Inflows are equal to borrowings and cash proceeds from stock sales. Spread is deducted as trading costs.

Inflows $\text{NT2} = \text{Borrowing amount NT2} + \text{Market price} \times \text{Sell NT2} - \text{Spread} \times \text{Sell NT2}$
Units: USD/Day
Inflows are equal to borrowings and cash proceeds from stock sales. Spread is deducted as trading costs.

Inflows $\text{TT1} = \text{Borrowing amount TT1} + \text{Market price} \times \text{Sell TT1} - \text{Spread} \times \text{Sell TT1}$
Units: USD/Day
Inflows are equal to borrowings and cash proceeds from stock sales. Spread is deducted as trading costs.

Initial capital $\text{FT1} = 1$
Units: USD
Initial capital is equal to 100

Initial capital $\text{FT2} = 1$
Units: USD
Initial capital is equal to 100

Initial capital $\text{NT1} = 83$
20
Units: USD
Initial capital is equal to 20

(137) Initial capital NT2 =
20
Units: USD
Initial capital is equal to 20

(138) Initial capital TT1 =
100
Units: USD
Initial capital is equal to 100

(139) Initial Cash FT1 =
10
Units: USD

(140) Initial Cash FT2 =
100
Units: USD

(141) Initial Cash FT3 =
100
Units: USD
Initial cash for FT

(142) Initial Cash NT1 =
20
Units: USD

(143) Initial Cash NT2 =
100
Units: USD
Initial amount of cash for NT

(144) Initial Cash TT1 =
100
Units: USD

(145) Initial debt FT1 =
0
Units: USD
Initial debt in USD

(146) Initial debt FT2 =
0
Units: USD
Initial debt in USD

(147) Initial debt FT3=
0
Units: USD
Initial debt in USD

(148) Initial debt NT1=
0
Units: USD
Initial debt in USD

(149) Initial debt NT2=
0
Units: USD
Initial debt in USD

(150) Initial debt TT1=
0
Units: USD
Initial debt in USD

(151) Initial earnings=
1
Units: USD
The initial earnings per share

(152) Initial Fundamental price FT1=
15
Units: USD
Expected price for FT1

(153) Initial Fundamental price FT2=
9
Units: USD
Initial fundamental price for FT2 is based on FT2 observations
and fundamental analysis of stock’s returns (dividends)

(154) Initial Fundamental price FT3=
7
Units: USD
Initial fundamental price of FT

(155) Initial Inventory FT1=
85
100
Units: Stocks

(156) Initial Inventory FT2 =
  100
Units: Stocks

(157) Initial Inventory FT3 =
  100
Units: **undefined**

(158) Initial Inventory NT1 =
  50
Units: **undefined**

(159) Initial Inventory NT2 =
  50
Units: Stocks
  Initial inventory is equal to 50 stocks

(160) Initial Inventory TT1 =
  100
Units: Stocks

(161) Initial price =
  10
Units: USD
  Initial stock price.

(162) Initial price NT1 =
  10
Units: USD
  Initial price for NT is based on her subjective beliefs about stock value

(163) Initial price NT2 =
  10
Units: USD
  Initial price for NT. It is equal to last observed market price

(164) Initial price TT1 =
  12
Units: USD
  Initial price TT

(165) INITIAL TIME = 0
Units: Day
The initial time for the simulation.

(166) Initial trend=
0
Units: 1/Day
Initial trend is trend at day 0. It is set to 0 by default.

(167) Input=
1 + \text{STEP}(\text{Step Height,Step Time}) + \\
(\text{Pulse Quantity/Pulse Duration})*\text{PULSE}(\text{Pulse Time,Pulse Duration}) + \\
\text{RAMP}(\text{Ramp Slope,Ramp Start Time,Ramp End Time}) + \\
\text{Sine Amplitude*}\text{SIN}(2*3.14159*\text{Time/Sine Period}) + \\
\text{STEP}(1,\text{Noise Start Time})*\text{Pink Noise}

Units: Dimensionless
Input is a dimensionless variable which provides a variety of

test input patterns, including a step, pulse, sine wave, and
random noise.

(168) Input 0=
1 + \text{STEP}(\text{Step Height 0,Step Time 0}) + \\
(\text{Pulse Quantity 0/Pulse Duration 0})*\text{PULSE}(\text{Pulse Time 0,Pulse Duration 0}) + \\
\text{RAMP}(\text{Ramp Slope 0,Ramp Start Time 0,Ramp End Time 0}) + \\
\text{Sine Amplitude 0*}\text{SIN}(2*3.14159*\text{Time/Sine Period 0}) + \\
\text{STEP}(1,\text{Noise Start Time 0})*\text{Pink Noise 0}

Units: Dimensionless
Input is a dimensionless variable which provides a variety of

test input patterns, including a step, pulse, sine wave, and
random noise.

(169) Interest rate=
0.0002
Units: percent/Day
Market interest rate. LIBOR

(170) Leverage FT1=
\text{IF THEN ELSE( Leverage measure=0 , ZIDZ( Debt FT1 , Capital FT1 ) ,}
\text{ZIDZ( Debt FT1 , Initial Cash FT1+Profit from trading FT1+Initial capital FT1 ) )}

Units: Dimensionless
Leverage is the ratio of debt over capital.

(171) Leverage FT2=
IF THEN ELSE( Leverage measure=0 , ZIDZ( Debt FT2 , Capital FT2 ) ,
ZIDZ( Debt FT2 , Initial capital FT2+Initial Cash FT2+Profit from trading FT2 ) )
Units: Dimensionless
Leverage is the ratio of debt over capital.

(172) Leverage FT3=
IF THEN ELSE( Leverage measure=0 , ZIDZ( Debt FT3 , Capital FT3 ) ,
ZIDZ( Debt FT3 , Initial Cash FT3+Initial capital FT3+Profit from trading FT3 ) )
Units: Dimensionless
Leverage is the ratio of debt over capital.

(173) Leverage measure=
1
Units: Dimensionless [0,1]
The model allows to use two measure of leverage: debt over equity (Leverage measure =0) and alternatively debt/cash+initial capital. The first measure captures market value of assets, and hence is very pro-cyclical, the second one is based on highly liquid assets only, i.e. initial capital, initial cash and profit from trading. The second metrics is not directly affected by market prices, and hence is less pro-cyclical.

(174) Leverage NT1=
IF THEN ELSE( Leverage measure=0 , ZIDZ( Debt NT1 , Capital NT1 ) ,
ZIDZ( Debt NT1 , Initial Cash NT1+Profit from trading NT1+Initial capital NT1 ) )
Units: Dimensionless
Leverage is the ratio of debt over capital.

(175) Leverage NT2=
IF THEN ELSE( Leverage measure=0 , ZIDZ( Debt NT2 , Capital NT2 ) ,
ZIDZ( Debt NT2 , Initial Cash NT2+Profit from trading NT2+Initial capital NT2 ) )
Units: Dimensionless
Leverage is the ratio of debt over capital.

(176) Leverage pressure FT1=
Leverage FT1/Target leverage FT1
Units: Dimensionless
Indicates whether actual leverage is higher or below target
leverage. It is equal to leverage over target leverage

(177) Leverage pressure $\text{FT2} =$
Leverage $\text{FT2}$/Target leverage $\text{FT2}$
Units: Dimensionless
Indicates whether actual leverage is higher or below target leverage. It is equal to leverage over target leverage

(178) Leverage pressure $\text{FT3} =$
Leverage $\text{FT3}$/Target leverage $\text{FT3}$
Units: Dimensionless
Indicates whether actual leverage is higher or below target leverage. It is equal to leverage over target leverage

(179) Leverage pressure $\text{NT1} =$
Leverage $\text{NT1}$/Target leverage $\text{NT1}$
Units: Dimensionless
Indicates whether actual leverage is higher or below target leverage. It is equal to leverage over target leverage

(180) Leverage pressure $\text{NT2} =$
Leverage $\text{NT2}$/Target leverage $\text{NT2}$
Units: Dimensionless
Indicates whether actual leverage is higher or below target leverage. It is equal to leverage over target leverage

(181) Leverage pressure $\text{TT1} =$
Leverage $\text{TT1}$/Target leverage $\text{TT1}$
Units: Dimensionless
Indicates whether actual leverage is higher or below target leverage. It is equal to leverage over target leverage

(182) Leverage $\text{TT1} =$
IF THEN ELSE( Leverage measure=0 , ZIDZ( Debt $\text{TT1}$ , Capital $\text{TT1}$ ) ,
ZIDZ( Debt $\text{TT1}$ , Initial Cash $\text{TT1}$+Profit from trading $\text{TT1}$+Initial capital $\text{TT1}$ ) )
Units: Dimensionless [0,200]
Leverage is the ratio of debt over capital.

(183) Market= INTEG ( 
Buy $\text{FT1}$+Buy $\text{FT2}$+Buy $\text{FT3}$+Buy $\text{NT1}$+Buy $\text{NT2}$+Buy $\text{TT1}$-Sell $\text{FT1}$-Sell $\text{FT2}$-Sell $\text{FT3}$
-Sell $\text{NT1}$-Sell $\text{NT2}$-Sell $\text{TT1}$,
0)
Units: Stocks
Market. Number of stocks bought and sold. Total amount equals 0, as trades cancel each other.

(184) Market order ratio = \( \frac{\text{Buy orders}}{\text{Sell orders}} \)
Units: Dimensionless
Market order ratio equals to buy orders over sell orders. It shows market pressure, i.e. whether there is higher demand or supply of shares. This ratio reflects demand and supply, but not the actual deals (executed orders). To calibrate the model, it can be used together or as an alternative to Market pressure.

(185) Market pressure = \( \text{IF} \quad \text{THEN ELSE} (\frac{\text{Buy orders} - \text{Sell orders}}{\text{Total shares outstanding}}) \)
Units: Dimensionless
Market pressure measures pressure on stock price based on total number of net orders outstanding: more net orders to buy - market price goes up, more net orders to sell - market price goes down. It can be used to calibrate the model or as an alternative to market order ratio.

(186) Market price = \( \text{INTEG} (\text{Pricing function, Initial price}) \)
Units: USD [0,100]
Market price reflects demand/supply conditions and earnings (fundamental factors) as well as random movements.

(187) Noise Correlation Time = 7
Units: Day
The correlation time constant for Pink Noise.

(188) Noise Correlation Time 0 = 14
Units: Day
The correlation time constant for Pink Noise.

(189) Noise Standard Deviation = 0.5
Units: Dimensionless
The standard deviation of the pink noise process.
(190) Noise Standard Deviation $0 = 0.1$
Units: Dimensionless
The standard deviation of the pink noise process.

(191) Noise Start Time $0 = 0$
Units: Day
Start time for the random input.

(192) Noise Start Time $0 = 0$
Units: Day
Start time for the random input.

(193) Noise traders Buy $=$
Demand NT1 + Demand NT2
Units: Stocks/Day
Sum of all buy orders from the Noise traders

(194) Noise traders Sell $=$
Supply NT1 + Supply NT2
Units: Stocks/Day
Total amount of shares noise traders offer to sell in the market

(195) Outflows FT1 $=$
Buy FT1 * Market price + Capital outflows FT1
Units: USD/Day
Cash outflows due to debt amortization and increase in inventory

(196) Outflows FT2 $=$
Buy FT2 * Market price + Capital outflows FT2
Units: USD/Day
Cash outflows due to buying of stocks and capital outflows

(197) Outflows FT3 $=$
Buy FT3 * Market price + Capital outflows FT3
Units: USD/Day

(198) Outflows NT1 $=$
Buy NT1 * Market price + Capital outflows NT1
Units: USD/Day
Cash outflows equal to buy orders multiplied by market price and capital outflows due to debt service and dividend payments

(199) Outflows NT2 $=$
Buy NT2*Market price + Capital outflows NT2
Units: USD/Day
Cash outflows equal to buy orders multiplied by market price and
capital outflows due to debt service and dividend payments

(200) Outflows TT1 =
Buy TT1*Market price + Capital outflows TT1
Units: USD/Day
Cash outflows equal to buy orders multiplied by market price and
capital outflows due to debt service and dividend payments

(201) Per share pricing increment =
0.05
Units: Dimensionless
Per share pricing increment reflects increase or decrease in
price based on number of shares sold or bought

(202) Pink Noise = INTEG(Change in Pink Noise, 0)
Units: Dimensionless
Pink Noise is first-order auto correlated noise. Pink noise
provides a realistic noise input to models in which the next
random shock depends in part on the previous shocks. The user
can specify the correlation time. The mean is 0 and the standard
development is specified by the user.

(203) Pink Noise 0 = INTEG(Change in Pink Noise 0, 0)
Units: Dimensionless
Pink Noise is first-order auto correlated noise. Pink noise
provides a realistic noise input to models in which the next
random shock depends in part on the previous shocks. The user
can specify the correlation time. The mean is 0 and the standard
development is specified by the user.

(204) Price NT1 =
  IF THEN ELSE( Allow noise trader own prices = 1, Initial price NT1,
Delayed market price NT1
  )
Units: USD
Price input selection. If Allow noise trader own prices = 1,
initial price for NT is used in the model, otherwise - delayed
market price (Perceived price NT).

(205) Price NT2 =
  IF THEN ELSE( Allow noise trader own prices = 1, Initial price NT2,
Delayed market price NT2
  )
Units: USD
Price input selection. If Allow noise trader own prices=1, initial price for NT is used in the model, otherwise - delayed market price (Perceived price NT).

(206) Pricing function=
  IF THEN ELSE( Pricing model alternatives=0 , (Initial price+Random movements -Market price)/(1+Adjustment time) , IF THEN ELSE( Pricing model alternatives =1 , (Initial price+Market pressure *Market price+Random movements -Market price)/(1+Adjustment time) , IF THEN ELSE( Pricing model alternatives =2 , (Initial price+Initial price*Per share pricing increment*Table of market elasticity (Market order ratio)+Random movements -Market price)/(1+Adjustment time) , (Initial price+Initial price*Per share pricing increment *Table of market elasticity(Market order ratio)+Market pressure *Market price+Random movements -Market price)/(1+Adjustment time) ))) )
Units: USD
Market pricing function calculates changes in initial market price. It depends on choice of pricing alternative, and can include each of method separately, both methods (market pressure and market order ratio) as well as none of them. In this case market price is exogenous and depends on random movements only.

(207) Pricing model alternatives= 2
Units: Dimensionless [0,3,1]
Selection of pricing function alternatives. If=0, neither Market pressure, nor Market Order Ratio are used in the model. If=1, Market Pressure is used in the model. If=2, Market order ratio is used in the model. If=3, both, Market pressure and Market Order Ratio are used in the model.

(208) Profit from trading FT1= INTEG ( Profitability from trading FT1-Dividends FT1, 0)
Units: USD
Profit from trading operations.
(209) Profit from trading FT2 = \( \text{INTEG} \) (Profitability from trading FT2-Dividends FT2, 0)
Units: USD

(210) Profit from trading FT3 = \( \text{INTEG} \) (Profitability from trading FT3-Dividends FT3, 0)
Units: USD

(211) Profit from trading NT1 = \( \text{INTEG} \) (Profitability from trading NT1-Dividends NT1, 0)
Units: USD

(212) Profit from trading NT2 = \( \text{INTEG} \) (Profitability from trading NT2-Dividends NT2, 0)
Units: USD

(213) Profit from trading TT1 = \( \text{INTEG} \) (Profitability from trading TT1-Dividends TT1, 0)
Units: USD

(214) Profit from valuation changes FT1 = (Market price-Initial price) \times \text{Stock inventory FT1}
Units: USD/Day
Market value of portfolio

(215) Profit from valuation changes FT2 = (Market price-Initial price) \times \text{Stock inventory FT2}
Units: USD/Day
Market value of portfolio

(216) Profit from valuation changes FT3 = (Market price-Initial price) \times \text{Stock inventory FT3}
Units: USD/Day
Market value of portfolio

(217) Profit from valuation changes NT1 = (Market price-Initial price) \times \text{Stock inventory NT1}
Units: USD/Day
Market value of portfolio

(218) Profit from valuation changes NT2 =
(Market price-Initial price)*Stock Inventory NT2
Units: USD/Day
Market value of portfolio. It depends on current market price and constantly changes.

(219) Profit from valuation changes TT1=
(Market price-Initial price)*Stock Inventory TT1
Units: USD/Day
Market value of portfolio

(220) Profitability from trading FT1=
Sell FT1*(Market price-Initial price)
Units: USD/Day
Profitability from trading activity, i.e. realized profit from trade

(221) Profitability from trading FT2=
Sell FT2*(Market price-Initial price)
Units: USD/Day

(222) Profitability from trading FT3=
Sell FT3*(Market price-Initial price)
Units: USD/Day

(223) Profitability from trading NT1=
Sell NT1*(Market price-Initial price)
Units: USD/Day

(224) Profitability from trading NT2=
Sell NT2*(Market price-Initial price)
Units: USD/Day

(225) Profitability from trading TT1=
Sell TT1*(Market price-Initial price)
Units: USD/Day

(226) Profitability FT1=
((+Profit from valuation changes FT1)-Capital FT1)/Capital FT1
Units: USD/Day
Profit equals to value of current assets minus initial price multiplied by initial inventory

(227) Profitability FT2=
((Profit from valuation changes FT2)-Capital FT2)/Capital FT2
Units: USD/Day
Profit equals to value of current assets minus initial price
multiplied by initial inventory

(228) Profitability FT3 = 
\[
\frac{(\text{Profit from valuation changes FT3}) - \text{Capital FT3}}{\text{Capital FT3}}
\]
Units: USD/Day
Profit equals to value of current assets minus initial price
multiplied by initial inventory

(229) Profitability NT1 = 
\[
\frac{(\text{Profit from valuation changes NT1}) - \text{Capital NT1}}{\text{Capital NT1}}
\]
Units: USD/Day
Profit equals to value of current assets minus initial price
multiplied by initial inventory

(230) Profitability NT2 = 
\[
\frac{(\text{Profit from valuation changes NT2}) - \text{Capital NT2}}{\text{Capital NT2}}
\]
Units: USD/Day
Profit equals to value of current assets minus initial price
multiplied by initial inventory

(231) Profitability TT1 = 
\[
\frac{(\text{Profit from valuation changes TT1}) - \text{Capital TT1}}{\text{Capital TT1}}
\]
Units: USD/Day
Profit equals to value of current assets minus initial price
multiplied by initial inventory

(232) Pulse Duration = 
2
Units: Day
Duration of pulse input. Set to Time Step for an impulse.

(233) Pulse Duration 0 = 
1
Units: Day
Duration of pulse input. Set to Time Step for an impulse.

(234) Pulse Quantity = 
5
Units: Dimensionless*Day
The quantity as a fraction of the base value of Input. For example, to pulse in a quantity equal to 50% of the current value of input, set to .50.

(235) Pulse Quantity 0 = 
0
Units: Dimensionless*Day
The quantity to be injected to customer orders, as a fraction of the base value of Input. For example, to pulse in a quantity equal to 50% of the current value of input, set to .50.

(236) Pulse Time=
    15
Units: Day
Time at which the pulse in Input occurs.

(237) Pulse Time 0=
    0
Units: Day
Time at which the pulse in Input occurs.

(238) Ramp End Time=
    5
Units: Day
End time for the ramp input.

(239) Ramp End Time 0=
    0
Units: Day
End time for the ramp input.

(240) Ramp Slope=
    -1
Units: 1/Day
Slope of the ramp input, as a fraction of the base value (per year).

(241) Ramp Slope 0=
    0
Units: 1/Day
Slope of the ramp input, as a fraction of the base value (per day).

(242) Ramp Start Time=
    4
Units: Day
Start time for the ramp input.

(243) Ramp Start Time 0=
    0
Units: Day
Start time for the ramp input.
Random movements = \[\text{MAX}(0, \text{Input 0-1})\]  
Units: Dimensionless

Absenteeism as a fraction of the labor force is determined by the test generator input for absenteeism (Input 0). Absenteeism is never less than zero (workers often fail to show up for their shift but never show up when they are not scheduled).

Rating adjustment delay FT1 =  
\[\text{DELAY1}(\text{Rating for FT1}, \text{Rating adjustment time})\]  
Units: Dimensionless
Delay to adjust rating

Rating adjustment delay FT2 =  
\[\text{DELAY1}(\text{Rating for FT2}, \text{Rating adjustment time})\]  
Units: Dimensionless
Delay to adjust rating

Rating adjustment delay FT3 =  
\[\text{DELAY1}(\text{Rating for FT3}, \text{Rating adjustment time})\]  
Units: Dimensionless
Delay to adjust rating

Rating adjustment delay NT1 =  
\[\text{DELAY1}(\text{Rating for NT1}, \text{Rating adjustment time})\]  
Units: Dimensionless
Delay to adjust rating

Rating adjustment delay NT2 =  
\[\text{DELAY1}(\text{Rating for NT2}, \text{Rating adjustment time})\]  
Units: Dimensionless
Delay to adjust rating

Rating adjustment delay TT1 =  
\[\text{DELAY1}(\text{Rating for TT1}, \text{Rating adjustment time})\]  
Units: Dimensionless
Delay to adjust rating

Rating adjustment time =  
\[1\]  
Units: Day
Time to adjust rating. Rating agencies usually do not adjust ratings immediately. Market prices change first, and only then agencies react to change in leverage.

Rating for FT1 =
Table of leverage and ratings (Leverage FT1)
Units: Dimensionless
This is the effect of leverage on ratings.

(253) Rating for FT2 =
Table of leverage and ratings (Leverage FT2)
Units: Dimensionless
This is the effect of leverage on ratings.

(254) Rating for FT3 =
Table of leverage and ratings (Leverage FT3)
Units: Dimensionless
This is the effect of leverage on ratings.

(255) Rating for NT1 =
Table of leverage and ratings (Leverage NT1)
Units: Dimensionless
This is the effect of leverage on ratings.

(256) Rating for NT2 =
Table of leverage and ratings (Leverage NT2)
Units: Dimensionless
This is the effect of leverage on ratings.

(257) Rating for TT1 =
Table of leverage and ratings (Leverage TT1)
Units: Dimensionless
This is the effect of leverage on ratings.

(258) Ratio of market price and expected price FT1 =
\[
\frac{(Expected\ price\ FT1-Market\ price)}{Market\ price}
\]
Units: Dimensionless
If market price is higher than expected (fundamental price), FT sells part or whole stocks portfolio.

(259) Ratio of market price and expected price FT2 =
\[
\frac{(Expected\ price\ FT2-Market\ price)}{Market\ price}
\]
Units: Dimensionless
If market price is higher than expected (fundamental price), FT sells part or whole stocks portfolio.

(260) Ratio of market price and expected price FT3 =
\[
\frac{(Expected\ price\ FT3-Market\ price)}{Market\ price}
\]
Units: Dimensionless
If market price is higher than expected (fundamental price), FT sells part or whole stocks portfolio.
(261) Ratio of market price and expected price NT1=
\[
\frac{(\text{Market price-Expected price NT1})}{\text{Expected price NT1}}
\]
Units: Dimensionless
If market price is higher than expected, NT buys part or whole stocks portfolio and vice-versa.

(262) Ratio of market price and expected price NT2=
\[
\frac{(\text{Market price-Expected price NT2})}{\text{Expected price NT2}}
\]
Units: Dimensionless
If market price is higher than expected, NT buys part or whole stocks portfolio and vice-versa.

(263) Ratio of market price and expected price TT1=
\[
\frac{(\text{Market price-Expected price TT1})}{\text{Expected price TT1}}
\]
Units: Dimensionless
If market price is higher than expected, NT buys part or whole stocks portfolio and vice-versa.

(264) SAVEPER =
\[
\text{TIME STEP}
\]
Units: Day
The frequency with which output is stored.

(265) Sell FT1=
\[
\text{IF THEN ELSE( Supply FT1>0 , IF THEN ELSE( Demand FT2+Demand FT3+Demand NT1} \\
+\text{Demand TT1+Demand NT2)>=Supply FT1 , Supply FT1 , Demand FT2} \\
+\text{Demand FT3} \\
+\text{Demand NT1+Demand TT1+Demand NT2 ) , 0}
\]
Units: Stocks/Day
Sell orders executed. Amount of stocks sold depends on demand and is less or equal supply. If there is no demand, 0 stocks are sold.

(266) Sell FT2=
\[
\text{IF THEN ELSE( Supply FT2>0 , IF THEN ELSE( Demand FT1+Demand FT3+Demand NT1} \\
+\text{Demand TT1+Demand NT2)>=Supply FT2 , Supply FT2 , Demand FT1} \\
+\text{Demand FT3} \\
+\text{Demand NT1+Demand TT1+Demand NT2 ) , 0}
\]
Units: Stocks/Day
Sell orders executed
(267) Sell FT3 =
    IF THEN ELSE ( Supply FT3 > 0 , IF THEN ELSE ( Demand FT1 + Demand FT2 + Demand NT1 + Demand TT1 + Demand NT2 >= Supply FT3 , Supply FT3 , Demand FT1 + Demand FT2 , Demand NT1 + Demand TT1 + Demand NT2 ) , 0 )

Units: Stocks/Day
Sell orders executed

(268) Sell NT1 =
    IF THEN ELSE ( Supply NT1 > 0 , IF THEN ELSE ( Demand FT1 + Demand FT2 + Demand NT3 + Demand TT1 + Demand NT2 >= Supply NT1 , Supply NT1 , Demand FT1 + Demand FT2 + Demand NT3 + Demand TT1 + Demand NT2 ) , 0 )

Units: Stocks/Day
Sell orders executed

(269) Sell NT2 =
    IF THEN ELSE ( Supply NT2 > 0 , IF THEN ELSE ( Demand FT1 + Demand FT2 + Demand NT3 + Demand TT1 + Demand NT1 >= Supply NT2 , Supply NT2 , Demand FT1 + Demand FT2 + Demand NT3 + Demand TT1 + Demand NT1 ) , 0 )

Units: Stocks/Day
Sell orders executed

(270) Sell order FT1 =
    IF THEN ELSE ( Demand function FT1 < 0 : AND : Stock inventory FT1 > - 1 * Demand function FT1 , - 1 * Demand function FT1 , IF THEN ELSE ( Demand function FT1 < 0 : AND : Stock inventory FT1 < - 1 * Demand function FT1 , Stock inventory FT1 , 0 ) )

Units: Stocks/Day
If demand function is negative and existing inventory can cover sales, sales orders are submitted to the marketplace

(271) Sell order FT2 =
    IF THEN ELSE ( Demand function FT2 < 0 : AND : Stock Inventory FT2 > - 1 * Demand function FT2 , - 1 * Demand function FT2 ,
IF THEN ELSE( Demand function FT2<0:AND:Stock Inventory FT2<-1*Demand function FT2 , Stock Inventory FT2 , 0 ) )
Units: Stocks/Day
If demand function is negative and existing inventory can cover sales, sales orders are submitted to the marketplace

(272) Sell order FT3=
IF THEN ELSE( Demand function FT3<0:AND:Stock Inventory FT3<-1*Demand function FT3 , -1*Demand function FT3 , IF THEN ELSE( Demand function FT3<0:AND:Stock Inventory FT3<-1*Demand function FT3 , Stock Inventory FT3 , 0 ) )
Units: Stocks/Day
If demand function is negative and existing inventory can cover sales, sales orders are submitted to the marketplace

(273) Sell order NT1=
IF THEN ELSE( Demand function NT1<0:AND:Stock Inventory NT1<-1*Demand function NT1 , -1*Demand function NT1 , IF THEN ELSE( Demand function NT1<0:AND:Stock Inventory NT1<-1*Demand function NT1 , Stock Inventory NT1 , 0 ) )
Units: Stocks/Day
If demand function is negative and existing inventory can cover sales, sales orders are submitted to the marketplace

(274) Sell order NT2=
IF THEN ELSE( Demand function NT2<0:AND:Stock Inventory NT2<-1*Demand function NT2 , -1*Demand function NT2 , IF THEN ELSE( Demand function NT2<0:AND:Stock Inventory NT2<-1*Demand function NT2 , Stock Inventory NT2 , 0 ) )
Units: Stocks/Day
If demand function is negative and existing inventory can cover sales, sales orders are submitted to the marketplace.

(275) Sell order TT1=
IF THEN ELSE( Demand function TT1<0:AND:Stock Inventory TT1<-1*Demand function TT1 , -1*Demand function TT1 , IF THEN ELSE( Demand function TT1<0:AND:Stock Inventory TT1<-1*Demand function TT1 , Stock Inventory TT1 , 0 ) )
Units: Stocks/Day
If demand function is negative and existing inventory can cover sales, sales orders are submitted to the marketplace.

102
Stock Inventory TTI
Units: Stocks/Day
If demand function is negative and existing inventory can cover sales, sales orders are submitted to the marketplace

(276) Sell orders =
   Fundamental traders Sell + Noise traders Sell + Technical traders Sell
   Units: Stocks/Day
   Sum of all sell orders outstanding

(277) Sell TT1 =
   IF THEN ELSE( Supply TT1 > 0 , IF THEN ELSE( Demand FT1 + Demand FT2 + Demand FT3 + Demand NT1 + Demand NT2 >= Supply TT1 , Supply TT1 , Demand FT1 + Demand FT2 + Demand FT3 + Demand NT1 + Demand NT2 ) , 0 )
   Units: Stocks/Day
   Sell orders executed

(278) Sine Amplitude = 0
   Units: Dimensionless
   Amplitude of sine wave in customer orders (fraction of mean).

(279) Sine Amplitude 0 = 0
   Units: Dimensionless
   Amplitude of sine wave in customer orders (fraction of mean).

(280) Sine Period = 4
   Units: Day
   Period of sine wave in customer demand. Set initially to 4 years to simulate the business cycle

(281) Sine Period 0 = 4
   Units: Day
   Period of sine wave in customer demand. Set initially to 4 years to simulate the business cycle

(282) Speculative trade NT1 =
   IF THEN ELSE( Effect of market price and supply elasticity NT1 > = 0 , 0 , Effect of market price and supply elasticity NT1 * Stock Inventory NT1 )
   Units: Stocks/Day
   Speculative trade depends on whether market price is above or below initial expected price. If it is above, Noise trader buys (contrary to fundamental trader), if it is below - she sells.
Speculative trade NT2=
  IF THEN ELSE( Effect of market price and supply elasticity NT2>=0, 0,
    Effect of market price and supply elasticity NT2*Stock Inventory NT2)
Units: Stocks/Day
Speculative trade depends on whether market price is above or
below initial expected price. If it is above, Noise trader buys
(contrary to fundamental trader), if it is below - she sells.

Spread=
  0.05
Units: USD
Initial spread

Step Height=
  0.2
Units: Dimensionless
Height of step input to customer orders, as fraction of initial
value.

Step Height 0=
  0
Units: Dimensionless
Height of step input to customer orders, as fraction of initial
value.

Step Time=
  5
Units: Day
Time for the step input.

Step Time 0=
  0
Units: Day
Time for the step input.

Stock inventory FT1= INTEG ( INTEGER( Buy FT1-Sell FT1 ),
  Initial Inventory FT1)
Units: Stocks

Stock Inventory FT2= INTEG ( INTEGER( Buy FT2-Sell FT2 ),
  Initial Inventory FT2)
Units: Stocks
Inventory of stocks
Stock Inventory $\text{FT3}= \text{INTEG} \left( \text{INTEGER} \left( \text{Buy FT3-Sell FT3}, \text{Initial Inventory FT3} \right) \right)
\text{Units: **undefined**}
\text{Inventory of stocks}

Stock Inventory $\text{NT1}= \text{INTEG} \left( \text{Buy NT1-Sell NT1}, \text{Initial Inventory NT1} \right)
\text{Units: Stocks}

Stock Inventory $\text{NT2}= \text{INTEG} \left( \text{Buy NT2-Sell NT2}, \text{Initial Inventory NT2} \right)
\text{Units: Stocks}
\text{Stock inventory equals initial inventory plus stocks bought minus stocks sold}

Stock Inventory $\text{TT1}= \text{INTEG} \left( \text{Buy TT1-Sell TT1}, \text{Initial Inventory TT1} \right)
\text{Units: Stocks}
\text{Inventory TT1 equals difference between initial inventory + bought stocks minus stocks sold}

Supply from debt service $\text{FT1}= \text{INTEGER} \left( \frac{(\text{Capital outflows FT1})}{\text{Market price}} \right)
\text{Units: Stocks/Day}
\text{Supply of stocks due to debt servicing needs and dividend payments}

Supply from debt service $\text{FT2}= \text{INTEGER} \left( \frac{(\text{Capital outflows FT2})}{\text{Market price}} \right)
\text{Units: Stocks/Day}
\text{Supply of stocks due to capital outflows}

Supply from debt service $\text{FT3}= \text{INTEGER} \left( \frac{(\text{Capital outflows FT3})}{\text{Market price}} \right)
\text{Units: Stocks/Day}
\text{Supply of stocks due to debt servicing needs and dividend payments}

Supply from debt service $\text{NT1}= \text{INTEGER} \left( \frac{(\text{Capital outflows NT1})}{\text{Market price}} \right)
\text{Units: Stocks/Day}
Supply of stocks due to debt servicing needs and dividend payments

(299) Supply from debt service NT2 = 
\[
\text{INTEGER}(\frac{\text{Capital outflows NT2}}{\text{Market price}})
\]
Units: Stocks/Day
Supply of stocks due to debt servicing needs and dividend payments

(300) Supply from debt service TT1 = 
\[
\text{INTEGER}(\frac{\text{Capital outflows TT1}}{\text{Market price}})
\]
Units: Stocks/Day
Supply of stocks due to debt servicing needs and dividend payments

(301) Supply FT1 = 
\[
\text{IF THEN ELSE}(\text{Sell order FT1} + \text{Supply from debt service FT1} < \text{Stock inventory FT1})
\]
\[
\text{Sell order FT1} + \text{Supply from debt service FT1}, \text{Stock inventory FT1}
\]
Units: Stocks/Day
Supply of stocks depends on supply from debt service/dividends and supply due to negative expected profit. Stock inventory limits the maximum supply.

(302) Supply FT2 = 
\[
\text{IF THEN ELSE}(\text{Sell order FT2} + \text{Supply from debt service FT2} < \text{Stock inventory FT2})
\]
\[
\text{Sell order FT2} + \text{Supply from debt service FT2}, \text{Stock inventory FT2}
\]
Units: Stocks/Day
Supply of stocks depends on supply from debt service/dividends and supply due to negative expected profit. Stock inventory limits the maximum supply.

(303) Supply FT3 = 
\[
\text{IF THEN ELSE}(\text{Sell order FT3} + \text{Supply from debt service FT3} < \text{Stock inventory FT3})
\]
\[
\text{Sell order FT3} + \text{Supply from debt service FT3}, \text{Stock inventory FT3}
\]
Units: Stocks/Day
Supply of stocks depends on supply from debt service/dividends and supply due to negative expected profit. Stock inventory limits the maximum supply.

(304) Supply NT1 =
IF THEN ELSE(Sell order NT1+Supply from debt service NT1<Stock Inventory NT1
, Sell order NT1+Supply from debt service NT1
, Stock Inventory NT1)
Units: Stocks/Day
Supply of stocks depends on supply from debt service/dividends
and supply due to negative expected profit. Stock inventory
limits the maximum supply.

(305) Supply NT2=
IF THEN ELSE(Sell order NT2+Supply from debt service NT2<Stock Inventory NT2
, Sell order NT2+Supply from debt service NT2
, Stock Inventory NT2)
Units: Stocks/Day
Supply of stocks depends on supply from debt service/dividends
and supply due to negative expected profit. Stock inventory
limits the maximum supply.

(306) Supply TT1=
IF THEN ELSE(Sell order TT1+Supply from debt service TT1<Stock Inventory TT1
, Sell order TT1+Supply from debt service TT1
, Stock Inventory TT1)
Units: Stocks/Day
Supply of stocks depends on supply from debt service/dividends
and supply due to negative expected profit. Stock inventory
limits the maximum supply.

(307) Table of leverage and ratings(
[(0,0)-(200,40)],(0,1),(1,1),(2,1),(3.5,1),(3.6,2),(3.8,3),(4.7,4),(5.5,
(6.9,6),(7.2,7),(8.5,8),(9,9),(10.1,10),(11.7,11),(11.9,12),(14,13),(14.9,
14),(16.2,15),(18.4,16),(19,17),(21.18),(33,19),(67,20),(100,20),(200,21))
Units: Dimensionless
Leverage and Ratings

(308) Table of market elasticity(
[(0,-20)-(50,2)],(0,0),(0.01,-1),(0.05,-0.8),(0.1,-0.5),(0.25,-0.3),(0.5,
-0.2),(0.8,-0.1),(1,0),(1.01,0.01),(1.025,0.05),(1.08,0.1),(1.1,0.2),(1.25
,0.3),(1.5,0.5),(1.8,0),(2,1),(3,1.5),(4,1.55),(5,1.6),(6,1.625),(20,1.75
),(50,1.8))
Units: Dimensionless
Table of demand elasticity

(309) Table of market pressure(
[(-1,-1)-(1,1)],(-1,-0.95),(-0.9,-0.85),(-0.8,-0.7),(-0.7,-0.6),(-0.6,-0.4

107
Table of market pressure shows elasticity of price based on demand and supply outstanding.

Table of ratings and cost of debt:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Cost of Debt</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0005</td>
</tr>
<tr>
<td>2</td>
<td>0.0005</td>
</tr>
<tr>
<td>3</td>
<td>0.0005</td>
</tr>
<tr>
<td>4</td>
<td>0.0005</td>
</tr>
<tr>
<td>5</td>
<td>0.0006</td>
</tr>
<tr>
<td>6</td>
<td>0.0007</td>
</tr>
<tr>
<td>7</td>
<td>0.0011</td>
</tr>
<tr>
<td>8</td>
<td>0.0013</td>
</tr>
<tr>
<td>9</td>
<td>0.0019</td>
</tr>
<tr>
<td>10</td>
<td>0.0032</td>
</tr>
<tr>
<td>11</td>
<td>0.0033</td>
</tr>
<tr>
<td>12</td>
<td>0.0054</td>
</tr>
<tr>
<td>13</td>
<td>0.0062</td>
</tr>
<tr>
<td>14</td>
<td>0.0075</td>
</tr>
<tr>
<td>15</td>
<td>0.0097</td>
</tr>
<tr>
<td>16</td>
<td>0.0102</td>
</tr>
<tr>
<td>17</td>
<td>0.0112</td>
</tr>
<tr>
<td>18</td>
<td>0.0116</td>
</tr>
</tbody>
</table>

Table of supply elasticity FT:

<table>
<thead>
<tr>
<th>Deviation</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>-0.98</td>
</tr>
<tr>
<td>-0.9</td>
<td>-0.95</td>
</tr>
<tr>
<td>-0.7</td>
<td>-0.9</td>
</tr>
<tr>
<td>-0.6</td>
<td>-0.85</td>
</tr>
<tr>
<td>-0.5</td>
<td>-0.8</td>
</tr>
<tr>
<td>-0.25</td>
<td>-0.7</td>
</tr>
<tr>
<td>-0.2</td>
<td>-0.6</td>
</tr>
<tr>
<td>-0.1</td>
<td>-0.5</td>
</tr>
<tr>
<td>-0.05</td>
<td>-0.4</td>
</tr>
<tr>
<td>-0.02</td>
<td>-0.3</td>
</tr>
<tr>
<td>-0.01</td>
<td>-0.2</td>
</tr>
<tr>
<td>0</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

Table of supply elasticity NT:

<table>
<thead>
<tr>
<th>Deviation</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>-0.9</td>
<td>-0.6</td>
</tr>
<tr>
<td>-0.7</td>
<td>-0.5</td>
</tr>
<tr>
<td>-0.6</td>
<td>-0.4</td>
</tr>
<tr>
<td>-0.5</td>
<td>-0.3</td>
</tr>
<tr>
<td>-0.2</td>
<td>-0.1</td>
</tr>
<tr>
<td>-0.1</td>
<td>-0.05</td>
</tr>
<tr>
<td>-0.05</td>
<td>-0.04</td>
</tr>
<tr>
<td>-0.02</td>
<td>-0.02</td>
</tr>
<tr>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>0</td>
<td>0.01</td>
</tr>
<tr>
<td>0.01</td>
<td>0.05</td>
</tr>
<tr>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>0.8</td>
<td>0.9</td>
</tr>
<tr>
<td>0.9</td>
<td>1</td>
</tr>
</tbody>
</table>

Target leverage FT1 = 5

Target leverage for FT1:

Target leverage FT2 = 5

Target leverage equals target debt over capital.

Target leverage FT3 = 5

Target leverage for FT1
(316) Target leverage NT1 = 5
       Units: Dimensionless
       Target leverage for NT

(317) Target leverage NT2 = 5
       Units: Dimensionless
       Target leverage for NT

(318) Target leverage TT1 = 5
       Units: Dimensionless
       Target leverage for NT

(319) Technical traders Buy = Demand TT1
       Units: Stocks/Day

(320) Technical traders Sell = Supply TT1
       Units: Stocks/Day

(321) TIME STEP = 0.125
       Units: Day
       The time step for the simulation.

(322) Total shares outstanding =
       Initial Inventory FT1 + Initial Inventory FT2 + Initial Inventory FT3 + Initial Inventory NT1
       + Initial Inventory TT1 + Initial Inventory NT2
       Units: Stocks
       Sum of all initial shares outstanding

(323) Trend input TT1 =
       TREND( Market price, Adjustment time TT1, Initial trend )
       Units: 1/Day
       Trend input switch. If negative trend is higher (or equal to)
       than positive, negative trend is used, and vice-versa.

(324) Trend trade TT1 =
       IF THEN ELSE( Effect of market price and supply elasticity TT1 >= 0, 0
       , Effect of market price and supply elasticity TT1 * Stock Inventory TT1 )
       Units: Stocks/Day
       Speculative trade depends on whether market price is above or
below initial expected price. If it is above, Noise trader buys (contrary to fundamental trader), if it is below - she sells.

(325) White Noise = Noise Standard Deviation*(((24*Noise Correlation Time/TIME STEP)^0.5*(RANDOM 0 1) - 0.5)
)
Units: Dimensionless
White noise input to the pink noise process.

(326) White Noise 0 = Noise Standard Deviation 0*(((24*Noise Correlation Time 0 /TIME STEP)^0.5*(RANDOM 0 1) - 0.5)
)
Units: Dimensionless
White noise input to the pink noise process.
ANNEX II. MODEL DIAGRAMS

Market

[Diagram of market dynamics showing supply, demand, pricing function, and various market pressures and adjustments.]
### Input parameters

<table>
<thead>
<tr>
<th>Individual inputs</th>
<th>Debt parameters</th>
<th>Pricing parameters</th>
<th>Trader group parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borrowing FT1</td>
<td>Initial Cash FT1</td>
<td>Initial Fundamental price FT1</td>
<td>Adjustment time FT1</td>
</tr>
<tr>
<td>Borrowing FT2</td>
<td>Initial Cash FT2</td>
<td>Initial Fundamental price FT2</td>
<td>Adjustment time FT2</td>
</tr>
<tr>
<td>Borrowing FT3</td>
<td>Initial Cash FT3</td>
<td>Initial Fundamental price FT3</td>
<td>Adjustment time FT3</td>
</tr>
<tr>
<td>Borrowing NT1</td>
<td>Initial Cash NT1</td>
<td>Initial price NT1</td>
<td>Adjustment time NT1</td>
</tr>
<tr>
<td>Borrowing NT2</td>
<td>Initial Cash NT2</td>
<td>Initial price NT2</td>
<td>Adjustment time NT2</td>
</tr>
<tr>
<td>Borrowing TT1</td>
<td>Initial Cash TT1</td>
<td>Initial price TT1</td>
<td>Adjustment time TT1</td>
</tr>
</tbody>
</table>

### Pricing model alternatives
- Debt amortization constant
- Interest rate
- Leverage measure
- Rating adjustment time
- Table of leverage and ratings
- Table of ratings and cost of debt

### Trader group parameters
- Table of supply elasticity FT
- Table of supply elasticity NT
- Table of market elasticity
- Table of market pressure
Trading
Earnings