Analysis of Investor Behavior in an Artificial Stock Market

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Abstract: *Building upon previous work in the field of behavioral finance and artificial stock markets, a model incorporating discrete and continuous interrelations is developed. Three different investor types are modeled as individual agents: fundamental analysts, technical analysts and noise traders. They differ in their intrinsic pricing mechanism and represent trading strategies that are observed in financial markets. The developed structure is able to reproduce the formation of speculative bubbles and other stochastical anomalies that are characteristic for financial time series.*

Introduction

When the sun shines in New York, stock prices rise at Wall Street. Just as weather proverbs occasionally predict the weather more accurate than meteorological forecasts, this statement seems to contain a surprisingly high validity. Saunders (1993) and Hirshleifer and Shumway (2003) find a significant correlation between the local weather and investors' behavior. These surveys can be assigned to the field of Behavioral Finance (BF), which promotes the integration of psychological aspects in merely rational models of capital markets (Shleifer 2000). This approach attracts increasing interest since the early 1980ies, when the prevalence of Muth's Efficient Market Hypothesis (EMH) (Muth 1961) was challenged by the observation of statistical anomalies of stock price movements (Campbell 2000; LeRoy and Porter 1981; Shiller 1981).

As a basic presumption of neoclassical capital market theory the EMH draws an unrealistic and narrow picture of the market participants (Malkiel, Mullainathan, and Stangle 2005; Malkiel 2003). Following the EMH stock prices reflect all available information as well as the expectations of investors considering future development. The market price therefore is at all times the best estimate of a stock's fundamental value (Fama 1970). This requires the investors to have an infinitesimal response time to new information and to decide purely rational and fast on matters of high complexity all the time (Copeland, Weston, and Shastri 2005). Furthermore homogeneity of the investors' expectations is assumed since the equilibrium models need all market participants to use a similar pricing strategy (Sansone and Garofalo 2005).

Since the classical approach fails to explain phenomena like the stock market crash of 1987 or the Dotcom-bubble (Ofek and Richardson 2003) in the late 1990ies, economic theory increasingly intends to integrate aspects of human behaviour in their models of financial markets (Mills 2004). Besides these outstanding occasions of irrational investor behavior less prominent anomalies of financial data are investigated. Volatility clustering and fat tail distribution of asset returns are examples for these so called stylized facts (Cont 2001, 2005; Dangl et al. 1999).

A stock market model with three different trader types

Building on previous work in the field of BF a simple stock market model is developed in this paper. The aim of the modeling process is to create a structure which is able to reproduce the observed macro-behavior of stock prices and the stylized facts of financial time series. For this purpose two important presumptions concerning the participants are made that contradict the assumptions of the EMH. On the one hand investors are assumed to be at least partially irrational. On the other hand investor's heterogeneity is expected (Peters 2003). While irrationality is integrated in the pricing strategy of investors, the aspect of heterogeneity is represented by implementing three different types of investors – fundamental analysts (FA), technical analysts (TA) and noise traders (NT). These investor types are characterized and derived from BF publications in the building process of the corresponding modules.

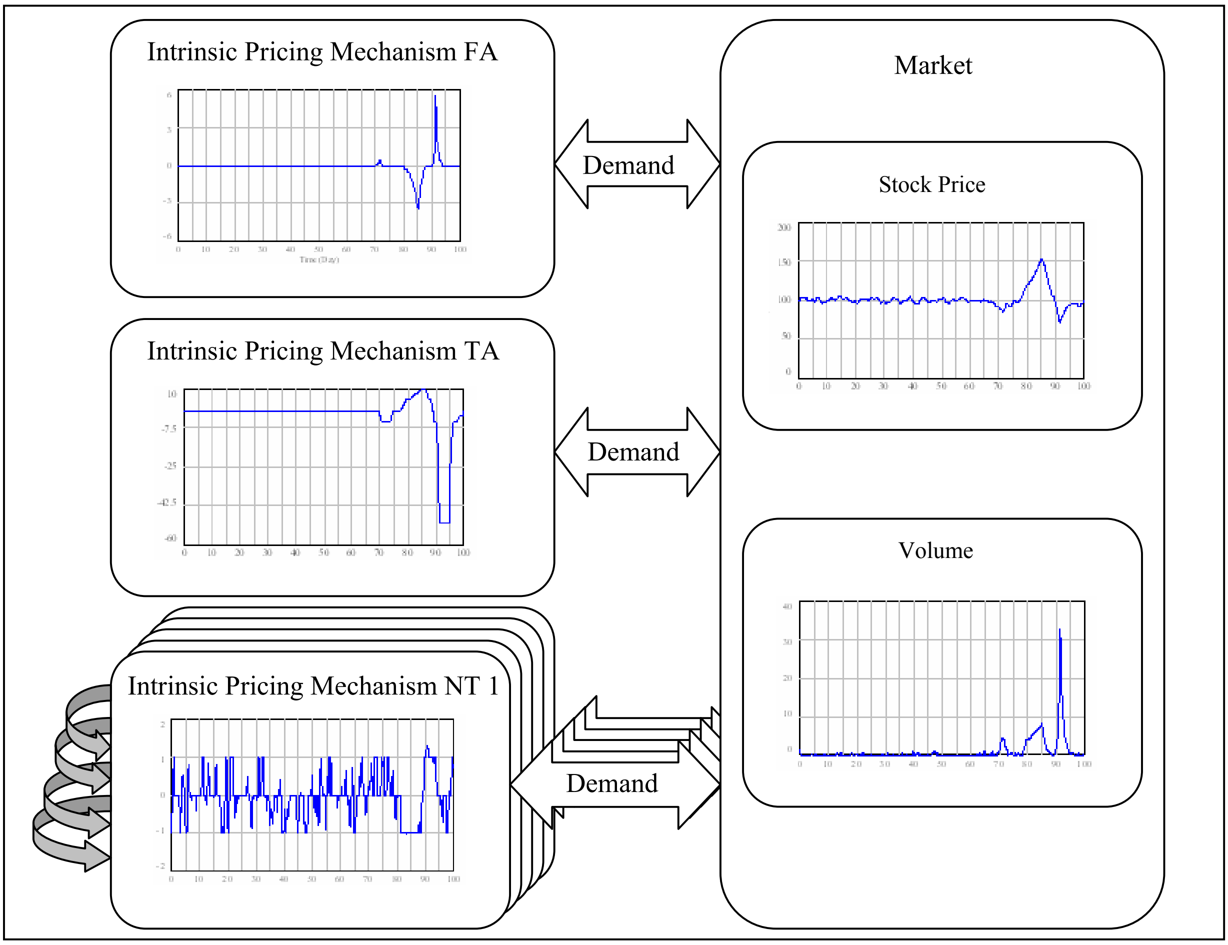

Figure 1: Overview of the model structure

Considering that capital markets are social systems with dynamic interaction the System Dynamics (SD) approach seems to be adequate for the construction of the model (Barber, Heath, and Odean 2003; Shiller, Fischer, and Friedman 1984). Even though Sterman (2000) challenges the reader of "Business Dynamics" to transform the speculative process of a stock price bubble described by Mill (1968) into a SD model, only few publications use the SD-approach to explain the observed behavior of capital markets (Provenzano 2002; Shimada 1978). The agent-based approach is more common for this purpose (Kaizoji 2000; Hommes 2006; Bak, Paczuski, and Shubik 1997; Giardina and Bouchaud 2003; Ghoulmie, Cont, and Nadal 2005). The developed model connects continuous SD-based and discrete agent-based simulation. This “hybrid-approach” is the reason for the unusually high proportion of discrete equations. While transactions and interactions at the market are formulated in discrete equations, the intrinsic decision making processes of the different investor types are modeled as continuous relations. Figure 1 gives an overview of the model structure that will be developed in this paper.

Positive Feedback Trading:A great number of publications concerned with the formation of speculative bubbles focus on two types of traders (e.g. Chiarella, He, and Wang 2006; De Long et al. 1990) – FA and TA who are also denominated as positive feedback traders – implicitly described by Mill (1968:137):

„When there is a general impression that the price of some commodity is likely to rise, from an extra demand, a short crop, obstructions to importation, or any other cause, there is a disposition among dealers to increase their stocks, in order to profit by the expected rise. This disposition tends in itself to produce the effect which it looks forward to, a rise of price: and if the rise is considerable and progressive, other speculators are attracted, who, so long as the price has not begun to fall, are willing to believe that it will continue rising. These, by further purchases, produce a further advance: and thus a rise of price for which there were originally some rational grounds, is often heightened by merely speculative purchases, until it greatly exceeds what the original grounds will justify. After a time this begins to be perceived; the price ceases to rise, and the holders, thinking it is time to realize their gains, are anxious to sell. Then the price begins to decline: the holders rush into the market to avoid a still greater loss, and, few being willing to buy in a falling market, the price falls much more suddenly than it rose.”

Although Mill refers to commodities instead of assets, he characterizes the sequence of positive feedback trading accurately (De Long et al. 1990; Södahl 2004). Figure 2 illustrates the interaction of the two investor types in a simple causal loop diagram.

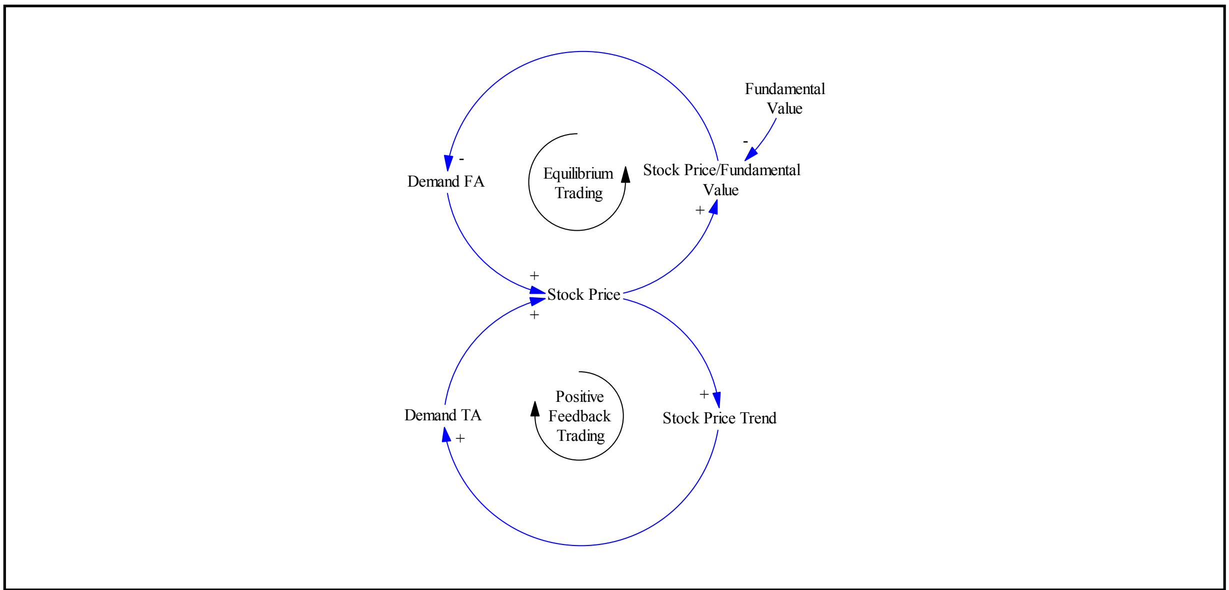

Figure 2: Causal loop diagram of FA and TA interaction

Fundamental Analysists: These two simplified counteracting policies represent two very prominent trading strategies. At first the mental pricing mechanism of the FA is described and its model structure is developed. The FA decision process is based on an intensive analysis of the underlying intrinsic value of an asset (Greig 1992; Külpmann 2002). FA compare the value derived from this analysis with the actual market price of an asset. If the market value exceeds the fundamental value the FA sell the asset and vice versa for undervalued stocks (Ali, Hwang, and Trombley 2003). The negative causal relation of price and demand has a stabilizing effect (Shleifer and Vishny 1997). Since it is not important how FA acquire the fair value of the stock, the valuation process is not explicitly included in the model. The result of this analysis is therefore included as the constant *FUNDAMENTAL VALUE.* The comparison of this value and the *Stock Price* yields the *value/price ratio* upon which the FA decide whether to sell or buy the stock. The table *REACTION TO V/P RATIO* defines thereby the strength of the demand reaction to an over- or undervalued stock. In the next step the FA demand or supply is transformed into buy or sell orders considering the each agents budget restrictions.

$$\textit{sell orders fa} = \begin{cases} 0 & \text{für } \textit{demand/supply fa} \geq 0 \\ \textit{demand/supply fa} & \text{für } |\textit{demand/supply fa}| < \textit{Stocks FA} \\ \textit{Stocks FA} & \text{für } |\textit{demand/supply fa}| > \textit{Stocks FA} \end{cases} \quad (1)$$

As defined in (1) the agents' sell orders are limited to the total amount of stocks in his account. Then again the investor can only buy as many shares as his cash balance allows (2).

$$\textit{buy orders fa} = \begin{cases} 0 & \text{für } \textit{demand/supply fa} \leq 0 \\ \textit{demand/supply fa} & \text{für } \textit{demand/supply fa} < \textit{Cash FA/Stock Price} \\ \textit{Cash FA/Stock Price} & \text{für } \textit{demand/supply fa} > \textit{Cash FA/Stock Price} \end{cases} \quad (2)$$

Since the group of FA is homogenous in itself, the number of FA participating in the market can by easily modified with the multiplier TOTAL FA IN THE MARKET. The Stock-Flow structure of the FA decision process is visualized in figure 3.

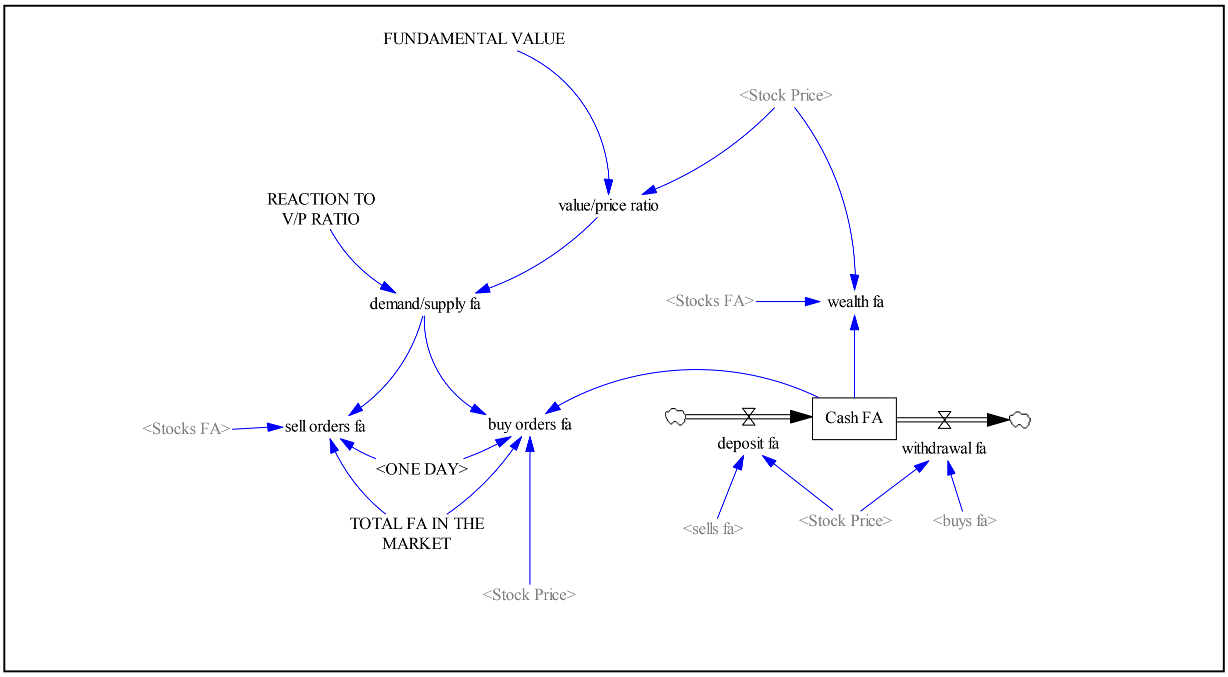

Figure 3: Stock-Flow diagram of FA intrinsic pricing process

Technical Analysis: As opposed to the analysis of underlying values technical analysis focuses on the study of past price movements (Eller and Dreesbach 2001; Murphy 2004). Edwards and Magee (1997:4) define technical analysis as „the study of the action of the market itself, as opposed to the study of the goods in which the market deals. It is the science of recoding, usually in graphic form, the history of trading (price changes, […]) in a certain stock […] and then deducting the probable future trend." Following the EMH technical analysis is irrational and will lead to losses in an efficient capital market (Fama 1970). Nevertheless the success of several technical trading strategies could be demonstrated (Eakins and Stansell 2004; Grinblatt and Moskowitz 1999). Since the process of technical analysis can be simplified as a trend-following-strategy it is incorporated in the TA intrinsic pricing process through Sterman's TREND-function (Sterman 1986). The output of the trend module is input to the table function *REACTION TO PERCIEVED TREND* which defines the demand of the TA. Analog to the restrictions mentioned for the FA, each agent's demand is limited by his budget. Figure 4 shows the Stock-Flow diagram of the TA intrinsic pricing mechanism.

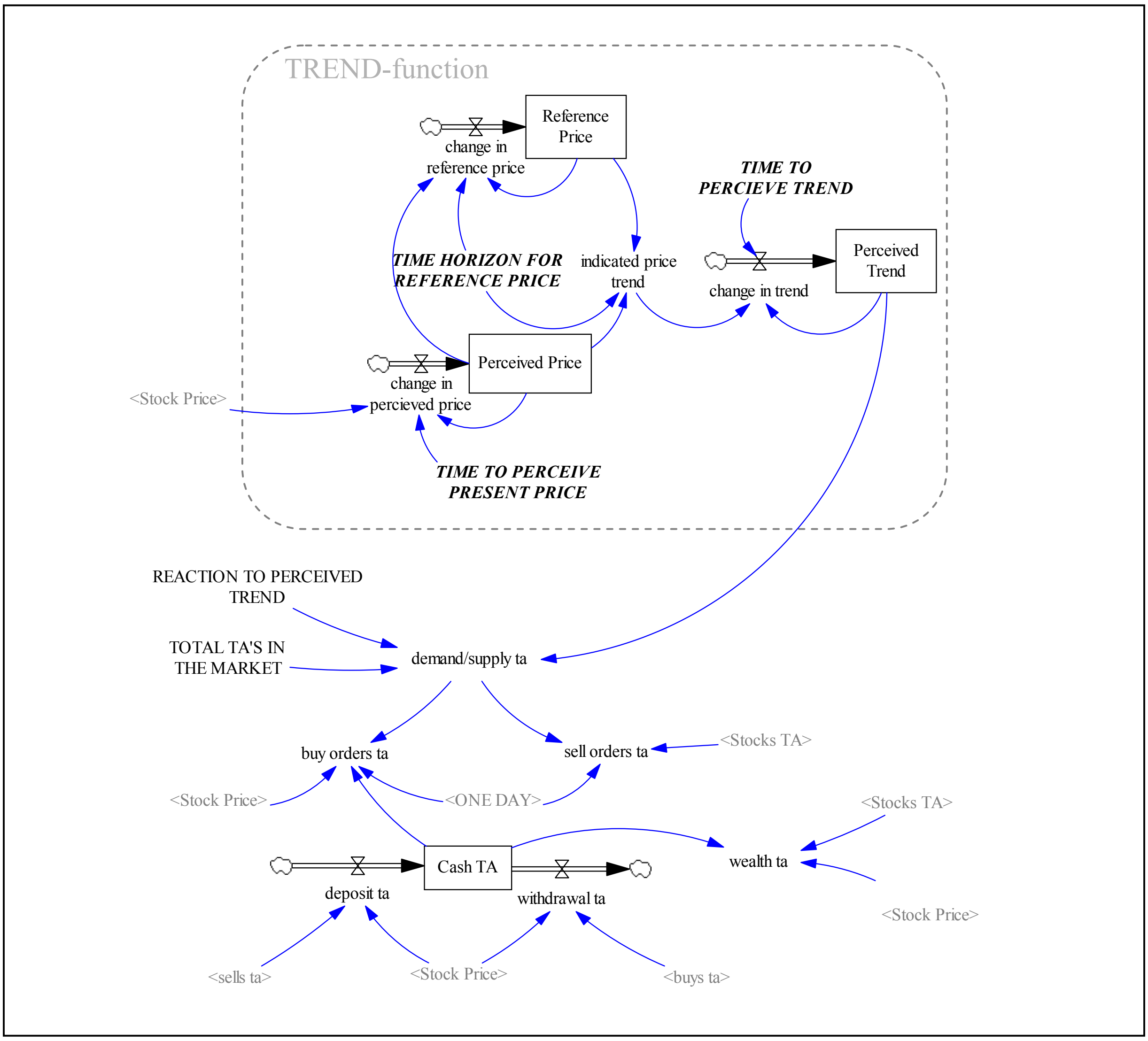

Figure 4: Stock-Flow diagram of TA intrinsic pricing process

Noise Traders: As the FA, the group of TA is in itself homogeneous. Hence it is not necessary to duplicate the structure of the intrinsic process. As with the FA, the number of TA is regulated by a simple multiplier. In contrast to this the agents of the third group of investors are explicitly modeled. This is necessary since the group of NT is not only distinguishable from the other investor groups but is in itself heterogeneous. Therefore the number of NT is fixed to 5 in the model. Unlike the other agent types NT do not follow a stringent trading strategy. The NT information is biased by random influences (Black 1986; Thaler 1993). The inaccuracy of their own information causes the NT to imitate other investors' actions (Barber, Odean, and Zhu 2006; Hwang and Salmon 2004). This process is referred to as herding (Bernhardt, Campello, and Kutsoati 2004; Welch 2000). The concept of individual threshold is used to regulate each agent's tendency to herd. If the discrepancy of the agent's own information and the market price passes the individual threshold, the agent follows the crowd (Cross et al. 2005; Granovetter 1978; Raden 1977). The part of the NT in the interaction of all agents is shown in figure 5, which is an extension of the earlier mentioned causal diagram.

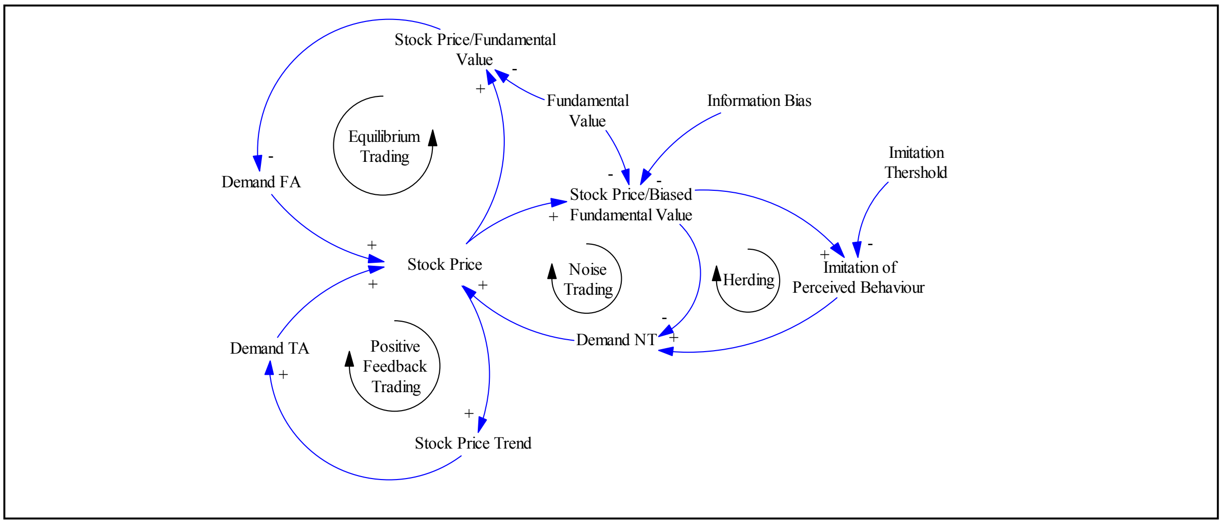

Figure 5: Causal loop diagram of all agents' interaction

The heterogeneity of the NT is represented through individual biases and individual thresholds. The bias is modelled as a random influence on the fundamental value of the stock. The budget restrictions for each agent are included in the same way as for the other investor groups.

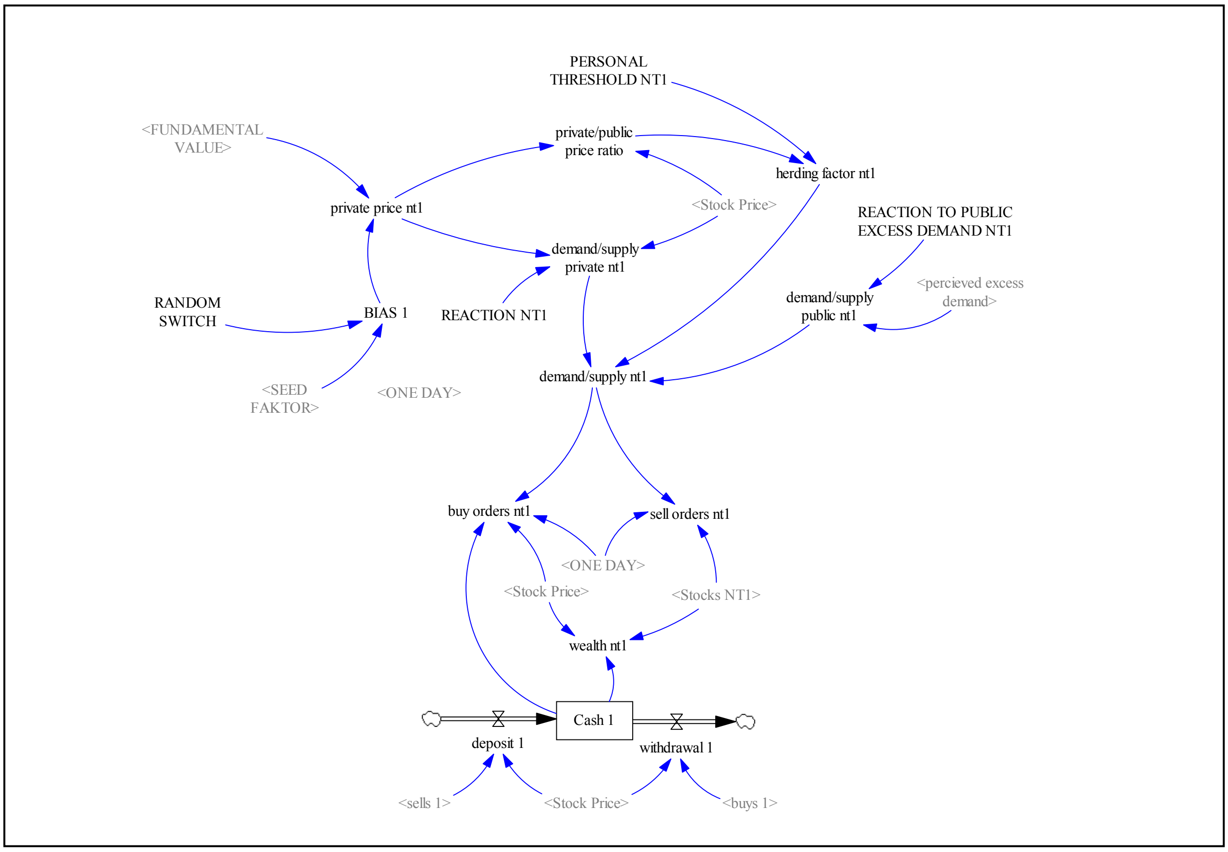

Figure 6: Stock-Flow diagram of TA intrinsic pricing process

However the formulation of the demand not only depends on the intrinsic price of the NT but – regulated through a herding factor – is influenced by the other investors' actions. The structural incorporation of each NT agent is illustrated by figure 6.

Stock Market Module: The construction for the market itself has to fulfill several guidelines. At first no stocks stay in the account of the intermediary (Garman 1976). The only pass the *Trading Floor* – which represents the market makers account – to the accounts of the agents involved in the trade. Secondly – to represent a sequential market structure - a buy order can only be completed if an corresponding sell offer exists (Kokot 2004; O'Hara 1997). The same counts vice versa for sell offers. Finally, all available shares are allocated proportionally to the initial demand of each agent. In this way the higher willingness to pay is represented. Figure 7 gives an overview of the market module.

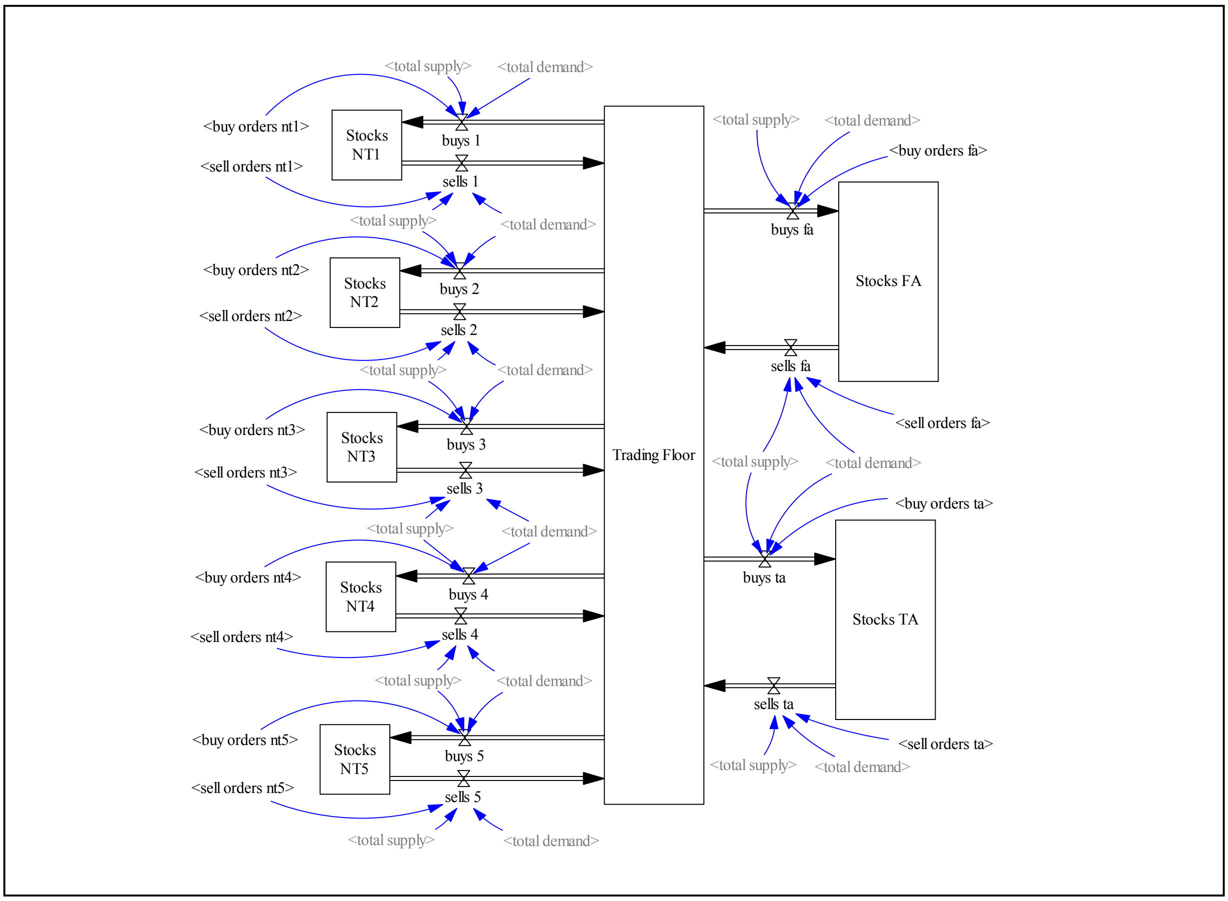

Figure 7: Stock-Flow diagram of the stock market

The stock price is determined as a function of the overall excess demand. The multiplier μ represents the market depth which determines the amount of uncompleted orders that is needed to move the price by one unit (Cont and Bouchaud 2000; LeBaron 2002).. Additionally to this multiplier the excess demand is transformed with the table function *PRICE REACTION TO EXCESS DEMAND/SUPPLY* to represent the nonlinear character of the relation of stock price and excess demand. This nonlinearity emerges from empirical transaction data (Kempf and Korn 1998). The Stock-Flow structure of the price formation process is illustrated in figure 8. The calculation of the trading volume is included in the pricing module.

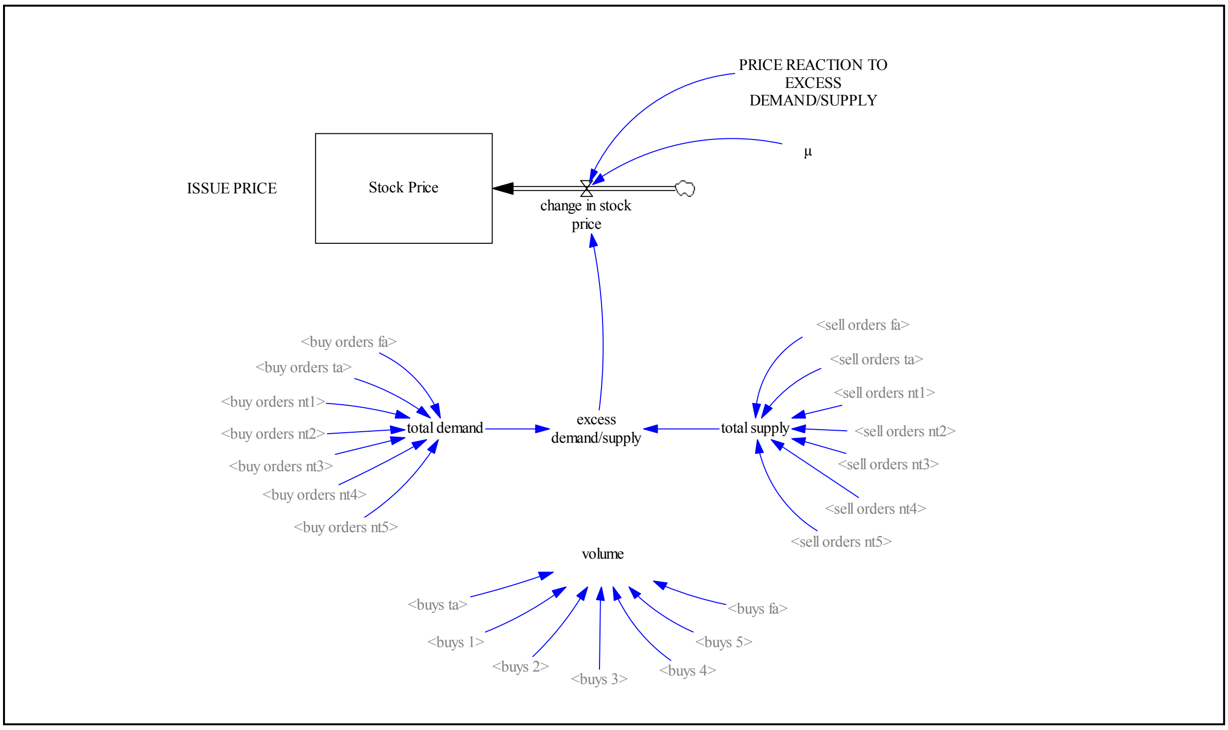

Figure 8: Stock-Flow diagram of the price formation process

Simulation Results and Stochastic Validation

The formulated aim of this paper is the presentation of a stock market model that is able to reproduce large misevaluations and speculative bubbles without an external shock simply caused through investors' interaction. Prior to the presentation of results the choice of the main parameters should be justified. Schwartz and Shapiro (1992) estimate the proportion of institutional investors to 70% of the overall transaction volume. Assuming that NT are particularly private investors and institutional traders apply technical trading strategies in the same amount as fundamental analysis (Keim and Madhavan 1995), all investor groups are about evenly represented in the base run. Nevertheless, the impact of other combinations will be tested. The budget of each agent contains 10 stocks worth $1000 and a cash balance of additional $1000.

Model Behavior: Figure 9 presents the simulation result of stock price and trading volume for different seed values of the NT random functions. It is worth to be mentioned that the volume increases during strong price changes. This circumstance actually corresponds to observed behavior of stock markets (Karpoff 1987). Furthermore, the simulated stock price returns to the fundamental value after large deviations. This attribute of financial time series is referred to as mean reversion (Bessembinder et al. 1995; Poterba and Lawrence H. Summers 1988). Not every in every run culminates in the formation of a speculative bubble. Only if the random orders of the NT cumulate enough to initiate a trend that TA can follow, their positive feedback trading strategy causes the stock price to deviate strongly from the fundamental value.

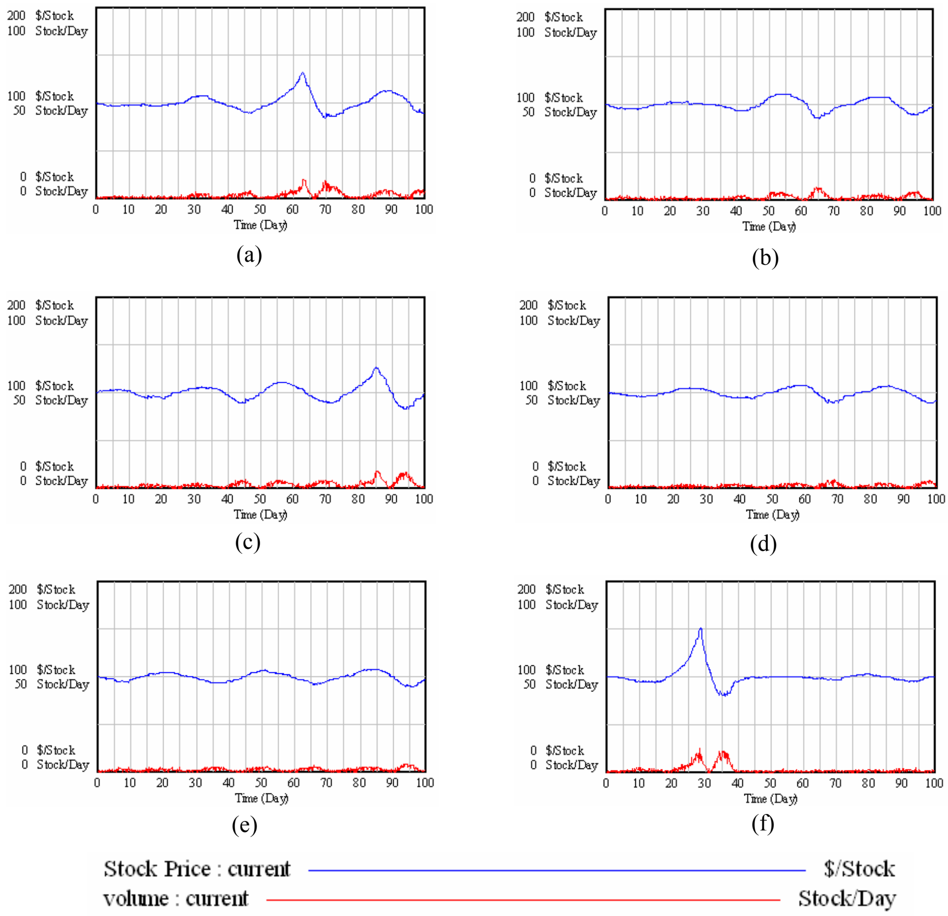

Figure 9: Simulation results of stock price and trading volume for different seed-values

The analysis of the impact of different proportions of trader groups determines the important role of the TA in the speculative process. The results of several sensitivity runs with changing agent distributions are shown in figure 10. If no TA are active in the market no bubble is building up. In contrast a higher amount of TA compared to the stabilizing FA leads to a stock price deviation that does not revert to the fundamental value.

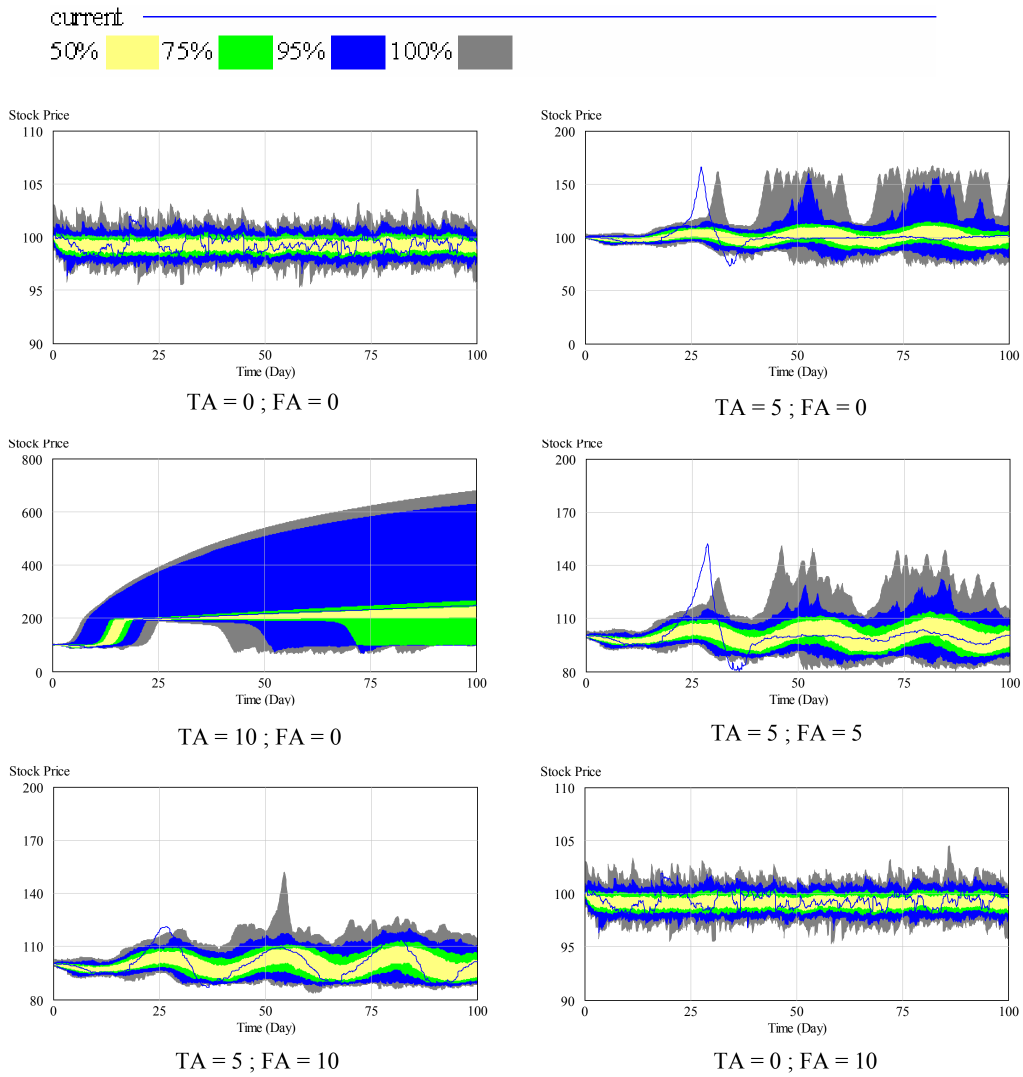

Figure 10: Impact of varying combinations of TA and FA

The process of herd formation is fairly represented in the NT order behavior. As illustrated in figure 11 the NT orders are randomly distributed until the extreme event of a market crash.[1] Their panic reaction leads to an alignment of behavior.

[1] The stock price movements of the corresponding simulation run are shown in figure 9 (f).

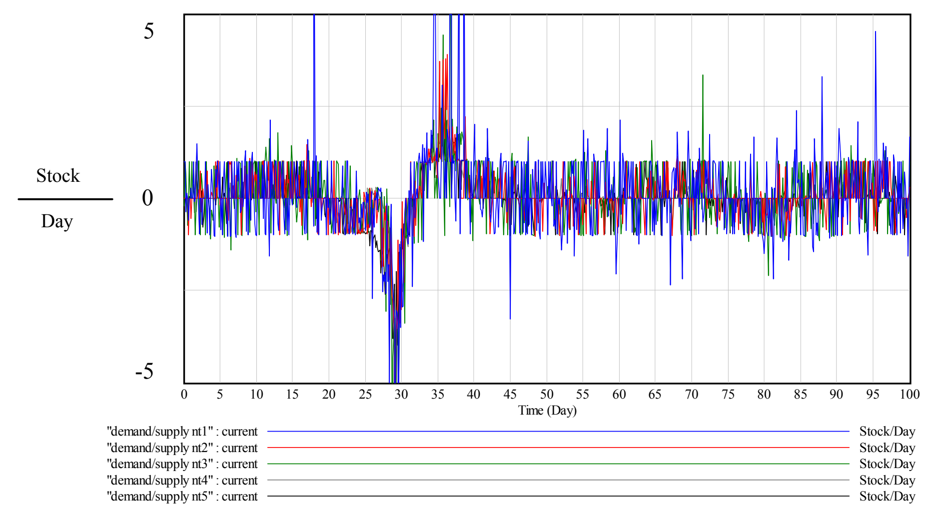

Figure 11: Order behavior of NT

Stochastic Properties: The examination of the simulation results delivers stochastic properties of stock market data. The heterogeneity of variances (Dangl et al. 1999) is revealed by the graphical presentation of simulated stock return variance in figure 12. The heterogeneity is obvious since the variance clearly varies while the simulation progresses. Additionally it is approved by the Levene-test for heteroscedasticity (Bollerslev 1986; Brown and Forsythe 1974) with 99.9% significance.

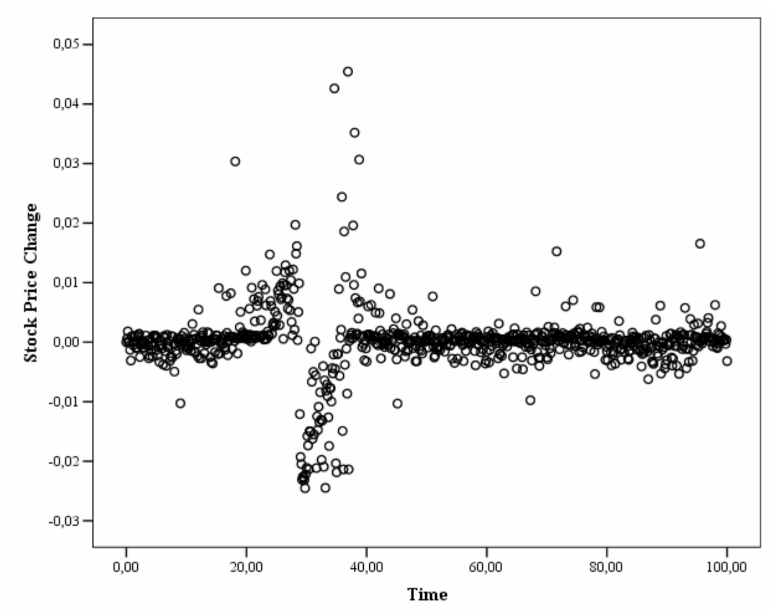

Figure 12: Variance of simulated stock returns over time

The comparison of the distribution of simulated stock returns and NASDAQ data is allegorized in figure 13. Test for skewness and kurtosis that measure the deviation of a distribution's properties in comparison to the normal curve (Cont and Bouchaud 2000) delivered similar results for the simulated and the market data. The strong leptokurtosis of both time series is a evidence for their fat-tail character.

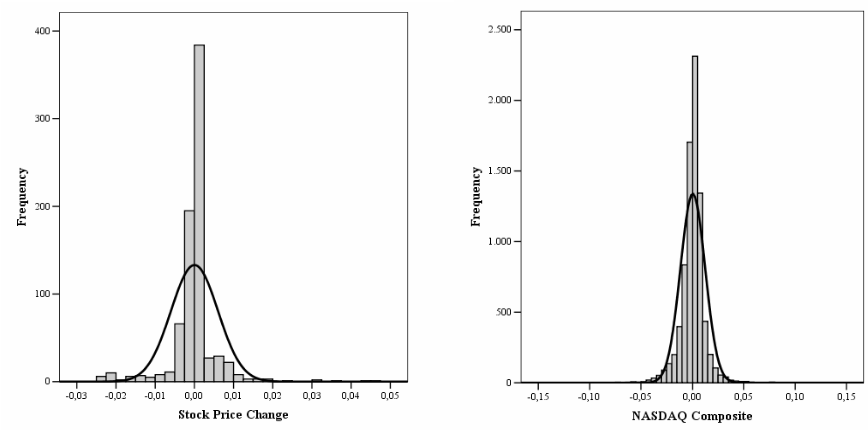

Figure 13: Histogram of simulated stock returns and NASDAQ Data

Conclusion and Outlook

In this paper a SD stock market model is build based on BF publications. The model structure is able to reproduce macro behavior as well was observed stochastical anomalies of financial time series as a result of the integration of psychological aspects in the agents' design (Cont 2001). In addition a "hybrid-approach" was chosen to integrate agent-based and SD modelling. Though intrinsic and behavioristic processes can be represented with this method, the structural flexibility concerning the agents' population is limited. Therefore an extension of the approach would require a more adequate software solution. Szilagyi and Jallo (2006) analysis of the social phenomenon of standing ovations offers an interesting perspective in this context.

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Model listing

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buy orders nt4=
	IF THEN ELSE("demand/supply nt4">=0, MIN( "demand/supply nt4", Cash 4/Stock Price/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

buy orders nt5=
	IF THEN ELSE("demand/supply nt5">=0, MIN( "demand/supply nt5", Cash 5/Stock Price/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

buy orders ta=
	IF THEN ELSE("demand/supply ta">=0, MIN( "demand/supply ta", Cash TA/Stock Price/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

sell orders nt3=
	IF THEN ELSE("demand/supply nt3"<0, MIN( (-1)*"demand/supply nt3", Stocks NT3/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

sell orders nt4=
	IF THEN ELSE("demand/supply nt4"<0, MIN( (-1)*"demand/supply nt4", Stocks NT4/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

sell orders nt5=
	IF THEN ELSE("demand/supply nt5"<0, MIN( (-1)*"demand/supply nt5", Stocks NT5/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

sell orders ta=
	IF THEN ELSE("demand/supply ta"<0, MIN( (-1)*"demand/supply ta", Stocks TA/ONE DAY),\
		 0)
	~	Stock/Day
	~		|

buy orders nt2=
	IF THEN ELSE("demand/supply nt2">=0, MIN( "demand/supply nt2", Cash 2/Stock Price/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

buy orders nt3=
	IF THEN ELSE("demand/supply nt3">=0, MIN( "demand/supply nt3", Cash 3/Stock Price/ONE DAY\
		), 0)
	~	Stock/Day
	~		|
```

```
sell orders nt2=
	IF THEN ELSE("demand/supply nt2"<0, MIN( (-1)*"demand/supply nt2", Stocks NT2/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

sell orders nt1=
	IF THEN ELSE("demand/supply nt1"<0, MIN( (-1)*"demand/supply nt1", Stocks NT1/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

percieved excess demand= INTEG (
	percieved change in aggregate demand,
		0)
	~	Stock/Day
	~		|

"demand/supply ta"=
	REACTION TO PERCEIVED TREND(1+(Perceived Trend))*TOTAL TA'S IN THE MARKET
	~	Stock/Day
	~		|

percieved change in aggregate demand=
	("excess demand/supply"-percieved excess demand)/time to perceive change in excess demand
	~	Stock/(Day*Day)
	~		|

time to perceive change in excess demand=
	0.25
	~	Day [0,10]
	~		|

PERSONAL THRESHOLD NT5(
	[(0,0)-(2,1)],(0,1),(0.25,0.98),(0.35,0.95),(0.4,0.9),(0.45,0.75),(0.5,0.5),(0.55,0.35\
		),(0.6,0.25),(0.65,0.15),(0.75,0.075),(0.85,0.025),(1,0),(1.14985,0.025),(1.25,0.075\
		),(1.35,0.15),(1.4,0.25),(1.45,0.35),(1.5,0.5),(1.55,0.75),(1.6,0.9),(1.65,0.95),(1.75\
		,0.98),(2,1))
	~	Dmnl
	~		|

"demand/supply private nt2"=
	REACTION NT2(private price nt2/Stock Price)
	~	Stock/Day
	~		|

BIAS 2=
	RANDOM NORMAL(0, 2, 1, 0.06*RANDOMSWITCH, 2*SEED FAKTOR)
	~	Dmnl
	~		|

private price nt1=
	FUNDAMENTAL VALUE*BIAS 1
	~	$/Stock
	~		|
```

```
private price nt3=
	FUNDAMENTAL VALUE*BIAS 3
	~	$/Stock
	~		|

private price nt4=
	FUNDAMENTAL VALUE*BIAS 4
	~	$/Stock
	~		|

"demand/supply public nt1"=
	REACTION TO PUBLIC EXCESS DEMAND NT1(percieved excess demand)
	~	Stock/Day
	~		|

"private/public price ratio nt2"=
	Stock Price/private price nt2
	~	Dmnl
	~		|

REACTION NT2(
	[(0,-100)-(2,100)],(0.25,-98.2456),(0.5,-10),(0.6,-5),(0.7,-2),(0.8,-1),(0.9,-1),(0.95\
		,0),(1,0),(1.05,0),(1.1,1),(1.2,1),(1.3,2),(1.4,5),(1.5,10),(1.75,100))
	~	Stock/Day
	~		|

REACTION NT3(
	[(0,-100)-(2,100)],(0.25,-98.2456),(0.5,-10),(0.6,-5),(0.7,-2),(0.8,-1),(0.9,-1),(0.95\
		,0),(1,0),(1.05,0),(1.1,1),(1.2,1),(1.3,2),(1.4,5),(1.5,10),(1.75,100))
	~	Stock/Day
	~		|

REACTION NT4(
	[(0,-100)-(2,100)],(0.25,-98.2456),(0.5,-10),(0.6,-5),(0.7,-2),(0.8,-1),(0.9,-1),(0.95\
		,0),(1,0),(1.05,0),(1.1,1),(1.2,1),(1.3,2),(1.4,5),(1.5,10),(1.75,100))
	~	Stock/Day
	~		|

REACTION NT5(
	[(0,-100)-(2,100)],(0.25,-98.2456),(0.5,-10),(0.6,-5),(0.7,-2),(0.8,-1),(0.9,-1),(0.95\
		,0),(1,0),(1.05,0),(1.1,1),(1.2,1),(1.3,2),(1.4,5),(1.5,10),(1.75,100))
	~	Stock/Day
	~		|

"demand/supply nt5"=
	"demand/supply private nt5"+"demand/supply public nt5"*herding factor nt5
	~	Stock/Day
	~		|

REACTION TO PUBLIC EXCESS DEMAND NT1(
	[(-100,-10)-(100,10)],(-100,-5),(-10,-2),(-2.5,-1.5),(0,0),(2.5,1.5),(10,2),(100,5))
	~	Stock/Day
	~		|

REACTION TO PUBLIC EXCESS DEMAND NT2(
	[(-100,-10)-(100,10)],(-100,-5),(-10,-2),(-2.5,-1.5),(0,0),(2.5,1.5),(10,2),(100,5))
	~	Stock/Day
```

```
	~		|

REACTION TO PUBLIC EXCESS DEMAND NT3(
	[(-100,-10)-(100,10)],(-100,-5),(-10,-2),(-2.5,-1.5),(0,0),(2.5,1.5),(10,2),(100,5))
	~	Stock/Day
	~		|

REACTION TO PUBLIC EXCESS DEMAND NT4(
	[(-100,-10)-(100,10)],(-100,-5),(-10,-2),(-2.5,-1.5),(0,0),(2.5,1.5),(10,2),(100,5))
	~	Stock/Day
	~		|

REACTION TO PUBLIC EXCESS DEMAND NT5(
	[(-100,-10)-(100,10)],(-100,-5),(-10,-2),(-2.5,-1.5),(0,0),(2.5,1.5),(10,2),(100,5))
	~	Stock/Day
	~		|

herding factor nt4=
	PERSONAL THRESHOLD NT4("private/public price ratio nt4")
	~	Dmnl
	~		|

herding factor nt5=
	PERSONAL THRESHOLD NT5("private/public price ratio nt5")
	~	Dmnl
	~		|

"demand/supply public nt4"=
	REACTION TO PUBLIC EXCESS DEMAND NT4(percieved excess demand)
	~	Stock/Day
	~		|

"demand/supply public nt5"=
	REACTION TO PUBLIC EXCESS DEMAND NT5(percieved excess demand)
	~	Stock/Day
	~		|

"demand/supply private nt1"=
	REACTION NT1(private price nt1/Stock Price)
	~	Stock/Day
	~		|

"demand/supply private nt4"=
	REACTION NT4(private price nt4/Stock Price)
	~	Stock/Day
	~		|

"demand/supply nt2"=
	"demand/supply private nt2"+"demand/supply public nt2"*herding factor nt2
	~	Stock/Day
	~		|

"demand/supply nt1"=
	"demand/supply private nt1"+"demand/supply public nt1"*herding factor nt1
	~	Stock/Day
	~		|
```

```
"demand/supply nt3"=
	"demand/supply private nt3"+"demand/supply public nt3"*herding factor nt3
	~	Stock/Day
	~		|

"demand/supply nt4"=
	"demand/supply private nt4"+"demand/supply public nt4"*herding factor nt4
	~	Stock/Day
	~		|

"private/public price ratio nt4"=
	Stock Price/private price nt4
	~	Dmnl
	~		|

"private/public price ratio nt5"=
	Stock Price/private price nt5
	~	Dmnl
	~		|

PERSONAL THRESHOLD NT2(
	[(0,0)-(2,1)],(0,1),(0.244648,1),(0.348624,1),(0.477064,1),(0.495413,1),(0.562691,1)\
		,(0.691131,0.973684),(0.740061,0.921053),(0.752294,0.758772),(0.75841,0.495614),(0.764526\
		,0.241228),(0.801223,0.100877),(0.850153,0.0131579),(1,0),(1.11315,0.00877193),(1.1682\
		,0.0921053),(1.20489,0.245614),(1.21713,0.385965),(1.22324,0.513158),(1.24159,0.776316\
		),(1.27217,0.921053),(1.37003,0.964912),(1.52294,0.982456),(1.63303,0.995614),(1.74924\
		,1),(2,1))
	~	Dmnl
	~		|

"demand/supply private nt3"=
	REACTION NT3(private price nt3/Stock Price)
	~	Stock/Day
	~		|

herding factor nt2=
	PERSONAL THRESHOLD NT2("private/public price ratio nt2")
	~	Dmnl
	~		|

"demand/supply private nt5"=
	REACTION NT5(private price nt5/Stock Price)
	~	Stock/Day
	~		|

herding factor nt1=
	PERSONAL THRESHOLD NT1("private/public price ratio")
	~	Dmnl
	~		|

"demand/supply public nt2"=
	REACTION TO PUBLIC EXCESS DEMAND NT2(percieved excess demand)
	~	Stock/Day
	~		|

"demand/supply public nt3"=
	REACTION TO PUBLIC EXCESS DEMAND NT3(percieved excess demand)
```

```
	~	Stock/Day
	~		|

PERSONAL THRESHOLD NT4(
	[(0,0)-(2,1)],(0,1),(0.244648,1),(0.348624,1),(0.477064,1),(0.495413,1),(0.562691,1)\
		,(0.691131,0.973684),(0.740061,0.921053),(0.752294,0.758772),(0.75841,0.495614),(0.764526\
		,0.241228),(0.801223,0.100877),(0.850153,0.0131579),(1,0),(1.11315,0.00877193),(1.1682\
		,0.0921053),(1.20489,0.245614),(1.21713,0.385965),(1.22324,0.513158),(1.24159,0.776316\
		),(1.27217,0.921053),(1.37003,0.964912),(1.52294,0.982456),(1.63303,0.995614),(1.74924\
		,1),(2,1))
	~	Dmnl
	~		|

"private/public price ratio nt3"=
	Stock Price/private price nt3
	~	Dmnl
	~		|

herding factor nt3=
	PERSONAL THRESHOLD NT3("private/public price ratio nt3")
	~	Dmnl
	~		|

private price nt2=
	FUNDAMENTAL VALUE*BIAS 2
	~	$/Stock
	~		|

PERSONAL THRESHOLD NT3(
	[(0,0)-(2,1)],(0,1),(0.244648,1),(0.348624,1),(0.477064,1),(0.495413,1),(0.562691,1)\
		,(0.691131,0.973684),(0.740061,0.921053),(0.752294,0.758772),(0.75841,0.495614),(0.764526\
		,0.241228),(0.801223,0.100877),(0.850153,0.0131579),(1,0),(1.11315,0.00877193),(1.1682\
		,0.0921053),(1.20489,0.245614),(1.21713,0.385965),(1.22324,0.513158),(1.24159,0.776316\
		),(1.27217,0.921053),(1.37003,0.964912),(1.52294,0.982456),(1.63303,0.995614),(1.74924\
		,1),(2,1))
	~	Dmnl
	~		|

PERSONAL THRESHOLD NT1(
	[(0,0)-(2,1)],(0,1),(0.244648,1),(0.348624,1),(0.477064,1),(0.495413,1),(0.562691,1)\
		,(0.691131,0.973684),(0.740061,0.921053),(0.752294,0.758772),(0.75841,0.495614),(0.764526\
		,0.241228),(0.801223,0.100877),(0.850153,0.0131579),(1,0),(1.11315,0.00877193),(1.1682\
		,0.0921053),(1.20489,0.245614),(1.21713,0.385965),(1.22324,0.513158),(1.24159,0.776316\
		),(1.27217,0.921053),(1.37003,0.964912),(1.52294,0.982456),(1.63303,0.995614),(1.74924\
		,1),(2,1))
	~	Dmnl
	~		|

wealth nt4=
	Cash 4+Stock Price*Stocks NT4
	~	$
	~		|

wealth nt5=
	Cash 5+Stock Price*Stocks NT5
	~	$
	~		|
```

```
wealth nt3=
	Cash 3+Stock Price*Stocks NT3
	~	$
	~		|

wealth nt2=
	Cash 2+Stocks NT2*Stock Price
	~	$
	~		|

μ=
	1
	~	Dmnl [0,5,0.1]
	~		|

buy orders fa=
	IF THEN ELSE("demand/supply fa">=0, MIN( TOTAL FA IN THE MARKET*"demand/supply fa", \
		(Cash FA/Stock Price)/ONE DAY), 0)
	~	Stock/Day
	~		|

buy orders nt1=
	IF THEN ELSE("demand/supply nt1">=0, MIN( "demand/supply nt1", Cash 1/Stock Price/ONE DAY\
		), 0)
	~	Stock/Day
	~		|

change in stock price=
	"PRICE REACTION TO EXCESS DEMAND/SUPPLY"("excess demand/supply")*μ
	~	($/Stock)/Day [-50,50,1]
	~		|

sell orders fa=
	IF THEN ELSE("demand/supply fa"<0, MIN((-1)*"demand/supply fa"*TOTAL FA IN THE MARKET\
		,Stocks FA/ONE DAY), 0)
	~	Stock/Day
	~		|

"private/public price ratio"=
	Stock Price/private price nt1
	~	Dmnl
	~		|

private price nt5=
	FUNDAMENTAL VALUE*BIAS 5
	~	$/Stock
	~		|

Cash 4= INTEG (
	deposit 4-withdrawal 4,
		INITIAL CASH)
	~	$
	~		|

Cash 5= INTEG (
	deposit 5-withdrawal 5,
```

```
		INITIAL CASH)
	~	$
	~		|

deposit 4=
	sells 4*Stock Price
	~	$/Day
	~		|

wealth nt1=
	Cash 1+Stock Price*Stocks NT1
	~	$
	~		|

withdrawal 1=
	buys 1*Stock Price
	~	$/Day
	~		|

deposit 1=
	sells 1*Stock Price
	~	$/Day
	~		|

deposit 2=
	sells 2*Stock Price
	~	$/Day
	~		|

deposit 3=
	sells 3*Stock Price
	~	$/Day
	~		|

withdrawal 4=
	buys 4*Stock Price
	~	$/Day
	~		|

deposit 5=
	sells 5*Stock Price
	~	$/Day
	~		|

Cash 1= INTEG (
	deposit 1-withdrawal 1,
		INITIAL CASH)
	~	$
	~		|

Cash 2= INTEG (
	deposit 2-withdrawal 2,
		INITIAL CASH)
	~	$
	~		|

Cash 3= INTEG (
```

```
		deposit 3-withdrawal 3,
			INITIAL CASH)
		~	$
		~		|

"demand/supply fa"=
		"REACTION TO V/P RATIO"("value/price ratio")
		~	Stock/Day
		~		|

withdrawal 5=
		buys 5*Stock Price
		~	$/Day
		~		|

withdrawal 3=
		buys 3*Stock Price
		~	$/Day
		~		|

withdrawal 2=
		buys 2*Stock Price
		~	$/Day
		~		|

RAMP SWITCH=
		0
		~	$/Stock [0,100,10]
		~		|

BIAS 1=
		RANDOM NORMAL(0, 2, 1, 0.12*RANDOMSWITCH, 1*SEED FAKTOR)
		~	Dmnl
		~		|

BIAS 3=
		RANDOM NORMAL(0, 2, 1, 0.1*RANDOMSWITCH, 3*SEED FAKTOR)
		~	Dmnl
		~		|

BIAS 4=
		RANDOM NORMAL(0, 2, 1, 0.03*RANDOMSWITCH, 5*SEED FAKTOR)
		~	Dmnl
		~		|

BIAS 5=
		RANDOM NORMAL(0, 2, 1, 0.05*RANDOMSWITCH, 1*SEED FAKTOR)
		~	Dmnl
		~		|

SEED FAKTOR=
		6.5
		~	Dmnl [0,100,0.5]
		~		|

RANDOMSWITCH=
		1
```

```
	~	Dmnl [0,1,1]
	~		|

REACTION NT1(
	[(0,-100)-(2,100)],(0.25,-98.2456),(0.5,-10),(0.6,-5),(0.7,-2),(0.8,-1),(0.9,-1),(0.95\
		,0),(1,0),(1.05,0),(1.1,1),(1.2,1),(1.3,2),(1.4,5),(1.5,10),(1.75,100))
	~	Stock/Day
	~		|

FUNDAMENTAL VALUE=
	100+RAMP(0.01, 1, 250)*RAMP SWITCH
	~	$/Stock
	|

volume=
	buys 1+buys 2+buys 3+buys 4+buys 5+buys fa+buys ta
	~	Stock/Day
	~		|

Reference Price= INTEG (
	change in reference price,
		Perceived Price/(1+Perceived Trend*TIME HORIZON FOR REFERENCE PRICE))
	~	$/Stock
	~	The reference condition is an exponentially weighted average of the past \
		values of the perceived present condition. It represents the value of the \
		input THRC periods in the past. Set initially in the steady state given \
		the user-supplied initial value of the perceived trend.
	|

change in trend=
	(indicated price trend - Perceived Trend)/TIME TO PERCIEVE TREND
	~	1/(Day*Day)
	~	The perceived trend adjusts via first-order smoothing to the indicated \
		value, with a time constant given by TPT.
	|

INITIAL CASH=
	1000
	~	$ [0,1000,100]
	~		|

TIME HORIZON FOR REFERENCE PRICE=
	9
	~	Day [0,50,1]
	~	The long the time horizon, the more short-term variation in the growth \
		rate of the input will be filtered out by the TREND function.
	|

TIME TO PERCEIVE PRESENT PRICE=
	0.25
	~	Day
	~	The average lag in the reporting and perception of the input.
	|

TIME TO PERCIEVE TREND=
	0.25
	~	Day
```

~ The time required for decision makers to adjust their beliefs and reports \
to the indicated trend. Represents report preparation and perception \
delays in the adjustment of growth expectations to new information.
|

Perceived Price= INTEG (
change in percieved price,
Stock Price/(1+Perceived Trend*TIME TO PERCEIVE PRESENT PRICE))
~ $/Stock
~ The perceived present condition of the input lags behind the true input to \
capture data reporting and perception delays. Set initially in the steady \
state given the user-supplied initial value of the perceived trend.
|

Cash TA= INTEG (
deposit ta-withdrawal ta,
INITIAL CASH*TOTAL TA'S IN THE MARKET)
~ $
~ |

change in percieved price=
(Stock Price - Perceived Price)/TIME TO PERCEIVE PRESENT PRICE
~ $/Stock/Day
~ The perceived present condition adjusts to the actual value of the input \
via first-order smoothing, with a time constant given by TPPC.
|

change in reference price=
(Perceived Price - Reference Price)/TIME HORIZON FOR REFERENCE PRICE
~ $/(Day*Stock)
~ The reference condition adjusts via first-order smoothing to the perceived \
present condition, with a time constant given by THRC, representing the \
historical horizon for trend calculation. The longer THRC, the farther \
back in history the decision makers consider when estimating growth rates.
|

indicated price trend=
(Perceived Price -Reference Price)/(Reference Price*TIME HORIZON FOR REFERENCE PRICE\
)
~ 1/Day
~ The indicated TREND is the growth rate of the input indicated now based on \
the reference condition and the perceived present condition. It may take \
time for decision makers to recognize and respond to this value. The \
indicated trend yields an unbiased estimate, in steady state, of the \
fractional growth rate in the input.
|

REACTION TO PERCEIVED TREND(
[(0.5,-100)-(1.5,100)],(0.95,-10),(0.955,-7.5),(0.96,-5),(0.970031,-2.5),(0.985015,-1.14035\
),(1,0),(1.01437,1.14035),(1.02966,2.5),(1.04,5),(1.04495,7.5),(1.05,10)],(0.9,-98.2456\
),(0.95,-10),(0.955,-7.5),(0.96,-5),(0.970031,-2.5),(0.985015,-1.14035),(1,0),(1.01437\
,1.14035),(1.02966,2.5),(1.04,5),(1.04495,7.5),(1.05,10),(1.1,100))
~ Stock/Day
~ |

Perceived Trend= INTEG (
change in trend,

```
		0)
	~	1/Day
	~	The Perceived TREND is the decision makers' belief about the current \
		fractional rate of change in the input.
	|

wealth ta=
	Cash TA+Stock Price*Stocks TA
	~	$
	~		|

TOTAL TA'S IN THE MARKET=
	5
	~	Dmnl [0,10,1]
	~		|

withdrawal ta=
	buys ta*Stock Price
	~	$/Day
	~		|

deposit ta=
	sells ta*Stock Price
	~	$/Day
	~		|

TOTAL FA IN THE MARKET=
	5
	~	Dmnl [0,10,1]
	~		|

withdrawal fa=
	buys fa*Stock Price
	~	$/Day
	~		|

wealth fa=
	Cash FA+Stock Price*Stocks FA
	~	$
	~		|

Cash FA= INTEG (
	deposit fa-withdrawal fa,
		INITIAL CASH*TOTAL FA IN THE MARKET)
	~	$
	~		|

ONE DAY=
	1
	~	Day
	~		|

deposit fa=
	sells fa*Stock Price
	~	$/Day
	~		|
```

```
"REACTION TO V/P RATIO"(
	[(0,-10)-(2,10)],(0.501529,-9.825),(0.691131,-2.018),(0.782875,-0.5263),(0.856269,0)\
		,(0.98,0),(1,0),(1.02,0),(1.10092,0),(1.21713,0.5263),(1.29664,1.842),(1.50459,9.912\
		))
	~	Stock/Day
	|

"value/price ratio"=
	FUNDAMENTAL VALUE/Stock Price
	~	Dmnl
	|

"PRICE REACTION TO EXCESS DEMAND/SUPPLY"(
	[(-100,-100)-(100,100)],(-100,-37.7193),(-50.4587,-33.3333),(-35.7798,-31.5789),(-19.8777\
		,-27.193),(-14.3731,-26.3158),(-9.32722,-24.1228),(-6.57492,-19.7368),(-3.82263,-10.9649\
		),(-2.29358,-3.50877),(0,0),(1.98777,1.31579),(4.12844,10.9649),(6.88073,21.4912),(\
		13.1498,26.3158),(23.5474,31.5789),(37.0031,35.0877),(49.6942,36.8421),(77.37,40.3509\
		),(100,40.7895))
	~	$/(Stock*Day) [0,20,0.5]
	~		|

Stock Price= INTEG (
	change in stock price,
		ISSUE PRICE)
	~	$/Stock
	~		|

ISSUE PRICE=
	100
	~	$/Stock [1,100,1]
	~		|

Trading Floor= INTEG (
	sells 1+sells 2+sells 3+sells 4+sells 5+sells fa+sells ta-buys 1-buys 2-buys 3-buys 4\
		-buys 5-buys fa-buys ta,
		0)
	~	Stock
	|

buys 4=
	IF THEN ELSE(total supply-total demand>=0, buy orders nt4, buy orders nt4*ZIDZ(total supply\
		, total demand))
	~	Stock/Day
	|

buys 5=
	IF THEN ELSE(total supply-total demand>=0, buy orders nt5, buy orders nt5*ZIDZ(total supply\
		, total demand))
	~	Stock/Day
	|

buys fa=
	IF THEN ELSE(total supply-total demand>=0, buy orders fa, buy orders fa*ZIDZ(total supply\
		, total demand))
	~	Stock/Day
	|
```

```
buys ta=
	IF THEN ELSE(total supply-total demand>=0, buy orders ta, buy orders ta*ZIDZ(total supply\
		, total demand))
	~	Stock/Day
	|

Stocks NT3= INTEG (
	buys 3-sells 3,
		INITIAL STOCKS PER TRADER)
	~	Stock
	~		|

Stocks NT4= INTEG (
	buys 4-sells 4,
		INITIAL STOCKS PER TRADER)
	~	Stock
	~		|

Stocks NT5= INTEG (
	buys 5-sells 5,
		INITIAL STOCKS PER TRADER)
	~	Stock
	~		|

total supply=
	sell orders nt1+sell orders nt2+sell orders nt3+sell orders nt4+sell orders nt5+sell orders fa\
		+sell orders ta
	~	Stock/Day
	~		|

Stocks FA= INTEG (
	buys fa-sells fa,
		INITIAL STOCKS PER TRADER)
	~	Stock
	~		|

sells 5=
	IF THEN ELSE(total supply-total demand<=0, sell orders nt5, sell orders nt5*ZIDZ(total demand\
		, total supply))
	~	Stock/Day
	|

sells fa=
	IF THEN ELSE(total supply-total demand<=0, sell orders fa, sell orders fa*ZIDZ(total demand\
		, total supply))
	~	Stock/Day
	|

sells ta=
	IF THEN ELSE(total supply-total demand<=0, sell orders ta, sell orders ta*ZIDZ(total demand\
		, total supply))
	~	Stock/Day
	|

"excess demand/supply"=
	total demand-total supply
	~	Stock/Day
```

```
	~		|

INITIAL STOCKS PER TRADER=
	10
	~	Stock [0,100,10]
	~		|

total demand=
	buy orders nt1+buy orders nt2+buy orders nt3+buy orders nt4+buy orders nt5+buy orders fa\
		+buy orders ta
	~	Stock/Day
	~		|

sells 4=
	IF THEN ELSE(total supply-total demand<=0, sell orders nt4, sell orders nt4*ZIDZ(total demand\
		, total supply))
	~	Stock/Day
	|

Stocks TA= INTEG (
	buys ta-sells ta,
		INITIAL STOCKS PER TRADER)
	~	Stock
	~		|

Stocks NT1= INTEG (
	buys 1-sells 1,
		INITIAL STOCKS PER TRADER)
	~	Stock
	~		|

Stocks NT2= INTEG (
	buys 2-sells 2,
		INITIAL STOCKS PER TRADER)
	~	Stock
	~		|

buys 1=
	IF THEN ELSE(total supply-total demand>=0, buy orders nt1, buy orders nt1*ZIDZ(total supply\
		, total demand))
	~	Stock/Day
	|

buys 2=
	IF THEN ELSE(total supply-total demand>=0, buy orders nt2, buy orders nt2*ZIDZ(total supply\
		, total demand))
	~	Stock/Day
	|

buys 3=
	IF THEN ELSE(total supply-total demand>=0, buy orders nt3, buy orders nt3*ZIDZ(total supply\
		, total demand))
	~	Stock/Day
	|

sells 1=
	IF THEN ELSE(total supply-total demand<=0, sell orders nt1, sell orders nt1*ZIDZ(total demand\
```

```
		, total supply))
	~	Stock/Day
	|

sells 2=
	IF THEN ELSE(total supply-total demand<=0, sell orders nt2, sell orders nt2*ZIDZ(total demand\
		, total supply))
	~	Stock/Day
	|

sells 3=
	IF THEN ELSE(total supply-total demand<=0, sell orders nt3, sell orders nt3*ZIDZ(total demand\
		, total supply))
	~	Stock/Day
	|

********************************************************
	.Control
********************************************************~
		Simulation Control Parameters
	|

FINAL TIME = 100
	~	Day
	~	The final time for the simulation.
	|

INITIAL TIME = 0
	~	Day
	~	The initial time for the simulation.
	|

SAVEPER =
    TIME STEP
	~	Day [0,?]
	~	The frequency with which output is stored.
	|

TIME STEP  = 0.125
	~	Day [0,?]
	~	The time step for the simulation.
	|
```