Modeling financial networks based on interpersonal trust

Anna Klabunde and Michael Roos*†

May 29, 2013

Abstract

We build a stylized model of a network of business angel investors and start-up entrepreneurs. Investors provide capital for entrepreneurs who invest it in the business and return part of the profit to the investors. Investors exchange information about returns from entrepreneurs. The initial level of trust between an investor and an entrepreneur is determined by a distance measure. Then, trust grows through better-than-average returns. If an investor is disappointed, trust decreases. If trust is below a certain threshold, a link is cut. The questions that can be addressed with the model are: How does the investors' trusting behavior influence market outcomes, such as their own return and the probability of successful exit for the entrepreneurs? Is there an optimal trusting behavior trom the investors' perspective, both collectively and individually? What is the best behavioral strategy from an entrepreneur's perspective? The model can easily be generalized to other settings. Once the basic mechanisms are well understood, more complex versions could be derived to study e.g. banking networks.

JEL-Classification: C63, D83, G24
Keywords: Angel investors, trust, agent-based computational economics

*Ruhr University Bochum, Germany. Corresponding author: Anna Klabunde; *Email*: anna.klabunde@rub.de *Phone:* +49-234-32-23107; *Fax:* +49-234-32-14453; *Address:* Universitaetsstr. 150, 44780 Bochum, Germany.

†Acknowledgement: The authors are grateful for helpful comments and suggestions by Pietro Terna, Alan Kirman, Sandra Margraf, Andrés Cardona, Gianluca Grimalda, participants at the essa@work Workshop 2013 in Osnabrück, participants at the 1st Conference of the Herbert Simon Society and seminar participants at Universitat Jaume I, Castellón and Ruhr University Bochum. They would like to acknowledge financial support by the RUB Research School.

1 ODD

1.1 Overview

1.1.1 Purpose

The questions that can be addressed with the model are: How does the investors' trusting behavior influence market outcomes, such as their own return and the probability of successful exit for the entrepreneurs? Is there an optimal trusting behavior trom the investors' perspective, both collectively and individually? What is the best behavioral strategy from an entrepreneur's perspective? Is there a possibility for the investors to tell productive entrepreneurs from unproductive ones? For this purpose, a simple network of investors and entrepreneurs is constructed in which agents form links based on trust. Those links can be cut again when trust is low. Investors provide capital for entrepreneurs who invest it, receive a return that the investors cannot observe, and return part of the return to the investors. Initial trust is based on a measure of cultural proximity. Trust increases if no disappointment occurs, and it drops after a disappointment. If trust is too low, a link is cut. Personal trust and cultural proximity are important determinants of the business angel segment of start-up financing (Prowse 1998 [7], Wong et al. 2009 [14], Kelly and Hay 2003 [5], Sudek 2006[11]). However, the model can easily be generalized to other settings. Eventually the model might be extended, e.g. by allowing lending and borrowing both ways. Once the basic mechanisms are well understood, more complex versions could be derived to study e.g. banking networks. The model was built in NetLogo (Wilensky 1999 [12].

1.1.2 Entities, state variables, and scales

Entities in the model are investors and entrepreneurs. They are connected through links. The model is not spatially explicit, although the spatial distance of the randomly distributed agents represents the cultural distance between two individuals. Investors have the following state variables:

- Culture
- Capital

Entrepreneurs have the following state variables:

- Culture

- Return
- Capital received from investors
- Private Wealth
- p_1 : Amount paid as return to the investor
- p_2 : Amount set aside to invest in own business the next period
- p_3: Amount added to private wealth

Links have the following state variables:

- Trust
- Returns sent through the link
- Amounts invested through the link

Global variables are:

- Number of investors
- Number of entrepreneurs
- Productivity parameter α
- Trust cutoff threshold c
- Disappointment threshold d
- $\triangle$: Length of memory
- Parameters of distribution of stochastic component of returns
- Maximum time budget investors can spend on maintaining links with entrepreneurs
- Maximum time budget investors can spend on maintaining links with other investors
- Amount that investors invest
- Length of run
- Trust increase when satisfied $tr1$

- Trust decrease when dissatisfied $tr2$
- Saving target of entrepreneurs (Capital from investor + private wealth must be larger than the saving target; identical for all entrepreneurs)
- Maximum amount that is set aside for private wealth by entrepreneurs each period (p_3 is set to this value if the entrepreneur can afford it)
- Adaptation-speed a: Parameter for adaptation heuristics when allocating profits between entrepreneur and investor

Spatial and temporal scales: The temporal extent of the model can be set with the variable "length of run". One discrete time step represents a year. Investors decide with whom and what amount to invest for the duration of one year.

1.1.3 Process overview and scheduling

In a time step of the model the following happens:

1. Only in the very first period: Investors form links to other investors that are spatially closest until their time-budget for relations to other investors is exhausted.
2. If investors have not exhausted their time budget on entrepreneurs, they create new links to new entrepreneurs. The cost of the links in terms of time is proportional to cultural distance.
3. Investors decide with whom of their associated entrepreneurs they want to invest this period and what amount to invest with whom.
4. Investors endow entrepreneurs with capital.
5. Entrepreneurs receive their return from production, which is determined by a linear production function plus a stochastic component that represents the uncertainty of the environment.
6. Each entreprenurs decides individually how much of the profit to set aside for his private wealth, how much to pay as an interest rate to the investors, and how much to invest in the business himself in the next period.
7. Investors receive their investment back plus interest payment from the entrepreneurs.

8. Investors update their trust towards the entrepreneurs.

9. If the trust to an entrepreneur is too low, the investor cuts the link.

10. If the sum of an entrepreneur's capital and private wealth is <= 0, he goes out of business and is replaced by a random new entrepreneur.

11. If the sum of an entrepreneurs capital and private wealth is higher than his saving target he or she exits the angel segment of the market (he can now obtain funding elsewhere, e.g. from a venture capital firm) and is replaced by a random new entrepreneur.

12. If investors have no capital left they exit the market and are replaced by a random new investor.

1.2 Design concepts

1.2.1 Basic principles

Trust can be defined as "firm belief in the reliability, truth, or ability of someone or something" (Oxford Dictionaries). Earle (2009, p. 786) [2] distinguishes *trust* as the "willingness, in the expectations of beneficial outcomes, to make oneself vulnerable to another based on a judgment of similarity of intentions or values" from *confidence* as "the belief, based on experience or evidence (e.g., past performance), that certain future events will occur as expected". While we agree that this distinction may sometimes be quite important, it is not for our purposes. We use trust in the wider sense comprising both trust and confidence in the definitions of Earle. In this view, not only the entrepreneur makes a decision based on judgment on whether there are good profit opportunities, but also the investor, namely that the entrepreneur who is trusted has both good intentions and abilities making it likely that the investment will generate a positive return. Trust is then a way of forming expectations and a heuristic decision rule allowing investors to deal with the true uncertainty about the outcome of funding startups. Trust is here a precondition for transactions to take place. How much is then invested with a particular entrepreneur is determined according to economic criteria only: the amount invested is proportional to the expected return from that investor, which is formed based on past experience.

1.2.2 Emergence

The properties of the network connecting the investors and entrepreneurs as well as the distribution of profits are emergent as they cannot be derived straightforwardly from the behavior of the agents.

1.2.3 Adaptation

In their decision whether or not to form a link with an entrepreneur, investors are influenced by cultural proximity, because they assume it to be a predictor of similar values and objectives of investor and entrepreneur (indirect objective seeking). This behavioral aspect reproduces behavior observed in real networks (see e.g. Bornhorst et al. (2004) [1], Glaeser et al. (2000) [4], Knack and Keefer (1997) [6]). Investors respond to the interest received from the entrepreneurs and adapt their links and the amount invested with them accordingly. In this second aspect of decision making the investors decide based on observed return (direct objective seeking).

1.2.4 Objectives

Investors aim at maximizing their wealth by choosing the entrepreneurs that they believe will provide them with the highest returns. Entrepreneurs also maximize their private wealth by choosing what proportion of their returns to keep, what proportion to invest in the business, and what proportion to pay as interest to the investor.

1.2.5 Prediction

Investors predict expected returns from an entrepreneur as an average of the other investors' return in their network in the previous $\triangle$ periods. Entrepreneurs do not explicitly predict a return. They rather compare the current period's return with that of the last and adjust their strategy heuristically (see below).

1.2.6 Sensing

All agents know all of their own variables and who they are connected with. Entrepreneurs do not know the productivity parameter or the mean and variance of the stochastic component. In each period, investors furthermore learn the return of the other investors in their network. Note that investors are also connected to the other investors that are spatially, i.e. culturally, closest. Everyones culture is common knowledge and observable to all agents.

1.2.7 Interaction

Investors and entrepreneurs interact directly with each other, with the entrepreneur receiving capital from the investor and paying an interest to him in return. Investors are connected in a local network that serves for transmitting information. Entrepreneurs implicitly compete for links to investors because investors have a limited time budget for links to entrepreneurs.

1.2.8 Stochasticity

Random numbers are used to assign a culture to each agent. Furthermore, the stochastic terms of the returns that entrepreneurs receive are drawn from a normal distribution. When investors pick a new entrepreneur to connect with and there is more than one with the same baseline trustworthiness, a random one is chosen.

1.2.9 Observation

The following outputs are observed:

- Average number of links of investors to entrepreneurs
- Wealth distribution of entrepreneurs
- Wealth distribution of investors
- Flows of capital investment
- Flows of returns to investors
- Average age of entrepreneurs
- Average duration of investment
- Proportion of entrepreneurs exiting the market voluntarily
- average p_1, p_2, p_3

1.3 Details

1.3.1 Initialization

Investors have the following state variables by assumption:

- Culture: Coordinates on a two-dimensional grid

- Capital: 1000

Entrepreneurs have the following state variables:

- Return: 0
- Culture: Coordinates on a two-dimensional grid
- Private Wealth: 0
- Capital: 0

Links have the following state variables:

- Trust: $1/(linklength + 0.1)$ [1]

How the values for global variables were obtained is described in section 2. They are:

- Number of investors: 210
- Number of entrepreneurs: 160
- Productivity parameter α: 1.6
- Trust cutoff threshold c: 0.2
- Disappointment threshold d: 0.6
- $\triangle$: Length of memory: 10 periods
- Parameters of distribution of stochastic component of returns: $\sim N(0, 0.8)$
- Maximum time budget investors can spend on maintaining links with entrepreneurs: 10
- Maximum time budget investors can spend on maintaining links with other investors: 10
- Amount that investors invest each period: 70
- Length of run: 200 periods
- Trust increase when satisfied $tr1$: 0.5

[1] Link length is the Euclidian distance between the connected investor and entrepreneur. 0.1 is added to rule out the possiblity that link length is 0.

- Trust decrease when dissatisfied $tr2$: 1.7
- Saving target of entrepreneurs: 600
- Amount that is set aside for private wealth by entrepreneurs each period: 6
- Adaptation-speed a: Parameter for adaptation heuristics when allocating profits between entrepreneur and investor: 5

In the setup procedure, investors form links to other random investors, who constitute their (fixed) network through which they receive information on others returns (see below).

1.3.2 Submodels

1.3.2.1 Create-links

Investors create links to the entrepreneurs whose culture value is closest to their own, starting with the closest, then the second closest, and so on. They have a fixed time budget each period for maintaining the relationship with the links. The time cost is equal to the cultural distance from the investor to the entrepreneur tc_{ij}. Investors can only form links as long as their overall budget in terms of time, $T_{i,t}$, is not exhausted, that is, as long as

$$T_{i,t} \geq \sum_{j=1}^{j=J} c_{i,j} \tag{1}$$

where entrepreneurs are sorted according to their distance to investor i, where $j = 1$ is the entrepreneur with the lowest cultural distance to investor i and $j = J$ is the last entrepreneur asked by the investor.

The trust value for new links is set to 1 / (cultural distance + 0.1). Investors do not create links to entrepreneurs they were previously connected to. If there is no entrepreneur to whom the investor could still be connected because it would require a higher time budget, he stops. Investors form links to other investors in the same manner during the setup procedure. They, too, are connected to other investors that are culturally closest. Those links among investors remain for as long as both ends of the link remain in the market.

1.3.2.2 Investment-decision

Investors decide with whom of their associated entrepreneurs they want to invest this period. They divide the amount they want to invest, which is fixed and the same for all investors, among the entrepreneurs they are connected to. The amount invested with each of them is proportional to the expected return from this entrepreneur, i.e., the investor keeps track of all returns received from the entrepreneurs. Each entrepreneur then receives the proportion of this periods total investment that is equal to the proportion of the investors total returns in the last 10 periods that fall upon this entrepreneur. In the very first period the investor invests an equal amount with all of his connected entrepreneurs. Every newly connected entrepreneur who has not yet had a chance to return anything to the investor receives the amount he would have received if the amount invested by the investor had been split up equally among all the entrepreneurs the respective investor is connected to.

1.3.2.3 Invest

Investors give a fixed amount of capital from their wealth to the entrepreneurs. Each of them receives the proportion determined in the previous step. The entrepreneur invests the capital units in his business.

1.3.2.4 Compute-return

Entrepreneurs learn their return, which is assumed to be determined by the following production function:

$$r_{i,t} = (\alpha + \epsilon_{i,t})(p_{2,i,t-1} + inv_{i,t}) \tag{2}$$

where $\sim N(0, 0.8)$, α is a productivity parameter, $p_{2,i,t-1}$ is the amount that the entrepreneur$i$ invested himself, and $inv_{i,t}$ is the total amount received from the investors this period. The stochastic component is determined per period and is idiosyncratic to the entrepreneurs. It represents the uncertainty of the environment.

1.3.2.5 Optimization-entrepreneurs

The entrepreneurs employ heuristics to adapt their strategy of deciding how much of their profits to return to the investors and how much to invest themselves in the firm. First, the entrepreneur computes his profit (subscript

i is suppressed to increase readability):

$$\pi_t = r_t - i_t \tag{3}$$

If $\pi_t > 0$ and $\pi_t > \pi_{t-1}$, the entrepreneur seeks to do more of what he seems to have done right. First, if $\pi_t \geq p_3$, he sets an amount of size p_3 aside for his private wealth. p_3 is a parameter that is fixed for a simulation run and the same for all entrepreneurs. If $\pi_t < p_3$, he sets the full π_t aside. Then, if $p_{1,t-1} > p_{1,t-2}$, he attributes part of the increase in his profits to the increase in p_1 (the amount paid as a return to the investors) and sets $p_(1,t) = p_(1,t-1) + a$, where a is the parameter for adaptation speed. If $\pi_t - p_3 < p_{1,t-1} + a$, he sets $p_{1,t} = \pi_t - p_3$. The rest of the profit, $\pi_t - p_3 - p_{1,t}$, if there is any, is distributed in the following way: If $\pi_t - p_3 - p_{1,t} \geq p_{2,t-1}$, the entrepreneurs sets $p_{2,t} = p_{2,t-1}$, where $p_{2,t}$ is the amount set aside for investment in his own business the next period. Any profit remaining is split up in half and added to $p_{1,t}$ and $p_{2,t}$ in equal proportions. If $\pi_t > 0$, $\pi_t > \pi_{t-1}$ and $p_{1,t-1} < p_{1,t-2}$, he does the opposite: he increases $p_{2,t}$ in a way analogous to the one described above. If $\pi_t > 0$, but $\pi_t < \pi_{t-1}$, he increases $p_{2,t}$ if $p_{1,t-1} > p_{1,t-2}$ in the way described above, because he believes that the lower profits are partly because $p_{1,t-1}$ was too high and $p_{2,t-1}$ was too low. Instead, he increases $p_{1,t}$ if $p_{2,t-1} > p_{2,t-2}$. If $\pi_t < 0$, $p_{1,t}$, $p_{2,t}$ and $p_{3,t}$ are all 0. In the very first year of existence, when entrepreneurs do not yet have any values to compare the current profit to, they split up equally what remains of their profit after subtracting p_3.

1.3.2.6 Inform-investors

If, for an entrepreneur i, $\pi_{i,t} > 0$, $p_{1,i,t}$ is paid to the investors. Each investor j receives the amount he invested with the entrepreneur, plus a proportion of $p_{1,i,t}$, so that

$$p_{1,ij,t} = p_{1,i,t} \frac{inv_{ij,t}}{inv_{i,t}} \tag{4}$$

where $inv_{i,t} = \sum_{j=1}^{j=J} inv_{ij,t}$. If $\pi_{i,t} < 0$, the entrepreneur has to pay the investor back using his private wealth that he accumulated in the previous periods. If his private wealth is not sufficient to pay back all that was invested with him, the entrepreneur returns an equal proportion of their investment to the investors that invested with him and goes bankrupt. Entrepreneurs inform investors how much they receive this period and the investors wealth is increased by that amount.

1.3.2.7 Update-trust

Investors update their trust towards the entrepreneur they invested with. If the return he or she received is at least d * average return of the other investors in the investor's network in the last $\triangle$ periods, the investor is satisfied. Otherwise he is dissatisfied. If the investor is dissatisfied, the trust decreases by $tr2$, otherwise it increases by $tr1$, given that he invested with the entrepreneur. Otherwise, trust does not change.

1.3.2.8 Cut-link

If the trust to an entrepreneur is lower than the trust cutoff threshold c, the investor cuts the link. The investors time budget is increased by the cultural distance to the dismissed entrepreneur, so that the investor can form new links in the next period.

1.3.2.9 Die

If an entrepreneur is bankrupt, he exits the market and is replaced by a new entrepreneur with random culture.

1.3.2.10 Exit

If an entrepreneur's private wealth plus the capital set aside for investing next period, $p_{2,i,t}$, is at least the size of the saving target, he exits the angel segment of the market and is replaced by a new entrepreneur with random culture. An entrepreneur also exits voluntarily if he has been inactive for 10 consecutive periods, i.e., if $p_{2,i,t}$, $\pi_{i,ti}$ and $inv_{i,ti}$ have been 0 for 10 periods.

1.3.2.11 Exit-investors

Investors whose capital has decreased to 0 or who have not invested for 10 consecutive periods exit the market.

1.3.2.12 Update-Variables

Variables are updated.

1.4 Graphical model representation

In figure 1, investor 1 invests with entrepreneurs 1, 2 and 3 and is connected to investors 2 and 3, with whom he exchanges information about returns.

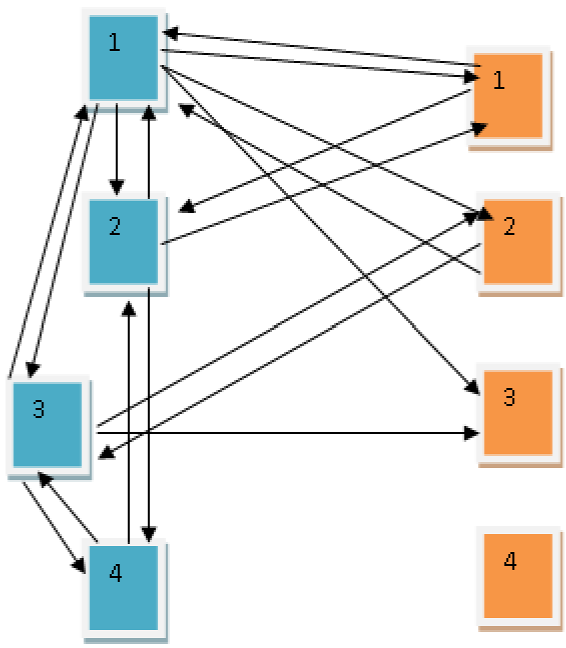

Figure 1 – Example of a detail of the investor-entrepreneur network. Investors are blue, entrepreneurs orange.

Investor 2 invests with entrepreneur 1; he is not connected to any other entrepreneur because his trust is not large enough. His investor-network includes investors 1 and 4. Investor 3 invests with entrepreneurs 2 and 3. Investor 4 does not trust anybody and is therefore not connected to any entrepreneurs. His investor network consists of investors 2 and 3. Now the following might happen: Entrepreneur 1 returns an equal amount of his profit to investors 1 and 2 who invested with him. Entrepreneur 2 returns different proportions of his profit to investors 1 and 3. Entrepreneur 3 decides that it is his best choice to return only their investment to the investors and nothing from his profit, so the trust of investors 1 and 3 in entrepreneur 3 decreases. The investors are satisfied with their investment with entrepreneurs 1 and 2, so their trust in them increases. Entrepreneur 4 has not been connected to anyone and has not invested anything himself in the last 10 periods, so he exits the market and will be replaced by a new entrepreneur next period.

1.5 Schematic model representation

Capital of an investor *j*

$$C_{j,t} = C_{j,t-1} - inv_{j,t} + \sum_{i=1}^{i=I}(p_{1,ij,t} + inv_{ij,t}) \tag{5}$$

where $inv_{ij,t}$ is the investor's investment with entrepreneur i and $p_{1,ij,t}$ is the amount taken from profit that is returned by entrepreneur i (can also be negative, if the entrepreneurs private wealth is not sufficient to pay back the full investment).

Return entrepreneurs

$$r_{i,t} = (\alpha + \epsilon_{i,t})(p_{2,i,t-1} + inv_{i,t}) \tag{6}$$

where $\epsilon_{i,t} \sim N(0, 0.8)$, α is a productivity parameter, $p_{2,i,t-1}$ is the amount that the entrepreneur$i$ invested himself, and $inv_{i,t} = \sum_{j=1}^{j=J} inv_{ij,t}$ is the amount invested with the entrepreneur this period.

Private wealth entrepreneurs

$$C_{i,t} = h(\sum_{t=1}^{t=200} \epsilon_{i,t}, \sum_{t=1}^{t=200} inv_{i,t}) \tag{7}$$

The wealth of an entrepreneur is a function of the stochastic component and the amount invested with the entrepreneur over time.

Amount invested with an entrepreneur

$$inv_{i,t} = g(\sum_{t=1}^{t=200} p_{1,i.t}) \quad (8)$$

The amount invested with an entrepreneur is a function of the sum of the past payments to his connected investors.

2 Calibration

The parameter space of the model was explored systematically, first using BehaviorSearch (described in Stonedahl and Wilensky, 2010 [10]), then the built-in Netlogo tool BehaviorSpace, checking how well different characteristics of real-world angel investor markets were approximated at each parameter combination. While the purpose of this model is not to recreate the real world angel investor market perfectly, but to have a very simple model of a trust-based market that can be expanded and built on, the match of model results with real-world angel market characteristics is not bad at all. The characteristics that were taken into consideration were: duration of an average investment, average number of investors per startup, average number of angel investments made by an investor per year, proportion of investments that angels lose money on, average annual rate of return per investment, and the distribution of returns.

2.1 Data

The information on average return on investment, average duration of an investment, the distribution of returns across investments, and the proportion of investments that angels lose money on are taken from Wiltbank and Boeker (2007) [13], who interviewed 539 US angels who are member of an angel club and exited investments between 1990 and 2007. The remaining market features, number of investors per startup and average number of angel investments made by an investor per year, are from Shane (2012) [9]. He uses data from the Entrepreneurship in the United States Assessment (EUSA), which is a representative survey of US adults from 2004 which served as a screening preface to the follow-up Panel Study of Entrepreneurial Dynamics, described in Reynolds (2007) [8]. Table 1 provides an overview.

Table 1 – Overview of angel market features used for calibration.

Measure	**Value used**	**Source**
Average annual rate of return[1]	0.31	Wiltbank and Boeker (2007) [13]
Average duration of investment	3.5 years	Wiltbank and Boeker (2007) [13]
x% of investments account for 3/4 of returns	7	Wiltbank and Boeker (2007) [13]
Distribution of returns across investments	right-skewed	Wiltbank and Boeker (2007) [13]
Proportion of investments that investors lose money on	0.5	Wiltbank and Boeker (2007) [13]
Number of investors per startup	4.9	Shane (2012) [9]
Average number of investments made by an investor per year	0.43	Shane (2012) [9]

[1] Annual rate of return of an investment: $(\frac{\sum_{t=s}^{t=T} p_{1,ij,t}+inv_{ij,t}}{\sum_{t=s}^{t=T} inv_{ij,t}})^{(T-s)^{-1}}-1$, where s is the point in time when the link between entrepreneur and investor is created and T is the point in time the investment is terminated.

2.2 Search of the parameter space

First, BehaviorSearch was used to search the parameter space; the tool automizes the search for parameters that minimize the distance to some measure. Here, I used *Average duration of investment*,*Rate of return*, *Proportion of investments that investors lose money on* and *Investors per startup* as measures and ran a separate search for each of them. For each search, the settings chosen for the search algorithm were the same. Numeric parameter values are encoded to strings of binary digits using a Gray code. The Gray code representation was chosen because on the one hand adjacent integers are (in contrast to a standard binary coding) just one bit mutation away from each other, and on the other hand there are larger "jumps" possible that makes it less likely for the search to get "stuck". Therefore genetic algorithms employing Gray codes are often found to be more successful (Forrest, 1993) [3]. I choose a mutation probability of each bit of 5%, an initial population of solutions of 50, a tournament size of 3 (i.e. the winner of each tournament of 3 solutions is selected for crossover), and a crossover rate of 70% of all reproductions. Each evaluation, the model is run three times, for 200 steps each time, and the measure is taken in the last three periods of each run, then averaged. The algorithm stops after 10000 model runs. The four best parameter combinations found this way are compared to determine how well they fulfill the other measures from table 1. The best parameter combinations found this way are displayed in table 2.

Table 2 – Best parameter combinations found with BehaviorSearch

Parameter	Parameter range	Best values found for duration	Best values found for rate of return	Best values found for proportion lost	Best values found for investors per startup
Number investors	[10, 20,..., 300]	210	210	210	160
Number entrepreneurs	[10, 20,..., 300]	30	160	260	280
Productivity parameter α	[1.0, 1.1,..., 3.0]	1.5	1.6	2	1.4
Trust cutoff threshold c	[0, 0.1,..., 1.0]	0.2	0.2	0.8	0.6
Disappointment threshold d	[0.5, 0.6,..., 1.0]	0.5	0.8	0.6	0.6
$\triangle$: Length of memory [1]	10	10	10	10	10
Mean of stochastic component of return	[-1.0, -0.9,..., 1]	0.7	0.1	-0.9	-1.0
Variance of stochastic component of return	[0, 0.1,..., 2]	0.4	0.2	1.9	0.8
Time budget investors can spend on entrepreneurs	[10, 15,..., 30]	10	10	25	25
Time budget investors can spend on other investors	[10, 15,..., 30]	10	10	25	20
Amount invested per period	[10, 20,..., 100]	30	70	40	70
Trust increase $tr1$	[0.1, 0.2,..., 1.5]	1.0	0.4	0.2	0.7
Trust decrease $tr2$	[0.1, 0.2,..., 3.0]	0.5	2.3	1.7	1.5
Saving target	[100, 200,..., 5000]	2800	100	2000	2900
Amount set aside p_3	[2,3,..., 10]	10	2	5	7
Adaptation-speed a	[1, 2,..., 10]	9	4	5	5

[1] The length of memory was held fixed.

2.3 Calibration chosen

Table 3 shows the average and variance after 100 runs for all of the measures obtained at each of the parameter combinations shown above.

Table 3 – Comparison of different calibrations after 100 runs at each parameter setting; variances in parentheses

Measure	Calibration 1: duration	Calibration 2: rate of return	Calibration 3: proportion lost	Calibration 4: Investors per startup	empirical value
Average annual rate of return	0.85 (0.13)	0.31 (0.00)	0.19 (0.01)	-0.01 (0.00)	0.31
Average duration of investment	4.59 (0.02)	1.91 (0.00)	1.08 (0.00)	1.05 (0.00)	3.52
x% of investments account for 3/4 of returns	27.52% (0.00)	46.39% (0.00)	24.99% (0.00)	29.09% (0.00)	7%
Distribution of returns	right-skewed	right-skewed	right-skewed (too many 0s)	right-skewed	right-skewed
Proportion lost	0.29% (0.00)	0.00% (0.00)	49.73% (0.00)	99.51% (0.00)	50%
Investors per startup	9.56 (0.43)	4.03 (0.03)	4.89 (0.03)	4.84 (0.00)	4.9
Investments made per year	0.33 (0.03)	1.63 (0.03)	5.63 (0.06)	8.47 (0.01)	0.43

In a last step the model was run 15120 times with parameter values around those found for "rate of return" to see whether the match with the other criteria could be improved. The calibration finally used is shown in table 4.

The match of the baseline calibration (average of 100 runs) is shown in table 5.

Table 4 – Baseline calibration

Parameter	Parameter range of final tests	Baseline calibration
Number investors	[210]	210
Number entrepreneurs	[160, 180,..., 260]	160
Productivity parameter α	[1.6]	1.6
Trust cutoff threshold c	[0.2]	0.2
Disappointment threshold d	[0.6]	0.6
$\triangle$: Length of memory [1]	10	10
Mean of stochastic component of return	[0]	0
Variance of stochastic component of return	[0.4, 0.5, ..., 0.8]	0.8
Time budget investors can spend on entrepreneurs	[10]	10
Time budget investors can spend on other investors	[10]	10
Amount invested per period	[70]	70
Trust increase $tr1$	[0.4, 0.5, 0.6, 0.7]	0.5
Trust decrease $tr2$	[1.5, 1.6, 1.7]	1.7
Saving target	[200, 400,..., 2800]	600
Amount set aside p_3	[5, 6, 7]	6
Adaptation-speed a	[5]	5

[1] The length of memory was held fixed.

Table 5 – Match of baseline calibration and several measures

Measure	Baseline calibration	empirical value
Average annual rate of return	0.09	0.31
Average duration of investment	3.56	3.52
x% of investments account for 3/4 of returns	26%	7%
Distribution of returns	right-skewed	right-skewed
Proportion lost	26%	50%
Investors per startup	3.9	4.9
Investments made per year	0.84	0.43

References

[1] F. Bornhorst, A. Ichino, K. H. Schlag, and E. Winter. "trust and trustworthiness among europeans: South-north comparison". CEPR Discussion Papers 4378, C.E.P.R. Discussion Papers, 2004.

[2] T. C. Earle. Trust, confidence, and the 2008 global financial crisis. *Risk Analysis*, 29(6):785–792, 2009.

[3] S. Forrest. Genetic Algorithms: Principles of Natural Selection Applied to Computation. *Science*, 261(5123):872–878, 1993.

[4] E. L. Glaeser, D. I. Laibson, J. A. Scheinkman, and C. L. Soutter. Measuring trust. *The Quarterly Journal of Economics*, 115(3):811–846, 2000.

[5] P. Kelly and M. Hay. Business angel contracts: the influence of context. *Venture Capital*, 5(4):287–312, 2003.

[6] S. Knack and P. Keefer. "does social capital have an economic payoff? a cross-country investigation". *The Quarterly Journal of Economics*, 112(4):1251–1288, 1997.

[7] S. Prowse. Angel investors and the market for angel investments. *Journal of Banking & Finance*, 22(6-8):785 – 792, 1998.

[8] P. D. Reynolds. *Entrepreneurship in the United States: The Future is Now*. Springer, 2007.

[9] S. Shane. The Importance of Angel Investing in Financing the Growth of Entrepreneurial Ventures. *Quarterly Journal of Finance*, 2:1250009 (42 pages), 2012.

[10] F. Stonedahl and U. Wilensky. Evolutionary Robustness Checking in the Artificial Anasazi Model. In *Proceedings of the AAAI Fall Symposium on Complex Adaptive Systems: Resilience, Robustness, and Evolvability*, 2010.

[11] R. Sudek. Angel investment criteria. *Journal of small business strategy*, 17(2):89–103, 2006.

[12] U. Wilensky. *NetLogo*. Northwestern University, Evanston, IL, 1999.

[13] R. Wiltbank and W. Boeker. Returns to Angel Investors in Groups, 2007.

[14] A. Wong, M. Bhatia, and Z. Freeman. Angel finance: the other venture capital. *Strategic Change*, 18(7-8):221–230, 2009.