Chapter 1

ODD

1.0.1 Overview

Purpose

A simple model of business angel investing is constructed in which investors form links to entrepreneurs 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 repay part of this return as interest to the investors. Investors are connected among themselves through a second network through which they exchange information on interest rates received. Initial trust between investor and entrepreneur 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; Wong et al., 2009; Kelly and Hay, 2003; Sudek, 2006). 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 from 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? 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).

Entities, state variables, and scales

Entities in the model are investors, entrepreneurs and 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 (Coordinates on a two-dimensional grid; grid size: 30 x 30)

- Capital (Personal wealth investors can use to invest; range $[0; +\infty]$)

Entrepreneurs have the following state variables:

- Culture (Coordinates on a two-dimensional grid; grid size: 30 x 30)
- Return (Output from production in a period; range $[-\infty; +\infty]$)
- Capital received from investors (range $[0; +\infty]$)
- Private Wealth (0 in the beginning, increases through savings; range $[0; +\infty]$)
- p_1 : Amount paid as return to the investor in a period (range $[0; +\infty]$)
- p_2 : Amount set aside to invest in one's own business the next period (range $[0; +\infty]$)
- p_3: Amount added to private wealth (range $[0; +\infty]$)

Links have the following state variables:

- Trust between the investor and the entrepreneur the link connects (range $[0; 10]$)
- Returns sent through the link from the entrepreneur to the investor in a period (range $[0; +\infty]$)
- Amounts invested through the link (sent from an investor to an entrepreneur; range $[0; +\infty]$)

Global variables are:

- Number of investors (range $[0, 1, 2, ..., 465]$)
- Number of entrepreneurs (range $[0, 1, 2, ..., 465]$)
- Productivity parameter α (parameter of production function; range $[1.0, 1.1, 1.2, ...3.0]$)
- Trust cutoff threshold c (a link is cut when trust falls to this level; range $[0, 0.1, 0.2, ...1.0]$)
- Disappointment threshold d (an investor is disappointed by an entrepreneur if the return from the investment with this entrepreneur is lower than d times average return of the other investors in his network and his own other investments; range $[0, 0.01, 0.02, ...1.00]$)
- $\triangle$: Length of memory (number of periods that investors remember and use for calculating the average return; range $[0, 1, 2, ...30]$)

- Parameters of distribution of stochastic component of the production function (mean: range $[-1.00, -0.99, ...0..., 0.99, 1.00]$; variance: range $[0, 0.01, 0.02, ..., 2.00]$)
- Maximum time budget investors can spend on maintaining links with entrepreneurs (range $[0, 1, 2, ..., 30]$)
- Maximum time budget investors can spend on maintaining links with other investors (range $[0, 1, 2, ..., 30]$)
- Amount that investors invest in total each period (range $[10, 11, 12, ..., 100]$)
- Length of run / number of periods (range $[0, 1, 2, ..., \infty]$)
- Trust increase when satisfied $tr1$ (amount by which trust between an investor and an entrepreneur increases in a period when the investor is satisfied; range $[0, 0.1, 0.2, ..., 1.5]$)
- Trust decrease when dissatisfied $tr2$ (amount by which trust between an investor and an entrepreneur decreases in a period when the investor is dissatisfied; range $[0, 0.1, 0.2, ..., 3.0]$)
- Saving target of entrepreneurs (Capital from investor + private wealth must be larger than the saving target for the entrepreneur to voluntarily exit the angel segment of the market; range $[100, 101, 102, ..., 10000]$)
- 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; range $[2, 3, 4, ..., 10]$)
- Adaptation-speed a: Parameter for adaptation heuristics when entrepreneurs allocate profits between themselves and the investor (range $[1, 2, 3, ..., 10]$)

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.

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 (1st network).
2. If investors have not exhausted their time budget on entrepreneurs, they create new links to new entrepreneurs (2nd network). 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 entrepreneur 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 (if the entrepreneur's return was high enough) plus interest payment from the entrepreneurs (if they decide so).
8. Investors communicate with other investors in their network about the return they received and update their trust towards the entrepreneurs accordingly.
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 entrepreneur's capital and private wealth is higher than his saving target he exits the business 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.

1.0.2 Design concepts

Basic principles

The most important basic principle that has to be defined and well distinguished from related concepts is that of *trust*. This is not straightforward. Hosmer noted in 1995: "There appears to be widespread agreement on the importance of trust in human conduct, but unfortunately there also appears to be equally widespread lack of agreement on a suitable definition of the concept" (Hosmer, 1995).

The notion of trust has been widely used recently in the context of the global financial crisis, (see e.g. Sapienza and Zingales, 2012; Knell and Stix, 2010; Roth, 2009; Wälti, 2012; Tonkiss, 2009). It is understood quite differently by the abovementioned authors: "Trust is the expectation that another person (or institution) will perform actions that are beneficial, or at least not detrimental, to us regardless of our capacity to monitor those actions" (Sapienza and Zingales, 2012, p. 124, using the definition by Gambetta, 2000), “confidence in the ability of the agent” (Wälti, 2012, p. 593), or “tacit assumptions we make that others share our understanding of an exchange, are operating according to common social norms” (Tonkiss, 2009, p. 197).

There are several ways to categorize definitions of trust, depending on the scientific field and on the purpose of introducing the concept; see Bigley and Pearce (1998) for a proposal to distinguish notions of trust according to whether interaction between strangers or familiar individuals is concerned. Here, it shall be attempted to first, characterize economic situations where trust is relevant, second, distinguish “trust" from a range of related concepts, third, introduce our own definition, fourth, explain how we use the concepts of *cultural proximity* and *transaction costs*, and fifth, to place our study in the large body of economic literature on the role of trust.

Most of the time, *vulnerability* is deemed necessary for trust to play a part in an economic transaction. The individual who trusts – the trustor – is in a position where he depends on someone else – the trustee – to perform a certain action in a certain way. Mayer et al. (1995) define trust as “the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party” (p. 712). Kollock (1994) states that “(...)an action demonstrates trust if it increases one’s vulnerability to another whose behavior is not under one’s control. It refers to the conscious regulation of one’s dependence on another” (p. 319).

Another element that is relevant is *uncertainty*, even *ambiguity*, about possible future states of the world and/or properties of the trustee. In a situation where all possible contingencies can be identified, the trustee can furthermore be observed perfectly and there is a clear-cut causality between the trustee’s abilities and the outcome of his actions, trust is not necessary. Clearly, start-up financing is not such a situation. Uncertainty with respect to the trustee’s ability and intentions can only be reduced over time, both through accumulating information about the other party, as well as by allowing reciprocity to become important. Yamagishi and Yamagishi (1994) argue that the higher the level of social uncertainty, the more likely trade takes place in a long-term relationship rather than in open markets between strangers. In cases of ambiguity, when possible future states of the world are unknown a priori, trust might replace a rational, probabilistic decision rule: “Trust begins where prediction ends” (Lewis and Weigert, 1985, p. 976).

The first important concept to distinguish from “trust" in the narrow sense is what Yamagishi and Yamagishi (1994) call *assurance*. Assurance relates to the *incentives* of the trustee to behave in the way desired by the trustor. These incentives might be that there is a high probability of the trustor and trustee to interact again in the future (in the sense of a repeated game), or that reputation matters in the context at hand, or that the institutions – formal or informal – are such that the trustee would be punished if he failed the trustor. From the trustor's perspective, assurance is the "perception of the incentive structure that leads the interaction partner to act cooperatively" (Yamagishi and Yamagishi, 1994, p. 129).

Another related concept is that of *confidence*. Trust and confidence are often used interchangeably, e.g. in Roth (2009) as well as in mainstream media and colloquial language. Earle (2009) suggests to clearly distinguish the two terms: "Trust is social and relational; confidence is instrumental and calculative. (...) Confidence is the belief, based on experience or evidence (e.g., past performance), that certain future events will occur as expected" (p. 786). Relating to an unknown trustee, *trust* means the belief that the other will stick to agreements, not abuse the trustor's vulnerability and act in the trustor's best interest, whereas *confidence* refers to the trustee's *competence* to perform the tasks or deliver the result expected from him.

The sense in which we use "trust" entails aspects of both "confidence" – investors form an expectation of future returns from a specific entrepreneur based on past experience with him – and "assurance" – investors are aware that entrepreneurs have an incentive to pay interest in order to receive future investments. It entails both an initial expectation as well as the potential to grow (or shrink) over time through a feedback mechanism (the way trust is used in Deyer and Chu, 2000). Therefore, we define trust fairly widely as "firm belief in the reliability, truth, or ability of someone or something" (Oxford Dictionaries).

Other important concepts are *cultural proximity* and *transaction costs*. In our model, investors initially decide based on the distance on a two-dimensional grid with whom of the entrepreneurs they form a link. The grid is thus interpreted as cultural space and investors are assumed to prefer those entrepeneurs that are culturally close. If one used the definition of "trust" by Yamagishi and Yamagishi (1994), "[trust is] a cognitive bias in the evaluation of incomplete information about the (potential) interaction partner" (p. 129), this would mean that the investors have a positive bias in the evaluation of the ability and goodwill of those entrepreneurs that are culturally close. That initial trust between individuals depends on cultural closeness is found by Glaeser et al. (2000) and Yuki et al. (2005).

Cultural closeness is determined among other things by the number of common acquaintances (Mayer and Puller, 2008), geographic distance (Etang et al., 2011; Guiso et al., 2009), race (Ravina, 2012; Mayer and Puller, 2008; McPherson et al., 2001), gender (Galak et al., 2011), nationality (den Butter and Mosch, 2003; Giannetti and Yafeh, 2012; Guiso et al., 2009), religion (Tadesse and White, 2010; Guiso et al., 2009; McPherson et al., 2001), organizational affiliation (McPherson et al., 2001) or educational background (Berger et al., 2013; Galak et al., 2011; McPherson et al., 2001).

There is a correlation between preferential attachment, higher initial level of trust towards culturally close individuals and lower *transaction costs* in evaluating and

Table 1.1: Basic concepts

Phase of the relationship	**Trust is determined by**	**Reason**
Beginning	Cultural distance	Cognitive bias Transaction costs
During investment relationship	Return received	Confidence Assurance

monitoring the trustee, because common social norms, “implicit, pre-existing and unspecified conditions for cooperation” (Nooteboom, 1996), lower the necessity for specification and monitoring of contracts. Also, the return from monitoring might be higher if the cultural distance is low (Zak and Knack, 2001). Bigley and Pearce (1998) provide an overview of the literature that relates trust and transaction costs.

Therefore, in the model the fixed time budget of investors can be understood as a budget of transaction costs that can be “spent" either on many culturally close individuals, because each relation requires only a small amount, or on fewer relations to culturally distant individuals. Table 1.1 summarizes the role of these basic principles for the model.

There are some similarities and some differences of our model compared to implementations of the classic trust game in the laboratory (see e.g. Berg et al., 1995). The trust game works as follows: Subjects A and B are randomly paired; they do not see each other and are not allowed to communicate. Subject A is provided with an amount of money M of which he can send any proportion M_a to subject B. On they way to B, the amount is multiplied with x, with $x > 1$. Of the amount xM_a that B receives he can decide how much he wants to return to A; this amount is denoted by $k_b(xM_a)$. The game is played only once. The theoretical predictions of the outcome of this game are that A should not send anything to B, and if B receives anything from A, he should not return anything to A. However, it is often observed in the lab that As do send significant amounts of money, and Bs do return significant amounts.

The trust game is similar to the very first interaction between investor and entrepreneur in our model, except that Bs in the trust game do not have to return anything, not even M_a, whereas entrepreneurs in our model do have to return the investment made with them; what they can decide is whether to return part of $xM_a - M_a$, using the trust game notation. Moreover, our game is repeated. If an entrepreneur - by assumption - reciprocates in the very first model step and pays back an interest to the investors, a chain of reciprocity can begin: the investors continue to invest with this entrepreneur, and - if his interest payment was larger than that of the other entrepreneurs - the investors raise the amount invested with this particular entrepreneur. If the entrepreneur's profit is higher in the following period, he attributes this to the fact that he paid interest to the investors, and pays more interest this period. Apart from the very first move on both the investor's and the entrepreneur's side, decisions are motivated by pure self-interest.

The trust game can be seen as a one-sided prisoner's dilemma (Kreps, 1990), and in this sense, the agents in our model initially play a version of tit for tat, which is shown to be the most successful strategy in a series of repeated prisoner's dilemma games (Axelrod, 1980; Axelrod and Hamilton, 1981).

However, in the standard versions of both the prisoner's dilemma and the trust game it is clear after the end of a round whether the other party cooperated or defected. The situation becomes much more complicated if the outcome of the game is somewhat stochastic and the trustee's actions are not fully observable. If there is the possibility for the trustee to return a low amount not because he abused the trustor's trust, but because his own payoff was low, it is not straightforward anymore whether or not the trustor should withdraw his trust towards the trustee. In the words of Kreps (1990), p. 105: "If A complains that his trust has been abused, B could reply (indignantly) that this is not the case; that A was simply unlucky. And, after all, this is a possible (but unlikely) outcome. What does A do? Carry out the threat and close off all possibilities of future cooperation? Or modify the threat to punish B (by choosing not to trust) for a long but finite length of time? And, if the second, for how long? And what should trigger this punishment?". Of course there is a trade-off: if a punishment is triggered too easily, the trustor might forgo immediate returns from cooperation, but if he trusts for too long, his trust might be abused. This is what we can study in our model: What are implications of different trusting behaviors in a repeated game with stochastic returns?

An important way in which our model deviates from simulations that are mere extensions of game theory models, we allow investors to cut links when they are dissatisfied and establish new ones. Tomassini et al. (2010) and Pestelacci et al. (2008) show that this can facilitate the spreading of cooperative strategies when agents change strategies via replicator dynamics. In our model, strategies are kept fixed throughout a model run.

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.

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; Glaeser et al., 2000; Knack and Keefer, 1997). 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).

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.

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).

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. Everyone's culture is common knowledge and observable to all agents.

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.

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.

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

1.0.3 Details

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]

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

Table 1.2: Baseline parameter values

Parameter	Baseline value
Number of entrepreneurs	160
Number of investors	210
Time budget investors	10
Productivity	1.6
Variance of random component of production function	.8
Total investment per investor and period	70
Disappointment threshold	.6
Trust cutoff	.2
Trust decrease	1.7
Trust increase	.5
Adaptation speed of entrepreneurs a	5
Saving target of entrepreneurs	600
Minimum amount set aside for consumption	6
Length of run	200 steps
Size of two-dimensional grid	30x30

How the values for global variables were obtained is described in the document 'Calibration'. They are shown in table 1.2. 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).

Submodels

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

$$T_{i,t} \geq \sum_{j=1}^{j=J} c_{i,j} \tag{1.1}$$

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.

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 period's total investment that is equal to the proportion of the investor's 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.

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.

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

$$r_{i,t} = (\alpha + \epsilon_{i,t})(p_{2,i,t-1} + inv_{i,t}) \tag{1.2}$$

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.

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):

$$\pi_t = r_t - i_t \tag{1.3}$$

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 entrepreneur 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.

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

$$p_{1,ij,t} = p_{1,i,t} \frac{inv_{ij,t}}{inv_{i,t}} \tag{1.4}$$

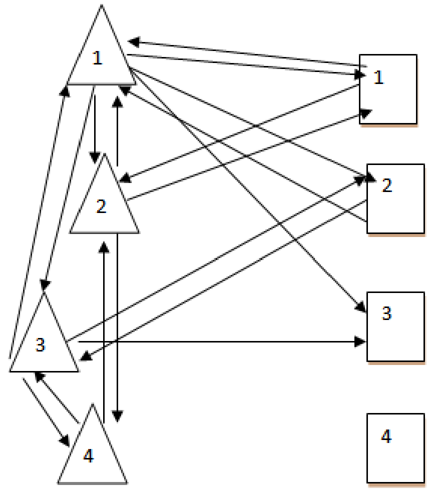
where $inv_{i,t} = \sum_{j=1}^{j=J} inv_{ij,t}$. If $\pi_{i,t} < 0$, the entrepreneur has to pay the investor back using his private wealth that he accumulated in the previous periods. If his private wealth is not sufficient to pay back all that was invested with him, the entrepreneur returns an equal 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.

Update-trust Investors update their trust towards the entrepreneur they invested with. If the return he 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.

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

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

Figure 1.1: Example of a detail of the investor-entrepreneur network.



Investors are triangles, entrepreneurs are squares.

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.

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

1.0.4 Graphical model representation

In figure 1.1, investor 1 invests with entrepreneurs 1, 2 and 3 and is connected to investors 2 and 3, with whom he exchanges information about returns. 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.

1.0.5 Schematic model representation

Capital of an investor j

$$C_{j,t} = C_{j,t-1} - inv_{j,t} + \sum_{i=1}^{i=I}(p_{1,ij,t} + inv_{ij,t}) \tag{1.5}$$

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 entrepreneur's private wealth is not sufficient to pay back the full investment).

Return entrepreneurs

$$r_{i,t} = (\alpha + \epsilon_{i,t})(p_{2,i,t-1} + inv_{i,t}) \tag{1.6}$$

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

$$C_{i,t} = h(\sum_{t=1}^{t=200} \epsilon_{i,t}, \sum_{t=1}^{t=200} inv_{i,t}) \tag{1.7}$$

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

$$inv_{i,t} = g(\sum_{t=1}^{t=200} p_{1,i.t}) \tag{1.8}$$

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

Chapter 2

Calibration

The parameter space of the model was explored systematically, using first BehaviorSearch (described in Stonedahl and Wilensky, 2010), 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.

2.0.6 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), who interviewed 539 US angels who are members 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). 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). Table 2.1 provides an overview.

2.0.7 Search of the parameter space

First, BehaviorSearch was used to search the parameter space; the tool automates 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

Table 2.1: Overview of angel market features used for calibration.

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

[1] Annual rate of return of an investment: $\left(\frac{\sum_{t=s}^{t=T} p_{1,ij,t} + inv_{ij,t}}{\sum_{t=s}^{t=T} inv_{ij,t}}\right)^{(T-s)^{-1}} - 1$, 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.

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 make it less likely for the search to get “stuck”. Therefore genetic algorithms employing Gray codes are often found to be more successful (Forrest, 1993). 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. For 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 2.1. The best parameter combinations found this way are displayed in table 2.2.

Table 2.2: 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.

2.0.8 Calibration chosen

Table 2.3 shows the average and variance after 100 runs for all of the measures obtained at each of the parameter combinations shown above.

Table 2.3: Comparison of different calibrations after 100 runs at each parameter setting.

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

Variances in parentheses.

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 2.4. The match of the baseline calibration (average of 100 runs) is shown in table 2.5.

Table 2.4: 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 2.5: 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

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