

Venture Capital and Specialization in Open Economies

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Abstract

Venture capital markets are commonly viewed as a prerequisite for high levels of innovative activity that leads to high levels of overall growth. The absence of a venture capital market in a given economy is often ascribed to market failures in financial intermediation resulting in *inefficient allocation of resources*. Information asymmetries are viewed as the source of market failure.

This paper analyses the impact of information asymmetries between intermediaries and savers in open economies in a stochastic model that uses a computer simulation. The model features two sectors producing consumer goods, one traditional good and one high-tech good, as well as two sectors producing intermediate inputs, named ‘soft machinery’ and ‘heavy machinery’, which are used in the production of consumer goods with different intensities. Machineries are composites of machines supplied under imperfect competition. A new machine increases the productivity of all factors employed in the production of the consumer goods. New businesses are started to develop new machines requiring an initial research and development (R&D) investment. The R&D investment includes tangible and intangible investments and can be financed either by bank credits or venture capital.

In the benchmark scenario, with symmetric information, the economy is parameterized such that specialization is incomplete. However, complete specialization in the traditional good occurs when savers do not have the same access to information as intermediaries. The specialization in the traditional good results from the reduced supply of venture capital, which not only finances high-tech start-ups, but also improves their management and thereby raises their probability of technical success. If the failure rate of venture-capital-financed business start-ups exceeds the expected failure rate, the supply of venture capital is reduced in the following periods. A higher than expected failure rate leads to lower than expected dividend payments. Hence, expected dividend payments are reduced in future periods and investment in venture capital funds is reduced. This affects individuals’ income, because the wage rates of skilled and unskilled labour increase more slowly, and because a larger part of savings now goes to business start-ups with a lower probability of success, which, in turn, lowers the interest rate.

Keywords: venture capital, uncertainty, specialization, intangible investments

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1. Introduction

Innovations are the crucial ingredients for economic growth and development. The amount of innovative activities depends on research and development (R&D), entrepreneurs and financing. Outside of large corporations, small, innovative high-tech firms in many countries often find it difficult to raise adequate financial resources. Venture capital markets constitute one possible source of risk-bearing capital which is predominantly made available to young, innovative and fast growing enterprises. Recently, concern has been raised in many countries that their venture capital market is not capable of financing a socially desirable level of high-tech innovation.

In this paper, venture capital's role in technological and sectoral specialization is studied in an open economy model in which the predominant mode of financing new technology-based firms influences the economy's specialization and growth. The model captures several heterogeneous agents who make discrete decisions under uncertainty. The main question to be addressed is: how does information asymmetry between intermediaries and savers affect venture capital supply, specialization and ultimately the level of welfare in an open economy? With this goal in mind, two different variants of the model are compared: In the benchmark scenario, savers form rational expectations with respect to future the rate of returns to different investment opportunities. In the second scenario, however, there is information asymmetry in the sense that savers form adaptive expectations with respect to future rate of returns based on past realizations of dividends and interest.

The results suggest that asymmetric distribution of information between savers and intermediaries can cause a significant loss of welfare if the failure rate of venture-capital-financed business start-ups exceeds the expected failure rate. In this case, savers invest less in the venture capital fund because of lower than expected dividend payments in the current period which result in lower expected dividend payments in future periods. As a result, venture capitalists will finance fewer high-tech business start-ups. The predominant financing of high-tech business start-ups with bank credits affects individuals' income in two ways, both of which prolong the time that an economy needs to reach the steady state: First, the productivity and therefore wages of skilled and unskilled individuals grow slower. Second, a larger part of resources spent on R&D in high-tech business start-ups is wasted, because, without management support from the venture capitalist, the rate of business failures among start-ups is higher. Both effects result in a lower interest rate compared with a situation with active venture capitalists. Furthermore, if high-tech business start-ups are financed with bank credits, the

probability of complete specialization increases. The reason for this is again that now a smaller number of high-tech business start-ups are successful. The supply of venture capital depends on the risk-aversion of savers and on the perceived risk, the variance of past returns of venture capital investment.

This paper is part of a more comprehensive analysis of venture capital markets in which two hypotheses are formulated about the causes there being a lack of a venture capital market: First, a lack of venture capital market can be ascribed to an *inefficient allocation of resources*, calling for correction or compensation through public policy interventions or, second, to an *efficient* pattern of *technological specialization* based on comparative advantages of the economy that does not justify any public intervention.

Inefficient allocation of resources can be ascribed to a market failure which is based on an asymmetric distribution of information among the actors of the venture capital market. Two sources of asymmetric information can be identified: First, savers and outside institutional investors have incomplete information about the quality of financial intermediaries and about the future rates of return; they inevitably base their portfolio selection choice on observations of the past (adaptive expectations). The implications of this information asymmetry are the subject of this paper. Second, intermediaries have incomplete information about the characteristics of innovative entrepreneurs, which gives rise to incentive problems. The literature distinguishes between *moral hazard* in which a borrower changes his investment plan after the contract is closed and thereby harms the creditor and *adverse selection* in which the riskiness of borrowers differs because of exogenous hidden characteristics. Other authors have pointed out that this information asymmetry gives venture capitalists a comparative advantage in financing innovative high-tech ventures because venture capitalists offer management support in addition to financial equity. This reduces the information asymmetry in the principal-agent relationship with the investee start-up (Amit et al. 1998) and raises the probability of successful technical development of the innovation. This effect also drives the model analysed here; venture capitalists raise the probability of technical success in innovative high-tech ventures during the start-up stage. Future research in this model structure will take asymmetric information between intermediaries and innovators into account.

This analysis of venture capital in open economies is intended to close a gap in the existing literature which is either empirical or confined to partial equilibrium models of venture capital. Existing analyses have overlooked the systemic interdependence among investors, bank creditors, venture capitalists and savers and have therefore failed to

address important policy issues — such as the role venture capital plays as a determinant of specialization and economic growth.

The remainder of this paper is organized as follows. Section 2 presents a short description of the model. Section 3 describes the parameterization of the model and presents simulation results of the model when asymmetric information is absent. Section 4 presents simulation results of the model with asymmetric information between the savers and the intermediaries. This scenario is compared with the benchmark scenario in Section 3. Section 5 concludes.

2. Theoretical Framework

The development of the venture capital market is explained in a model that considers discrete decisions of heterogeneous agents, adaptive expectations and fundamental uncertainty in the innovation process.¹ The economy's growth is driven by product innovations; both the nature and the quantity of product innovations depend on the available financing opportunities.

The model features four types of markets: (i) markets for the primary factors, skilled and unskilled labour, (ii) markets for two intermediate inputs, named 'heavy machinery' and 'soft machinery', (iii) financial markets for bank credits and venture capital and (iv) two consumer goods markets, traditional and high-tech good.

Heavy and soft machinery are aggregates of differentiated capital inputs, named machines. Machines are specific to one type of machinery. Aggregation is done according to CES functions (Dixit-Stiglitz functions). The parameter σ_j , which defines the degree of differentiation, can take values between zero and one; the elasticity of substitution between any two machines is identical. Every new machine increases the productivity of all production factors. The growth of the economy is thus driven by product innovations. After the start-up stage, all machines for the heavy machinery are produced using only unskilled labour at constant marginal costs, while all machines for the soft machinery are produced using only skilled labour at constant marginal costs. The soft and the heavy machinery are used in the production of the consumer goods, one high-tech good and one traditional good under perfect competition. Furthermore, the production of consumer goods uses skilled and unskilled labour. Unskilled labour and

¹ Appendix 2 gives a technical description of model, and states the most important equations. For a full description of the model see Schertler (1999).

heavy machinery are used with higher intensity in the production of the traditional good than in the production of the high-tech good. Skilled labour and soft machinery are used with a higher intensity in the production of the high-tech good. The productivity of the machineries and of the primary factors in the consumer goods sectors is determined by the number of available machines. Appendix 1 gives an overview of the economy's production side.

In order to develop a new machine, an entrepreneur must initially make a R&D investment; machines are subsequently produced under monopolistic competition. The R&D investment includes tangible as well as intangible investments for a prototype of the new machine. Intangible investments are modelled as human capital demand. When a prototype of a machine for the soft machinery is developed, a high proportion of the investment is spent on human capital, while a high proportion is spent on physical capital when a prototype for the heavy machinery is developed. Tangible investments can be fully liquidated after an unsuccessful business start-up, intangible investments, however, cannot. The technical success of machine innovations is determined by a random variable only realized after financing decisions have been taken and investments have been made.

Only skilled individuals can become innovators and entrepreneurs; in each period a number of individuals decide whether they want to develop a new machine or whether they want to stay in their current employment. Because skilled individuals do not have the means to finance the R&D investment themselves, they have to raise capital in the financial market. All individual investment decisions are based on comparisons of present values of the expected profits, with the present value of the expected wage income stream of a skilled individual serving as opportunity costs. The present value depends on the mode of financing: bank loan versus venture capital. In calculating the expected values, each skilled individual who decides to become an innovator assumes that he is the last innovator.² This implies no further changes in the wage rates of skilled and unskilled labour or in the output of the traditional and the high-tech good. Therefore, changes in these values are not considered ex ante. In the start-up stage, the innovator does not realize any income, because the prototype is only developed and not sold at this stage.

Both intermediaries, the bank and the venture capitalist, know the type of machine an innovator wants to develop and the probability its being developed successfully. The

² This assumption has no effect on the decision calculus, it only serves to simplify the modelling of expectations.

probability that it will be developed successfully is exogenous in the case of bank credit financing, while the venture capitalist influences the probability of success positively for all those innovators developing a machine for the soft machinery. This assumption builds on a central result of existing theoretical analyses of individual venture capital relationships (Amit et al. 1998).

The bank provides loans at an interest rate equal to the expected average costs.³ To keep this first simulation as simple as possible, it is assumed that the venture capitalist and the bank offer capital to innovators at identical interest rates, which depend only on the characteristics of the machineries, i.e., on the share of tangible investment of the total R&D investment and on the probability of technical success. Venture capital and loans are offered for the same length of time. A share of the interest payments that the intermediaries receive from the successful innovators is used to cover the loss of intangible investments of the unsuccessful innovators, the other share is given to savers in the form interest payments on deposits or dividends on venture capital investment. In every period, the available volume of loans and venture capital funds is determined by the level of savings in the current period, the returns to tangible investments of unsuccessful innovators of the last period and by the share of interest payments of successful innovators used to cover the losses from intangible investment of the unsuccessful innovators. These volumes determine the number of business start-ups in each period.

The number of skilled and unskilled individuals is exogenously given. While unskilled individuals always supply labour on the labour market, skilled individuals either supply human capital or become innovators and entrepreneurs. The total income of all individuals includes the wage incomes of unskilled and skilled individuals, the profits of the successful innovators and the interest payments on deposits and the dividends on venture capital investment. An exogenous share of the total income is consumed; the rest is saved.

A representative individual decides which proportion of the savings is invested in the venture capital fund. The balance of savings is given to the bank as deposits. The development of the dividends and the interest payments of deposits are uncertain. In order to solve the portfolio selection problem of the representative, risk-averse

³ This interest rate includes only the risk of technical failure. The risk of bankruptcy is not considered because entrepreneurs can only go bankrupt under specific conditions. Insolvency can only happen if the number of machines of one machinery dramatically increases and therefore, the economy completely specializes.

individual, an exponential expected utility function is assumed. Therefore, the representative individual assumes that the interest payments and the dividends follow a normal distribution. The representative individual bases his decision only on the first two moments of the unknown distributions. In every period, these two moments are calculated from their past realizations.

In an open economy, the wage rates of skilled and unskilled individuals are determined by the prices of the traditional and the high-tech good. In each period, the output of the traditional and the high-tech good are determined such that the markets of the primary factors skilled and unskilled labour clear. These values are calculated at the end of each period. The length of a period is determined by the available volume of loans and funds. The number of machines for the soft and heavy machinery and therefore the productivity of the factors employed in the production of consumer goods increases over time. The expected present value of further machine innovations declines, whereas the wage rate of skilled labour needed to produce existing number of machines rises. The model ultimately reaches a steady state when the present value of expected wage income of a skilled individual exceeds the expected present value of becoming an innovator.

The output of the consumer goods rise with the number of machines employed by soft machinery and by heavy machinery. The possibility of complete specialization arises from the increasing economics of scale in the production of the machines. When $[p_T/p_H] \leq [p_T/p_H]_H$, the economy completely specialises in the high-tech sector.⁴ On the other hand, when $[p_T/p_H] \geq [p_T/p_H]_T$, the economy completely specialises in the production of the traditional good. Specialization occurs, when the number of machines either in soft machinery or in heavy machinery dramatically increases while the number employed by the respective other machinery remains unchanged. Innovation in the machinery sectors also depends on the overall specialization of the economy, because each innovator anticipates the specialization of the economy which affects the expected profits of an innovative activity. Furthermore, innovation activities in the machinery sectors depend on the financing opportunities offered. Therefore, specialization depends indirectly on the financial opportunities.

⁴ The definitions of price relations are presented in the Appendix 2.

3. Parameterization and Benchmark

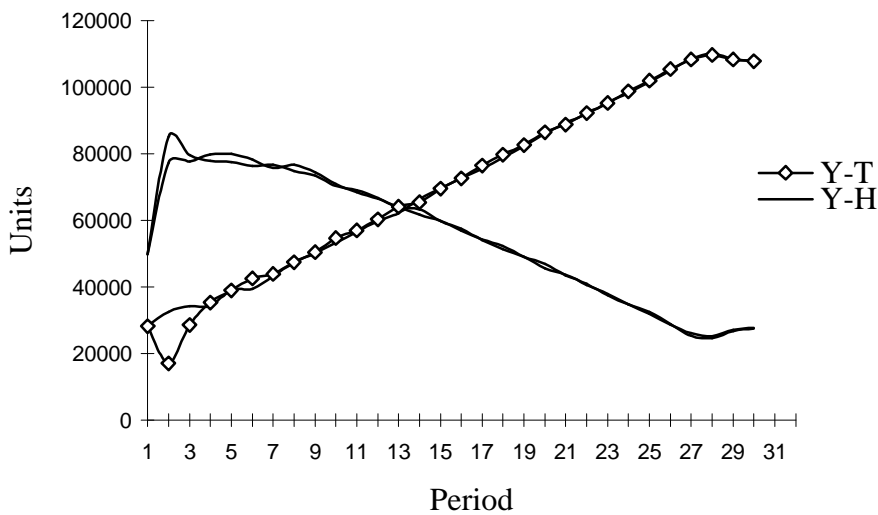
An increasing number of machines employed by a machinery sector implies increasing competition in this sector. Since machines for the heavy machinery are produced with unskilled labour, an increasing number of machines raises the wage rates of unskilled individuals. An increasing number of machines for the soft machinery results in higher wage rates of skilled individuals, while the wage rates of unskilled labour and the prices of soft and heavy machinery decrease. Furthermore, an increasing number of machines depresses entrepreneurs' profit, because demand is not sufficiently elastic to compensate for the revenue loss due to lower prices of the machines. Moreover, the chosen parameters have to ensure that the wage rates of skilled individuals is higher than the wage rates of unskilled individuals.

For the purpose of this paper, the chosen parameters have to fulfil a further condition: When savers have access to the same information as intermediaries, the economy does not completely specialise and the first-best allocation of capital is realized. In this case, savers directly undertake the financing of all machines for the heavy machinery, while the venture capitalist is given sufficient capital to finance all high-tech business start-ups, i.e., all start-ups developing a machine for the soft machinery. Appendix 3 presents the parameters used.

The number of machines for the soft and heavy machinery, determined under the assumption of equally distributed information, provides a benchmark for welfare analysis. To make the different simulation runs for welfare analysis comparable, two procedures are possible: either each simulation run breaks at the end of a given period or all simulation runs break at the end of the period in which the longest simulation run reaches its steady state. From a welfare view, it is not possible to let each simulation run individually breaks at its steady state, because all simulation runs converge to an identical steady state. Simulation runs which need longer than others to reach the steady state show a higher average income than simulation runs which need only a short time. The difference between these two types of simulation runs is fundamental: while the short simulation runs show high growth rates and therefore a relative low average income; the long simulation runs show, in most periods, very low growth rates combined with a relative high income. Therefore, all simulations are stopped in period 30; 30 is the shortest number of periods that the simulation runs need to reach the steady state when information is symmetrically distributed.

The benchmark scenario for the simulation results of Section 4 is obtained under the assumption that savers form rational expectations with respect to the future rate of return to different investment opportunities. The fundamental uncertainty of the innovation process is reflected in the benchmark, but the volatility of the benchmark is very low, as the following figures will demonstrate. This benchmark provides information about the optimal growth path and the optimal number of machines in each machinery and about the optimal production sample. Welfare is measured by the income of all individuals, which includes wage incomes of skilled and unskilled individuals, the dividends and interest as well as the profits of the successful innovators.

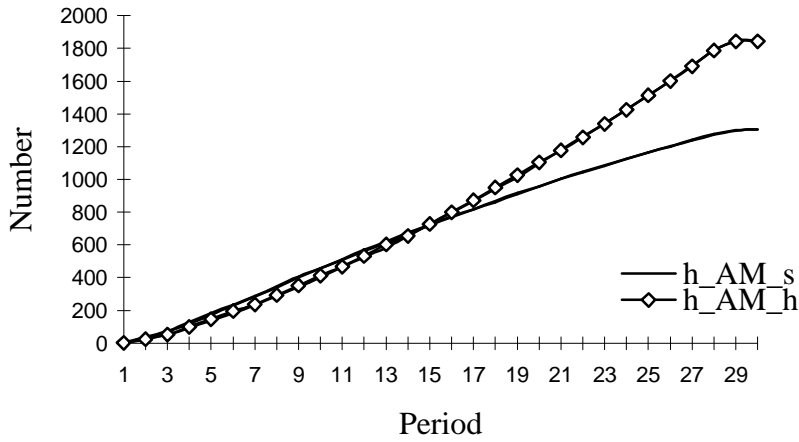
Figure 1: Development of the consumer good output



Y-T denotes the output of the traditional good.
Y-H is the output of the high-tech good.

The 40,000 skilled and the 40,000 unskilled individuals produce over 50,000 units of the high-tech good and over 20,000 units of the traditional good in the first period (see Figure 1). Note that in the first period only one machine is available for each machinery. Over time, the increasing number of machines for the machineries reduces the output of the high-tech good, while the output of the traditional good increases. Therefore, the economy shows a specialization which is, however, never complete in the benchmark scenario. The volatility of the benchmark decreases over time. The reason for the high volatility in the first periods is, of course, that machines developed very early in the life of the economy affects the productivity of other factors more than do the machines developed later.

Figure 2: Development of the number of machines

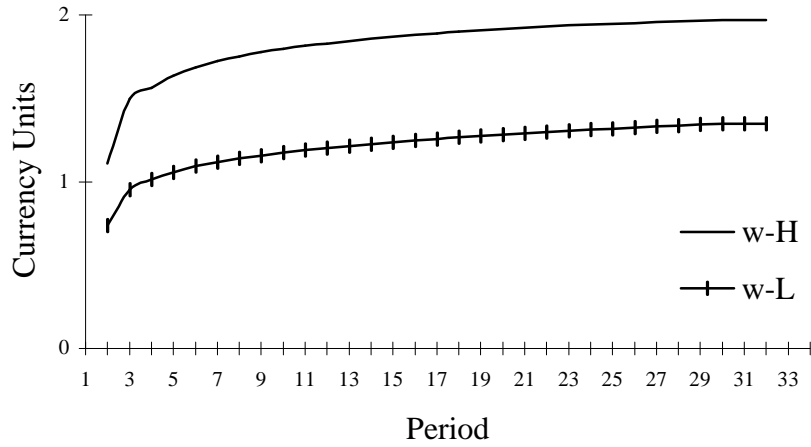


h_AM_s denotes the number of machines for the soft machinery.
 h_AM_h is the number of machines for the heavy machinery.

In period 30 about 3,000 of the 40,000 skilled individuals are innovators (see Figure 2). Until about the 15th period, the number of machines for the soft machinery matches approximately the number of machines for the heavy machinery. At that time, the output level of the traditional good begins to surpass the output level of the high-tech good. Economic intuition suggests that the skilled labour used in the research sector reaches a critical mass which creates bottlenecks in the production of the high-tech good and reduces the profits of innovators of machines for the soft machinery.

The wage rate of skilled labour always exceeds the wage rate of unskilled labour, because the productivity of skilled labour is higher in both consumer good sectors (see Figure 3). Note that the wage rates do not fluctuate nearly as much over time as the output of the consumer goods and the number of machines.

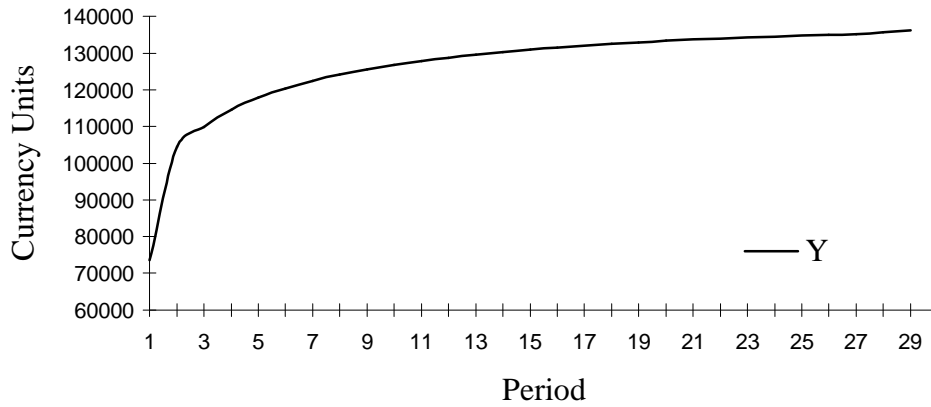
Figure 3: Development of wage rates



w-H denotes the wage rate of skilled labour.
w-L is the wage rate of unskilled labour.

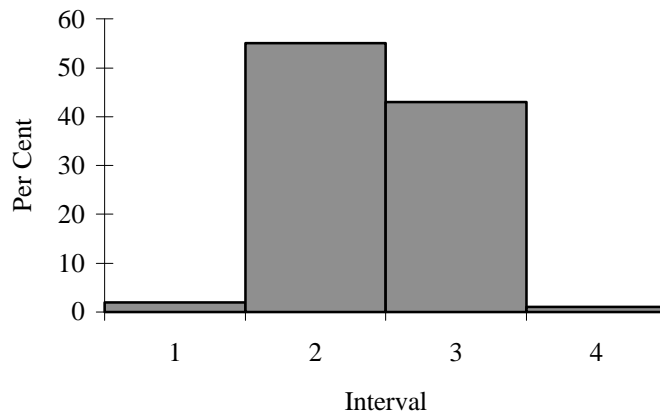
All simulation runs reach a national income of around 136,000 units after 31 to 35 periods. The national incomes of the total life time of the economy in different simulation runs, i.e. the income streams, are used for welfare analysis. Figure 4 depicts the development of the national income stream of one simulation run in the benchmark scenario. The national income of every period is discounted to the beginning of period 0 using r_R (three per cent) as the discount factor. These values are added up and the sum is divided by the number of periods. The total feasible domain of discounted income streams is divided in four equal intervals. The frequency distribution from 1000 simulation runs shows that only a few simulation runs fall in the intervals at either extreme of the domain (see Figure 5). Note that the difference between the maximal and the minimal discounted, averaged national income in the benchmark scenario is quite small compared with the difference in the scenario with asymmetric information that will be presented in Section 4.

Figure 4: Development of national income



Y denotes the national income.

Figure 5: Frequency distribution of national income with symmetric information



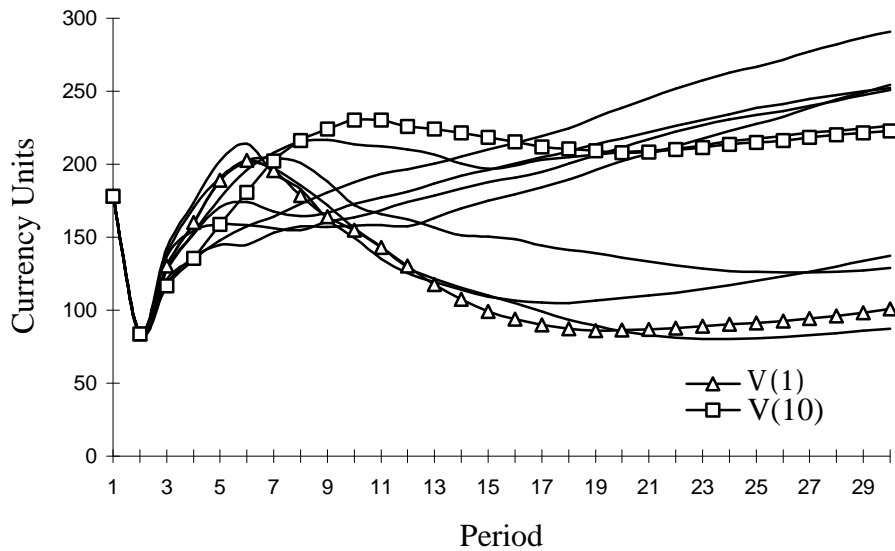
Interval 1: 81,400-81,500; Interval 2: 81,500-81,600; Interval 3 81,600-81,700, Interval 4: 81,700-81,800. MIN 81,437, MAX 81,732, AVERAGE 81,592. Total number of runs: 1,000.

4. Simulation Results for Asymmetric Information

The data from a large number of simulation runs are used to make predications for the probabilities of reaching different states of national income. Due to asymmetric information, the ex ante probability that a simulation run effectively reaches the first best allocation, i.e., the optimal allocation of capital, is very small. Therefore, the discounted national income of simulation runs with asymmetric information between savers and intermediaries falls below the national income in the benchmark simulation runs. Average national income depends on the development of the venture capital market. The share of savings spent in the venture capital funds depends on the risk aversion of savers. The parameter that defines the risk aversion is denoted by q . Risk-aversion increases when this parameter increases. While the initial share of savings in the venture capital fund is exogenously given due to the risk aversion, the development of this share in one or the other direction depends on the endogenous success of the venture capitalist. An early sequence of technological failures may undermine a venture capital market that would ultimately be welfare improving in the steady state. Furthermore, the supply of venture capital during the growth stage of the economy influences the production side and the individuals' income significantly by influencing the probability of technical success in high-tech business start-ups. In order to enable savers to solve the portfolio selection in the first periods, starting values of past interest and dividend rates have to be given. These values have been chosen such that there is always a significant venture capital market to begin with.

The figures in this Section depict ten simulation runs with asymmetric information between savers and intermediaries. All simulation runs are started with identical initial parameters. Two simulation runs are of special interest: the simulation run denoted by 1, with an underdeveloped venture capital market and the simulation run denoted by 10, with a well-developed venture capital market. Simulation run 1 is symbolised by a triangle; simulation run 10 by a rectangle.

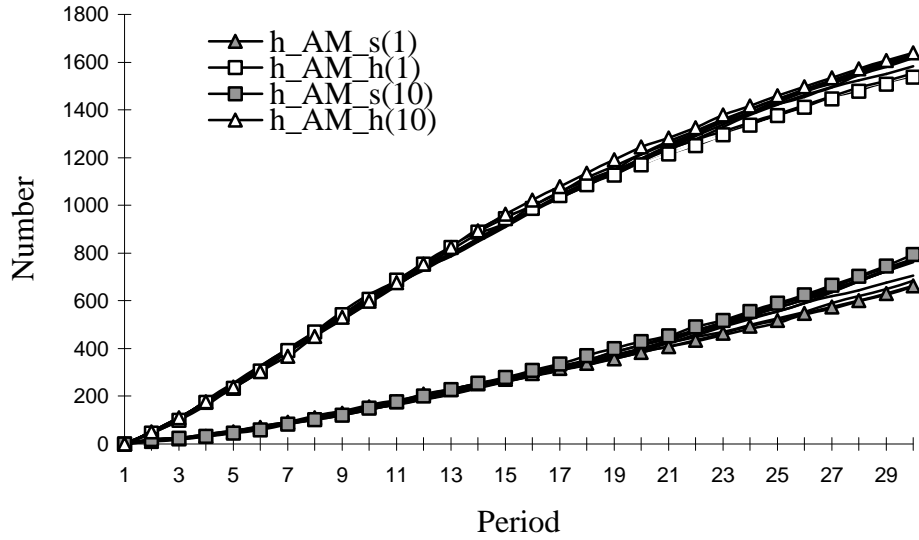
Figure 6: Development of savings invested in the venture capital funds



$V(x)$ denotes savings invested in the venture capital funds.

In all simulation runs, savings spent in the venture capital funds increase in the first periods, while they may decrease in the middle of the economy's life-time (see Figure 6). A reduced venture capital funds volume occurs after an episode of financial failures suffered by the venture capitalist. Savings invested in the venture capital funds dramatically decreases in simulation run 1, because the realized failure rates exceed the expected failure rates, whereas in simulation run 10 the realized failure rates are equal the expected failure rates. Every increase in savings given to the bank as a deposit, raises the expected present value of an innovator developing a machine for the heavy machinery compared with the expected present value of an innovator developing a machine for the soft machinery, because the venture capitalist will be able to extend his management support to fewer high-tech start-ups, so that overall the number of machines for the soft machinery will decrease.

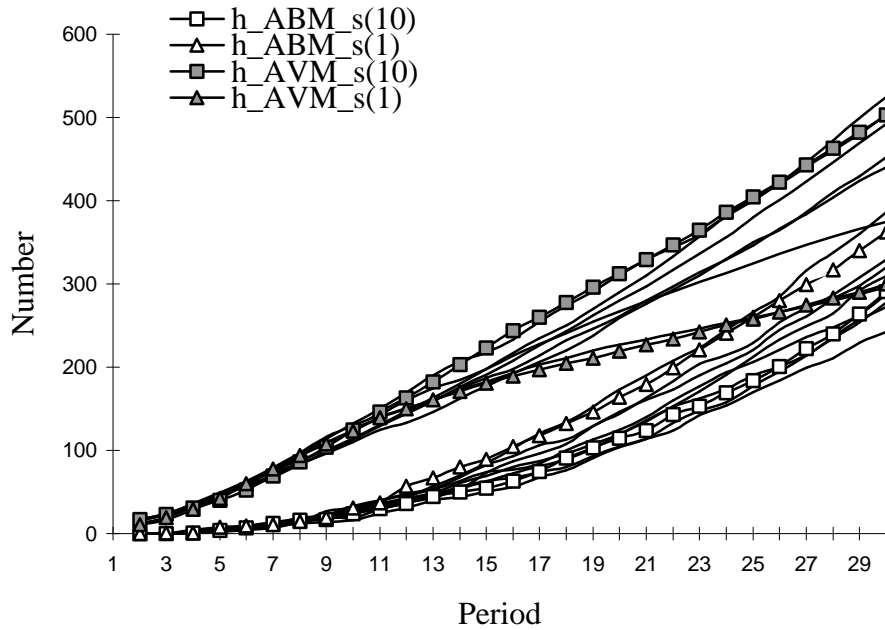
Figure 7: Development of machines



$h_AM_s(x)$ denotes the number of machines for the soft machinery in simulation run x .
 $h_AM_h(x)$ is the number of machines for the heavy machinery in simulation run x .

In simulation run 10, more capital is invested in business start-ups developing a machine for the soft machinery than in simulation run 1 (see Figure 7). Compared with the benchmark simulation runs, the number of machines for the heavy machinery in the simulation runs with asymmetric information is almost 83 per cent in the given time (the number of machines for the heavy machinery in the benchmark simulation is about 1,840, while in the simulation runs with asymmetric information it is about 1,500). However, the number of machines for the soft machinery is only 50 per cent (the number of machines for the soft machinery in the benchmark simulation is about 1,300, while in the simulation runs with asymmetric information it is about 650). Clearly, part of this difference is due to the high risk-aversion of the savers. All simulation runs with asymmetric information reach a steady state similar to the benchmark simulation runs, but they need much more time to reach this state; the growth rate of machines for the heavy machinery is mostly equal zero before the steady state is reached, while the growth rate of the machines for the soft machinery is very low. The difference in the number of machines is based on the different supply of financing opportunities (see Figure 8).

Figure 8: Development of machines depending on the mode of financing

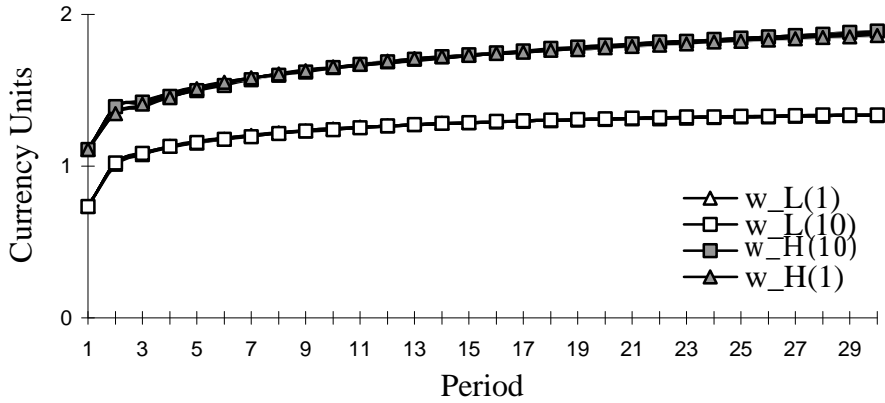


$h_ABM_s(x)$ denotes the number of machines for the soft machinery financed by bank credits in simulation run x .

$h_AVM_s(x)$ is the number of machines for the soft machinery financed by venture capital in simulation run x .

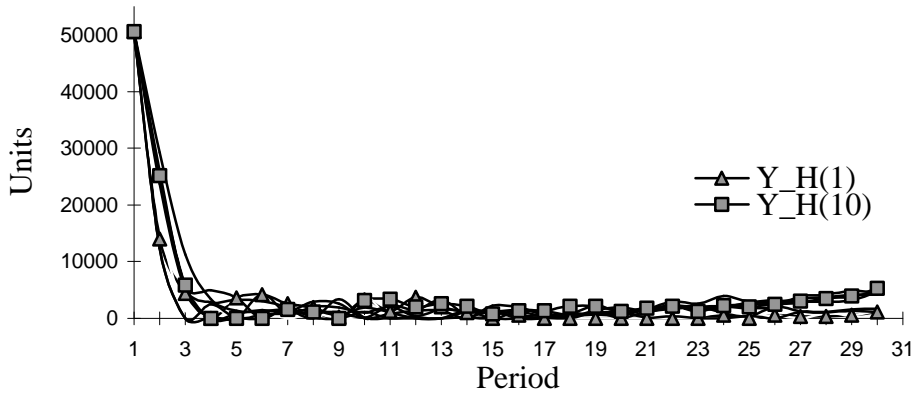
This different investment behaviour influences the wage rates of skilled and unskilled labour and the rate of interest. Note that the wage rates of skilled and unskilled labour in simulation run 10 exceed the wage rates in simulation run 1. In addition, the output of the high-tech good in simulation run 10 exceeds the high-tech good production in simulation run 1, while the contrary holds for the output of the traditional good (see Figure 9, Figure 10 and Figure 11).

Figure 9: Development of wage rates



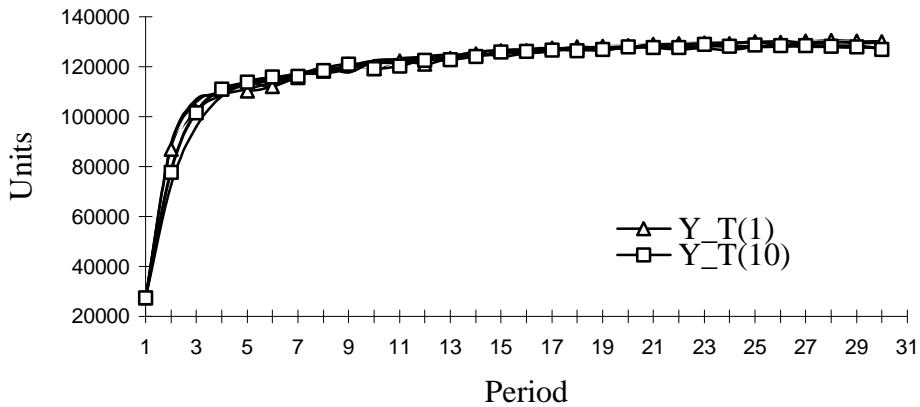
$w_L(x)$ denotes wage rate of unskilled labour in simulation run x .
 $w_H(x)$ is wage rate of skilled labour in simulation run x .

Figure 10: Development of high-tech good production



$Y_H(x)$ denotes output of high-tech good in simulation run x .

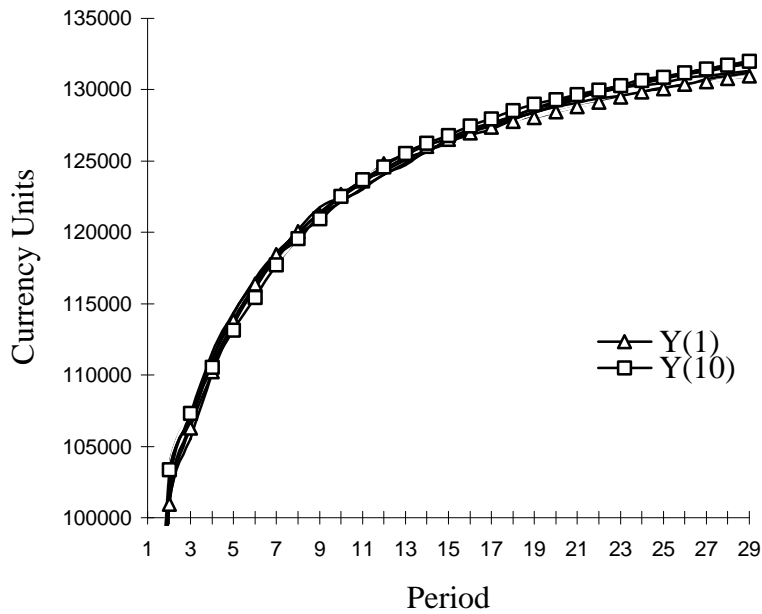
Figure 11: Development of traditional good production



$Y_T(x)$ denotes output of traditional good in simulation run x .

Because simulation run 10 shows a more developed venture capital market for all periods after the seventh period compared to simulation run 1, welfare of the economy measured by the income of all individuals in simulation run 10 exceeds welfare in simulation run 1 (see Figure 12). The unequal distribution of venture capital in simulation run 10 compared with simulation run 1 in the first periods does not significantly affect the individuals' income, while in the later periods, this unequal distribution leads to a lower level of national income.

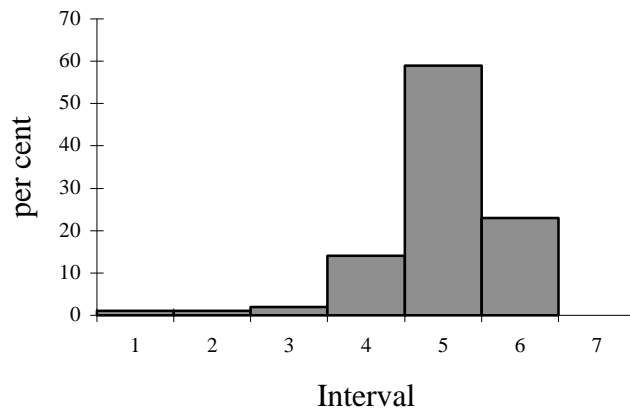
Figure 12: Development of national income



$Y(x)$ denotes national income in simulation run x .

Because information between savers and intermediaries is asymmetric, it is highly unlikely that the economy will achieve the first-best allocation of capital. Therefore the income of individuals is lower when the information problem is taken into account. On the average, benchmark simulation runs achieve an income level of 81,592, but the average simulation runs under asymmetric information only achieve an income level of 79,148. Furthermore, the variance of national income over time seems to differ: in the benchmark simulation runs, the realized maximum national income exceeds the realized minimum national income by three hundred units; with asymmetric information the difference is about six hundred. Moreover, 98 per cent of all benchmark simulation runs lie within two intervals, while 82 per cent of all simulation runs with asymmetric information lie within two intervals (see Figure 13).

Figure 13: Frequency distribution of national income with asymmetric information



Interval 1: less 78,800, Interval 2: 78,800-78,900, Interval 3: 78,900-79,000, Interval 4: 79,000-79,100, Interval 5: 79,100-79,200, Interval 6: 79,200-79,300, Interval 7: 79,300-79,400, MIN 78,676, MAX. 79,305, AVERAGE 79,148. Total number of runs 1,000.

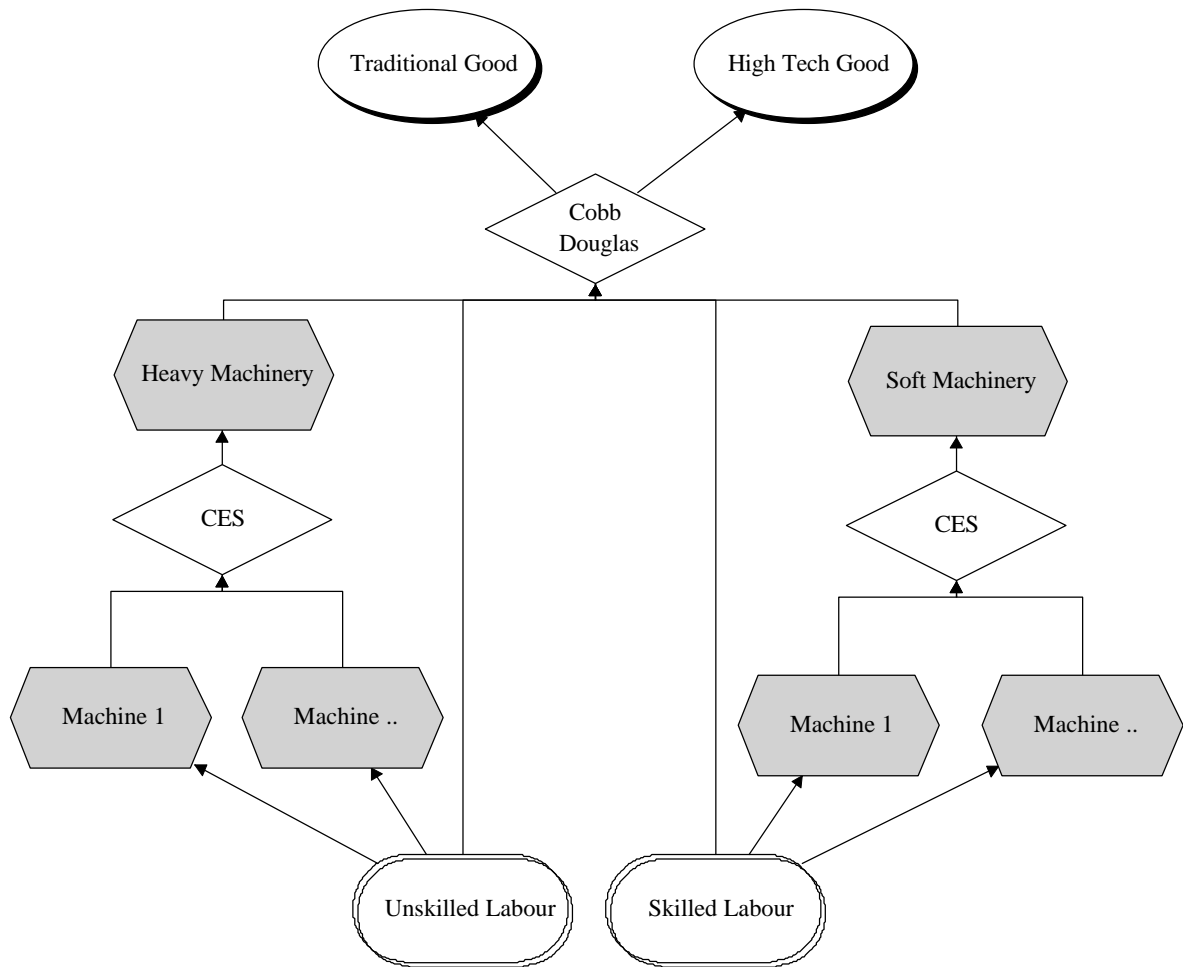
5. Conclusions

In this paper, the development of a venture capital market has been analysed in a model which captures several characteristics of the innovation process: heterogeneous agents who make discrete decisions and the fundamental uncertainty of the innovation process. The model was too complicated for an analytical solution. Instead, the model was analysed by means of computer simulations.

Two scenarios were analysed: In the benchmark scenario, savers and intermediaries have the same access to informations. Therefore, savers directly undertake the financing of all machines for the heavy machinery, while the venture capitalist is given sufficient capital to finance all high-tech business start-ups. In this scenario, specialization is incomplete due to parameterization. In the second scenario, information asymmetry is taken into account.. Complete specialization occurs when savers do not have the same access to information as intermediaries and the failure rate of venture-capital-financed business start-ups exceeds the expected failure rate, which results in a lower supply of venture capital. Therefore, the development of the venture capital market and the dynamics of specialization in this open economy are interdependent. Individuals' income depends on the supply of the venture capital. Venture capitalists have a comparative advantage in financing high-tech business start-ups characterised by a high proportion of intangible R&D investments; they provide management support in addition to equity. Venture capital financing increases the probability of technical success of high-tech business during the start-up stage, which, in turn, increases dividends relative to the interest rate. Furthermore, the overall growth rate is higher if venture capital is offered.

The development of venture capital markets depends on the realization of unsuccessful business start-ups combined with the degree of information asymmetry between the savers and intermediaries.

6. Appendix 1: Production Side of the Economy



Appendix 2: The Main Equations of the Model

1. Sets and Subsets of Skilled Individuals

The set of skilled individuals H has several subsets, namely one of active entrepreneurs and, therein, those of start-ups financed with venture capital and bank credit, respectively. Every skilled individual is an element of the set H at every point in time, but the affiliation to subsets may change over time. If the skilled individual i starts an enterprise to develop a machine for the machinery $j \ j \in \{h, s\}$ in period T , he will become an element of the subset ‘active and nonactive entrepreneurs of the machinery j ’ $H_{U|M_j}$ in period T . If he successfully develops the prototype, he will become an element of the subset ‘active entrepreneurs’ H_A and of the subset ‘active entrepreneurs of the machinery j ’ $H_{A|M_j}$ in the period $T + 1$, because the machine is only developed but not sold in the start-up stage. If the skilled individual i finances his R&D investment with venture capital (bank credit), he will become an element of the subset $H_{U|V|M_j}$ ($H_{U|B|M_j}$) in the period T , and if he successfully develops the prototype, he will become an element of the subset $H_{A|V|M_j}$ ($H_{A|B|M_j}$) in the period $T + 1$.

2. Heavy and Soft Machineries

Active entrepreneurs producing a machine try to maximise their profits in every period. The optimal price of each machine is given with a constant mark-up over marginal costs; the amount of the mark-up depends negatively on the elasticity of demand in the machinery j . The optimal output of each machine for the machinery j depends negatively

on the number of machines in the machinery j and on the sum of the factor demands of the consumer good sectors. Furthermore, profits depend on the specialization of the economy. If the economy completely specializes in the high-tech sector, profits are given by:

$$\mathbf{p}_h = \frac{1 - \mathbf{r}_1}{h_{A|M_h} d} b_3 \bar{h} w_H^* - r_{K_1} E_0 \quad \text{and} \quad \mathbf{p}_s = \frac{1 - \mathbf{r}_2}{h_{A|M_s} d} b_4 \bar{h} w_H^* - r_{K_2} E_0 \quad \text{with } d := b_2 + b_4 \mathbf{r}_2,$$

where \mathbf{r}_j denotes the parameter of differentiation in the machinery j , $h_{A|M_j}$ is the number of elements of the subset $H_{A|M_j}$, r_{K_j} is the interest rate, E_0 is the R&D investment, \bar{h} is the number of skilled individuals, who are working in the production process and w_H^* denotes the equilibrium wage rate of skilled labour. Furthermore, b_2 (skilled labour), b_3 (heavy machinery) and b_4 (soft machinery) denote the partial elasticity in the production of the high-tech good.

If the economy completely specializes on the production of the traditional good, profits are given by:

$$\mathbf{p}_h = \frac{1 - \mathbf{r}_1}{h_{A|M_h} a} a_3 \ell w_L^* - r_{K_1} E_0 \quad \text{and} \quad \mathbf{p}_s = \frac{1 - \mathbf{r}_2}{h_{A|M_s} a} a_4 \ell w_L^* - r_{K_2} E_0 \quad \text{with } a := a_1 + a_3 \mathbf{r}_1,$$

where ℓ denotes the number of unskilled individuals, w_L^* is the equilibrium wage rate of unskilled labour and a_1 (unskilled labour), a_3 (heavy machinery) and a_4 (soft machinery) denote the partial elasticity in the production of the traditional good.

If the economy does not specialize, profits are given by:

$$P_h = \frac{(1 - r_1) [\ell w_L^* (a_3 d - b_3 c) + \bar{h} w_H^* (b_3 a - a_3 b)]}{h_{A|M_h} (da - cb)} - r_{K_1} E_0,$$

$$P_s = \frac{(1 - r_2) [\ell w_L^* (a_4 d - b_4 c) + \bar{h} w_H^* (b_4 a - a_4 b)]}{h_{A|M_s} (da - cb)} - r_{K_2} E_0,$$

with $b := b_1 + b_3 r_1$ and $c := a_2 + a_4 r_2$,

where b_1 denotes the partial elasticity of unskilled labour in the production of the high-tech good and a_2 is the partial elasticity of skilled labour in the production of the traditional good.

3. Development of a New Machine

The probability of successful development of a new machine for the heavy machinery is given by Ψ_{M_h} and for the soft machinery by Ψ_{M_s} . Ψ_{M_h} is independent of the mode of financing, but the probability of technical success in the case of soft machinery is greater when it is financed with venture capital $\Psi_{M_{s,V}}$ such that $\Psi_{M_{s,V}} > \Psi_{M_{s,B}}$, where $\Psi_{M_{s,B}}$ is the probability of technical success in case of credit financing. This is solely, because venture capital financing is assumed to raise the probability of technical success for innovators developing a machine for the soft machinery; bank financing is assumed to leave that probability unchanged.

It follows that the expected present value of the innovative activity h , i.e. the expected present value of developing a machine for the heavy machinery, does not depend on the

mode of financing, while the expected present value of the innovative activity s does depend on the mode of financing.

If the economy completely specializes on the production of the high-tech good, the expected present values of the innovative activities are given by:

$$E[\mathbf{p}_h]_{PV} = \left[\Psi_{M_h} E[\mathbf{p}_h] + (1 - \Psi_{M_h}) E[w_H^*] \right] \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t},$$

$$E[\mathbf{p}_{s,m}]_{PV} = \left[\Psi_{M_{s,m}} E[\mathbf{p}_s] + (1 - \Psi_{M_{s,m}}) E[w_H^*] \right] \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t}, \quad m \in \{V, B\}$$

where T_K denotes the period of validity and r_R is the riskless interest rate. The foundation stage t_0 is not included in the discount factor, because an innovator gets no income in the start-up stage. With the probability of success he earns the expected profit in each period $t \in [t_0 + 1, \dots, T_K]$; with the probability of failure he earns the wage income of a skilled individual in each period $t \in [t_0 + 1, \dots, T_K]$.

If the economy completely specializes in the traditional sector, expected present values of the innovative activities are given by:

$$E[\mathbf{p}_h]_{PV} = \left[\Psi_{M_h} E[\mathbf{p}_h] + (1 - \Psi_{M_h}) E[w_H^*] \right] \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t},$$

$$E[\mathbf{p}_{s,m}]_{PV} = \left[\Psi_{M_{s,m}} E[\mathbf{p}_s] + (1 - \Psi_{M_{s,m}}) E[w_H^*] \right] \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t}, \quad m \in \{V, B\}.$$

If the economy does not specialize, expected present values of the innovative activities are given by:

$$E[\mathbf{p}_h]_{PV} = \left[\Psi_{M_h} E[\mathbf{p}_h] + (1 - \Psi_{M_h}) E[w_H^*] \right] \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t},$$

$$E[\mathbf{p}_{s,m}]_{PV} = \left[\Psi_{M_{s,m}} E[\mathbf{p}_s] + (1 - \Psi_{M_{s,m}}) E[w_H^*] \right] \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t}, \quad m \in \{V, B\}.$$

The profit that an innovator of a machine for the heavy machinery expects to earn $E[\mathbf{p}_h]$ is calculated under the assumption that the number of machines for the heavy machinery increases by one, while the number of machines for the soft machinery is unchanged. The profit that an innovator of a machine for the soft machinery expects to earn $E[\mathbf{p}_s]$ is calculated under the assumption that the number of machines for the soft machinery increases by one, while the number of machines for the heavy machinery is unchanged. After the skilled individual has calculated the expected present values of the innovative activities, he calculates the present value of the opportunity costs, i.e. the wage income of a skilled individual:

$$E[w_H^*]_{PV} = E \left[\sum_{t=t_0}^{T_K} w_H^*(t) / (1+r_R)^t \right].$$

Thereby he assumes that the wage rate of a skilled individual does not change.

If the venture capitalist offers funds to finance start-ups, the skilled individual compares the expected present value of the innovative activity h with the expected present value of the innovative activity s and venture capital finance and with the opportunity costs.

Otherwise he compares the expected present value of the innovative activity h with the expected present value of the innovative activity s financed by bank credit and, again, with the opportunity costs.

After the skilled individual i has decided, this decision changes the membership of the subsets. For example, if he has decided to develop a machine for the heavy machinery and to finance his R&D investment with a bank credit, he becomes an element of the subsets $H_{U|B|M_h}$ and $H_{U|M_h}$. The success of the business start is observed at the beginning of the next period. This observation changes again the membership of the subset, i.e. if the bank credit financed business start-up of the skilled individual i was successful, he becomes an element of the subset $H_{A|B|M_h}$ and $H_{A|M_h}$.

4. Financial Market

The interest rates for the R&D investment are equal to the expected average costs of the bank and are given by:

$$r_{K_j} = \frac{\sum_{t=t_0}^{T_K} \frac{(1+j_{M_j}(\Psi_{M_j}-1))r_R}{(1+r_R)^t} + \frac{(1-\Psi_{M_j})(1-j_{M_j})+r_R\Psi_{M_j}}{(1+r_R)^{T_K}}}{(1-r_R)\Psi_{M_j} \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t}} + \frac{(1-\Psi_{M_j})(1+3j_{M_j}r_R-r_R-j_{M_j})}{\frac{1+r_R}{(1-r_R)\Psi_{M_j} \sum_{t=t_0+1}^{T_K} \frac{1}{(1+r_R)^t}}}, \quad j \in \{s, h\},$$

where j_{M_j} denotes the share of the tangible investments in the development of machines for machinery j .

Both intermediaries spend a proportion of the received interest payment of the successful innovators to build up the losses through the intangible investments of the failed innovators as well as the reserve, which was built to pay interest and dividends to the savers in the first saving period.

The interest as well as the dividends to the savers are calculated on the periodic credit and fund volume. For the credit and fund volume of the period T , the interest payment and dividend are given for all $t \in [T + 1, \dots, T + T_K]$ by:

$$D_{m_I(T)} = \sum_j r_{K_j} E_0 A_{m|M_j}(T) - \frac{Q_{m_I(T)}}{T_K - 1} - \frac{1}{T_K - 1} \sum_j (1 - j_{M_j}) E_0 (U_{m|M_j}(T) - A_{m|M_j}(T)),$$

with $m \in \{V, B\}$,

where $A_{m|M_j}(T)$ denotes the number of successfully founded enterprises with the credit or fund volume $B_I(T)$ and $V_I(T)$, respectively; $U_{m|M_j}(T)$ denotes the number of founded enterprises with the credit or fund volume and $Q_{m_I(T)}$ is the reserve built of the intermediary m . For interest payment as well as dividend of the period T , the following expression applies:

$$D_m(T) = \sum_{t=1}^{T-1} D_{m_I(t)} + Q_{m_I(T)} \quad m \in \{V, B\}.$$

The credit volume as well as the fund volume of the period T is given by the sum of the savings of this period, of the tangible investment returns of failed innovators in the last period, of the accumulated intangible investments and the accumulated reserves:

$$m_I(T) = m(T) + \sum_j \mathbf{j}_{M_j} E_0 \left[U_{m|M_j}(T-1) - A_{m|M_j}(T-1) \right] + \sum_{t=T-T_K-1}^{T-2} \frac{Q_{m_I(t)}}{T_K-1} + \frac{1}{T_K-1} \sum_{t=T-T_K-1}^{T-2} \sum_j \left(1 - \mathbf{j}_{M_j} \right) E_0 \left[U_{m|M_j}(t) - A_{m|M_j}(t) \right], \quad \text{with } m \in \{V, B\}.$$

5. Income and Portfolio Selection

The disposable income of all individuals is given by the sum of the interest payment on deposits D_B , the dividends on venture capital investment D_V , the wage income of the unskilled and skilled individuals and the profits of the successful innovators:

$$Y = D_B + D_V + w_L^* \ell + w_H^* (h - h_A) + \sum_i \mathbf{p}_i | i \in H_{A|B} + \sum_i \mathbf{p}_i | i \in H_{A|V},$$

where h_A is the number of elements of H_A and \mathbf{p}_i is the profit, which is earned by the successfully innovative, skilled individual i .

The following share of the savings is invested in the venture capital fund:

$$v^* = \begin{cases} 1 & \text{if } E(r_B) - E(r_V) + 2q[\mathbf{s}_V^2 - \mathbf{s}_{VB}] \leq 0 \\ \frac{E(r_V) - E(r_B) + 2q[\mathbf{s}_B^2 - \mathbf{s}_{VB}]}{2q[\mathbf{s}_V^2 + \mathbf{s}_B^2 - 2\mathbf{s}_{VB}]} & \text{else} \\ 0 & \text{if } E(r_V) - E(r_B) + 2q[\mathbf{s}_B^2 - \mathbf{s}_{VB}] \leq 0 \end{cases},$$

where q denotes the parameter of the expected utility function.

The complementary share is given to the bank as deposits:

$$k^* = \begin{cases} 1 & \text{if } E(r_V) - E(r_B) + 2q[\mathbf{s}_B^2 - \mathbf{s}_{VB}] \leq 0 \\ \frac{E(r_B) - E(r_V) + 2q[\mathbf{s}_V^2 - \mathbf{s}_{VB}]}{2q[\mathbf{s}_V^2 + \mathbf{s}_B^2 - 2\mathbf{s}_{VB}]} & \text{else} \\ 0 & \text{if } E(r_B) - E(r_V) + 2q[\mathbf{s}_V^2 - \mathbf{s}_{VB}] \leq 0 \end{cases},$$

where

$$\mathbf{s}_m^2(T) = \frac{1}{T} \sum_{t=1}^T [r_m(t) - \bar{r}_m]^2 \quad \text{and} \quad \bar{r}_m(T) = \frac{1}{T} \sum_{t=1}^T r_m(t) \quad \text{for } m \in \{V, B\} \quad \text{and}$$

$$\mathbf{s}_{VB}(T) = \frac{1}{T} \sum_{t=1}^T (r_V(t) - \bar{r}_V)(r_B(t) - \bar{r}_B),$$

with

$$r_m(T) = \frac{D_m(T)}{\sum_{t=1}^T m(t)}$$

as the dividend rate of investment in the venture capital fund for $m = V$ and the interest rate on deposits for $m = B$ in period T . The expected values are given by:

$$E[r_m(T+1)] = r_m(T).$$

6. Equilibrium Values

The wage rates of skilled and unskilled labour are determined by the prices of the traditional and the high-tech good, which are given by the world market prices.

Furthermore, wage rates depend on the number of the machines for the soft and heavy machinery $h_{A|M_j}$:

$$w_L^* = \left[p_H^{a_1+a_3-1} p_T^{(b_2+b_4)} \left(\frac{\frac{r_h-1}{h_{A|M_h}}}{r_h} \right)^{b_3(1-a_1)+(b_1-1)a_3} \left(\frac{\frac{r_s-1}{h_{A|M_s}}}{r_s} \right)^{a_2b_4-b_2a_4} \right]^{\frac{1}{a_1+a_3-b_1-b_3}}$$

$$w_H^* = \left[p_H^{a_1+a_3} p_T^{-(b_1+b_3)} \left(\frac{\frac{r_h-1}{h_{A|M_h}}}{r_h} \right)^{a_3b_1-b_3a_1} \left(\frac{\frac{r_s-1}{h_{A|M_s}}}{r_s} \right)^{a_4(b_1+b_3)-b_4(a_1+a_3)} \right]^{\frac{1}{a_1+a_3-b_1-b_3}},$$

where p_H denotes the price of the high-tech good and p_T is the price of the traditional good, respectively. In each period, the market of the primary factors skilled and unskilled labour clears. Therefore the output of the high-tech good as well as the output of the traditional good are given by:

$$Y_T^* = \begin{cases} \frac{\ell w_L^*}{a p_T} & \text{if } \frac{p_T}{p_H} \geq \left[\frac{p_T}{p_H} \right]^T \\ \frac{\ell dw_L^* - \bar{h} bw_H^*}{p_T(da - cb)} & \text{if } \left[\frac{p_T}{p_H} \right]_H < \frac{p_T}{p_H} < \left[\frac{p_T}{p_H} \right]^T \\ 0 & \text{if } \frac{p_T}{p_H} \leq \left[\frac{p_T}{p_H} \right]^H \end{cases}$$

$$Y_H^* = \begin{cases} \frac{\bar{h}w_H^*}{p_H d} & \text{if } \frac{p_T}{p_H} \leq \left[\frac{p_T}{p_H} \right]_H \\ \frac{\bar{h}aw_H^* - c\ell w_L^*}{p_H(da - cb)} & \text{if } \left[\frac{p_T}{p_H} \right]_H < \frac{p_T}{p_H} < \left[\frac{p_T}{p_H} \right]_T \\ 0 & \text{if } \frac{p_T}{p_H} \geq \left[\frac{p_T}{p_H} \right]_T \end{cases} ,$$

where

$$\left[\frac{p_T}{p_H} \right]_H := \left[\frac{\bar{h}(b_1 + b_3 \mathbf{r}_h)}{\ell(b_2 + b_4 \mathbf{r}_s)} \right]^{a_1 + a_3 - b_1 - b_3} \begin{pmatrix} \frac{\mathbf{r}_h - 1}{h \frac{\mathbf{r}_h}{A|M_h}} \end{pmatrix}^{a_3 - b_3} \begin{pmatrix} \frac{\mathbf{r}_s - 1}{h \frac{\mathbf{r}_s}{A|M_s}} \\ \mathbf{r}_s \end{pmatrix}^{a_4 - b_4} \quad \text{and}$$

$$\left[\frac{p_T}{p_H} \right]_T := \left[\frac{\bar{h}(a_1 + a_3 \mathbf{r}_h)}{\ell(a_2 + a_4 \mathbf{r}_s)} \right]^{a_1 + a_3 - b_1 - b_3} \begin{pmatrix} \frac{\mathbf{r}_h - 1}{h \frac{\mathbf{r}_h}{A|M_h}} \end{pmatrix}^{a_3 - b_3} \begin{pmatrix} \frac{\mathbf{r}_s - 1}{h \frac{\mathbf{r}_s}{A|M_s}} \\ \mathbf{r}_s \end{pmatrix}^{a_4 - b_4} .$$

Appendix 3: Parameters Used

For the simulation the following parameters are used:

Production intensities		Machinery sectors		Others	
a_1	0.11	r_h	0.9	p_T	1
a_2	0.17	r_s	0.9	p_H	1.025
a_3	0.33	j_{M_h}	0.9	r_R	0.03
a_4	0.39	j_{M_s}	0.5	T_K	200
b_1	0.1	Ψ_{M_h}	0.9	ℓ	40000
b_2	0.18	$\Psi_{M_{s,V}}$	0.85	h	40000
b_3	0.28	$\Psi_{M_{s,B}}$	0.15	q	500
b_4	0.44	E_0	10	s	0.01

where

$a_1 (b_1)$ – Intensity of unskilled labour in the traditional (high-tech) sector

$a_2 (b_2)$ – Intensity of skilled labour in the traditional (high-tech) sector

$a_3 (b_3)$ – Intensity of the heavy machinery in the traditional (high-tech) sector

$a_4 (b_4)$ – Intensity of the soft machinery in the traditional (high-tech) sector

r_j – Parameter of the production function of the machinery $j \in \{h, s\}$

j_{M_j} – Share of tangible investments of machinery $j \in \{h, s\}$

- Ψ_{M_h} – Probability of technical success of machine development for the heavy machinery
- $\Psi_{M_{s,V}}$ – Probability of technical success of machine development for the soft machinery, financed by venture capital
- $\Psi_{M_{s,B}}$ – Probability of technical success of machine development for the soft machinery, financed by bank credit
- E_0 – R&D investment
- p_T – Price of the traditional good
- p_H – Price of the high-tech good
- r_R – Riskless interest rate
- T_K – Period of validity
- ℓ – Number of unskilled individuals
- h – Number of skilled individuals
- q – Parameter of the risk utility function
- s – Saving rate

7. Literature

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