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A Theoretical Analysis

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Chapter 1

Introduction

The financial sector in general, and banks specifically, receive significant attention from the general public and the economic profession particularly at times when they are not properly functioning. A severe impact of financial crisis upon real economic activity is undisputed (e.g., Japan and Asian crisis). A prerequisite for welfare-improving policy interventions is a firm knowledge of the functions and interdependence of the financial and real sector even in non-crisis times. Empirical papers[1] have already identified a positive correlation between financial development[2] and economic growth. There is also evidence that the causality runs from finance to growth.
Opposed to general belief, financial intermediaries are still the major participants in the financial sector and have even significantly gained in the relative supply of finance (Allen and Santomero 1998, p. 1468). Thus, the importance of their behavior is palpable. This thesis analyses economic mechanisms explaining financial intermediaries' impact upon and interdependency with economic growth.

The effect of finance in general, and specifically financial intermediaries, upon economic growth has always drawn the attention of economists. Already Bagehot ([1873], 1991), Schumpeter ([1912], 1934), Gurley and Shaw (1955 and 1967), and Goldsmith (1969), to name the most cited early contributors, have addressed this topic. However, these early contributions were lacking a formal

[1] See for example e.g. Levine (1997, 2003 and forthcoming)

[2] "Economists refer to improvements in the extent or efficiency of the financial system as financial development." (Khan 2000, p. 4)

apparatus by which to reveal the underlying mechanisms in an analytical way. The required analytical framework became available with the development of endogenous growth models[3] (Pagano 1993). Thereafter, interest in this topic was revived. Meanwhile, Levine's articles (e.g., 1997) examining the finance growth nexus are within the top ten of citation[4] and download[5] rankings. Despite the increased research activity, the behavior of financial intermediaries has, so far, received limited attention in the growth context. This contrasts to the literature discussing monetary transmission channels where financial intermediaries' liability- and asset-management is seen as a potential transmission channel of monetary policy. The according behavior of financial intermediaries is described in this context as influential for (at least) short-term economic activity (e.g., Peek, Rosengren and Tootell 1999).

This thesis extends the existing finance-growth literature by analyzing financial intermediaries' reaction to liquidity- and solvency- risk. Financial intermediaries are, thereby, not treated as black boxes but as optimizing agents. As a result, financial intermediaries' actions regarding liquidity and solvency risk can be explained, as well as their impact on, and interdependence with, economic growth. The understanding of these mechanisms is a prerequisite for the recommendation and evaluation of governmental interventions.

The analysis of the growth impact of finance requires the extension of a suitable growth model. Only so-called endogenous growth models translate changes in behavior into a persisting change of the growth rate. Further, in the long-run relative prices and assets are endogenous. This requires the use of general equilibrium models instead of partial equilibrium models. The two basic risks faced by the financial intermediary are liquidity and solvency risk. These are used to 'open' the black box of financial intermediation by allowing financial intermediaries to choose their exposure to liquidity and insolvency risk respec-

[3]The major contributions establishing endogenous growth models are Romer (1986 , 1990), Lukas (1988), Segerstrom, Anant and Dinopoulos (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).

[4]In the period of 1990-2000 Levine's papers rank ninth (Coupé 2003) and in the latest total citation index his papers are on rank eight (Incites 27.01.2006, viewed on 27.01.2006).

[5]Levine's papers are the third most downloaded in 2005 (Logec 10.02.2006, viewed on 10.02.2006).

tively. In order to allow for more transparency of the models, the impact of the two risks are analyzed in separate models.

Liquidity risk for banks esteems from deposit transfers to other banks and deposit withdrawals. Here, the focus is on transfers. Assuming that financial intermediaries cannot fully diversify deposit transfers, there is a risk of illiquidity. In other words, there will be a net deposit outflow, whereby, the bank with the net deposit inflow can demand according assets. However, bank assets are illiquid, and banks usually balance the stochastic gaps with interbank credits. With interbank information frictions, these interbank credits are costly. This induces banks to hold 'unproductive' reserves as a buffer against costly illiquidity.
The link to economic growth is provided by using the above mechanism as an extension in a general equilibrium endogenous growth model, where the driving force of growth is research and development (R&D). Due to asymmetric information, credit applicants must be screened, whereby research activity depends upon bank-finance. The impact of banks and their screening activity has been modeled by King and Levine (1993b). The allocation of resource towards R&D activities depends in their model upon the spread between the loan and deposit interest rate (King and Levine 1993a). Via the aforementioned extension of their model, this spread is endogenized. This allows for a better understanding of the connection between the banking system and economic growth, and according policy interventions are discussed.

Solvency risk for banks esteems from loan default risk. In the real world, some undiversifiable risk will remain despite the superior diversification abilities of banks. Still, banks offer safe deposit returns to households on their liability side. They can do so by using their equity capital as a buffer against stochastic loan defaults. In the model, banking activity is depicted by a savings and portfolio choice. The banker chooses how much earnings to retain (save) and how much to invest in risky loans (portfolio). With given bank equity capital, the leverage and thus the exposure to solvency risk is determined by the chosen volume of loans. Therefore, bank equity capital gains importance for the allocation of finance and thus resources in an economy.
This bank behavior establishes a concrete finance-growth nexus. Again, growth

esteems from R&D activity that requires external finance. Failed R&D efforts not only cause an immediate slowdown in economic growth but also an overproportional loss of bank equity capital. Risk averse bankers will react by curtailing new loans to the R&D sector. Thereby, a two-way influence between bank equity and economic growth is established.

This thesis is organized into 6 chapters. According to the Modigliani-Miller theorem (Modigliani and Miller 1958) finance is neutral and thus economically unimportant. Therefore, Chapter 2 discusses the financial system, financial markets, and financial intermediaries from the finance literature perspective. Besides defining and introducing important concepts, the issue of financial intermediation and the underlying assumptions that induce their importance are clarified.

Chapter 3 supplies the required growth theory for the following discussion of the finance-growth nexus literature. Additionally, the choice of endogenous growth models as the basis for the following extensions is motivated.

Chapter 4 uses the introduced growth models and discusses existing extensions for finance and especially financial intermediaries in the finance-growth nexus literature. The shortcomings are identified and used to motivate the new model variations presented in this thesis.

Chapter 5 depicts the model incorporating liquidity risk for financial intermediaries. Interbank credits balance stochastic deposit transfers. The bank optimizes publicly observable reserve holdings and thus expected illiquidity cost. It is shown how this optimization choice affects economic growth and how policy intervention can improve the situation.

Chapter 6 implements bank's risk aversion in combination with solvency risk within an endogenous growth model. Thereby, banks hold equity capital as a buffer against insolvency and can offer safe deposits to even more risk averse households. Fluctuations in economic growth affect bank capital overproportionately, whereby banks will reduce their exposure to risky loans. Due to the complexity of the problem, two different approaches are used.

The first model variant assumes no financial frictions and allows for market and bank finance of R&D activities. The focus is upon risk-shifting from households to banks. Banking activity is explained endogenously by heterogenous risk

aversions. Thereby, this model also contributes to the literature discussing bank- versus market-based financial systems.
The second model variant is similar to most of the existing finance-growth literature where the R&D sector is assumed to rely on bank finance and no market finance is available.

The main results are subsumed and discussed at the end of each chapter. The quintessence of this thesis is presented in the final chapter.

Chapter 2

Finance, Financial Markets, and Financial Intermediaries

Usually, finance relates to lending and borrowing of money. However in order to avoid additional complexity, money is excluded from the following analysis. Finance then denotes the task of obtaining required economic resources to fulfill an economic task.
Assuming a standard economic production function, the factors of production receive their marginal product. With instantaneously risk-free production, finance is superfluous, as the inputs are simply remunerated with the output. However, more realistically production takes time, and output is available only after the use of inputs. Then, either the factors of production must be willing to wait for remuneration, or other agents must supply the remuneration until the output is realized. Risky production has a similar effect. If output is uncertain, either the factors of production have to suffer fluctuations in their remuneration, or another agent must be willing to bear this risk. Hence, with time-consuming or risky production the issue of finance gains importance.

Within the financial sector, financial markets and financial intermediaries can be distinguished. Broadly defined financial intermediaries are all entities in the business of accumulating savings and lending them to third parties. In a more narrow definition financial intermediaries are in the business of issuing deposits and granting loans, i.e. banking. Since no money is included in this analysis, and issues regarding the difference of financial intermediaries are not in the focus, the terms financial intermediary and bank are used interchangeably. Indirect finance via banks is thus frequently denoted bank lending. Regarding the financial market, it is important to distinguish between the primary market and the secondary market. On the primary market firms issue new securities, while the secondary market facilitates the transferring of existing securities' ownership. Thus, only primary market activity finances new economic activity, while security trading in the secondary market just increases liquidity of existing financial assets.

This chapter describes financial intermediaries in detail. The headings are chosen in line with the rudimental questions: "What do financial intermediaries do?" (Allen and Santomero 2001), and "What is Different About Banks?" (Fama 1985). Section 2.1 describes the basic setup of a bank and defines the according technical terms. The focus is upon the business of intermediation of savings and the role of bank reserves and bank equity. More elaborate functions of banks follow in Section 2.2. Section 2.3 discusses the future importance of banks, considering the recent trends of disintermediation and securitization.

2.1 What do Financial Intermediaries do?

Discussing financial intermediation in a general equilibrium framework implies several borrower-lender relationships. In all following models, the household is assumed to be a net saver. The household deposits at least some of its savings at the bank. Thus, the household is the lender and the bank is the borrower. However the bank, acting as a financial intermediary, does not keep these savings, but lends them to firms. The bank is thereby a borrower as well as a lender. In order to minimize the potential for confusion, the lender to the bank, i.e. the household, is denoted creditor[1]. The borrower of the bank, i.e. the firm, is denoted debtor. Thus, while the terms borrower and lender are also used to describe market relationships, the use of the term creditor and debtor always relates to banks in this thesis.

[1] Since the creditor has 'positive credit', i.e. deposits at the bank, he is also denoted depositor (Mishkin 1998). However, in the growth finance literature "creditor" is more frequently used.

A typical bank balance sheet is depicted by Table[2] 2.1. The asset side subsumes

Bank Balance Sheet

Assets		**Liabilities**	
Reserves	0,75 %	Equity capital	3,68 %
Interbank credits	28,66 %	Interbank credits	28,11 %
Securities	17,60 %	Bank obligations	23,72 %
Loans	43,97 %	Deposits	36,78 %
Tangible assets	0,47 %		
Others	8,55 %	Others	7,71 %

Table 2.1: Bank Balance Sheet

the investment of banks, while the liability side shows the sources of funds. The main business of a typical bank is granting loans to firms and financing these by 'accepting' deposits from households. To a certain extent, banks also invest by buying commercial papers of firms in the secondary market and by granting interbank credits either via the over-the-counter or money market.

While all of above assets are used for their yield, this does not hold for reserves (Bernanke 1993, p. 56). Reserves serve as a buffer against liquidity risk[3]. Liquidity risk denotes the risk that"... depositors may at any time demand payments the institution can meet, if at all, only at extraordinary costs." (Tobin 1996, p. 345) Therefore, reserves are either storage or very liquid and thus low return assets, e.g., government treasury notes. Abstracting from regulatory minimum reserve holdings, the bank optimizes reserve holdings. The optimal amount is achieved once the expected marginal cost of illiquidity is matched by the expected marginal opportunity cost of holding reserves. This provides a link with the liability side. If the bank can easily cover a liquidity shortage by borrowing in the interbank market, the optimal reserve ratio decreases. This liquidity management and its impact upon growth is at

[2] The percentages depict the aggregate balance sheet for monetary financial institutions in October 2005, according to the Deutsche Bundesbank data (Deu 2005). For simplification the positions of the Bundesbank have been further aggregated according to the following scheme. Assets: Reserves (3+4), Interbank (10), Securities (6+12+14), Loans (11), Tangible assets (24), Others (16-19+25). Liabilities: Equity capital (18), Interbank credits (1), Bank obligations (6), Deposits (2), Others (10+13-17+21)

[3] The negative risk is actually the risk of illiquidity. However, the technical term is liquidity risk.

the heart of the new model variation in Chapter (5).
The cheapest source of funds for banks are deposits. However, deposits can be withdrawn by the creditor basically without notice[4]. Therefore, the 'inexpensive' financing of the long-term assets with short-term deposits is achieved at the cost of a high maturity mismatch and according liquidity risk.

Similar to reserves on the asset side, equity capital has a special role on the liability side. First of all, it is not a real liability, but rather the price the bank owner pays to be the residual claimant. Secondly, unlike regular firms, banks have such a small equity/asset ratio[5] that it cannot be regarded as an important source of finance. Similar to reserves the role of equity is to serve as a buffer, although to a different risk. The asset side of the bank consists of risky loans and a fraction of them defaults. Without perfect diversification the default rate is stochastic. The bank remains solvent only as long as the value of total assets is in excess of total liabilities. The inclusion of this solvency risk is at the heart of the model variations in Chapter (6).

It is important to note that liquidity and solvency risk are two very different concepts. Liquidity risk is a matter of timing. The banks assets might be sufficient to cover liabilities, i.e. the bank is solvent; however, the bank-intrinsic value of the assets cannot be used to fulfill depositors' demand due to the maturity mismatch. Accordingly, bank equity capital cannot serve as a buffer against illiquidity, and reserves are not a buffer against solvency risk. Further, illiquidity is a temporary problem and can be resolved if a third party is willing to lend, as opposed to insolvency, which describes a permanent loss.

In above description, the bank simply channels the savings of the household to the firm. Since there was no real service involved, the question regarding why the household is not directly investing via the capital market arises. In an Arrow-Debreu general equilibrium model markets are complete, transaction costs are zero, and information symmetric. In this case market investment is a perfect substitute for deposits from the households' point of view. Respectively,

[4]Thereby, deposits can be used for payments and the provision of the payment system is also one of the banks' functions (Freixas and Rochet 2002).

[5]In Table 2.1 the equity ratio is below 8 %. However, this is the ratio to total assets and not risky assets. The regulatory equity ratios are calculated in a different way.

direct finance is a perfect substitute for bank loans from the firms' point of view. Thus, in line with the well-known Modigliani-Miller (1958) theorem, firms would be indifferent between bank finance and market finance whereby financial intermediaries become superfluous (see e.g., Fama 1980, and Freixas and Rochet 2002). As a result the assumptions of the Arrow-Debreu model have to be relaxed in order to motivate the existence and relevance of banks. This is typically done by introducing asymmetric information and transaction costs. The following section describes how banking mitigates these market imperfections.

2.2 What is Different About Banks?

The financial sector in the real world is imperfect. These imperfections can be used to motivate the existence of banks channeling financial funds beside, or even instead of, the financial market. Basically, banks mitigate the initial imperfections by means of pooling and the use of special screening and monitoring technologies. This section is organized along the banking function classification by Freixas and Rochet[6] (2002) and clarifies under which assumptions banks are superior to markets.

2.2.1 Transforming Assets

If there are fixed costs of issuance, these cannot be subdivided. Small lenders cannot finance large loans. Further, indivisibility disables diversification. Therefore, there are economies of scale that can be realized by banks, but not by the market. The bank bundles all its (individually small) deposits and disburses the cost and the remaining risk over the large number of creditors.

Also the bank can transform a continuum of short-term deposits into a long-term loan. Whilst the market can do this as well, the cost of trading ownership in the secondary market is likely to be higher than the cost of revolving deposits.

[6]The function of "Offering access to a payment system" (Freixas and Rochet 2002, p. 2) is omitted here, as it relates more to monetary analysis than to economic growth.

If trading in the secondary market is costly, liquidation of financial assets becomes costly. By the law of large numbers the realized idiosyncratic liquidity need of a pool of savers will be closer to the estimated liquidity need compared to the individual realization. Due to this congruence, less illiquid assets will be costly liquidated and the expected return increases. In other words, banks can transform illiquid assets into liquid deposits (Diamond and Dybvig 1983).

2.2.2 Managing Risk

In this section, three different risks - intertemporal risk (Allen and Gale 1995b), liquidity risk, and credit risk (Freixas and Rochet 2002) - are distinguished. Risk in itself only matters if agents are risk averse. Therefore, the following arguments presume risk averse households.

Intertemporal risk relates to the volatility of returns over time. This volatility cannot be diversified at a point in time, but evens out over time (Allen and Gale 1995a). The market can offer no product to avoid this systemic risk. Financial intermediaries offer a smooth return on their deposits even if they are not fully diversified. The intertemporal risk is, thereby, shifted upon the intermediary, and causes fluctuation of its equity capital. With long-lived financial intermediaries that care about their long-term average return such risk-shifting is Pareto-improving (Allen and Gale 1995b).

Liquidity risk esteems have been described in the previous subsection. However, with risk averse agents the problem of illiquidity gains an additional facet. Risk averse agents dislike fluctuations in returns, even if the average return does not change. Therefore, diversification of liquidity is useful even if the average cost of holding illiquid assets is zero. By pooling the liquidity needs of creditors on their liability side, the bank can diversify the liquidity risk and offer a smooth return on deposits (Diamond and Dybvig 1983).

Similar, the pooling of debtors on the bank asset side diversifies the credit risk associated with the individual borrowers. Banks can, thus, be interpreted as portfolio optimizers (Pyle 1971). Small transaction costs are sufficient to allow banks to realize economies of scale in diversification and thereby offer superior diversification to the market. Credit risk is also diminished by monitoring the borrower. The problems evolving due to asymmetric information are discussed in the following subsection.

2.2.3 Processing Information

A major market imperfection that is usually used to explain the existence and importance of financial intermediaries is asymmetric information. The asymmetry can be assumed at two stages.
Ex-ante to the lending contract the borrower has more knowledge about his creditworthiness than the lender. The interest rate cannot serve as a sorting device since an increase might crowd out creditworthy borrowers with low but relatively safe productivity. Then the fraction of risky borrowers in the applicant pool increases, whereby the expected return to the lender can decrease despite the risen contractual interest rate (Stiglitz and Weiss 1981). In order to avoid this so-called adverse selection (Akerlof 1970), the lender has to screen the credit applicants and their projects. Screening is the costly effort of accumulating information ex-ante to the lending decision.
Ex-post to the lending decision asymmetric information regarding the actions of the borrower decision induces the so-called moral hazard problem (Stiglitz and Weiss 1981). With limited liability, a proportion of the downside risk is shifted to the lender, whereby the borrower has an incentive to invest in excessively risky projects. Collateral requirements ease the problem for the bank only to a limited extent. Whilst collateral increases the repayment in the case of a default, it does not improve the borrower's choice of projects, since rising collateral requirements diminish expected profits of low risk projects to a greater extent than the expected profits of high risk projects (Broll and Gilroy 1986). Further, the borrower can simply claim insolvency to avoid the loan redemption. Again, increasing the interest rates would merely amplify the problem. The lender must therefore engage in costly monitoring to gain the relevant information.

The information produced by screening and monitoring is a typical nonrival good. Therefore, individual research by each lender is suboptimal. Information cannot be traded as the buyer cannot evaluate the quality of the information (Hirshleifer 1971). Further, with small and illiquid (little trading) financial

markets, the achieved information is nonexcludable as the behavior of informed agents is visible. Thereby, the typical prisoners dilemma arises. All agents attempt to free ride on the information produced by the other agents, and as a result, no agent is willing to invest in information production (Grossman and Stiglitz 1980). Due to this nonrivalry and nonexcludability markets will fail[7] to induce optimal screening and monitoring.
Banks process information about their debtors and can realize economies of scale as they use the information for a pool of creditors. Further, the use of the information is realized largely within the bank (Leland and Pyle 1977) which is an approximation to excludability.

Banks can realize economies of scale in monitoring as they avoid the previously mentioned duplication of monitoring costs. The bank then acts as a delegated monitor (Diamond 1984). With asymmetric information the question arises: Who monitors the monitor? (Krasa and Villamil 1992) If monitoring is only required to avoid pretended bankruptcy, banks require less monitoring as diversification will diminish the number of bank bankruptcies (Townsend 1979, and Diamond 1984).

2.3 Do Financial Intermediaries Remain Relevant?

The previous section has shown that banks' real services are at large the mitigation of information costs via expertise and decrease of transaction costs via economies of scale. Yet, financial innovation allow financial function initially performed by financial intermediaries to be performed by the market. Further, banks themselves also use these improved conditions, for example, by securitization, i.e. they bundle their assets (loans) and sell these on the secondary market. Empirically a shift towards market finance has also been observed and is discussed as so-called disintermediation (e.g., Allen and Santomero 2001, and Buch 2002). These developments have induced the presumption that financial intermediaries' economic relevance is diminishing. If this were the case, the

[7] Even rating agencies are of little help as information asymmetries between the lender and the agency might induce the same problem at a different level (Allen 1990).

focus of this thesis upon banks' behavior for economic growth would become less relevant. Therefore, this section shows that financial intermediaries are and remain relevant.

Firstly, Allen and Santomero (1998) even find for the US that opposite to the general believe "[t]he amount of financial claims held directly by households has clearly fallen dramatically. Intermediation has become significantly more important and has been the predominant source of new financial resources flowing into the capital markets over the past several decades." (Allen and Santomero 1998, p. 1468) Also for the UK and Germany there are empirical studies that do not support the disintermediation view (Schmidt, Hackethal and Tyrell 1999). The presumption of decreasing financial intermediation rather esteems from the strong increase of financial market activity. However, banks' assets relative to GDP have actually risen rather than declined in the US (Allen and Santomero 2001).

Secondly, by large financial innovation and new financial markets are used by the financial intermediaries themselves, rather than by households and firms (Allen and Santomero 1998, p. 1461). Further, while these secondary market activities improve liquidity and efficiency, they do not have such a direct macroeconomic impact as banking activity which relates to primary finance (Stiglitz 1993).

Thirdly, "[i]n practice, the cachet of a banker often enables his customer also to obtain credit from other sources or to float paper in open markets" (Tobin 1996, p. 343). This influence of the banker's action is a result of the aforementioned nonexcludability of information. Visible bank loan provision signals to the market that the borrower has been screened and judged creditworthy (e.g., Fama 1985, and James 1987). Similarly, the monitoring of the bank implies a positive externality for market finance, as all lenders will profit from diminishing moral hazard of the borrower.
Thus, even if firms would increasingly use market finance, the importance of bank loans is not diminishing, as market finance would dwindle in line with the banks' reappraisal of the borrower.

Fourthly, Merton (1995) opposes this view and identifies a "financial-innovation spiral", i.e. whilst markets take over some former banking functions the improved market performance allows banks to innovate former impossible financial products. Once these are fully developed, the market might supply these and the cycle begins allover again. Similarly, the evolvement of "electronic money" can be interpreted as a new kind of banking instead of a substitute for banking services (Bossone 2001).

2.4 Summary

This chapter has shown that indivisibility and economies of scale cause indirect bank finance to be superior to market finance. Banks are superior to the market in regard to size and maturity transformation, since they can economize on transaction costs by pooling small and short-term deposits. The size of the bank also allows for improved risk diversification and management of liquidity and default risk. Additionally, the bank has an advantage in the processing of information, i.e. screening and monitoring of loan applicants and debtors. Levine emphasizes that these are real services, so that a distinction between a real and financial sector is misleading (Levine 1997, p. 689). According to this view it is obvious that the financial sector is of macroeconomic importance.
Moreover, it has been shown that there is reason for an ongoing importance of banks, as securitization and disintermediation have not alter the basic, real services the banks offer. Instead, financial innovations and markets are utilized by banks themselves.

Chapter 3

Growth Models

This chapter elucidates relevant growth models to enable an in-depth discussion of models combining finance and growth both within the existing literature and within this thesis. The major characteristics are identified and compared. Furthermore, the chapter motivates the growth context chosen in this thesis.

Modern growth-literature distinguishes between exogenous, endogenous, and semi-endogenous growth models. Since the innovation of this thesis is done within endogenous growth models, these will be illustrated in the most detail. The subsequent sections utilize advanced textbook presentations by Barro and Sala-I-Martin (2004), Jones (2002) and Aghion and Howitt (1998). However, the models as well as their presentation have been vigorously altered to accommodate the discussion of endogeneity and extensions regarding finance.

3.1 Exogenous Growth: The Ramsey Model

> "[Ramsey's 1928 article] is, I think, one of the most remarkable contributions to mathematical economics ever made, both in respect of the intrinsic importance and difficulty of its subject, the power and elegance of the technical methods employed, and the clear purity of illumination with which the writer's mind is felt by the reader to play about it subject. The article is terribly difficult reading for an economist, but it is not difficult to appreciate how scientific and aesthetic qualities are combined in it together."

(Keynes 1930, p. 153)[1]

The standard exogenous growth models are the so-called Solow model and its extension the so-called Ramsey model. In the Solow model (1956, 1957) the savings rate is determined exogenously, whilst it is an optimal choice of the household in the Ramsey model. The initial Ramsey model (1928) was altered by Cass (1965) and Koopmans (1965) and is presented as a slight variation of its standard textbook version as can be found for example in Barro and Sala-I-Martin (2004). The model depicts a closed economy with profit maximizing firms and utility maximizing households[2]. Households optimize via their consumption choice. Firms optimize the use of capital and labor input and take technology as given public good. Technology and population are assumed to grow at the exogenous rates g and n.

3.1.1 Firms

Exogenous growth models assume constant returns to scale production functions $F(K_t, L)$. In order to allow for long-term growth and comparability with later models so-called Hicks-neutral technology, which grows at the exogenous given rate g, is added[3].

$$\dot{A} = gA_t \tag{3.1}$$

This requires the production function to be of the Cobb-Douglas form to achieve steady state growth (Barro and Sala-I-Martin 2004, pp. 78). The firm's output is thus described by $A_tF(K_t, L) = A_tK_t^{\alpha}L^{1-\alpha}$ and g can also be interpreted as total factor productivity growth. For the following analysis the

[1] Attention got drawn to this quote via the following webpage: http://cepa.newschool.edu/het/essays/growth/optimal/ramseygr.htm (9.11.2005).

[2] The firms and households are homogenous, i.e. representative. In order to ease the notation, their number is normalized to one.

[3] Usually labor-augmenting, also called Harrod-neutral (1942) technology is assumed in the presentation of the Ramsey model. However, the comparison with the following endogenous growth models is improved by using Hicks-neutral technology (1932). The difference between the two is that growth in the Hicks-neutral technology does not alter the ratio of the marginal returns and thus the optimal input ratios, while growth of Harrod-neutral technology increases the marginal product of labor, which alters the optimal input ratio.

capital intensity $k_t \equiv K_t/L$ is used for convenience. Profits are

$$\begin{aligned} \pi &= L\left(\frac{AK^{\alpha}L^{1-\alpha} - rK - wL}{L}\right) \\ &= \left(A_t k_t^{\alpha} - r_t k_t - w_t\right) L. \end{aligned}$$

The representative firm maximizes profits by choosing the optimal amount of capital and labor, taking the interest rate r_t and wages w_t as given. The according first order conditions are

$$r_t = A_t \alpha k_t^{\alpha-1} \tag{3.2}$$

$$w_t = Ak_t^{\alpha} - rk_t. \tag{3.3}$$

3.1.2 Households

Population is assumed to grow at the exogenous rate n. This growth is easiest implemented when the individuals maximize utility of their dynasty, i.e. the utility of their descendents is also accounted for. The utility function of the form

$$V = \int_s^{\infty} u(c_t) e^{n(t-s)} e^{-\rho(t-s)} dt$$

depicts this behavior[4]. The instantaneous utility function $u(c_t)$ - also called felicity function (Blanchard and Fischer 1989, p. 39) - is multiplied by $e^{n(t-s)}$ to account for the utility of descendents, while the term $e^{-\rho(t-s)}$ discounts the utility at the time preference rate ρ. Note that $n - \rho < 0$ is already required to avoid unbounded utility even with zero consumption growth. V can be interpreted as the present 'utility-value' the representative individual associates with a certain dynasty consumption schedule. In a growth context it is convenient to assume a utility function in the form of $u(c_t) = \frac{1}{1-\theta} c_t^{1-\theta}$. The representative individual optimizes its consumption c_t within its intertemporal budget constraint (Appendix 3.A.1)

$$\dot{k} = r_t k_t - nk_t + w_t - c_t, \tag{3.4}$$

[4] These kind of formulation is also called Benthamite welfare function (Blanchard and Fischer 1989, p. 81).

and thereby also optimizes capital accumulation[5]. The solution method is dynamic optimization, and the optimal consumption path is given by the so-called Euler Equation (Appendix 3.A.1):

$$\frac{\dot{c}}{c} = \frac{r_t - \rho}{\theta} \tag{3.5}$$

The representative household chooses a 'steeper' consumption path if the (positive) spread between the interest rate and the personal discount rate is large and vice versa. The intuition is that the spread is an incentive to save, in other words to forgo present consumption in favor of increased future consumption. The constant intertemporal elasticity of substitution (CIES) $1/\theta$ is a measure of the individual's desire to smooth consumption and thus dampens the intertemporal allocation of consumption due to the spread.

Further, the so-called transversality condition (Blanchard and Fischer 1989, p. 40) (Appendix 3.A.1)

$$\lim_{t\to\infty} \left[u'(c_t)e^{(n-\rho)t}k_t\right] = 0 \tag{3.6}$$

has to hold. The transversality condition has two interpretations. Firstly, for positive assets it assures that accumulation is purposeful, i.e. to increase utility via consumption at a future state. If the present value of the 'ultimate' capital stock measured in marginal utility units is positive, it is an indication for purposeless unconsumed resources. Therefore, an optimal consumption path requires this value to be zero. Secondly, for negative assets (borrowing) it assures that no Ponzi games can take place, i.e. debt must not grow at a rate exceeding the interest rate.

3.1.3 Equilibrium

An equilibrium is achieved once the capital and labor markets clear at the optimal choices of the individuals. The household's intertemporal budget constraint (3.4) including the equilibrium interest (3.2) and wage rate (3.3) is

[5] In order to economize on variables, the capital market equilibrium (household assets = capital) is already implemented in the household decision, where possible. Further the inclusion of population growth allows capital depreciation to be neglected, because technically they have the same effect within this context: they certeris paribus decrease capital per capita. Population growth is highlighted here as it will be of importance in the upcoming discussion.

(Appendix 3.A.1)

$$\frac{\dot{k}}{k} = A_t k_t^{\alpha-1} - n - \frac{c_t}{k_t}. \tag{3.7}$$

The Euler Equation (3.5) including the equilibrium interest rate (3.2) is

$$\frac{\dot{c}}{c} = \frac{\alpha A_t k_t^{\alpha-1} - \rho}{\theta}. \tag{3.8}$$

These two differential equations describe the solution. On the balanced growth path (steady state) consumption and capital have to grow at the same rate by definition. Therefore in the steady state [(3.7) = (3.8)]

$$\frac{c_t}{k_t} = A_t k_t^{\alpha-1} - n - \frac{\alpha A_t k_t^{\alpha-1} - \rho}{\theta} = \text{constant},$$

which implies that $A_t k_t^{\alpha-1}$ must be constant and per capital consumption and capital grow at the exogenous growth rate $(1-\alpha)^{-1} g$ (Appendix 3.A.1). In order to enable the outside steady state analysis with a phase-diagram the following variables are defined: $\hat{k}_t \equiv A_t^{\frac{1}{\alpha-1}} k_t$ (capital per efficient unit of labor) and $\hat{c}_t \equiv A_t^{\frac{1}{\alpha-1}} c_t$ (consumption per efficient unit of labor), where the situation $\dot{\hat{k}} = \dot{\hat{c}} = 0 \Longleftrightarrow \dot{k}/k = \dot{c}/c = (1-\alpha)^{-1} g$ depicts the steady state. Using these definitions the economy can be depicted by (Appendix 3.A.1)

$$\dot{\hat{k}} = \hat{k}_t^{\alpha} - n\hat{k}_t - \hat{c}_t - \frac{1}{1-\alpha} g \hat{k}_t \tag{3.9}$$

$$\dot{\hat{k}} = 0 \Longleftrightarrow \hat{c}_t = \hat{k}_t^{\alpha} - \left(n + \frac{1}{1-\alpha} g\right) \hat{k}_t \tag{$\dot{\hat{k}} = 0$}$$

and (Appendix 3.A.1)

$$\frac{\dot{\hat{c}}}{\hat{c}} = \frac{\alpha \hat{k}_t^{\alpha-1} - \rho}{\theta} - \frac{1}{1-\alpha} g \tag{3.10}$$

$$\dot{\hat{c}} = 0 \Longleftrightarrow \hat{k}_t^{\alpha-1} = \frac{\theta}{1-\alpha} \frac{g}{\alpha} + \frac{\rho}{\alpha}. \tag{$\dot{\hat{c}} = 0$}$$

The dynamics can be best analyzed by considering the phase diagram in Figure 3-1.

If the consumption level $\hat{c}_t$ is above the $\dot{\hat{k}} = 0$ line, savings do not suffice to maintain the capital intensity and it will decrease $\dot{\hat{k}} < 0$ (3.9), and vice versa.

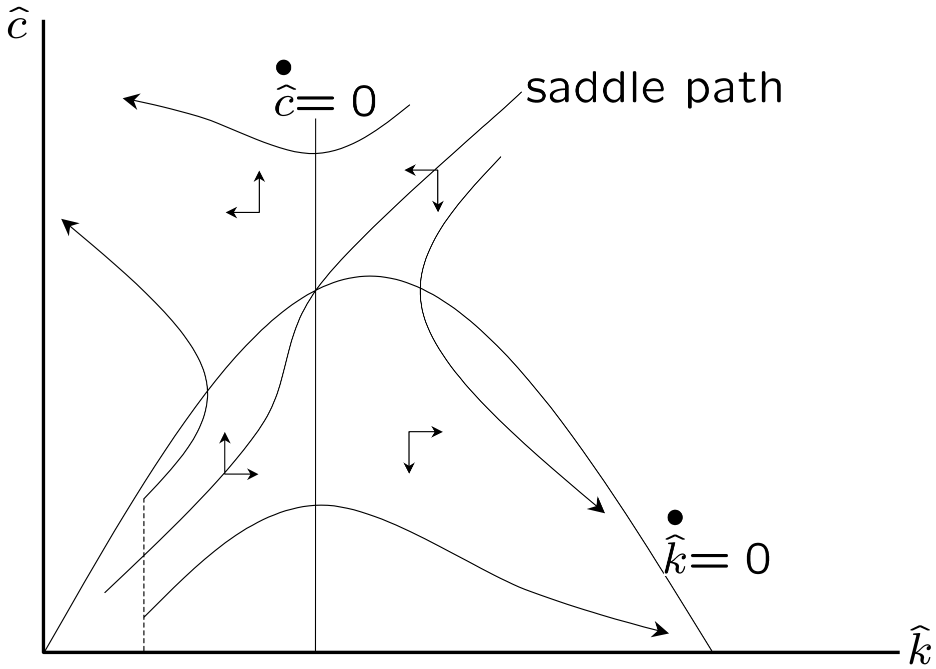

Figure 3-1: Phase Diagram Ramsey Model

If the capital intensity is below (left to) the $\dot{\hat{c}} = 0$ line, the marginal return on capital will be in excess of $\rho + \theta g (1 - \alpha)^{-1}$ inducing further postponement of consumption and thus $\dot{\hat{c}} > 0$ (3.10). To the right of the $\dot{\hat{c}} = 0$ line the marginal return falls short of $\rho + \theta g (1 - \alpha)^{-1}$ and the representative individual chooses a $\dot{\hat{c}} < 0$ consumption schedule. These motions are indicated by the arrows and it can be seen that two out of the four areas have the potential to allow a motion towards the steady state (southwest and northeast). The according path is the so-called saddle path, as all other paths diverge. What remains to be shown is that it is rational for the representative individual to consume in accordance with the saddle path. It can be seen that all trajectories above the saddle path will result in $\hat{k} = 0$[6] and therefore $\hat{c} = 0$. Such behavior is clearly

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[6]Since $\dot{\hat{c}} > 0$ and $\dot{\hat{k}} < 0$ the economy strives towards $\hat{k} = 0$ at an accelerating speed (3.9). Negative capital stock (liabilities) cannot be accumulated. Firstly this would violate the

not optimal[7].

Beneath the saddle path the consumption is relatively too low, and capital will be accumulated in excess of the steady state level. The economy approaches the crossing of the $\overset{\bullet}{\hat{k}} = 0$ schedule and the abscissa. The combination of low consumption (ergo high marginal utility) and a relatively large capital stock violates the transversality condition (Appendix 3.A.1, Equation 3.36), whereby this path can also be excluded.

Therefore it can be concluded that the economy will remain on the stable path and approach the unique and stable steady state solution[8] with $\hat{c} = \hat{k} = 0$ and (Appendix 3.A.1, Equation 3.36)

$$\begin{aligned} \dot{c}/c &= \dot{k}/k = (1-\alpha)^{-1} g \\ \dot{Y}/Y &= n + (1-\alpha)^{-1} g. \end{aligned}$$

3.1.4 Summary

As the name 'exogenous growth model' indicates, the growth rate is exogenous in the long-term and determined by the given technology and population growth. Neither personal preferences (ρ and θ) nor government interventions affect the long-term growth rate. The reason is that marginal return of the accumulated factor capital is approaching zero, while existing capital is diluted by population growth. Thereby, exceeding a critical value of capital, the marginal product will fall short of 'dilution costs' of capital and growth via accumulation comes to a standstill.

The households' preferences affect savings, however, these have a growth impact only during the stages of transition dynamics, i.e. outside the steady state. For this thesis it is sufficient to note that exogenous growth models are thus not suited for extensions which explain impacts upon the long-term growth rate[9].

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transversality condition (3.6), secondly in a closed economy with homogenous agents there is no creditor accepting such a debt contract.

[7] Technically the jump from positive consumption to zero consumption violates the Euler equation (3.5), in the moment when $k = 0$ (Blanchard and Fischer 1989, p. 47).

[8] The trivial solution $k = 0$ is of no interest.

[9] The comparative statics and extended analysis of the transitional dynamics of a similar Ramsey model can be found e.g. in Barro and Sala-i-Martin (2004) .

3.2 Endogenous Growth Models

> "[T]he job of any model of *endogenous growth* is simply to keep the marginal product of capital from falling too fast as capital accumulates." (Solow 1992, p. 40)[10]

The shortcoming of exogenous growth models to define instead of explaining the growth rate has induced the development of so-called endogenous growth models. Characteristically for endogenous growth models is the determination of the growth rate within the model via the individuals' decision - and therefore preferences - to accumulated or/and allocate resources. Policy options thereby gain importance, because any policy which influences the accumulation or allocation decisions also affects the growth rate. The following analysis is tailored to support the subsequent literature discussion and ease the understanding of the new models introduced in this thesis. The discussion of extensions regarding the Pareto optimality, potential policies, and variation of the assumptions are kept to a minimum. One subsection is devoted to the so-called scale effect, since it is an important point of critique in the evaluation of endogenous growth models.

3.2.1 Positive Externalities of Capital Accumulation: AK Model

In the exogenous growth model technology growth was a defined fixed constant. Here this assumption is exchanged for the assumption that technology growth is a function of capital accumulation. To facilitate the discussion, the growth rate of capital intensity[11] is used as the driving force for technology growth like in Frankel (1962):

$$\dot{A} = A\left(1-\alpha\right)\frac{\dot{k}}{k} \tag{3.11}$$

There are several economic intuitions of such an externality, however as Sørensen and Whitta-Jacobsen aptly put it, "[t]here may be a bit of hand waving involved here" (Sørensen and Whitta-Jacobsen 2005, p. 223). The capital inten-

[10] Quotation found in Costa (2003).

[11] The standard reference (Romer 1986) uses aggregate (knowledge) capital accumulation.

sity can be used as proxy for a "development modifier" (Frankel 1962, p. 998), which enters the final good production function just as technology and can be interpreted accordingly. The notion of learning by doing, i.e. knowledge accumulation as a by-product of investment, is highlighted by Arrow (1962) and also adopted by Romer (1986), who highlights that the new knowledge is largely nonexcludable. Positive externalities of human capital is at the heart of Lukas' (1988) intuition; the productivity of human capital within the firm depends upon the (frictionless) interaction with the firm's environment. Therefore, a productivity gain requires an increase of the total economy's human capital and is as such an externality.
Since the technology production function is the only alteration to the previous model (Equation (3.11) instead of (3.1)), the solution follows immediately.

Equilibrium

As before, the capital accumulation is given by the solved intertemporal budget constraint (3.7) and the optimal consumption schedule (3.8). Both are a function of the marginal return of capital which is determined by the first order condition of the firm (3.2). With the specific assumption of the technology growth (3.11) , the interest rate will be a constant:

$$\begin{aligned} r &= A\alpha k^{\alpha-1} \qquad (3.2') \\ \frac{\dot{r}}{r} &= \frac{\dot{A}}{A} + (\alpha-1)\frac{\dot{k}}{k} = (1-\alpha)\frac{\dot{k}}{k} + (\alpha-1)\frac{\dot{k}}{k} = 0 \end{aligned}$$

Defining $a \equiv Ak^{\alpha-1}$ $(= r/\alpha)$, capital (3.7) and consumption (3.8) growth can be rewritten as

$$\frac{\dot{k}}{k} = a - n - \frac{c}{k} \qquad (3.7')$$

and

$$\frac{\dot{c}}{c} = \frac{\alpha a - \rho}{\theta}. \qquad (3.8')$$

The balanced growth path $\left(\dot{k}/k = \dot{c}/c\right)$ is given by

$$c = \left(a - n - \frac{\alpha a - \rho}{\theta}\right) k. \qquad \text{(AK bgp)}$$

This is in line with the transversality condition. Capital accumulation (3.7′) comes to a halt once $\dot{k} = 0$, i.e.

$$c = (a - n)\, k. \qquad (\dot{k} = 0)$$

These two equations are depicted in the phase diagram in Figure 3-2 and used for the exposition of the dynamics.

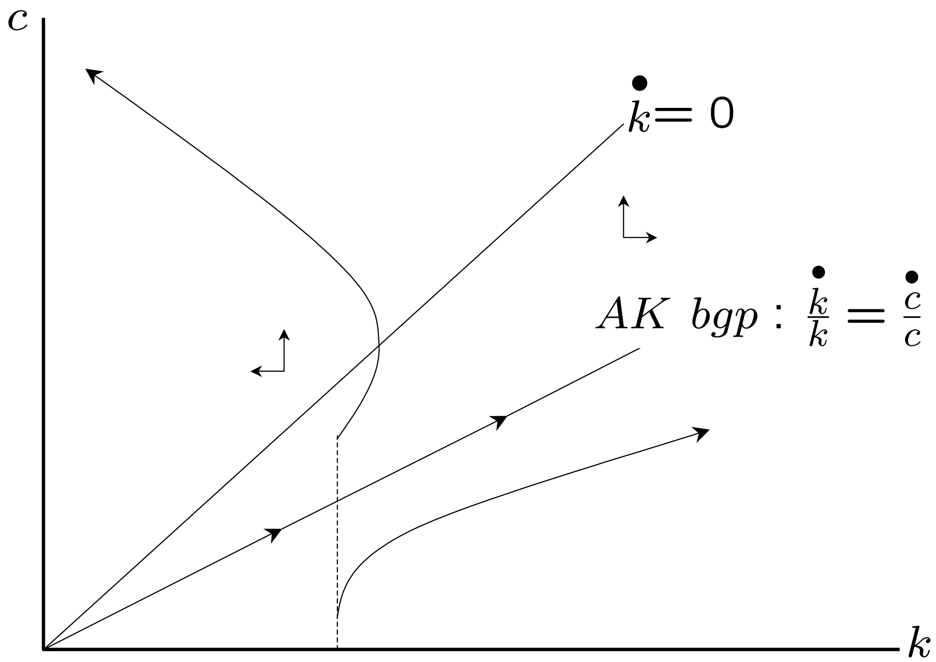

Figure 3-2: Phase Diagram AK Model

The consumption growth rate is determined exclusively by parameters (3.8′) and is therefore constant and positive if $\alpha a - \rho > 0$, which is assumed hereafter. Since the marginal return on capital is a constant, consumption growth does not adjust, and the dynamics are a given by the capital motion (3.7′). The $\dot{k} = 0$ line divides the quadrant in an area of decreasing (above) and increasing (below) capital intensity. The two arrows indicate that technically the system is instable: Once a consumption to capital ratio is chosen that deviates from

the balanced growth path ($AKbgp$), the preceding choices further divert from the balanced growth path. The reason is that the consumption growth cannot adjust and capital accumulation is decreasing in the consumption to capital ratio, whereby initial deviations becomes self-reinforcing.
What remains to be shown is that the economy will always remain on the balanced growth path. In the following paragraphs it is shown that all other paths violate the setup of the model (proof by contradiction).
Above the balanced growth path ($AKbgp$), the consumption to capital ratio c/k is 'too high' and capital accumulation is insufficient, whereby the ratio further increases. Once the $\dot{k} = 0$ line is crossed, the capital intensity even decreases in absolute values and strives to zero. When the last unit of capital is consumed ($k = 0$), the economy crashes. This is obviously a suboptimal growth path, whereby rational individuals restrain from choosing consumption in excess of the balanced growth path. Technically the jump from the last positive consumption to zero consumption also violates the Euler Equation (3.5). Beneath the balanced growth path the consumption to capital ratio c/k is 'too low'. Capital grows in excess to consumption, whereby the ratio decreases further and $\dot{k}/k_{t\to\infty} = a - n$ (3.7′), which violates the transversality condition (3.6) (Appendix 3.A.2). As a result, only the balanced growth with $\dot{c}/c = \dot{y}/y = \dot{k}/k$ remains as the unambiguous long-term solution.

By using the constant marginal return on capital $A\alpha k^{\alpha-1} = \alpha a$ in the per capita production function $y = Ak^{\alpha}$, one reveals why this type of model is denoted AK[12]:

$$\begin{aligned} y &= Ak^{\alpha-1}k \\ &= ak \end{aligned} \tag{3.12}$$

Due to the constant marginal return to capital, steady state growth can be achieved via capital accumulation. The accumulation itself is a choice of the individuals, according to their preferences and market prices, whereby the solution is endogenous and subject to government policies that affects prices

[12] According to Barro and Sala-i-Martin (2004) AK type models esteem from von Neumann (1937).

and thus decisions.

Discussion

In AK-type models, technology growth is depicted as an externality of (human) capital accumulation. The externality is assumed to exactly offset the otherwise decreasing marginal return of the accumulated factor, whereby the marginal return is constant (3.12). This situation is shown in Figure 3-3. The accumulation decision determines the growth rate, which is an endogenized function of the households preference. Due to the externality the accumulation decision is not Pareto optimal, as the household optimizes via the market interest $r = a\alpha$ which falls short of the real marginal return on capital a (3.12). Governmental interventions, such as subsidizing capital accumulation with a lump sum tax, can increase the growth rate and welfare by internalizing the technology externality. The fact that technological progress is a plain externality in the AK model is not consistent with the real world observation of firms investing intentionally in R&D. The following models focus explicitly upon the incentives to invest in technology production.

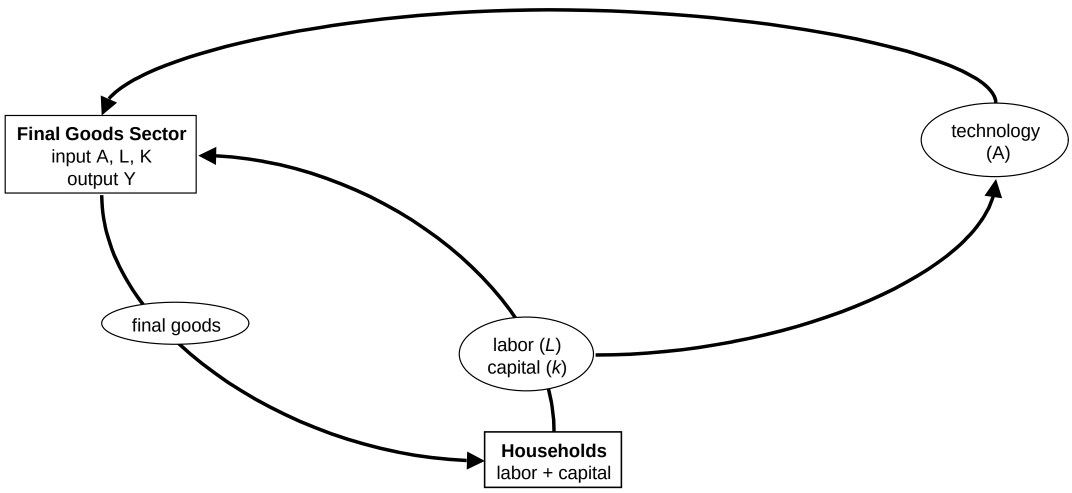

Figure 3-3: Schema AK Model

3.2.2 Increasing Product Varieties: Romer Model

Romer (1990) has applied Dixit and Stiglitz's (1977) concept of 'love of variety' to the production function. He splits production into two stages and distinguishes between an intermediate good sector and a final good sector. An increase of the variety of intermediate inputs is assumed to spur productivity of the final good sector similar to technology improvements in the previous model. To allow for Schumpeter like entrepreneurial behavior, Romer (1992) has introduced market power into his model. Due to patent rights, the technology for the production of the new variation is excludable and allows for a monopoly. This fills the previous gap, as the value of a new monopoly licence is an incentive for intentional R&D investments. In this kind of model the nonrival characteristic of technology is used by allowing free utilization of the total technology stock in the R&D process.

As shown in Figure 3-4 the economy consists of a final good sector, intermediate good sector, a R&D sector, and households. The final good sector produces final goods, using labor and intermediate goods as inputs. The intermediate good sector uses final goods as inputs and obtains the right to produce a certain intermediate good variety from the R&D sector. The R&D sector develops technologies for new intermediate good varieties using existing technology and labor as input. The household supplies labor inelastically and optimizes via its consumption choice.

Final Good Sector

The production of the final good sector is a function labor allocated to this sector (L_F) and the variety (A) and amount (X) of intermediate inputs[13][14]

$$Y = L_F^{1-\alpha} \sum_{i=1}^{A} X_i^{\alpha}. \tag{3.13}$$

[13] Instead of achieving perfect competition in the final good sector by a mutlitude of final good sectors, perfect competition is simply assumed to simplifiy notation.

[14] This specification of a production function originates from Ethier (1982). Similarily, Romer (1987) and (1990) used this specification to model technological change and growth, driven by newly invented variations of productive inputs.

The representative firm producing the final good maximizes profits according to the profit function $\pi_Y = Y - wL_F - \sum_{i=1}^{A} P_i X_i$ with P_i denoting the price of intermediate input X_i. Using the first order conditions, the demand for intermediate inputs and the wage rate can be derived (Appendix 3.A.2)

$$X_i = L_F \left(\frac{\alpha}{P_i}\right)^{\frac{1}{1-\alpha}}, \tag{3.14}$$

$$w = (1-\alpha)\left(\frac{Y}{L_F}\right). \tag{3.15}$$

The intermediate inputs enter the production function in an additive separable way. Thereby, they are neither complements nor substitutes, and a new intermediate input does not affect the first order conditions of the existing goods. Later it will be shown that all X_i have the same price and marginal productivity, and will be used in equal quantities, whereby the production of final output simplifies to the familiar form

$$Y = AL_F^{1-\alpha}X^{\alpha}. \tag{3.16}$$

Here the technology-like effect of the variety of intermediate goods becomes obvious. With constant population long-term growth is equivalent to the 'technology' growth. The technology growth is a result of the R&D activities described in the next paragraph.

R&D Sector

The most important property of this model type is that technology progress is the result of a purposeful research effort. Property rights induce excludability, whereby the invention of a new product variation results in a marketable monopoly licence for the production of the according new intermediate good variation. Following Romer (1990) technology improvements are a result of labor (human capital) allocation towards R&D activities (L_R).

$$\dot{A} = \delta L_R A \tag{3.17}$$

For the R&D activities, existing technology can be used for free as it is nonrival and only partially excludable. Marginal innovation of a researcher is δA. The value of the according licence is denoted V, and free entry to research will take place until the marginal cost of research (the wage bill) equals the marginal revenue product:

$$w = \delta A V \tag{3.18}$$

The value of a new monopoly itself is a function of the monopoly power and is elaborated upon in the next subsection.

Intermediate Goods Sector (Monopoly)

The intermediate good producer has to obtain a licence for production. Then he holds a monopoly position and faces the intermediate good demand of the final good producer (3.14). For simplicity the average and marginal production cost of the intermediate good itself is set to one unit of final output. The according monopoly profits $\pi_m = (P_i - 1)X_i$ can be maximized statically by the optimal choice of the intermediate good price P_i, since they do not contain any intertemporal arguments. The Cournot price is (Appendix 3.A.2)

$$P = \frac{1}{\alpha} \tag{3.19}$$

for all intermediate inputs which explains the aforementioned simplification of Equation (3.16). The steady state present value of such an monopoly is (Appendix 3.A.2)

$$\begin{aligned} V(t) &= \int_t^\infty \pi_m e^{-r(v,t)(v-t)} dv \qquad (3.20) \\ &= \frac{Y\alpha(1-\alpha)}{rA}. \qquad (3.21) \end{aligned}$$

Households

The household problem is altered in two ways. Firstly, it is assumed that the representative household and thus population do not grow. This assumption is necessary as the growth model introduced in this section cannot achieve balanced growth with growing population. A detailed discussion regarding population growth follows in Section 3.2.4. The second alteration is that, due to the lack of real capital, households cannot accumulate capital and the intertemporal budget constraint must be slightly adjusted. The households assets are the ownership of the intermediate good monopolies and denoted a. The decision the household faces is saving (in new monopoly licences) versus consumption.

$$\dot{a} = ra + wL - c$$

Since work satisfaction and wages are the same in the final good and R&D sector, labor allocation is not an explicit choice of the household. The previous Euler Equation (3.5) with zero population growth $n = 0$ still applies.

Equilibrium

In equilibrium the labor market $L = L_F + L_R$ and capital market $a = AV$ must be balanced while fulfilling the first order conditions of the agents. The equilibrium wage rate satisfies the first order condition for labor of the final good sector (3.15) and the R&D sector (3.18). The labor market clearing requires (Appendix 3.A.2)

$$r = \delta\alpha\left(L - L_R\right). \tag{3.22}$$

Higher interest rates thus reduce the labor allocation towards R&D activities in favor of final good production. The intuition is that the present value of new innovations decreases with rising interest, whereby labor demand of that sector decreases.

Since there is no real capital in this simplified model, using the term "interest rate" might appear misplaced. However, the intuition is that allocation of labor towards the R&D sector diminishes present final good production and thus consumption. The according utility loss must be balanced via according future utility gains, i.e. consumption gains. These gains are a result of the R&D output: the new innovation, and according productivity increases. Therefore, it can be said that savings accrue in the form of consumption (present production) foregone in favor of future consumption (productivity) increases.

With the labor market equilibrium (3.22) the Euler Equation (3.5) can be rewritten

$$\frac{\dot{c}}{c} = \frac{\delta\alpha\left(L - L_R\right) - \rho}{\theta},$$

which must equal the technology progress (3.17) on the balanced growth path. The steady state R&D activity (Appendix 3.A.2) and technology progress are

$$L_R = \frac{\delta \alpha L - \rho}{\theta + \alpha} \tag{3.23}$$

$$\frac{\dot{A}}{A} = \delta \frac{\delta \alpha L - \rho}{\theta + \alpha}. \tag{3.24}$$

Ergo growth is endogenous in the sense that the time and risk preferences (ρ, θ) determine the growth rate. Further, any policy that affects the allocation of labor also affects the growth rate.

Discussion

As opposed to the AK model, the technological progress her is a result of an intentional research effort. By assuming that the new technology is nonrival, but partially excludable a typical monopoly arises. The monopoly profits give the market incentive for the initial research outlays. In the presented form the technology progress is driven by labor allocation towards the R&D (see Figure 3-4).

The constant marginal return (δL_R) of the accumulating factor A is what allows unbounded steady state growth. Romer even states that "in this sense, unbounded growth is more like an assumption than a result of the model" (Romer 1990, p. 84).

The labor allocation towards research depends upon the personal preferences and can be affected by governmental policies. Like in the AK model the market solution is not Pareto-optimal. The intermediate good monopolies cause static inefficiencies as they supply only at the Cournot price (markup $1/\alpha$). Research and thus the growth rate are also suboptimal, since the positive impact of a new innovation upon the production of future innovation is not internalized. However, simply decreasing monopoly power, e.g., by relaxing patent rights, would diminish the incentive for R&D worsening so-called "dynamic inefficiency". Dynamic inefficiency describes the situation where an inefficient amount of R&D is realized. Even without interventions, R&D is already suboptimal, since the inventors do not take into account the positive externality of their invention upon future research. Therefore, more elaborate schemes, such as a lump sum financed subsidy on the intermediate good, are required.

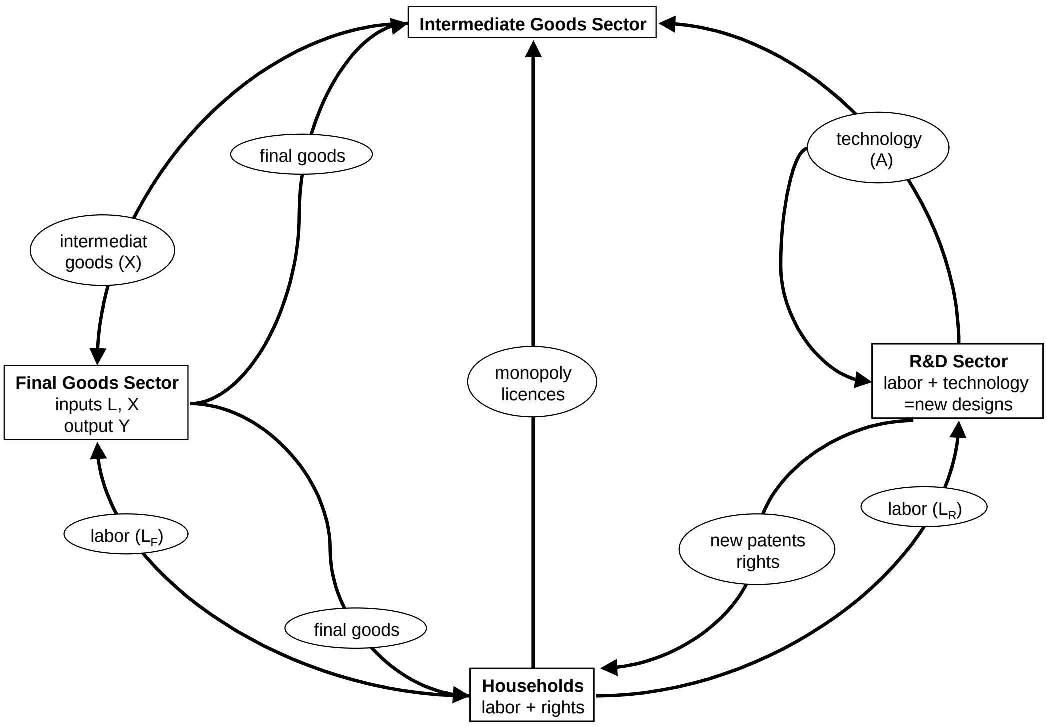

Figure 3-4: Schema Romer and Schumpeterian Growth Model

3.2.3 Product Quality Ladder: Schumpeterian Growth Model

The Romer model has refreshed the interest in Schumpeter's hypothesis of growth. The previous model already grasped the notion of purposely R&D in prospect of a resulting monopoly position. However, Schumpeter's concept that new technologies substitute older ones and therefore 'destroy' older monopolies has not been included. This process of so-called creative destruction was modeled by Segerstrom, Anant and Dinopoulos (1990), Grossman and Helpman (1991), and Aghion and Howitt[15] (1992). Figure 3-5 depicts this

[15] Aghion and Howitt (1998) cite Segerstrom, Anant, and Dinopoulos (1990) as the earliest attempt to model creative destruction. They also provide a very simple benchmark model

as a "vertical" (Aghion and Howitt 1998) movement on a "quality ladder" (Grossman and Helpman 1991), whereby intermediate products on the lower steps lose competitiveness. In this context the previously modeled increase in product varieties can be depicted as an additional ladder in the horizontal direction. Both mechanisms are not mutually exclusive, however for simplicity the following analysis is confined to a single intermediate product (ladder).

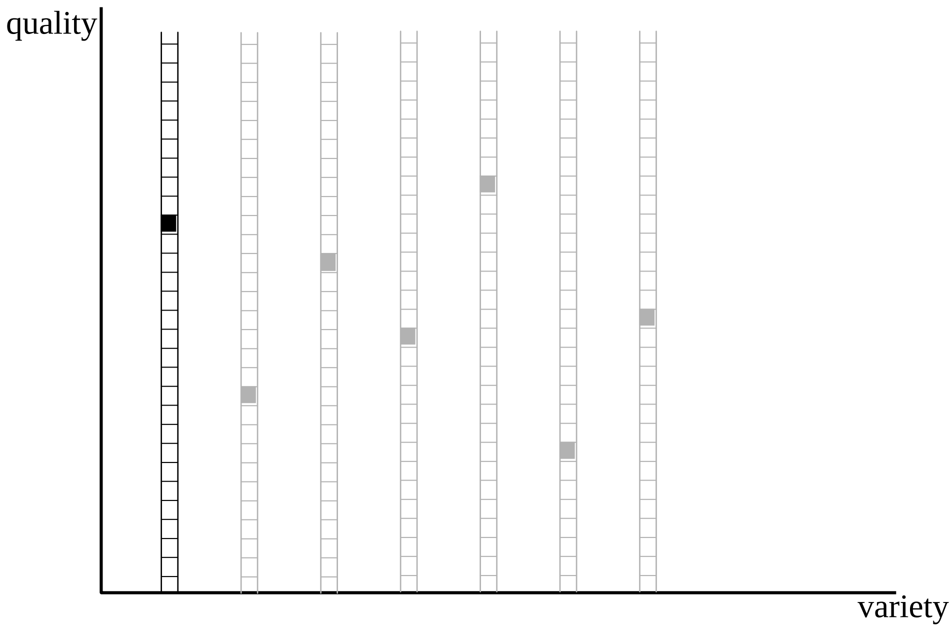

Figure 3-5: Quality Ladder and Increasing Varieties

Further it is assumed that innovation is drastic, in other words an existing intermediate product monopoly cannot compete with the following quality of intermediate good and will go out of business as soon as research is successful.

Just as in the Romer model Figure 3-4 and the role of economic actors still apply. There are only two differences. Firstly, the R&D sector does not invent an additional intermediate good variety but an improved intermediate good.

(Aghion and Howitt forthcoming).

Secondly, the intermediate good producer faces the risk that a latter, better intermediate good drives him out of business.

Final Good Sector

The final product Y is produced with the intermediate input X_i, which is associated with the technology A_i[16].

$$Y = A_i L_F^{1-\alpha} X_i^{\alpha} \tag{3.25}$$

Profits are $\pi_y = A_i X_i^{\alpha} L_F^{1-\alpha} - P_i X_i - w_i L_F$. Accordingly, the first order conditions for the intermediate good and labor are

$$P_i = \alpha A_i X_i^{\alpha-1} L_F^{1-\alpha} \tag{3.26}$$

$$w_i = A_i X_i^{\alpha} L_F^{-\alpha}, \tag{3.27}$$

and thus the same as in the previous Romer model.

R&D Sector

The R&D sector employs labor L_R to produce innovations that increase the productivity of the intermediate good in the final production by the constant factor γ, i.e. $A_{i+1} = \gamma A_i$. The time required until research is successful (resulting in an innovation) is random. Technically this is depicted by a Poisson process, where the probability of a researcher being successful before a certain time T is given by $1 - e^{\lambda T}$ and the flow probability, i.e. success probability for an infinitely short period of time, is given by the Poisson arrival rate λ (Aghion and Howitt 1998, p. 55). Assuming that each researcher's success is independent of the others'[17], the Poisson processes are additive and the

[16] The notation is oriented at Aghion and Howitt, i.e. the setup is written in technology terms (i) and not in time (t). Note that Aghion and Howitt call them t and τ.

[17] This assumption causes the linearity in L_R of the technology production function (3.28). It means that the chance of finding a new innovation is not affected by other researchers. Alternatively, it could be assumed that the chance is diminishing, e.g. because other researchers fish ideas out of a pool with a fixed amount of ideas. Similarly, it could be imagined that joint research projects have increasing returns to scale, whereby the probability of success would increase.

expected amount of innovations I at each point in time is a function of the aggregate research effort:

$$I = \lambda L_R$$

This can be translated into the growth rate of the technology stock A[18]

$$\dot{A} = \lambda L_R \ln \gamma A. \tag{3.28}$$

Denoting the value of a new patent V_{i+1}, the expected return of research is $\lambda L_R V_{i+1}$. Therefore, expected profits are $\pi_R = \lambda L_R V_{i+1} - w_i L_R$, and the according first order condition is

$$w_i = \lambda V_{i+1}. \tag{3.29}$$

Note that this equation contains an "inter-technology" element, since wages are a function of today's technology (i), while the marginal revenue product hinges upon the next technology ($i + 1$).

Intermediate Good Sector

The intermediate good sector differs from the previous product variation model only in regard to the duration of the monopoly position. The fact that an improved intermediate good is now assumed to be a substitute to the existing intermediate good limits the present value of the monopoly licence. In this simple model innovations are assumed to be "drastic", i.e. only the latest intermediate input is competitive (Aghion and Howitt 1998, p. 74) and the previously existing monopoly is out of business immediately after new innovation. The likelihood in each period of time that the monopoly position is lost depends upon the research activity λL_R. The expected present value is then (Appendix 3.A.2)

$$V = \frac{\pi_X}{r + \lambda L_R}. \tag{3.30}$$

[18] The impact of one innovation can be written $\ln A_{i+1} - \ln A_i = \ln \gamma$. Translating this into terms of time, the amount of innovations per period must be used. This is not one but $\lambda L_{R\&D}$

$$\ln A_{t+1} - \ln A_t = \lambda L_{R\&D} \ln \gamma.$$

This depicts the average growth rate of technology. For continuous time, $\lim_{\Delta t \to 0} \ln A_{t+\Delta t} - \ln A_t = \partial (\ln A) / \partial t$. The latter is equivalent to the growth rate $\dot{A}/A$.

The discount rate consists of the foregone interest r and the probability λL_R that the monopoly licence becomes worthless due to a new innovation. For simplicity, it is assumed that the monopolist does not pay V immediately, but rather a licence fee $\pi_{X_i} e^{-\lambda L_R t}$ over time[19].

Equilibrium

The steady state output growth is a function of research efforts as the steady state intermediate input is constant. Combining the final good production function (3.25), the technology growth rate (3.28), and $\dot{X} = 0$ the steady state growth rate is depicted by[20]

$$\frac{\dot{y}}{y} = \lambda L_R \ln \gamma. \tag{G}$$

Discussion

The quality ladder model in this section differs from the product variation model only in regard to the "direction" of the innovation. The innovation improves existing intermediate goods instead of adding new varieties of intermediate goods (Figure 3-5). Since the improved intermediate products enter the production function as substitutes instead of being additively separable, former patents loose their value. This so-called business stealing effect (Aghion and Howitt 1998) is increasing the effective discount factor of the monopoly profits (3.30) and thus diminishes the incentive for R&D. An interesting source of inefficiency results: too much research could take place, as the researcher strives to capture the whole future expected monopoly rents, whilst for the social welfare the redistribution of the existing rent from the present to the

[19] If one assumes a perfect credit market between the innovation firm and the monopolist (e.g. vertical integration as in Aghion and Howitt, 1998), then it does not matter if it is a once off payment or a periodical licence fee. Further, one can imagine that the licence simply becomes more expensive once the latest innovation is utilized. Here, the monopolist and the innovator are treated seperatly in order to reveal their optimization.

[20]

$$\begin{aligned} \ln y_t &= \ln A_t + \alpha \ln X_t \\ \frac{\dot{y}}{y} &= \frac{\dot{A}}{A} = \lambda L_R \ln \gamma \end{aligned}$$

next monopolist is not a gain. The fraction of research that exceeds the social optimum can be interpreted as unproductive rent-seeking activity.

3.2.4 Scale Effect

The presented intermediate product variety and quality ladder models share the characteristic that the growth rate of technology (3.17 and 3.28) is increasing in the population. The standard AK model (Romer 1986), with aggregate capital accumulation as the source for the positive externality upon technology growth, also shares this feature. This is the so-called scale effect and implies that large countries grow faster than small countries. Further, with an increasing population the growth rate itself is growing. This is in contrast to empirical observations[21] (Jones 1995).
Technically, the scale effect can be easily eliminated by using the fraction[22] of researchers in the total population as the driving force for technology growth:

$$\dot{A} = \delta \frac{L_R}{L} A$$

However, such a connection is not empirically observed. Worse, it implies that 1 researcher out of a population of 10 is producing the same technological progress as 1 million out of a population of 10 million (Jones 1995, S. 763). Therefore, eliminating the scale effect is achieved at the cost of technically unproductive labor at the aggregate level which is an unsolvable inconveniency of endogenous growth models (Sørensen and Whitta-Jacobsen 2005, p. 234).
Fortunately, even if the scale effect cannot be usefully eliminated, endogenous growth models are not necessarily falsified by empirical observations. Some of the most forceful arguments for this claim are:

- The theory of endogenous growth applies only to leading countries. Countries in the catching-up process copy, rather than innovate technology and thus should be excluded in the empirical tests. (Jones 1995, S. 777)

[21] Although Romer was already aware of the scale effect, he noted in his abstract: " ...large countries may always grow faster than small countries. Long-run evidence is offered in support of the empirical relevance of these possibilities". (Romer 1986)

[22] Similarly, in the AK model presentation the spillover to technology is assumed to be a function of the capital intensity (also used by Frankel, 1962 and Lucas, 1988), which eliminates the scale effect.

- Technology is nonrival and with the weak assumption that it diffuses across boarders, the relevant population is not bound to one country, but rather to a usefully defined multinational area (Jones 1995, S. 777). Using the world population, the scale effect no longer contrasts empirical observations, i.e. world growth increased with world population (Kremer 1993).
- For R&D activities human capital rather than physical labor is the vital input (Romer 1990). There is no proper match between countries' labor endowment and human capital endowment, whereby the standard classification as a large country is erroneous.

Considering these limitations of the empirical literature, the use of endogenous growth models can be considered valid, as long as the examined questions are unrelated to population size or growth.

3.3 Semi-Endogenous Growth

The innovation technology itself is at the center of the discussion regarding endogenous versus semi-endogenous growth. Jones (1995) points out that the technology production functions (3.17, 3.28) in the Romer and Schumpeterian model are a special case of

$$\dot{A} = \delta L_R^{\lambda} A^{\phi} \tag{3.31}$$

with the assumption $\lambda = \phi = 1$. This critical assumption was also highlighted by Gries, Wigger and Hentschel (1994), who altered the Lucas-Uzawa model to discuss the underlying mechanism of endogenous growth and criticize that the required choice of parameters is "just as exogenous as the original postulate". λ determines the marginal productivity of researchers. Since researchers are productive λ is positive. When there are economies of scale within research $\lambda > 1$, however, this case is not very likely for the aggregate level. Thus $0 < \lambda \leq 1$ is a weak assumption. The assumption $\lambda = 1$ is not critical, since changes of $\lambda \in (0, 1]$ do not affect the main characteristics of the solution.
The exponent ϕ describes the influence of existing technologies upon the development of new technologies. If $\phi < 0$, the development of new technologies

increases in complexity with the technology level. This is also called "fishing out", and can be interpreted as negative externality of present research upon future research. If $\phi > 0$, R&D eases with the level of technology, alike a positive externality. If $\phi > 1$ this positive externality would cause exponential growth. Jones (1995) argues that the assumption $\phi = 1$ is discretionary and unrealistic, and $\phi \neq 1$ will cause non-endogenous steady state growth. For $\phi > 1$ the growth rate is increasing exponentially. Interesting is the case $0 < \phi < 1$. This combination results in constant steady state growth, however eliminates the scale effect and any policy options.

Proposition 1 *The steady state growth rate depends upon the (exogenous) population growth rate if* $0 < \phi < 1$*, whereby it is not affected by policies.*

Proof. The technology growth rate (3.31) is in the steady state constant by definition:

$$\frac{\dot{A}}{A} = \delta \frac{L_R^\lambda}{A^{1-\phi}} = \text{constant}$$

The long-term labor force of the research sector grows at the same rate as the population $\dot{L}_R / L_R = n$, since the fraction of researchers in the population would otherwise strive towards zero, whereby the economy becomes trivial. The growth of the technology growth rate can be written

$$\lambda n - (1 - \phi) \dot{A}/A.$$

If this term is negative, technology growth decreases and vice versa, whereby the system is stable and the steady state growth rate is

$$\frac{\dot{A}}{A} = \frac{\lambda n}{(1 - \phi)}.$$

■

Therefore, the steady state growth rate is not endogenous in the sense that it is affected by the preferences or policy options. However, technology growth is still endogenous insofar as it is determined within the system via the allocation of resources. Thus, these types of models are denoted "semi-endogenous" (Jones 1995, S. 761).

The discussion regarding semi- versus endogenous growth has been enriched by the works of Aghion and Howitt (1998), Dinopoulos and Thompson (1998), Peretto (1998) and Young (1998), which allow for a growth of quality and variety of intermediate products[23], that is a vertical as well as horizontal innovation in Figure 3-5.

If the growth of varieties is equivalent to the population growth, the number of researchers per sector, and thus quality growth, can remain constant and endogenous (Jones 1999).

However, Jones (1999) once again shows that these models rely on a very specific value of a parameter. Endogenous growth only results if and only if the relation (ϱ) of sector (variety) and population growth equals exactly one. For $\varrho \neq 1$ growth becomes semi-endogenous. If the number of varieties is growing slower than the population ($\varrho < 1$), more researchers are available for qualitative progress and technology growth explodes (Jones 1999). If, on the other hand, population growth falls short of the growth of varieties ($\varrho > 1$), the number of researchers for each variety, and thus quality progress, strives towards zero, whereby the growth rate becomes semi-endogenous again (Jones 1999).

Subsuming endogenous growth models rely on the strong and arbitrary assumptions $\varrho = 1$ or $\phi = 1$, respectively. Therefore one might consider endogenous growth models unrealistic and not suited to discuss questions of long-term growth. However, such a conclusion is precipitous. Preferences and thus policy options do have a level impact in semi-endogenous growth models and the speed of the transitional dynamics relies upon ϕ. Already with $\phi = 0$ the half-life of the spur in total factor productivity growth is 35 years, while the half-life for the wage increases is even 62 years (Jones 1995, p. 773). Further, the half-life is rising in ϕ and for $\phi = 0.5$ the previous values increase to 69 and 120 years, respectively (Jones 1995, p. 773). Since empirical estimates of ϕ go up to 0.75 (Sørensen and Whitta-Jacobsen 2005) the economy will remain within the transitional dynamics for a very long time.

During this unbalanced growth, semi-endogenous models share the features

[23] Some papers model the increase in variety at the consumption level (love of variety) instead of the intermediate good level. The effect is basically identical.

of endogenous growth models. Therefore endogenous growth with $\phi = 1$ can be understood as a simplification for the examination of these transitional dynamics.

3.4 Summary

All models have been presented in a form that reduces the steady state growth to the technology growth rate. This is consistent with the present empirical observations that total factor productivity is the main driving force for growth in industrialized countries (Sørensen and Whitta-Jacobsen 2005, p. 152). The results are subsumed by Table 3.1. The key difference in the models is the technology production function.

Exogenous growth models simply assume (instead of explaining) technology growth. Therefore, they are not suited to the examination of a long-term finance-growth nexus, and limited to the examination of transitional dynamics.

In endogenous growth models the steady state technology growth rate is a function of individuals preferences. The individual decisions affect the technological progress through three channels.
Firstly, in AK models technology growth is an externality of capital accumulation (Figure 3-3). Due to these positive externality, the market solution is characterized by suboptimal capital accumulation.
Secondly, in the Romer model allocation of labor to the research sector increases the varieties of intermediate inputs. This larger variety of intermediate inputs increases the productivity in the final good production.
Thirdly, the allocation of labor[24] to the research sector increases the quality, and thus productivity of intermediate goods in the Schumpeterian model.
In the Romer and Schumpeterian model, technology progress is the result of a purposely research effort in order to invent an excludable and thus marketable licence (Figure 3-4). The resulting monopoly position is used to recover the initial research outlays. Accordingly, these models suffer the static inefficiency

[24] These models usually focus upon the allocation of human resources, however can also be varied to accommodate accumulation of resources as the driving force for growth.

of a monopoly and additionally dynamic inefficiency of nonoptimal research. In the Romer model dynamic inefficiency is caused by the positive externality of new innovations upon future research productivity. In the Schumpeterian model, business stealing, is a negative externality of research. In the Schumpeterian model it depends therefore upon the extent of business-stealing versus positive research externalities, if there is too much or too little research.
All endogenous growth models fulfill Solow's quote (p. 23) that the marginal product (of technology) is not falling too fast as it (technology) accumulates. However, these models have been criticized for the so-called scale effect that they contain, i.e. they imply that large countries grow faster than small countries. This led to the development of semi-endogenous growth models.

Semi-endogenous growth models share the features of endogenous growth models as long as they are in the transitional dynamics. Due to the relaxed assumption of the technology productivity parameter ϕ can take values between zero and one instead of $\phi = 1$. The marginal productivity of technology is decreasing and steady state growth becomes a function of the production parameters and particularly the population growth rate. Ergo, the steady state growth rate is not influenced by preferences nor policies, whereby these models are unsuited to examine steady state impacts of finance.

Subsuming the literature, semi-endogenous growth models appear to be the most acceptable description of real world economic growth. Thus, any interdependencies of finance and economic growth should depict transitional dynamics phenomena. However, phases of transitional dynamics are very long-lasting and mimic the features of endogenous growth models. In order to focus upon the relevant mechanisms regarding finance, endogenous growth models are used in this thesis. This is consistent with the vast majority of literature analyzing the finance growth nexus.

	Exogenous	Endogenous			Semi-Endogenous
Name Keywords	Solow-Model Ramsey-Model	AK	Romer New Variety	Schumpeterian Quality Ladder	Semi-Endogenous
Seminal Papers	Solow (1956, 1957) Cass (1965) Koopmans (1965)	Romer (1986)	Romer (1990)	Segerstrom et al. (1990) Grossman & Helpman (1991) Aghion & Howitt (1992)	Jones (1995, 1999)
Technology-progress	$\dot{A} = gA$	$\dot{A} = (1-\alpha)\left(\dot{k}/k\right)A$	$\dot{A} = \delta L_R A$	$\dot{A} = \delta L_R A$	$\dot{A} = \delta L_A^\lambda A^\phi$ $\dot{A}/A = \lambda n/(1-\phi)$
Steady State	exogenous definition	capital accumulation decision	labor allocation decision	labor allocation decision	exogenous parameter
Incentive		return on savings	monopoly	monopoly	monopoly
Marketfailure	no	externality	monopoly public good	monopoly public good business stealing	static yes dynamic no
Scale Effect	no	yes	yes	yes	no
Policy Options	no	yes	yes	yes	no

Table 3.1: Overview Growth Models

3.A Appendix

3.A.1 Ramsey Model Appendix

Auxiliary Calculations

Total capital belongs to the representative household. The motion of total capital equals income net of consumption. Calculating the per capita capital motion, the growth rate of the population and the according dilution of capital has to be taken into account. The result is (3.4):

$$\begin{aligned}
\dot{K} &= rK_t + wL_t - cL_t \\
\frac{\dot{K}}{K} &= r + w\frac{1}{k} - c\frac{1}{k} \\
\frac{\dot{k}}{k} &= \frac{\dot{K}}{K} - \frac{\dot{L}}{L} = r + w\frac{1}{k} - c\frac{1}{k} - n
\end{aligned}$$

In equilibrium the market clearing interest rate (3.2) and wage (3.3) can be used in (3.4) which results in (3.7):

$$\begin{aligned}
\dot{k} &= r_t k_t - nk_t + w_t - c_t = r_t k_t - nk_t + Ak_t^{\alpha} - rk_t - c_t \\
&= Ak^{\alpha} - nk - c
\end{aligned}$$

In the steady state the interest rate (marginal return on capital) will be constant, thereby the per capita capital growth rate can be identified as $(1-\alpha)^{-1} g$:

$$\begin{aligned}
Ak^{\alpha-1} &= \text{constant} \\
&\Rightarrow \frac{\dot{A}}{A} + (\alpha - 1)\frac{\dot{k}}{k} = 0 \\
&\Rightarrow \frac{\dot{k}}{k} = \frac{1}{1-\alpha} g
\end{aligned}$$

Steady state output grows at a higher rate, as the population is growing as well:

$$\begin{aligned} Y &= LAf(k) = LAk^{\alpha} \\ \frac{\dot{Y}}{Y} &= n + g + \alpha \frac{1}{1-\alpha} g \\ &= n + \frac{1}{1-\alpha} g \end{aligned}$$

Dynamic Optimization

The method of dynamic optimization is very well explained in the appendix of Barro and Sala-I-Martin (2004) and is applied in this appendix to the maximization problem of the household. The first step is to set up the so-called (present-value) Hamiltonian

$$H = u(c_t)e^{(n-\rho)t} + \lambda_t \left[(r_t - n)\, k_t + w_t - c_t \right],$$

which has to be differentiated with respect to the control variable c_t and the state variable k_t:

$$\frac{\partial H}{\partial c_t} = u'(c_t)e^{(n-\rho)t} - \lambda_t = 0 \tag{3.32}$$

$$\Rightarrow \ln u'(c_t) + (n-\rho)\, t = \ln \lambda_t$$

$$\Rightarrow \frac{u''}{u'}\dot{c} + n - \rho = \frac{\dot{\lambda}}{\lambda} \tag{3.33}$$

$$\frac{\partial H}{\partial k_t} = \lambda\,(r_t - n) = -\dot{\lambda}$$

$$\Rightarrow (r_t - n) = -\frac{\dot{\lambda}}{\lambda} \tag{3.34}$$

This results in $\left[\frac{u''}{u'}c_t\right]\frac{\dot{c}}{c} + n - \rho + (r_t - n) = 0$. Further, the transversality condition $\lim_{t\to\infty}[\lambda(t)k(t)] = 0$, which can be rewritten (3.32)

$$\lim_{t\to\infty}\left[u'(c_t)e^{(n-\rho)t}k_t\right] = 0,$$

must hold. The curvature of the utility curve in the consumption-utility-diagram is best described by $\frac{u''}{u'}c_t \equiv -\theta$, which resembles the intertemporal elasticity of substitution, and is in this case constant, i.e. not affected by growth. This constant intertemporal elasticity of substitution measures the desire of the individual to smooth consumption (Blanchard and Fischer 1989, p. 40). The functional form is more commonly known as constant relative risk aversion (CRRA), however in this model savings are risk-free, whereby the former notion is more useful. In a growth context constant θ is also required to achieve steady state growth. Combining (3.33) and (3.34) results in the so-called Euler Equation (also known as Ramsey- or Keynes-Ramsey rule):

$$\begin{aligned} \left[\frac{u''}{u'}c_t\right]\frac{\dot{c}}{c}+n-\rho+(r_t-n) &= 0 \\ -\theta\frac{\dot{c}}{c}+n-\rho+(r_t-n) &= 0 \\ \frac{\dot{c}}{c} &= \frac{r_t-\rho}{\theta} \end{aligned} \tag{3.5}$$

Variables in Efficient Units of Labor

$$\begin{aligned} \frac{\dot{\hat{k}}}{\hat{k}} &= \frac{\dot{k}}{k}+\left(\frac{1}{\alpha-1}\right)\frac{\dot{A}}{A}=\frac{Ak^{\alpha}-nk-c}{k}+\left(\frac{1}{\alpha-1}\right)g \\ &= Ak^{\alpha-1}-n-\frac{c}{k}+\left(\frac{1}{\alpha-1}\right)g=\hat{k}^{\alpha-1}-n-\frac{\hat{c}}{\hat{k}}+\frac{1}{\alpha-1}g \\ \dot{\hat{k}} &= \hat{k}^{\alpha}-n\hat{k}-\hat{c}-\frac{1}{1-\alpha}g\hat{k} \end{aligned}$$

$$\begin{aligned} \frac{\dot{\hat{c}}}{\hat{c}} &= \frac{\dot{c}}{c}-\frac{1}{1-\alpha}g=\frac{\alpha Ak^{\alpha-1}-\rho}{\theta_t}-\frac{1}{1-\alpha}g \\ \frac{\dot{\hat{c}}}{\hat{c}} &= \frac{\alpha\hat{k}^{\alpha-1}-\rho}{\theta_t}-\frac{1}{1-\alpha}g \end{aligned}$$

Transversality Condition in the Ramsey Model

In order to proof in which cases the transversality condition holds / does not hold, it is best to integrate the Euler Equation (3.5) to obtain

$$c_t = c_0 e^{\frac{\bar{r}-\rho}{\theta}t}$$

where $\bar{r} = \int_0^{v=t} r_v dv/t$ denotes the average interest rate. Using this in the transversality condition (3.6) results in

$$\begin{aligned}
\lim_{t\to\infty}\left[u'(c_t)e^{(n-\rho)t}k_t\right] &= 0 \\
\lim_{t\to\infty}\left[(c_0 e^{\frac{\bar{r}-\rho}{\theta}t(-\theta)}e^{(n-\rho)t}k_t\right] &= 0 \\
\lim_{t\to\infty}\left[c_0 e^{(n-\bar{r})t}k_t\right] &= 0. \qquad (3.35)
\end{aligned}$$

Since $c_0 > 0$, the transversality condition requires

$$\begin{aligned}
\frac{\dot{k}}{k} + n - \bar{r} &< 0 \\
\frac{\dot{\hat{k}}}{\hat{k}} + \frac{1}{1-\alpha}g + n - \bar{r} &< 0. \qquad (3.36)
\end{aligned}$$

In the steady state the interest rate is $\left(3.2,\ \dot{\hat{c}} = 0\right)$

$$\begin{aligned}
r &= A\alpha k^{\alpha-1} \\
&= A\alpha\left(\hat{k}A^{\frac{1}{\alpha-1}}\right)^{\alpha-1} \\
&= \alpha\hat{k}^{\alpha-1} = \frac{\theta g}{1-\alpha} + \rho,
\end{aligned}$$

and the average interest rate will approximate it. Therefore, the steady state is consistent with the transversality condition (3.36) if the personal rate of time preference is sufficiently large (holds by assumption) :

$$\begin{aligned}
0 + \frac{1}{1-\alpha}g + n - \left(\frac{\theta g}{1-\alpha} + \rho\right) &< 0 \\
&iff \\
n\frac{1-\theta}{1-\alpha}g &< \rho
\end{aligned}$$

If the economy is outside the steady state and beneath the balanced growth path depicted in Figure 3-1, it will approach the crossing of the $\dot{\hat{k}} = 0$ locus with the abscissa. Setting $\lim_{t\longrightarrow\infty}\overset{\bullet}{\hat{k}}=\hat{c}=0$ in Equation $\left(\overset{\bullet}{\hat{k}}=0\right)$ results in

$$\hat{k}_{t\rightarrow\infty}^{\alpha-1}=\left(n+\frac{1}{1-\alpha}g\right),$$

and the average interest rate will approach (3.2)

$$\begin{aligned}\lim_{t\rightarrow\infty}\bar{r}_t &= \lim_{t\rightarrow\infty}\alpha\hat{k}_t^{\alpha-1}\\ &= \alpha\left(n+\frac{1}{1-\alpha}g\right).\end{aligned}$$

This low interest rate violates the transversality condition (3.36)

$$0+\frac{1}{1-\alpha}g+n-\alpha\left(n+\frac{1}{1-\alpha}g\right)=(1-\alpha)\left(n+\frac{1}{1-\alpha}g\right)>0,$$

whereby this path can be excluded.

3.A.2 Endogenous Growth Models Appendix

AK Model Transversality Condition

Since the household side did not change the transversality condition is the same as in the Ramsey model (3.6) and can be rewritten as before (3.35): $\lim_{t\rightarrow\infty}\left[c_0e^{(n-\bar{r})t}k_t\right]=0$. Using the fact that the marginal return on capital is a constant ($r=\alpha a$) in the AK model, the transversality condition can be rewritten

$$\frac{\dot{k}}{k}+n-\alpha a<0. \tag{3.37}$$

On the balanced growth path consumption and capital grows at the rate $(\alpha a-\rho)/\theta$ (3.8′), i.e.

$$\begin{aligned}(\alpha a-\rho)/\theta+n-\alpha a &= \\ \frac{(1-\theta)\,\alpha a+\theta n-\rho}{\theta} &< 0.\end{aligned}$$

The last inequality holds, since for bounded utility the following is assumed:

$$\begin{aligned}\int_0^\infty \frac{1}{1-\theta}\left(c_0 e^{\frac{\bar{r}-\rho}{\theta}t}\right)^{1-\theta} e^{(n-\rho)t} dt &< \infty \\ &\Rightarrow \frac{\bar{r}-\rho}{\theta}(1-\theta)+(n-\rho) \leqslant 0 \\ &\Rightarrow \frac{\bar{r}(1-\theta)-\rho+\theta n}{\theta} \leqslant 0\end{aligned}$$

Beneath the balanced growth path $\frac{\dot{k}}{k} > \frac{\dot{c}}{c}$ and $\lim_{t\rightharpoonup\infty} c_t/k_t = 0$, i.e. $\lim_{t\rightharpoonup\infty} \dot{k}/k = a-n$ (3.7′) whereby the transversality condition is violated (Equation 3.6 and 3.37):

$$\begin{aligned}\frac{\dot{k}}{k}+n-\alpha a &= a-n+n-\alpha a \\ (1-\alpha)\,a &> 0\end{aligned}$$

Romer Model

Equation (3.14) is derived as follows

$$\begin{aligned}\pi_Y &= L_F^{1-\alpha}\sum_{i=1}^{A}(X_i)^\alpha - wL_F - \sum_{i=1}^{A}P_iX_i \\ \frac{\partial \pi_Y}{\partial X_i} &= L_F^{1-\alpha}\alpha {X_i}^{\alpha-1} - P_i = 0 \\ &\Rightarrow\ {X_i}^{\alpha-1} = L_F^{\alpha-1}\frac{P_i}{\alpha} \\ X_i &= L_F^{\frac{\alpha-1}{\alpha-1}}\left(\frac{P_i}{\alpha}\right)^{\frac{1}{\alpha-1}} = L_F\left(\frac{\alpha}{P_i}\right)^{\frac{1}{1-\alpha}}.\end{aligned}$$

Equation (3.15) is derived as follows

$$\begin{aligned}\frac{\partial \pi_Y}{\partial L_F} &= (1-\alpha)\,L_F^{-\alpha}\sum_{i=1}^{A}(X_i)^\alpha - w = 0 \\ 0 &= (1-\alpha)\frac{Y_F}{L_F} - w.\end{aligned}$$

Equation (3.19) The intermediate good market equilibrium X_i can be substituted in (3.20) using the first order condition of the final good producer

(3.14). Maximization then leads to Equation (3.19):

$$
\begin{aligned}
V(t) &= \int_t^{\infty} \pi_m e^{-r(v,t)(v-t)} dv \\
&= \int_t^{\infty} (P_i - 1) L_F \left(\frac{\alpha}{P_i}\right)^{\frac{1}{1-\alpha}} e^{-r(v,t)(v-t)} dv \\
\frac{\partial V}{\partial P_i} &= \int_t^{\infty} \left[\begin{array}{c} L_F \left(\frac{\alpha}{P_i}\right)^{\frac{1}{1-\alpha}} \\ +(P_i - 1) L_F \frac{1}{1-\alpha} \left(\frac{\alpha}{P_i}\right)^{\frac{1}{1-\alpha}-1} \left(-\frac{\alpha}{P_i^2}\right) \end{array} \right] e^{-r(v,t)(v-t)} dv = 0
\end{aligned}
$$

Since the discount factor will never be exactly zero, the bracket has to become zero

$$
\begin{aligned}
0 &= L_F \left(\frac{\alpha}{P_i}\right)^{\frac{1}{1-\alpha}} + (P_i - 1) L_F \frac{1}{1-\alpha} \left(\frac{\alpha}{P_i}\right)^{\frac{1}{1-\alpha}-1} \left(-\frac{\alpha}{P_i^2}\right) \\
&= 1 + (P_i - 1) \frac{1}{1-\alpha} \left(\frac{\alpha}{P_i}\right)^{-1} \left(-\frac{\alpha}{P_i^2}\right) \\
0 &= 1 - (P_i - 1) \frac{1}{1-\alpha} P_i^{-1} \\
P_i - 1 &= P_i - \alpha P_i \\
P &= \frac{1}{\alpha}
\end{aligned}
$$

The subscript is no longer required, as this holds for all intermediate goods.

Equation (3.21) results by using the equilibrium price (3.19) and quantity(3.14) in Equation (3.20): The average discount rate is $\tilde{r}(v,t) \equiv [1/(v-t)] \int_t^v r(\omega)\, d\omega$ and with $P = 1/\alpha \Rightarrow \pi_m = \frac{1-\alpha}{\alpha} L_F (\alpha^2)^{\frac{1}{1-\alpha}}$. These identities are used to derive the development of the monopoly value V over time[25]:

$$\begin{aligned}
V(t) &= \int_t^{\infty} \pi_m e^{-\int_t^v r(\omega)d\omega} dv \\
&= \int_t^{\infty} (1-\alpha)\, L_F(v) \alpha^{\frac{1+\alpha}{1-\alpha}} e^{-\int_t^v r(\omega)d\omega} dv \\
\dot{V} &= \int_t^{\infty} (1-\alpha)\, L_F(v) \alpha^{\frac{1+\alpha}{1-\alpha}} r\,(t)\, e^{-\int_t^v r(\omega)d\omega} dv - (1-\alpha)\, L_F \alpha^{\frac{1+\alpha}{1-\alpha}} e^{-\int_t^t r(\omega)d\omega} \\
&= r(t)V(t) - (1-\alpha)\, L_F \alpha^{\frac{1+\alpha}{1-\alpha}}
\end{aligned}$$

In the steady state $\dot{V} = 0$ and thus

$$V = \frac{(1-\alpha)\, L_F \alpha^{\frac{1+\alpha}{1-\alpha}}}{r}$$

Using the equilibrium intermediate good price results in $X = L_F \alpha^{\frac{2}{1-\alpha}}$ and therefore $Y = AL_F \alpha^{\frac{2\alpha}{1-\alpha}}$ and $\alpha Y/A = L_F \alpha^{\frac{2\alpha}{1-\alpha}+1}$. In above equation this results in

$$V = \frac{(1-\alpha)\, \alpha Y}{rA}.$$

Equation (3.22) Labor market equilibrium results from (3.18) = (3.15):

$$\begin{aligned}
\delta AV &= (1-\alpha) \left(\frac{Y}{L_F}\right) \\
\delta A \frac{Y\alpha(1-\alpha)}{rA} &= (1-\alpha) \left(\frac{Y}{L_F}\right) \\
\delta \frac{\alpha}{r} &= \frac{1}{L_F} \\
r &= \delta \alpha L_F \\
r &= \delta \alpha\, (L - L_R)
\end{aligned}$$

[25] The integral can be derived applying the Leibniz-Rule:

$$\begin{aligned}
I(x) &= \int_{a(x)}^{b(x)} F(t,x)dt \\
\frac{\partial I(x)}{\partial x} &= \int_{a(x)}^{b(x)} \frac{\partial F(t,x)}{\partial x} dt + F\,(b\,(x)\,, x)\, \frac{\partial b}{\partial x} - F\,(a\,(x)\,, x)\, \frac{\partial a}{\partial x}
\end{aligned}$$

Equation (3.23) The steady state R&D activity is derived by equalizing the technology progress (3.17) with the Euler Equation (3.5), considering the labor market equilibrium (3.22):

$$\begin{aligned}
\delta L_R &= \frac{\delta\alpha\left(L-L_R\right)-\rho}{\theta} \\
\delta L_R+\frac{\delta\alpha L_R}{\theta} &= \frac{\delta\alpha L-\rho}{\theta} \\
L_R &= \frac{\delta\alpha L-\rho}{\theta}\frac{\theta}{\theta+\alpha}=\frac{\delta\alpha L-\rho}{\theta+\alpha}
\end{aligned}$$

Equation (3.30) Similar to the Romer model the value of the monopoly licence depends upon the present value of future monopoly profits. However, unlike the Romer model there is a chance that the monopoly licence becomes worthless due to a new invention. The likelihood depends upon research activity for the next technology $L_{R_{(i+1)}}$ and the time span. Since the probability that research is successful before time T is $1-e^{-\lambda L_{R(i+1)}T}$ (Aghion and Howitt 1998, p. 55), the probability for non-success is $e^{-\lambda L_{R(i+1)}T}$. The expected present value of an existing licence is thus[26]:

$$\begin{aligned}
V_i(t) &= \int_t^\infty \pi_X e^{-\int_t^v r(\omega)d\omega} e^{-\lambda L_{R(i+1)}(v-t)}dv \\
&= \int_t^\infty \pi_X e^{-\left(\int_t^v r(\omega)d\omega+\lambda L_{R(i+1)}(v-t)\right)}dv \\
\dot{V} &= \int_t^\infty \pi_X\left(r\left(t\right)+\lambda L_{R(i+1)}\right)e^{-\left(\int_t^v r(\omega)d\omega+\lambda L_{R(i+1)}(v-t)\right)}dv \\
&\quad -\pi_X e^{-\left(\int_t^t r(\omega)d\omega+\lambda L_{R(i+1)}(t-t)\right)} \\
&= \left(r\left(t\right)+\lambda L_{R(i+1)}\right)V(t)-\pi_X
\end{aligned}$$

[26] The integral can be derived applying the Leibniz-Rule:

$$\begin{aligned}
I(x) &= \int_{a(x)}^{b(x)} F(t,x)dt \\
\frac{\partial I(x)}{\partial x} &= \int_{a(x)}^{b(x)} \frac{\partial F(t,x)}{\partial x}dt+F\left(b\left(x\right),x\right)\frac{\partial b}{\partial x}-F\left(a\left(x\right),x\right)\frac{\partial a}{\partial x}
\end{aligned}$$

The present value of an existing licence does not change over time and thus

$$V_i = \frac{\pi_X}{r_t + \lambda L_{R(i+1)}} \tag{3.38}$$

Thereby, only steady state solutions can be calculated unambiguously. Outside of the steady state everything depends upon expectations of $L_{R(i+1)}$.

Chapter 4

Review and Discussion of the Finance and Growth Literature

Financial development has been shown to correlate positively with economic growth[1]. This is true for the financial sector in general and for financial intermediaries in particular. Here the focus is upon financial intermediaries and the literature regarding financial markets will only be briefly discussed. A connection between finance and growth has already been emphasized by Bagehot ([1873], 1991), Schumpeter ([1912], 1934), and Gurley and Shaw (1955 and 1967). According to Schumpeter bank loans supply the required purchasing power and thereby enable the entrepreneur to realize innovation. Early empirical support for the view that financial intermediaries foster growth was supplied by Goldsmith (1969). Examining 35 countries for the period 1860-1963 he identified a positive correlation between the fraction of financial intermediaries assets to GDP and GDP growth itself (Khan 2000). Similarly, financial repression was identified as growth retarding (McKinnon 1973).

However, suitable theoretical models, which translate the level effect of financial efficiency into a growth effect, became available only with the development of endogenous growth models (Pagano 1993), which have been discussed in Chapter 3.
As discussed in Chapter 2, finance gains importance if there are some frictions

[1] See e.g. Levine (1997), Beck, Levine and Loayza (2000), Lucchetti, Papi and Zazzaro (2001) and Levine (2003).

within the financial system. Therefore, the models discussing the finance-growth nexus allow for initial frictions and show that financial development eases these frictions, whereby there is an impact upon growth.
This chapter utilizes the growth models explicated in Chapter 3 to discuss the finance-growth nexus literature. Here the focus is upon theoretical causation from banks to growth in closed economies. Excellent existing surveys of the relevant literature are for example Pagano (1993), Beci and Wang (1997) and most prominent Levine (1997 and 2004). To avoid too many duplications of information from these surveys, some of the literature is omitted in this review, in favor of more in-depth discussion of classical references and approaches closest to the newly developed models in Chapter 6 and 5.

Depending on the underlying growth model, two channels for a financial impact can be distinguished.
In AK-type models the growth rate is a function of capital accumulation. If financial development affects the accumulation of capital, the transmission mechanism upon growth is denoted "capital accumulation channel".
Similarly, the so-called "capital allocation channel" describes the growth enhancing effect if financial development changes the allocation of resources in favor of the R&D sector. The underlying growth model is then an intermediate product variety or quality ladder model. However, the production of innovation can require different resources than capital, e.g., labor as in sections 3.2.2 and 3.2.3, whereby the denotation "capital allocation channel" might be misleading. Capital in this context should be broadly interpreted as financial capital, which enables the use of the required resources.
The capital accumulation and allocation channels are not mutually exclusive and can both be depicted within an intermediate good variety and quality ladder growth model. Nevertheless, to ease the overview of the literature, it is discussed along this criteria. In the subsections classical citations are discussed in more detail, while the subsequent work is discussed briefly[2].

Once the literature is clustered in line with the underlying growth model, it is

[2] This chapter draws upon and extends many excellent surveys, e.g. Levine (1997 and forthcoming), and Becsi and Wang (1997). For more detailed discussion of especially the older literature the interested reader is referred to these.

further distinguished by the underlying economic function of the bank. Levine distinguishes five functions of the financial system and discusses the literature accordingly in his widely cited survey (Levine 1997, p. 691):

- mobilization of savings
- allocation of resources
- exertation of corporate control
- facilitating risk management
- risk pooling and management
- ease the trading of goods, service, contracts

He also emphasizes that by fulfilling these functions the financial system produces a real service and is therefore not a mere 'veil of finance'. In this chapter a slightly different clustering is used in order to identify more clearly the real service of financial intermediaries. It can be argued that, for example, the mobilization of savings and allocation of reserves are not a function, but rather the result of improved corporate control, risk pooling and management. Thus, here the different real services produced by the financial intermediaries are used. In the examined finance-growth literature these are

- diminishing liquidity risk,
- diminishing default risk,
- screening and monitoring of borrowers.

By offering these real services, banks can foster capital accumulation and improve the capital allocation.

The newer literature also frequently strives to answer Levine's question "Why does financial structure change as countries grow?" (Levine 1997, p, 721). In other words, these papers examine the theoretical possibility of a two way causality between the correlation of financial development and growth. In order to provide a balanced overview, some of these models are also included in this review. To allow a better focus upon the theory, the empirical results are separated into another section.

4.1 Capital Accumulation Channel

The driving force for economic growth within an AK growth model is capital accumulation[3]. Therefore financial intermediaries need to foster the accumulation of capital in order to have a positive impact upon growth.

How do financial intermediaries affect capital accumulation? Most of the literature allow some form of initial financial frictions, which are then alleviated by the introduction of financial intermediaries. The initial financial frictions have an impact upon capital accumulation in two different ways. Firstly, they can cause capital accumulation to fall short to savings, if some of the savings are lost in the financial process. Reasons for such a gap are, for example, dead-weight cost due to individual storage holding and information cost. Secondly, the frictions cause a spread between the marginal rate of return on capital (loan rate) and marginal rate of return on savings. The resulting change in the cost of funds (return on savings) can have an impact upon the investment (savings) decision.

Banks alleviate these frictions and thereby narrow the spread, i.e. ceteris paribus, they allow for higher returns on savings (deposit rate) and/or lower loan interest rate. The intuition is that capital accumulation (savings and investment) increase and, due to the AK mechanism, so does the growth rate. However, rising interest rates do not necessarily increase savings.

The following excursion thoroughly examines economic agents' savings choice. While a decrease of the loan interest rate certainly spurs loan demand and productive investments, an increase in the deposit rate can even decrease savings. The reason is that an increase in the return on savings can be split into two potentially contrary effects. The substitution effect of increasing returns always induces postponing of consumption, i.e. increase savings. Per contra, the income effect can induce decreasing savings (Pagano 1993).

Figure 4-1 depicts the choice between current consumption c_t and future consumption c_{t+1}[4], in other words the savings choice. The optimum is at the tangency point of the intertemporal budget constraint and an indifference curve

[3] Becsi and Wang (1997) provide a good overview of the finance growth nexus regarding AK growth models.

[4] c_{t+1} can also be interpreted as net present value of all future consumption.

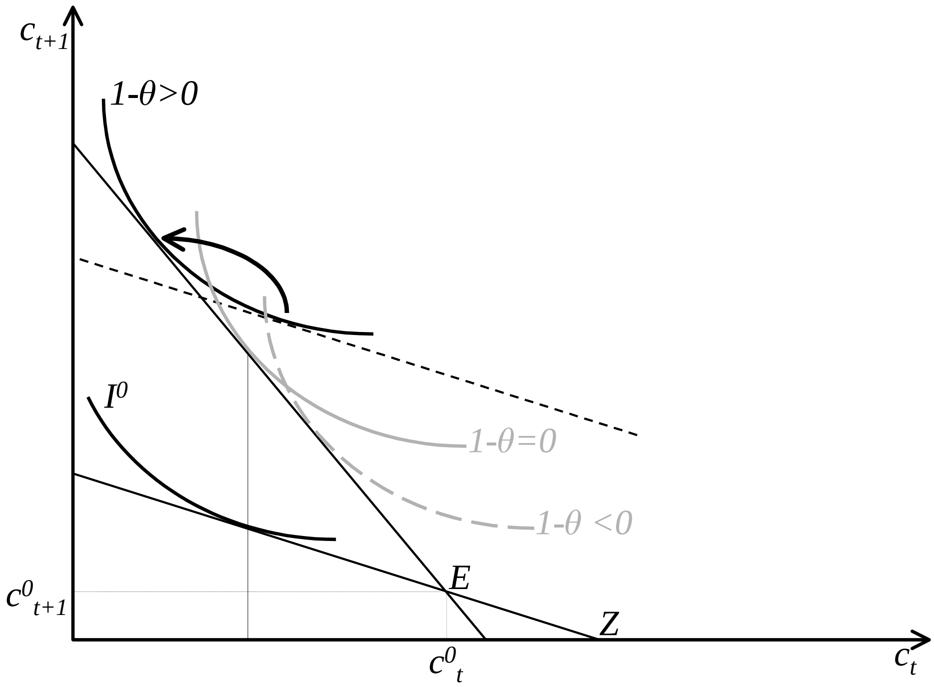

Figure 4-1: Interest Sensitivity of Savings

I^0. The negative slope of the intertemporal budget constraint is given by the interest factor $(1 + r)$. In this context the slope can also be interpreted as the price ratio of current consumption to future consumption.

The initial endowment is c^0_t, c^0_{t+1}. This endowment can be 'traded' at the rate of transformation $(1 + r)$. A rise in the interest factor, e.g., due to improved financial intermediation, twists the intertemporal budget constraint at the so-called endowment point E. Taking as a starting point an optimal choice in the area left of E[5], i.e. for the case of net savings[6], it can be seen that the increased interest income enables higher future consumption.

This impact upon real income is separately depicted by the dotted budget con-

[5] Frequently the endowment point E is assumed to be at Z. This is correct if the simple case of income only in period t is assumed, and all future consumption has to be finance via savings.

[6] In a closed economy with homogenous individuals it is impossible that everybody dis-saves (right to E) in the long-run.

straint. The intuition for the income effect is that increased returns on savings improve total lifetime wealth and thus allow for more consumption in all periods. This is nothing else than a reduction of present savings. The substitution effect (arrow in Figure 4-1) is more intuitive. The agent substitutes current consumption in favor of now relatively cheaper future consumption. This substitution effect overcompensates the income effect in Figure 4-1 (indifference curve "$1-\theta>0$").

However, the alternative grey indifference curves indicate the possibility of different results. Obviously the extent of the substitution effect depends upon the curvature of the indifference curves. A measure for this curvature is the so-called intertemporal elasticity of substitution $-u'/[cu'']$ (Barro and Sala-I-Martin 2004, p. 91). To be more exact, the relevant[7] case of a constant intertemporal elasticity of substitution is assumed. The instantaneous utility function[8] then takes the form $u(c)=\frac{1}{1-\theta}c^{1-\theta}$. The curvature is thus given by θ^{-1}. Three cases can be distinguished.

If $1-\theta=0$, the substitution and income effect exactly balance. The utility function becomes logarithmic $u(c)=\ln c$, and the savings rate becomes insensitive to changes of the interest rate. This situation is depicted by the grey indifference curve.

If $1-\theta<0$[9], the substitution effect is outweighed by the income. In this case current consumption even increases, and the savings rate decreases accordingly (dotted curve).

If $1-\theta>0$, the intuitive case of an increasing savings rate due to higher returns results.

The same logic can be applied when examining the impact of decreasing volatility (risk) of returns on savings (Turnovsky 2000, p. 565). Regarding risk, $-(1-\theta)$ depicts the so-called constant relative risk aversion (Pratt 1964). Lower volatility increases the total utility of risk averse agents, similar to increased income. This 'income effect' causes higher consumption and lower

[7] The growth literature usually uses these kind of utility functions. Other utility function do not allow for constant savings ratios with economic growth and are thus not suited to describe steady states.

[8] Total utility is the sum of all, in our case two, instantaneous utilities.

[9] Of cause the initial utility function is then slightly altered for useful result, e.g. $-\frac{1}{\gamma}c^{\gamma}$ or $b+\frac{1}{\gamma}c^{\gamma}$.

savings. On the other hand, lower volatility of returns[10] makes saving less risky and thus induces more savings. In order to achieve the 'normal' reaction of an increased savings rate due to decreased risk, again $1 - \theta > 0$ must hold. Having identified the importance of the functional form of the utility function, the capital accumulation channel literature can be more exactly discussed.

4.1.1 Liquidity Insurance

Banks are associated with the provision of liquidity. They pool the savings of the society and can quite accurately anticipate future demand for liquidity. Thus they can invest the optimal amount into high-yielding, but illiquid assets. From the individuals' point of view banks are therefore transforming illiquid assets into liquid deposits (Diamond and Dybvig 1983, p. 402). The following literature integrates this liquidity providing service of banks, by acknowledging that less savings need to accrue in form of unproductive storage. Therefore, even with fixed savings rates, real capital accumulation increases which spurs positive externalities and growth in an AK framework.

Bencivenga and Smith (1991) is the classical reference for applying this liquidity transformation function of financial intermediaries into the growth context (Freixas and Rochet 2002, p. 186). They assume that productive capital investment is illiquid. Without financial markets and financial intermediaries, the premature liquidation of capital investments is therefore costly. These liquidation costs are a problem for individuals, who do not know ex-ante, when they wish to consume their savings. As a result each individual agent allocates only a fraction of his savings into productive long-term investment and the other fraction into liquid but unproductive reserves (e.g., storage). Unlike the illiquid long-term investment these liquid reserves do not increase the real capital stock and therefore do not cause technology improvements. Capital accumulation is diminished additionally, by costly liquidation of long-term investments by the (ex-post) impatient agents. This situation is depicted in Figure (4-2), which extends the AK model (Figure 3-3, page 27) for reserves

[10] These intuitions change if the volatility is in the endowment, instead of the returns. In that case the agents have an incentive for precautionary savings.

and liquidation cost. These drive a wedge between savings and capital accumulation.

$$\begin{aligned} \text{capital accumulation} &\neq \text{savings} \\ \text{capital accumulation} &= \text{savings} - \text{reserves} - \text{liquidation cost} \end{aligned}$$

Without financial intermediaries, a relatively large fraction of savings is used for individual reserve holdings and liquidation costs (dashed lines). The solution is ex-post inefficient as the patient agents will suffer foregone returns (non-required reserves), and the impatient agent will suffer losses due to costly liquidation of long-term investments.
Introducing financial intermediaries, Bencivenga and Smith (1991) show that these improve capital accumulation. Banks pool all agents' liquidity needs and hold the correct amount of liquid reserves by the law of large numbers. Therefore, less savings are 'wasted' by excessive reserves or liquidation of illiquid investments (Figure 4-2). With the underlying AK growth model, the increased capital accumulation causes higher growth rates as an externality.

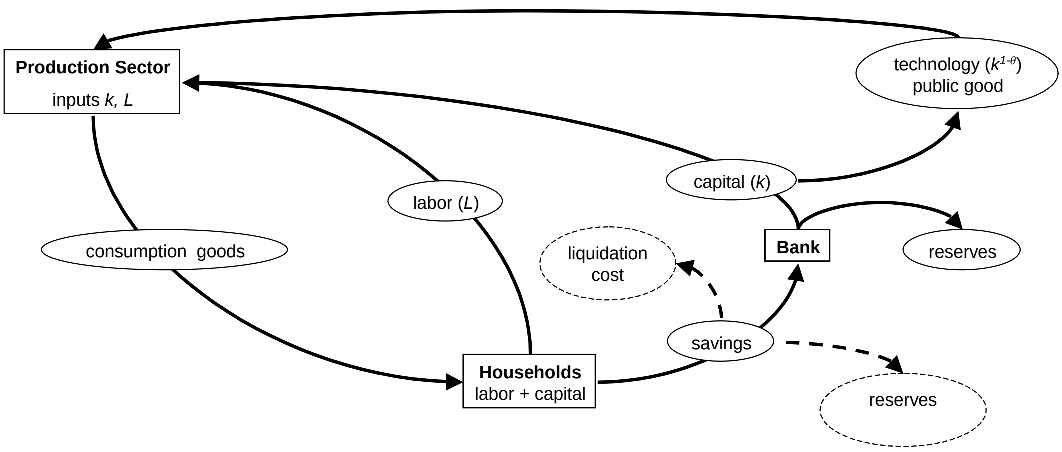

Figure 4-2: Liquidity Insurance by Banks in an AK Model

In more detail the Bencivenga and Smith model is a three period overlapping generation general equilibrium model. That they use basically an AK model can be seen by the entrepreneur's production function: $\bar{k}_t^{1-\theta} k_t^{\theta} L_t^{1-\theta}$

(Bencivenga and Smith 1991, p. 198). The entrepreneur takes the "technology" $\bar{k}_t^{1-\theta}$ (average capital intensity) as given, whereby technology improvements become an externality of capital accumulation. Rewriting $\bar{k}_t^{1-\theta}k_t^{\theta}L_t^{1-\theta} = Ak_tL_t^{1-\theta}$, with $A = 1$ the typical AK structure becomes more visible.

In each period risk averse agents enter the economy. These agents are endowed with one unit of labor when young (period one) and none later. Thus they rely upon their savings for their middle (period 2) or old age (period 3) consumption. In their middle age, a fraction of π realize that they are patient entrepreneurs, while the leftover $(1 - \pi)$ turn out to be impatient consumers. Consumers wish to consume all their savings, while entrepreneurs save it to have productive capital in period three. Initially, Bencivenga and Smith assume all period one income is saved. Ergo, the optimization problem is a portfolio choice between an illiquid asset (consumable in period 2 only at extra cost) and a liquid asset. The side condition is that in period one the agent only knows the probability distribution of his future consumption preference. The solution of the risk averse agents is a mixed portfolio which is ex-post inefficient. Ex-post patient entrepreneurs will have held too much reserves and suffer forgone returns, while ex-post impatient consumers suffer costly liquidation of their assets.

In contrast to the individual, due to the law of large numbers, the bank can better estimate its liquidity needs, i.e. withdrawal of deposits, and holds according liquid reserves. Banks can, thereby, offer perfectly liquid deposits with a high rate of return, whereby all savings are channeled through the banking system (Bencivenga and Smith 1991, p. 200). Basically bank reserves are utilized like a public good to insure the society's liquidity risk and substitutes individual liquidity holdings which would have been only partially utilized. Further, because Bencivenga and Smith assume that banks estimate deposit withdrawing with total accuracy, there is no need for costly liquidation of long-term investments. Therefore capital accumulation increases and thus economic growth as an externality also increases, if the savings rate is fixed or rising. Furthermore, even with endogenously decreasing savings[11] (due to a strong

[11] In an extension of their benchmark model (Bencivenga and Smith 1991, pp. 204) allow for variable (endogenous) savings in the first period. However, they assume a logarithmic utility function. The above discussion showed that in this case, savings are insensitive to

negative income effect as discussed above), there can be a positive impact upon growth (Bencivenga and Smith 1991, p. 196). It is sufficient that the decrease of savings is overcompensated by the shift from liquid to long-term assets and lower liquidation of long-term assets, whereby total long-term asset accumulation and growth increase.

In a later paper Bencivenga, Smith, and Starr (1995) refine the above model by relaxing the assumption of non-existing financial markets and allow for a secondary securities market. Such a market improves liquidity, as the initial investor in long-term capital assets can transfer his ownership instead of costly liquidating the real capital itself. Thus, less individual reserves are required. Following the logic of Bencivenga and Smith (1991) this should foster growth. However, the agents can now invest some of their savings in the secondary market. Unlike new loans and initial public offerings, the transfer of ownership via the secondary market, does not produce new real capital. The seller of the share simply consumes the revenue. Therefore, the impact upon real capital accumulation and growth is ambiguous. If the decrease in unproductive reserves is matched by also unproductive secondary market investments, the growth rate remains unchanged. Only if some of the foregone reserves are used for genius capital formation the growth rate increases and vice versa.

The assumption that banks' perfectly anticipate the liquidity demand (Bencivenga and Smith 1991), i.e. deposit withdrawals, has been eased by Ennis and Keister (2003). If the bank can only estimate the liquidity needs, there is a chance that deposit withdrawals are in excess of reserves. In this case the bank itself has to undertake the costly liquidation of its long-term assets. Yet, due to perfect competition and zero expected profits, this negative scenario implies that not all deposits can be redeemed, i.e. the bank defaults.
Already the possibility of such a bank-default can induce so-called bank runs. A bank run describes a situation where all depositors withdraw their deposits, not because they require the funds, but because they fear that the bank holds insufficient reserves and thus they would suffer a loss (Diamond and Dybvig 1983). In this case their expectation is self-fulfilling, because no bank holds

changes in the rate of return or risk and thus remain 'quasi-exogenous'.

sufficient reserves to cover a complete withdrawal of deposits. The bank run itself is inefficient due to massive (unnecessary) and costly liquidation of long-term investments. Such a destruction of capital has also a negative growth effect within the AK-framework.
Noteworthy is that already the possibility of bank runs induce inefficiently high reserve holdings, and thus diminishes growth (Ennis and Keister 2003). The risk of deposit default induces households to hold some private reserves and banks to increase their reserves. Therefore, total reserve holdings are larger and the growth improving effect of banks' is lower than in Bencivenga and Smith's (1991) analysis.

4.1.2 Monitoring and Screening

The classical reference for applying the monitoring service of financial intermediaries into the growth context is Greenwood and Jovanovic (1990) (Freixas and Rochet 2002, p. 186). They use an AK-growth model and assume asymmetric information between firms and the lenders of capital. Additionally, banks are assumed to be better monitors than the individuals (Diamond 1984), and thus all savings are channeled through the banking system. Improvements in the banks' monitoring ability lower transaction costs and allow for a higher rate of return on savings, whereby capital accumulation increases. Due to the AK-type production this also increases the growth rate. Further, Greenwood and Jovanovic (1990) incorporate a two-way causality between the monitoring ability of the bank and economic growth, by assuming that there are economies of scale in monitoring.
To be precise they assume two production sectors with constant marginal returns to capital[12]. One sector offers a safe but low rate of return, while the other sector offers a higher but risky return. Further, the realization of the return is only known by the individual entrepreneur, and outsiders must engage in costly monitoring to acquire this information. Since the information is nonrival but costly to produce, there is an incentive problem if they are nonexcludable similar to a public good. Allowing information to be exclud-

[12] Their linear production function can be interpreted as a short-cut to model the externality of capital accummulation upon technology.

able, there is the potential for realizing economies of scale by the avoidance of double monitoring. The economizing upon monitoring costs increases the expected net return from risky projects. There will be a shift in capital allocation from safe but low return projects towards risky high return projects. The savings ratio itself will remain constant as they assume a logarithmic utility function (Greenwood and Jovanovic 1990, p. 1079), whereby the savings ratio is interest inelastic. The shift in the savings allocation is sufficient to cause a jump in the output level. The according increase in income levels allows for higher savings and thus induces ongoing higher capital accumulation. Thereby, a positive impact upon the growth rate is established.

In their survey, Beci and Wang (1997) developed a graphical representation that elucidates possible growth impacts of financial frictions, within the AK-framework. Figure 4-3 depicts the marginal return on capital, which is the constant a in the AK model. Formally, the constant marginal return on aggregate capital has been established by Equation (3.12, page 26). With a CIES utility function the Euler equation can be depicted as a line in the return - growth plane.

$$\frac{\dot{c}}{c} = \frac{r-\rho}{\theta} \tag{EE}$$

The slope of this line (EE) depends upon the intertemporal elasticity of substitution θ^{-1}. The positive slope in Figure 4-3 depicts the case $\theta > 0$, i.e. the intuitive case where increasing returns are not overcompensated by a strong, negative income effect. Screening and monitoring costs (m_0) cause a spread between the initial marginal return on capital and the 'net' return on savings r similar to a capital income tax. The return net of these costs is depicted by the grey line. A decrease of these financial frictions, e.g., due to improved financial intermediation, increases the net return on capital to $a - m_1$.
The increasing net return induces a relative postponement of consumption into the future, i.e. an increase of the growth rate from g_0 to g_1.
An alternative mechanism to decrease monitoring (screening) costs is improved monitoring (screening) due to financial development which results in less moral hazard (adverse selection). With monitoring (screening) costs m_0, but increasing monitoring (screening) abilities, the average quality of credit financed capital investments (quality of creditors) improves. In other words, the expected

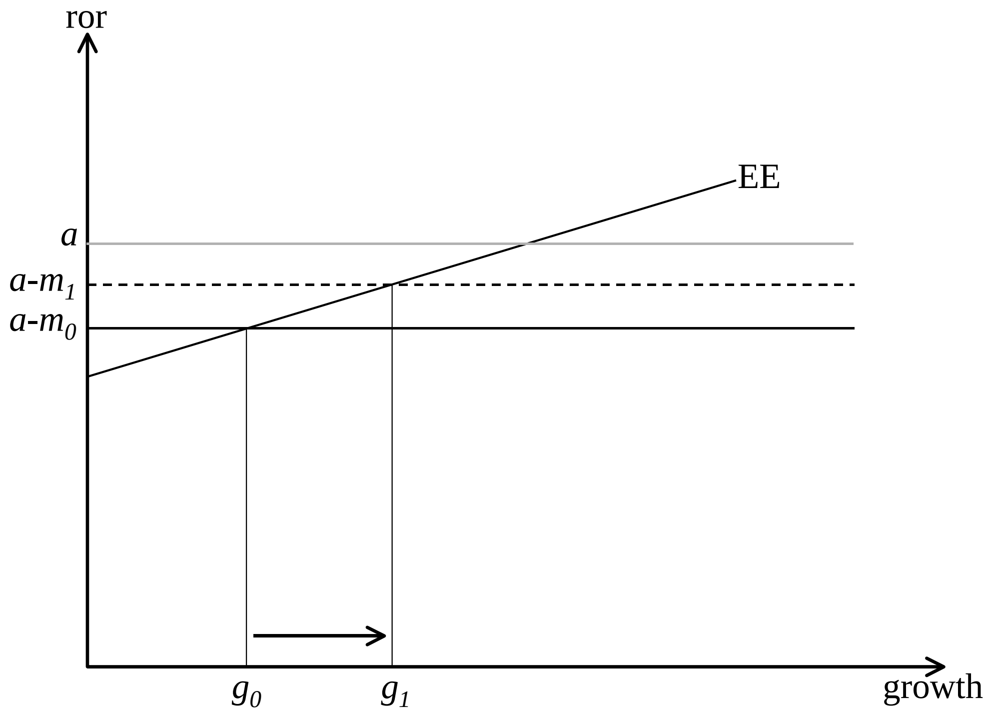

Figure 4-3: AK Growth and Increased Savings

marginal return on capital a increases. Ceteris paribus such an improvement would shift the initial a and $a - m_0$ lines in Figure 4-3 upwards, and spur growth.

Banks have an advantage in screening and monitoring due to economies of scale (Section 2.2.3). Beci and Wang let the spread m decrease as depicted in Figure 4-4, "indicating that scale effects on costs dominate, and financial efficiency increases with growth" (Becsi and Wang 1997, p. 54). While the last part of this quotation is certainly in line with the graph, the first part can be challenged. Due to constant growth of capital and the consequent growth of lending, economies of scale would cause a shift in the whole EE curve over time. The decreasing spread in Figure 4-4 rather depicts "economies of growth" and not economies of scale in loans. Such 'economies of growth' are difficult to justify. Learning by doing for example would shift the whole curve over time

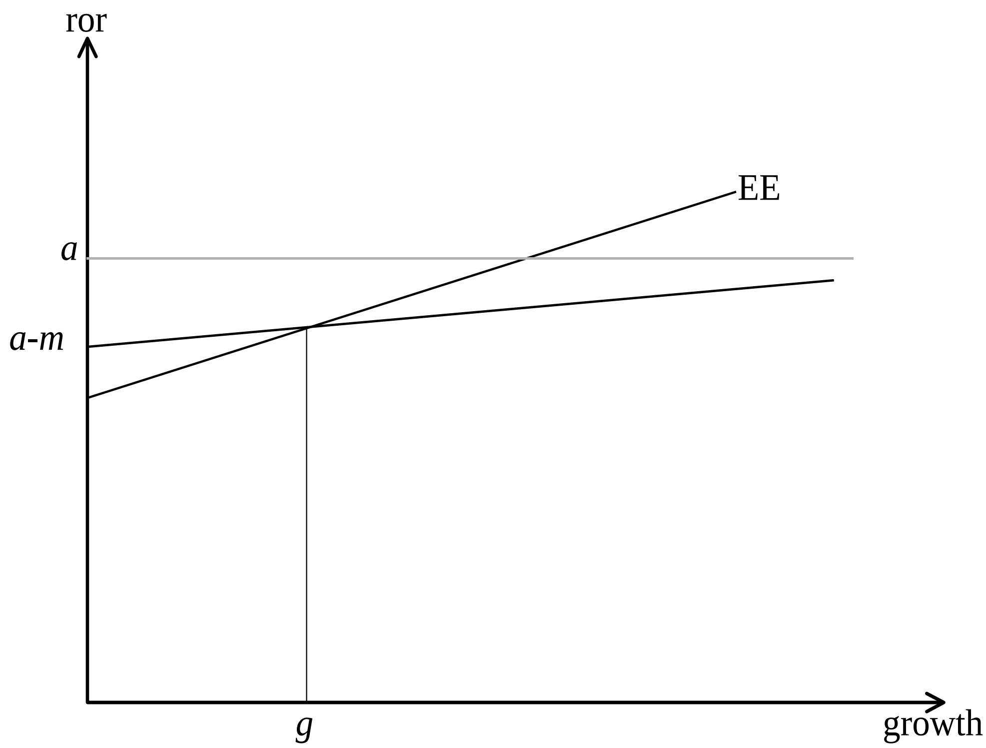

Figure 4-4: AK Growth Model with "Economies of Growth"

and is therefore not suitable as an explanation. One possible explanation is that higher growth rates can be associated with faster turnarounds of credits. If the creditor has to apply for new or additional credit shortly afterwards, he has an incentive to reduces his moral hazard. Under the assumption of this hypothesis, monitoring cost can decrease with higher growth rates and Figure 4-4 is correct. Regular economies of scale in screening and monitoring would decrease the spread over time, i.e. shift the curves similar to Figure 4-3.

Economies of scale also imply surprising possibilities for policy interventions. Decreasing the number of banks, e.g., by limiting banking licence, would increase the average size of existing banks, and allow for the realization of more economies of scale. Therefore, the cost of intermediation decreases and higher growth rates can be achieved (Becsi and Wang 1997, p. 53). However, existing banks might use their market power to act monopolistically and increase the spread between their loan and deposit rates in order to realize profits[13]. In this case, the positive impact of economies of scale upon the growth rate is at least partially diminished.

The issue of bank market power is also is tackled by Amable and Chatelain (2001). In their model, banks are the only source of finance by assumption[14]. Similar to Bencivenga and Smith (1991) model the individuals have a log-linear utility function and a portfolio choice between risky deposits (capital accumulation) and unproductive storage. The deposit rate and thus capital accumulation is depressed by banks' market power.
Banks' market power depends upon the financial infrastructure. Tax financed infrastructure increases competition[15] between banks and the return on deposits as opposed to storage. Thus, a larger fraction of the fixed savings accrue on deposits and are intermediated into productive capital. The increase in capital causes an increase in labor productivity and wages, whereby capital accumulation and growth are fostered.
The point made by Amable and Chatelain is that infrastructure is costly and needs to be financed with distorting capital taxes. Therefore, there is a trade-off between inefficient low competition and inefficient taxing. The optimal policy intervention is to provide tax financed infrastructure until the marginal welfare cost of the distortional tax equals the marginal welfare gain due to improved banking competition.

[13]Government interventions are further complicated if the steady state is non-unique as in Jungblut (2004). In his model, increasing returns to scale in the banking sector cause multiple equilibria. Thereby, the development of the economy is determined by the coordination of expectations. Both, too tight as well as too loose monetary policy increases the probability of financial crisis and an accordingly economic slowdown.

[14]They focus upon less developed countries, where financial markets are empirically unimportant, and this assumption is weak (Amable and Chatelain 2001, p. 485).

[15]Good infrastructure decreases the market power of banks, e.g. because it diminishes the traveling cost of bank clients to competing banks. A better suited reason for developed countries could be improved banking supervision, whereby information regarding alternative banks' health is more readily available. This would decrease costly information seeking of individual bank clients and ease the change of banks.

4.1.3 Summary and Discussion

Capital accumulation drives growth in AK models. Above discussed models include banks and show that their existence and development improves capital accumulation. There are two different ways to implement such an improvement. Banks can improve the transformation of savings into real capital formation and/or cause an increasing savings rate.

In a Bencivenga and Smith (1991) style model not all savings are used for capital accumulation as some are held in unproductive storage to serve as a buffer against liquidity risk. Banks can provide liquidity insurance. Thereby, they improve the transformation of savings into capital accumulation and increase the latter.
Adding secondary financial market into this framework further improves liquidity (Bencivenga, Smith and Starr 1995). However, this positive effect can be undermined by large investments of savings into unproductive transfers of ownerships. Thereby, capital accumulation can even decrease.
Including the risk of bank illiquidity, the possibility of bank runs induces increased storage holding. Thereby the positive impact of banks upon growth is impeded (Ennis and Keister 2003).

Information cost can have a similar impact to liquidity cost. They influence the use of savings and thereby the capital accumulation. Information cost can 'distort' the investment decision in favor of low risk, low return projects, whereby income growth and capital accumulation is dampened. Greenwood and Jovanovic (1990) demonstrated that banks superior monitoring abilities diminish these 'distortions'. They enable a higher average return on savings and thereby increased capital accumulation.

An additional mechanism by which capital accumulation is increased is the impact financial intermediaries (and their development) has upon the rate of return on savings and the savings rate. Financial intermediaries can improve the efficiency of finance and thus increase the return on savings (Becsi and Wang 1997). With a sufficiently strong substitution effect, this causes a shift in the intertemporal consumption choice in favor of increased savings. Capital accumulation and growth increase as a result.

However, it is important to acknowledge that a strong negative income effect can also induce a decrease in savings. In this case improved financial intermediation would cause a decrease of capital accumulation and growth. This special case is possible in all of the above models, by assuming an according utility function.

In addition to the models discussed Levine (1991 and 1992), Bencivenga and Smith (1993), and Saint-Paul (1992) also combine AK models with finance.

It remains to be said that the Bencivenga and Smith (1991) model and the subsequent extensions have been classified within the accumulation channel, despite the use of allocation (deposits versus storage) in the intermediate analysis. The reason for this clustering is that the driving force for all above models is capital accumulation.

The model could be technically altered to accommodate the capital allocation channel, by assuming that growth results from capital allocated to a R&D sector, instead from an externality of capital accumulation. A short, non-technical description of such a model variety follows. If the R&D sector has to compete for capital with a 'standard production' sector and investments in both sectors differ in their liquidity, Bencivenga and Smith-type banks would increase the growth rate via the capital allocation channel. The reason is that capital accumulation in the standard production sector does not have a positive externality upon growth, while capital allocated to the R&D sector fosters growth.

The economic intuition for a difference in liquidity can be seen in the more opaque characteristic of R&D investments as well as in the high degree of sunk cost of R&D. The opaque characteristic of R&D projects makes it difficult to establish a fair market price for the traded shares in the secondary market[16] (Akerlof 1970), compared to more transparent standard production firms. The cost of individual "liquidation" via transfer of ownership can be seen in the accordingly higher discount on R&D shares resale value. Further, R&D outlays are, to a greater extent, the wage bill (non-retrievable) and the investment in specialized equipment, which has hardly any alternative uses if the firm

[16] This mechanism is also used in Bencivenga, Smith and Starr (1995).

itself is liquidated. This contrasts to standard production firms' assets, which consist, to a large fraction, of standard machinery and buildings, which have alternative uses and thus can be sold more easily. Ergo, it seems plausible that R&D investments are less liquid.
However, it can also be argued that R&D and standard investments differ in their riskiness rather than their liquidity. Such a distinction is used in the new model developed in Chapter 6.

4.2 Capital Allocation Channel

> "[The banker] stands between those who wish to form new combinations and the possessors of productive means. ... He makes possible the carrying out of new combinations, authorizes people, in the name of society as it were, to form them. He is the ephor of the exchange economy." (Schumpeter [1911], 1934, p. 74)

In the Romer and Schumpeterian growth models (Sections 3.2.2 and 3.2.3), growth is generated by the allocation of resources towards a R&D sector. Thus, any changes regarding the resource allocation immediately affect the growth rate. How do financial intermediaries affect the allocation of resources? Similar to above discussed capital accumulation channel, banks ease existing financial friction by their superior ability to screen and monitor lenders as well as diminishing risk. Banks, thereby, affect factor prices and the allocation of resources.

The major difference between this and the previous section is that savings as well as capital accumulation can remain constant. For a positive impact upon the growth rate, it is sufficient that the level of resources allocated to successful research activity increases. Thus, in order to focus upon allocation, the following discussion largely overlooks the impact upon accumulation.

4.2.1 Screening

The fact that not all credit applicants are equally creditworthy and that banks have competence in screening credit applicants is used by the seminal paper of King and Levine (1993). They use a Schumpeterian growth model (Section 3.2.3), where the growth rate is determined by the allocation of labor towards the R&D sector (see Figure 4-5). Wages in the R&D sector are credit financed, depicted by the dotted lines in Figure 4-5. In order to grant these credits, banks must engage in costly screening of the credit applicants' creditworthiness. These screening costs increase the cost of credit finance and thus drive a wedge between the wage rate and the marginal cost of (credit financed) labor in the R&D sector. The higher the screening cost, the less labor is allocated towards R&D activities whereby the growth rate decreases.

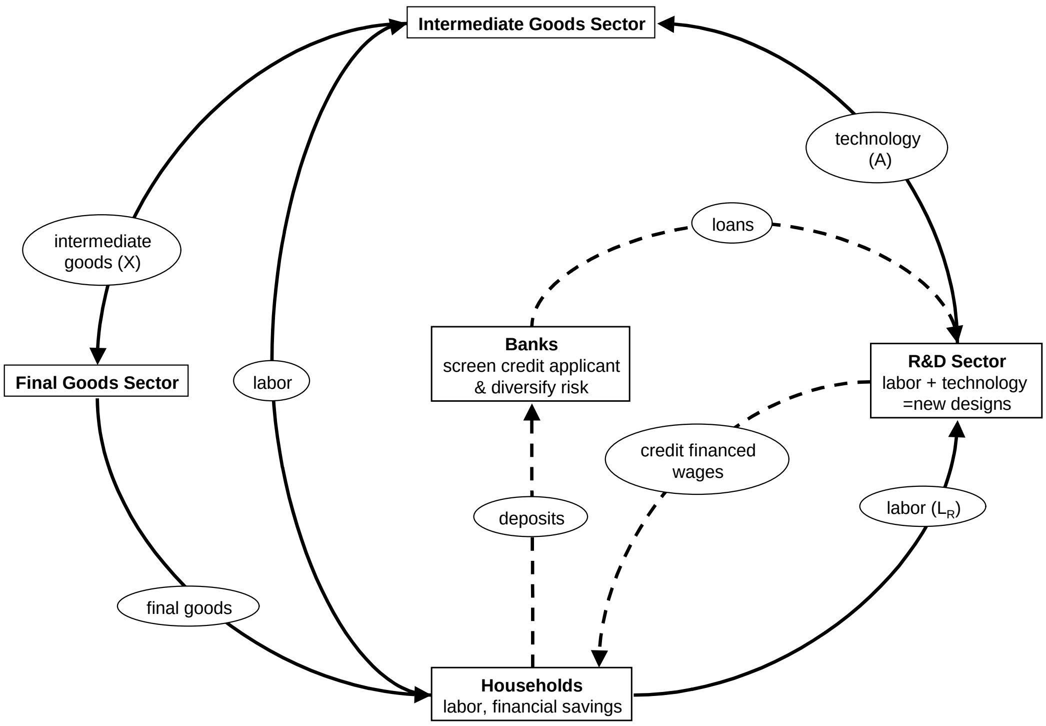

Figure 4-5: Schumpeterian Growth Model with Bank Finance

Since this model (King and Levine 1993a) is extended in Chapter 5, a more in-depth discussion follows. The success of R&D activities is uncertain. This real world fact is included in the model, by assuming that the time until success is stochastic for each individual research project. Further, research projects require more than the entrepreneur's labor input. Thus external finance is

useful (diversification) and necessary (King and Levine 1993a).
The need for screening esteems from assuming two types of agents who differ in their entrepreneurial skills. Only a fraction of the population has the ability to engage productively in R&D activities. The other fraction of the population has no entrepreneurial skills and would fail for sure if they engage in R&D activities. However, knowledge regarding the individual skill level is private, and all agents do apply for finance. These asymmetric information are the source of market failure. Banks have the ability to identify entrepreneurial skills through costly screening. King and Levine assume that these screening costs are sufficiently low, to allow for deposit rates that are superior to the expected return of a 'gamble' by financing directly without screening. As a result, all finance is indirect via the banking system and there are no financial markets.
The financial aspect of the model is depicted by the doted lines in Figure 4-5. The R&D sector pays its work force by taking out bank loans and transferring the according deposits to the household. In aggregate[17], these deposits are balanced by the households' savings. Technology growth itself is driven by labor allocated to the R&D sector instead of its alternative use in the intermediate[18] good sector.
Even with perfect competition between banks, there will be a spread between the loan rate (r_l) and the deposit rate (r_d), i.e. $r_l > r_d$, as the bank needs to cover its screening costs. The interest rate spread drives a wedge between the marginal present value cost of credit financed labor $(1 + r_l)\, w / (1 + r_d) > w$ and the wage rate w. It is important to notice that the discount rate is the opportunity cost of foregone deposit returns r_d, and not the loan rate r_l[19]. The initial financial friction, therefore, increases the effective wage bill in the R&D sector, and thus dampens the R&D demand for labor. Vice versa, financial

[17] The exact acceptance and distribution of deposits is not included in King and Levine's (1993) analysis. This is part of the extension in Chapter 5, and will be elaborated upon there.

[18] That labor is used in the intermediate good sector instead of the final good sector has no influence upon the model outcomes.

[19] The opportunity cost of the loan is not the redemption of the loan. This can be seen in two ways. Firstly, an immediate redemption of a new loan means that there is no loan and thus nothing to evaluate. Secondly, if the loan rate is used to calculate present values of loans, the present value becomes independent of the loan rate. In other words, creditors would be indifferent between high and low loan rates which is obviously incorrect.

development, which decreases the screening costs, decreases the spread and induces increased allocation of labor towards R&D and thus higher growth rates.
The impact upon the labor allocation via the demand side is strengthened if the deposit rate also changes, and households are risk averse (CIES with $1-\theta>0$).

The unambiguously positive impact of financial development in the above model (King and Levine 1993a, p. 519 and p. 525) has been challenged by easing the assumption that the R&D sector is the exclusive debtor of banks (Galetovic 1994). By allowing other non-innovative sectors to require and demand bank loans, the allocation of credits depends upon the relative financial frictions of the sectors. An improvement of financial intermediation then increases the total amount of finance channeled by the banking system. However, whether the R&D sector receives more or less resources also depends upon the relative financial frictions. Similar to the income and substitution effect, the amount of resources allocated to the R&D sector hinges upon the increase of total resources allocated via the financial system (income effect) and the relative gains in credits and thus in purchasing power (substitution effect). If financial development decreases intermediation cost of loans to non-innovative sectors more than to the R&D sector, a relative shift on the bank's asset side against R&D lending will result (Galetovic 1994). If this relative shift (negative substitution effect) is large, it can outweigh the efficiency gains due to financial development. Less resources are allocated to R&D and the growth rate is depressed.
In order to derive these results, Galetovic (1994) uses a Romer growth model (Section 3.2.2). Labor is allocated between a consumption good producing sector, a capital producing sector, and the R&D sector. Capital itself is the input of intermediate good production. Due to decreasing marginal returns, capital accumulation is not a source of long-term growth (unlike the AK model). Galetovic does not explicitly model the financial friction, but assumes that all finance is indirect via banks and states that their "information gathering, screening, and monitoring" matters most for growth (Galetovic 1994, p. 6). Basically, he allows for different loan rates and thus different effective marginal

labor costs. If financial development diminishes the spread, and thus loan rate, for the non-innovative sectors more than for the R&D sector, the differences in the effective marginal labor cost will increase. Therefore, the non-innovative sector's loan demand increases relatively more, and there will be a shift in the bank's asset portfolio against the R&D sector. The relative gain in credits allows the non-innovative sector to increase its share in the labor demand as well. Thus, labor is withdrawn from the R&D sector and growth is depressed. By associating credits for "capital" with long-term finance, and the financing of researchers' wage bills with short-term finance, Galetovic also emphasis the importance of short-term loans for growth.

Allowing for self-selection in addition to screening, increased (interbank) financial frictions can even foster growth. This unusual and counterintuitive result has been shown by Huang and Xu (1999)[20]. They extend a Schumpeterian growth model by allowing for asymmetric information about the success type of researchers. The information asymmetry is sufficiently high so that all researchers rely upon bank finance. The innovation of their model is the inclusion of the fact that entrepreneurs require finance over a period of time and the entrepreneur himself and the bank learn about the credibility during this time. They assume three consecutive stages of finance and the possibility for self-selection.
At stage one, finance is granted to all applicants as they are ex-ante identical. At stage two, the researcher learns if he is able (creditworthy) or not. At stage three, the bank can identify the ability of the researcher. The private payoffs for unable researchers are assumed to be the lowest when finance is rejected at stage three. Thus, unable researchers will self-select already in stage two, if they expect to suffer a lack of finance at stage three.
However, when unable researchers expect ongoing bank finance at stage three, no self-selection at stage two will take place. Such ongoing bank finance of unable researchers results if the credit at stage three is profitable (ex-post), despite the ex-ante non-profitability of the joint second and third stage credit.

[20] A similar result in a different context is derived by Bencivenga and Smith (1993). In their model improvements in the production technology decrease self-selection and thus increase credit rationing by banks.

Since the stage two bad credit can be considered a sunk cost in stage three, the bank cannot trustworthy precommit to withhold stage three credits.
For this special case, increased interbank frictions can improve the outcome. The frictions reduce the marginal return of lending at stage three for the bank. If the frictions are high, financing unable researchers at stage three will be unprofitable for the bank. Thereby, unable researchers anticipate that they will not obtain ongoing finance and choose to self-select at stage two, i.e. they do not apply for credits. The allocation of resources is improved as able researchers receive more resources at stage two, and the growth rate increases.

4.2.2 Monitoring

While screening activity of banks takes place before a credit is granted, monitoring describes the activity ex-post to the loan contract. With asymmetric information and limited liability of the borrower, the lender has to assure that the borrower is not diverting funds to unproductive or more risky uses (moral hazard). Further, the borrower might falsely pretend to default, whereby costly monitoring of the real outcome of his projects is required. Monitoring cost cause a spread between the loan and deposit rate exactly the same way as aforementioned screening costs.

The difference between the capital accumulation channel and the capital allocation channel is most obvious in the model of Morales (2003). In her model economic growth is associated with lower capital accumulation. She uses a Schumpeterian growth model and assumes that banks have a special monitoring technology which induces better efforts of entrepreneurs than the market can do. The R&D sector and the intermediate good producers compete for financial capital. While increase real capital accumulation increase intermediate output, it does so at the cost of dampened R&D activities and reduced technology growth.
The implication for policy interventions is that subsidies to the bank, reduces monitoring cost and fosters growth, while direct subsidies to the R&D sector can decrease the effort of entrepreneurs and diminish growth. Yet, subsidies must be financed with distortionary taxes, whereby the welfare effect of subsidizing banks is ambiguous, despite fostering growth.

The literature also discuss a two way causality between financial development and growth. De la Fuente and Marín (1996) extend an overlapping generation version of the Romer growth model for endogenous effort of the entrepreneur and monitoring effort of banks. Similar to previous literature asymmetric information regarding the effort of the credit financed entrepreneur induces a moral hazard problem which is diminished by bank monitoring. Bank finance is superior to market finance, because they can avoid duplications of costly monitoring and thereby realize economies of scale.
The key difference of their work is that monitoring effort of the bank itself is endogenous. The effort of the bank is determined by the relative factor price between capital and labor, which are the input factors for monitoring. As a result, changes of the relative factor price, due to economic growth, feedback upon the optimal monitoring effort of the bank.
Economic growth increases the marginal productivity of labor and capital. However, labor cannot be accumulated and the productivity improvements are balanced by higher wages. Capital, on the other hand, can be accumulated. Thus, additional capital is used for monitoring purposes. The result is an increased monitoring effort of the bank. The according decrease in the loan-deposit spread depicts endogenous financial development. As in previous models the decreasing spread also induce more allocation of resources to the R&D sector and thus higher growth rate.

4.2.3 Default Risk Diversification

Risk averse agents are willing to engage in risky activities only at a risk premium. This risk premium increases the cost of credit financed resource for the R&D sector similar to aforementioned monitoring and screening costs. One typical function of banks is to allow for improved diversification of risk (Section 2.2). Then the risk premium decreases, and in line with it, the cost for the R&D sector of credit financed resource. R&D activity increases and growth is fostered.
Most of the literature (e.g., King and Levine 1993, and Morales 2003) assumes that the bank can perfectly diversify the risk associated with R&D activities. The introduction of financial intermediaries is improving diversification and

possibly growth in one step in these models, however interdependencies are not explicitly discussed. Especially, improvements of diversification over time are not depicted by those models.

Improved diversification can be used to explain reversed causality of the finance and growth correlation. In a Romer growth model, the amount of new product variation increases over time (Equations 3.13 and 3.17 in Section 3.2.2). If the risky R&D projects are not perfectly correlated, there is a scope for diversification. Further, if diversification is not immediately perfect as in King and Levine (1993), growth and the according increase in R&D projects improves the scope for diversification. Blackburn and Hung (1998) formalize this idea. Similar to de la Fuente and Marín (1996) banks advantage over market finance is the avoidance of duplication of costly monitoring. However, instead of focusing upon monitoring of R&D projects, they include the famous question 'who monitors the monitor' (Krasa and Villamil 1992). In their model depositors have to monitor banks in case of a bank default to avoid bank cheating. This additional level of costly monitoring increases the spread between loan rates and the rate of return on savings, whereby credit financed R&D becomes more costly. In other words, R&D and thus economic growth is dampened by imperfect diversification. Economic growth allows banks to better diversify and less cases of bankruptcy will occur. Thereby, costly monitoring of banks decreases, the spread dwindles, and more resources are channeled towards R&D activities. The result is a two-way causation of economic growth and improved financial efficiency. An interesting special case in their model is the possibility of a zero growth trap. If the economy is not developed sufficiently, the low diversification can cause prohibitively high monitoring cost. In this case there will be no R&D investment and no growth. Blackburn and Hung (1998) suggest financial liberalization as a potential way out.

4.2.4 Summary and Discussion

Just as in the capital accumulation channel, the literature generally assumes initial imperfections within the financial sector which are alleviated by the introduction and improvements of banks. However, the underlying growth models are of Romer- and Schumpeterian-type and no increased capital accumulation is required. Growth is a function of resource allocation towards the R&D sector. The initial financial imperfections cause a relative increase in the cost of resources for credit financed sectors.

In the King and Levine (1993) model banks screen credit applicant and lend to creditworthy researchers. Any improvement in the screening technology then diminishes the cost of credit financed R&D, increase the amount of finance channeled to researchers, and thus allows them obtain a larger fraction of the productive means just as described in the Schumpeter quotation on page 72. However, since the relative purchasing power is of importance in order to obtain a certain share of the (fixed) labor force, the impact of improved screening is ambiguous if banks lend to non-research sectors as well. If the screening of non-research sectors improves relatively more than screening in the R&D sector, the latter will suffer a relative loss in credit. Due to the importance of relative purchasing power, less resources would be allocated to R&D activities and growth would be depressed (Galetovic 1994).
An alternative to screening is a scheme that induces self-selection of bad credit applicants. Such a scheme depends upon trustworthy commitment of adverse consequences is the bad credit applicant does not self-select. In very special circumstances, financial development can undermine banks' ability to precommit, if it eases for example ongoing finance of bad creditors. Huang and Xu (1999) show that in such a case financial development diminishes growth.

If creditors differ in their action ex-post to the lending decision, monitoring is required. Better monitoring assures that researchers use more effort and research productivity and growth is fostered (Morales 2003). Productivity growth works against the decreasing marginal productivity of capital and allows for increased use of capital in production. If capital is also an input for banks' monitoring, the bank will increase its monitoring efforts due to technology growth (de la Fuente and Marín 1996). Thereby, improvements in financial intermediation are endogenous and there is a two-way causality between finance and growth.

Such a two-way causality has also been shown by Blackburn and Hung (1998) . However, they use the increasing number of intermediate inputs in Romer-type growth models to allow for increasing diversification of risk. The increase in diversification diminishes the risk of banking default and the according costly monitoring of banks. Financing R&D activities becomes relatively cheaper and more R&D takes place, which allows for even more diversification and growth.

4.3 Empirics

There exists a vast and increasing amount of empirical literature examining the relevance of the finance and growth nexus in general and also for bank efficiency and growth more specifically. Since the task in this thesis is to deepen the theoretical understanding of the finance growth nexus, this section gives only a very brief overview of the latest literature conclusions. More in-depth discussion can be found in the surveys of e.g., Levine (1997, 2003 and forthcoming), Wachtel (2003), and especially Eschenbach (2004), who provides an extensive table of most recent relevant papers. Very accessible is Khan (2000).

The quintessence of the empirical literature is that the level of financial development in general is positively correlated with economic growth. Especially, banks' development level is positively associated with economic growth (Levine, Loayza and Beck 2000, p. 31).
The level of financial development can only be measured by proxies. For example the proxies used by Levine et al. (2000) to measure the level of bank development are

- $\frac{\text{M3}}{\text{GDP}}$ as a common measure for financial depth,
- $\frac{\text{credits to the private sector}}{\text{GDP}}$ as a measure for R&D finance,
- $\frac{\text{credits by nongovernmental banks}}{\text{total credits}}$ as a proxy for efficiency, i.e. state credits are presumed inefficient, and
- $\frac{\text{credits to the private sector}}{\text{total credits}}$ as a proxy for efficiency, i.e. controlling for credit financed government expenditure.

Of cause, correlation does not necessarily imply causation. However, the causal impact of banks' upon growth can empirically not be rejected and the economic impact is relevant (Levine et al. 2000, p. 35). For example Argentina would have enjoyed an increase of 1 percentage point of real per capita GDP, if its banking sector would have developed according to the average of developing countries (Levine et al. 2000, p. 35). The importance of banks is further strengthened by the finding of Levine and Zervos (1998) that equity markets are not an adequate substitute for a well developed banking system.
Regarding the economic mechanism via which banks might influence growth, the capital accumulation and allocation channel have been distinguished. There is support for both channel, i.e., financial development fosters (human) capital accumulation and total factor productivity growth (Benhabib and Spiegel 2000). Models implying that increased liquidity diminishes savings or growth are not supported empirically (Levine and Zervos 1998).
Table 4.1 provides a short overview of the latest empirical literature and some literature omitted by Eschenbach (2004).

Another topic frequently examined in empirical works is the performance of market- versus bank-based financial systems. Generally, the market-based financial sector of the U.S. is considered to depict a very high level of financial development, while bank-based financial sectors, as for example the German financial sector, are associated with 'underdeveloped' financial markets[21] (Allen and Gale 1995b, p. 180). Therefore, it is easy to presume that bank-based systems will suffer lower growth rates. Empirically not the question of market- versus bank-based systems matters for growth, but rather if the existing financial sector provides financial services on a high level (Levine 2002). A prerequisite for an efficient provision of financial services is a well functioning legal framework, which is therefore empirically relevant for growth (Levine 2002). Another finding is that developed economies are more prone to market finance, while developing economies are bank-based (Tadesse 2002). However, the microstructure of the economy is also of importance. Economies relying on small firms perform better with bank-based financial systems (Tadesse 2002). In line

[21] Allen and Gale (1995) examine non-technically welfare implications of both systems. They basically find that no system is dominating the other.

with these results, Beck and Levine also established that stock markets and banks affect economic growth rather as complements than substitutes (Beck and Levine 2004).

Author	Year	Sample	Method	Main findings
Levine, Loayza and Beck	2000	71 countries	GMM dynamic panel estimators pure cross-sectional, instrumental variable	Bank development fosters economic growth
Lucchetti, Papi and Zazzaro	2001	Italy	Data Envelopment Analysis	Banks affect growth, even if human capital is controlled for
De Avila	2003	EU	Panel data and ANOVA	Bank efficiency fosters growth
Christopolous and Tsionas	2004	10 developing countries	Panel unit root and cointegration tests	Evidence of long run causality of financial development to growth
Guiso, Sapienza and Zingales	2004	Italy	OLS and probit	Local financial institutions foster small enterprise setup and growth
Shan	2005	Ten OECD and China	VAR	At most weak support for financial development causing growth
Beck et al.	2005	44 countries and 36 industries	OLS and instrumental variables	Fin. dev.fosters growth especially of small firms and their large clients

Table 4.1: Finance and Growth Empirics

4.4 Summary

The development of endogenous growth models enabled the formal description of the long presumed connection between the level of financial development and economic growth. Banks can foster growth either by increased capital accumulation within an AK model, or improved capital allocation in a Romer and Schumpeterian growth model. Most models allow for market imperfections which are eased by banks real services. Table 4.2 subsumes the literature.

Several reasons why banks foster capital accumulation have been formalized. Due to the law of large numbers, banks can offer liquid deposits (liquidity insurance) even if their own assets are highly illiquid. Less savings, thereby, accrue in the form of unproductive reserves and real capital accumulation increases. Similarly, superior monitoring by banks diminishes the deadweight loss of monitoring cost and allow for increased capital formation.
Necessary for the capital accumulation channel to work is that the diminished risk and increased return on savings, respectively, do not strongly diminish the savings rate. Such a situation could occur if the income effect of the efficiency gain is strongly negative and outweighs the substitution effect. However, all of the above models assume CRRA utility function with $1 - \theta \geq 0$, whereby the savings rate remains constant or is even increasing in diminished risk and increased returns. Further, there is no empirical support for the hypothesis that financial development diminishes capital accumulation.

Models using capital allocation towards an R&D sector as the driving force for growth usually do not utilize liquidity risk. Rather these models focus upon banks' ability to process information ex-ante and ex-post to the lending decision by screening and monitoring. Usually, it is assumed that the R&D sector is more opaque and thus relies more upon bank-finance than the final good sector. Improved information processing by banks then changes the relative financing cost in favor of the R&D sector. As a result, the R&D sector will attract more resources, and technology growth increases.

Article	Real Service of Banks	Bank's Objective
Capital Accumulation Channel		
Greenwood and Jovanovic (1990)	Monitoring	Profit maximization
Bencivenga and Smith (1991)	Liquidity insurance	Profit maximization
Bencivenga et al. (1995)	Liquidity insurance	Profit maximization
Amable and Chatelain (2001)	Supply loans	Use of market power for profit maximization
Ennis and Keister (2003)	Liquidity insurance	Profit maximization, preventing bank runs
Capital Allocation Channel		
King and Levine (1993)	Screening	Profit maximization
Galetovic (1994)	Supply loans	Profit maximization, via asset portfolio
De la Fuenté and Marín (1996)	Monitoring	Profit maximization
Blackburn and Hung (1998)	Monitoring, risk diversification	Profit maximization, signaling honesty with bank capital
Huang and Xu (1999)	Screening, inducing self-selection	Profit maximization, commitment
Morales (2003)	Monitoring	Profit maximization

Table 4.2: Overview Bank-Growth Literature

The consensus view of the empirical literature can be subsumed by the following three statements. The correlation between financial development and growth is at least partially due to a growth-fostering impact of finance. Financial intermediaries do play a significant role. The growth impact occurs via capital allocation rather than capital accumulation.

In regard to policy interventions the literature suggests that additional frictions like taxes upon banking activities retard growth (King and Levine 1993a). In fact subsidizing banks can be a better way to foster growth than subsidizing R&D directly (Morales 2003). However, due to its costs, such an intervention is not necessarily welfare-increasing.
The existence of economies of scale implies that an oligopolistic or even monopolistic banking sector could provide financial services more efficiently than a polypolistic banking sector. An artificial limitation of banking licences can therefore foster growth. On the other hand, such an argument must be balanced with the loss of efficiency due to monopoly pricing (Becsi and Wang 1997).

What is missing in the literature? The majority of the aforementioned models focus upon the link from bank services to economic growth, modelling the bank itself in a rather mechanical way. With the exception of Ennis and Keister (2003), and Blackburn and Hung (1998), banks themselves do not face any risk as they can perfectly diversify liquidity and credit risk. For the purpose of narrowing the focus to a certain link between banks and growth, such assumptions are useful. Nevertheless, banks do face liquidity risk, and it can easily be argued that the default risk of R&D loans cannot fully be diversified either (Ingves 2001, p. 8). In fact, the large maturity mismatch between banks' assets and liabilities make banks themselves highly illiquid and liquidity management is one of the key tasks of bank management. Further, banks are highly leveraged (Table 2.1, page 8), and thus certainly face a significant solvency risk.

Despite banks' ability to diversify risk by their size and modern financial instruments, complete diversification cannot be achieved in the real world. Ennis and Keister (2003) acknowledged banks' imperfect foresight regarding their deposit withdrawals. They focus in their analysis upon the systemic risk of bank runs. However, it can be argued that banks in developed financial systems care more about frequently occurring liquidity needs due to interbank deposit transfers of their customers, than the systemic risk of a bank run. The prime example of individual liquidity risk and cost is the Long Term Capital Management (LTCM) crisis. The cost of serving the sudden withdrawal of liquid liabilities, in combination with illiquid assets, caused the effective liquidation of the LTCM (Scholes 2000). In order to include and examine the impact of bank liquidity risk, Chapter 5 extends an endogenous growth model for stochastic deposit transfers and interbank frictions.

Bank deposits in well developed economies are perceived as a safe investment (quasi no default and liquidity risk) by households. It is noteworthy that the function of transforming risky loans into safe deposits is accounted for in the finance-growth literature only due to perfect diversification. However, in the real world, banks achieve the quasi safe return on deposits by using their equity as buffer to smooth loan defaults. Therefore, the intertemporal risk (see Section 2.2) is transferred to the bank. A possible explanation for the neglect of this important effect in the discussed literature is that the bank is owned by the representative household. In this case the diminished losses on deposits are exactly offset by increased losses on equity, whereby no transfer of risk occurs. In order to depict the transfer of default risk, the representative deposit holder must differ from the bank owner, i.e. heterogeneous agents are required. Therefore, Chapter 6 uses heterogenous agents in an endogenous growth model to examine the impact of bank solvency risk upon economic growth.

Chapter 5

Banks' Liquidity Risk and Interbank Frictions

One important function of banks is to provide liquidity. From an outside point of view, banks 'transform' illiquid loans into liquid deposits. However, in order to make deposits liquid, i.e. to serve deposit withdrawals, the bank itself holds some liquid assets. The bank can only maintain the illiquid loans as long as deposit withdrawals do not exceed the liquid assets. In other words, the banks balance sheet contains a large maturity mismatch of assets (loans) and liabilities (deposits). Ceteris paribus, the bank itself is therefore very exposed to the risk of illiquidity.

In the real world, banks can cover temporary liquidity shortages by interbank credits. Considering the interbank market's function as a device for the allocation of funds as well as its size, it is of presumable importance. However, a connection between the interbank market efficiency and economic growth has not been previously examined[1]. There is good reason to believe that there are high information frictions in the interbank market. Banks' assets are very difficult to evaluate, whereby banks themselves are the most opaque borrowers of all financial institutions (Merton 1995, p. 25). The financial strength of banks is difficult to evaluate even for experts evident in their disagreements (Morgan 2002). The example of Resona supports this view. Resona, the fifth-

[1] The discussed article by Huang and Xu (1999) focuses upon consortium banking, i.e. several banks coordinate a joint credit to a borrower.

largest Japanese bank at the time, was able to report a capital-adequacy ratio of 6%, although its real capital-adequacy ratio had been as low as 2% (*Rainy Day for Resona* 2003).

The following model attempts to fill this gap, using a simplified version (Aghion and Howitt, 1998) of King and Levine's (1993) model as a starting point. The underlying growth mechanism is the standard Schumpeterian growth model. Likewise to King and Levine (1993), banks screen credit applicants, allocate according credits, and issue deposits to households. The model is extended by allowing for imperfect diversification of liquidity risk.
As in the real world, deposits are used as a means of payment. The more banks there are, the higher the chance that deposit transfers between two banks do not exactly match. In this case the 'net recipient' bank gets a claim against the bank of the transferring depositor. Interbank credits can be used in order to avoid prohibitively costly liquidation of assets (loans). However, due to interbank information frictions, these credits are assumed to include a deadweight cost. Figure 5-1 depicts the addition of deposit transfers and interbank credits to the King and Levine model (Figure 4-5 on page 73).
The extension of these costly interbank credits induce banks to hold publicly observable reserves. Reserves can be used as collateral in order to avoid the interbank risk premium. Despite optimal reserve holdings, the liquidity risk will increase the loan-deposit spread. Thereby, credit financed R&D activity becomes less attractive and less labor is allocated to this growth-producing sector. Therefore, the growth rate becomes a function of interbank frictions.

Sections 5.1 describes the model setup. Section 5.2 solves the model and discusses the comparative statics. Possible policy interventions are discussed in a non-formal manner in Section 5.3. The results are summarized, and the key assumptions are discussed in detail in Section 5.5.

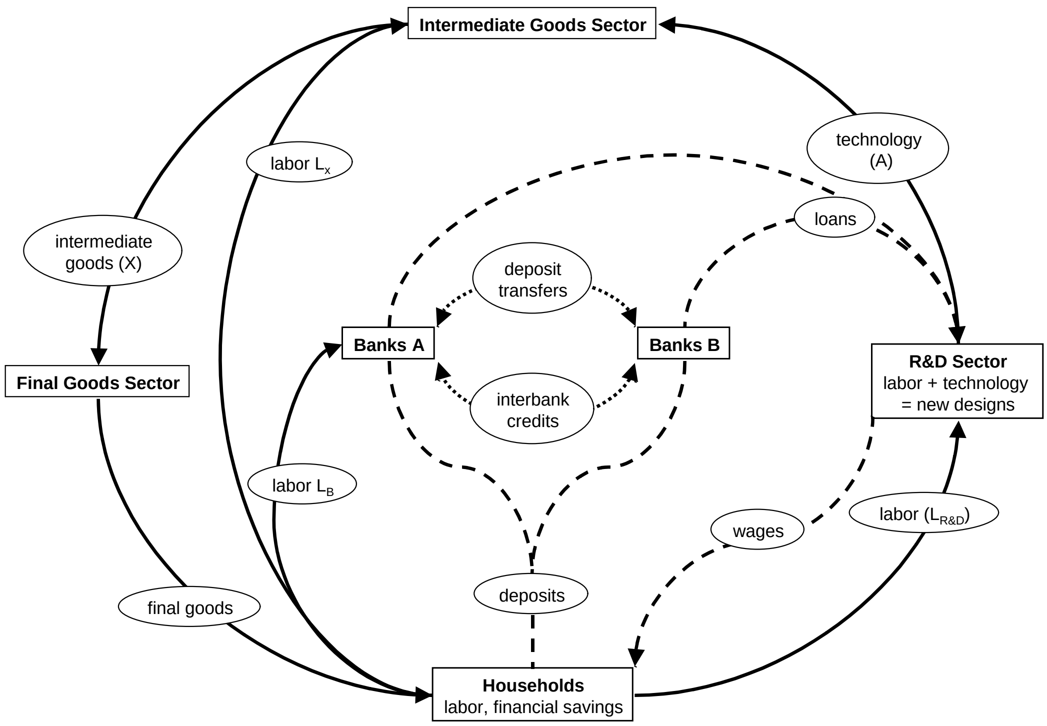

Figure 5-1: Schumpeterian Growth Model with Interbank Frictions

5.1 A Model with Reserve Optimizing Banks

As in Aghion and Howitt (1998), the production side of the model consists of final good sector, intermediate good sector and R&D sector. The final good sector produces consumption goods, using intermediate goods as input. Intermediate goods are supplied by a monopoly producer, which uses labor and existing technology as factors of production. The monopoly position is obtained by means of a patent-licence, which allows the production of the latest intermediate good. New patents are produced with labor by a competitive R&D sector. Financing is frictionless for final and intermediate good producers by assumption, but more complex for the R&D entrepreneur. He is assumed to rely upon bank finance due to imperfect information. Banks can reveal the relevant information by screening.

Additionally, intraperiod stochastic deposit transfers by the depositors are permitted so that banks can face illiquidity or excessive liquidity at the end of the period. These balance in the aggregate, but induce a demand for interbank credits. Banks' asset quality is not public knowledge, as opposed to reserve holdings. Thus, reserve-backed interbank credits do not have a spread, while unbacked credits do. The representative household supplies labor inelastically to the sectors and optimizes via its consumption choice.

5.1.1 Final Good Sector

The final product (y_i) is produced with the intermediate input (x_i), which is associated with the technology (A_i)[2].

$$y_i = A_i x_i^\alpha \tag{5.1}$$

Profits of the final good producer are the difference between the final product and outlays for x at price p: $\pi_y = Ax^\alpha - px$. The first order condition for the use of intermediate inputs is

$$p = \alpha A x^{\alpha-1} \tag{5.2}$$

The resulting profit $\pi_y = (1-\alpha)Ax^\alpha$ is given to the workforce by a lump-sum transfer[3]. All produced final goods are non-storable consumption goods

$$y = c. \tag{5.3}$$

5.1.2 Intermediate Good Sector

The intermediate good sector can produce the intermediate good (x) with one unit of labor (L_x).

$$x = L_x \tag{5.4}$$

[2] The notation is oriented at Aghion and Howitt, i.e. the setup is written in technology terms (i) and not in time (t). Note that Aghion and Howitt call them t and τ. King and Levine (1993) allow for a variety of intermediate inputs and different levels of technology. Thus indexing for technology is not helpful and they use a time index. Where the indexes are not required, they are suppressed in favor to clarity.

[3] The inclusion of labor as a factor of production is an alternative, although it complicates the model without providing additional insight.

Labor is employed at the market wage rate (w). The intermediate producers' profits are

$$\pi_x = p(x)x - wL_x, \tag{5.5}$$

and the first order condition for the use of labor in intermediate manufacturing is

$$w = \frac{\partial p(x)}{\partial x}x + p(x). \tag{5.6}$$

Innovations are assumed to be "drastic", i.e. only the latest intermediate input is competitive (Aghion and Howitt 1998, p. 74). The intermediate good producer who obtains a licence for the latest patent obtains a monopoly position. With perfect competition in the patent market, the price of innovation equals the present value of the expected monopoly profits V.

$$V = \frac{\pi_x}{r_d + \lambda L_{R\&D}} \tag{5.7}$$

The discount rate consists of the foregone interest r_d and the probability $\lambda L_{R\&D}$ that the patent becomes worthless due to a new innovation. For simplicity, it is assumed that the monopolist does not pay V immediately, but rather a licence fee $\pi_{x_i} e^{-\lambda L_{R\&D_i} t}$ over time[4].

5.1.3 R&D Sector

The R&D sector employs labor $L_{R\&D}$ to produce innovations that increase the productivity of the intermediate good in the final production by the constant factor γ, i.e. $A_{i+1} = \gamma A_i$. The time required until an innovation "occurs" from research is random with a Poisson arrival rate $\lambda L_{R\&D}$, i.e. the expected amount of innovations I in one period is

$$I = \lambda L_{R\&D}.$$

[4]If one assumes a perfect credit market between the innovation firm and the monopolist (e.g. vertical integration as in Aghion and Howitt), then it does not matter if it is a once off payment or a periodical licence fee. Further, one can imagine that the licence simply becomes more expensive once the latest innovation is utilized. Here, the monopolist and the innovator are treated seperatly in order to reveal their optimization.

This can be translated into the growth rate of the technology stock (A)[5]

$$\frac{\dot{A}}{A} = \lambda L_{R\&D} \ln \gamma \tag{5.8}$$

The present value of a new patent is denoted V_{i+1}. The expected return of research is then $\lambda L_{R\&D_i} V_{i+1}$. Since profits from the monopolistic use of this patent will accrue over time, it is assumed that the innovation firm will receive a periodical licence fee $\pi_{x_{i+1}} e^{-\lambda L_{R\&D_{i+1}} t}$ instead of a single payment V_{i+1}. The implicit credit relationship between the monopolist and the innovation firm is assumed perfect. However, employees in the R&D sector do not wish to rely on future licence-revenues, but rather to be paid immediately before they start working. Market finance is assumed to be excluded by information asymmetries. Thus, their wages have to be bank financed at the loan interest rate r_l. If this finance is imagined as a revolving credit in each period, the present value of profits is $\pi_{R\&D} = \lambda L_{R\&D} V_{i+1} - w_i \frac{r_l}{r_d} L_{R\&D}$[6] and the according first order condition is

$$w_i \frac{r_l}{r_d} = \lambda V_{i+1}. \tag{5.9}$$

5.1.4 Bank

Banks issue deposits (D), and pay an interest rate of r_d for them. They lend credit (K) at the loan rate r_l. Not all credit applicants are creditworthy. Banks are assumed to have the capability to screen credit applicants and determine creditworthiness. Screening costs are proportional to the number of researchers involved in a research project, i.e. f units of bank labor are required per

[5] Since each innovation increases the available technology by a constant rate γ, the growth of A is exponential. The impact of one innovation can be written $\ln A_{i+1} - \ln A_i = \ln \gamma$. Translating this into terms of time, the amount of innovations per period must be used. This is not one but $\lambda L_{R\&D}$

$$\ln A_{t+1} - \ln A_t = \lambda L_{R\&D} \ln \gamma$$

This is equivalent to the average growth rate of technology $\frac{\dot{A}}{A}$.

[6] For this calculation, it is assumed that the single innovation firm is sufficiently large to repay past debt by its periodic revenue and thus Ponzi finance is avoided. Taking out a new credit for the new production will be equivalent to a revolving constant credit. The present value of current labor costs financed by an infinitely revolving credit is then $\int_{v=0}^{\infty} r_l w_i L_{R\&D} e^{-r_d v} dv = \frac{r_l}{r_d} w_i L_{R\&D}$. This is only correct for the steady state.

researcher. wf thus denotes the ex-ante agency cost per screened researcher. However, since only a fraction ϕ of all possible applicants are creditworthy, and only these are granted a credit, the cost per accepted debitor increases to wf/ϕ. Banks employment is thus $L_B = \frac{f}{\phi}\frac{K}{w}$. For simplicity it is assumed that banks pay their employees with deposits. The balance-sheet constraint requires that liabilities, i.e. deposits (D) equal assets, i.e. credits (K) , its own wage bill (wL_B) and its reserve holdings (RD).

$$\begin{aligned} K + wL_B + RD &= D \\ 0 &= (1-R)D - \left(1 + \frac{f}{\phi}\right)K \end{aligned} \tag{5.10}$$

Banks' profits are also affected by stochastic interbank deposit transfers within this period (Freixas and Rochet 2002). Since banks do not know at which bank the final receiver of their deposits will be, it is possible that deposit outflows exceed deposit inflows. In this case, the bank becomes an interbank debtor.

Due to asymmetric information between banks, an interbank credit is available at the deposit rate (r_d) if and only if it is covered by reserves (public knowledge), but only at the penalty rate r_p if it is not covered. For simplicity, the interbank spread is assumed to be a deadweight cost and proportional to r_d, i.e. the penalty factor p_f is constant $r_p = r_d p_f$. This setup induces banks to hold a fraction R of deposits as precautionary reserves (Baltensperger and Milde 1987, Freixas and Rochet 2002). The stochastic net outflow as a fraction of initial deposits is described by the fraction g.

If the bank can cover this deposit outflow by it's reserves ($R \geqq g$), the cost of interbank credits ($-r_d gD$) equals the foregone cost of deposits ($r_d gD$).

If reserves are not sufficient to cover the stochastic deposit gap ($g > R$), the bank needs an interbank credit at cost $r_p > r_d$. Profits are thus given by (see Appendix 5.A.1)

$$\pi_B = \left\{ \begin{array}{lr} r_l K - r_d D + \overbrace{r_d gD - r_d gD}^{\text{interbank credit enters neutrally}} & \text{if} \quad g \leq R \\ r_l K - r_d D - \underbrace{r_d(p_f - 1)D(g-R)}_{\text{illiquidity affects profits}} & \text{if} \quad g > R \end{array} \right\}$$

Letting $\psi(g)$ denote the distribution function of g, expected profits can be depicted

$$E[\pi_B] = r_l K - r_d D - r_d(p_f - 1) \int_R^1 D\,(g - R)\,\psi(g) dg.$$

Without loss of generality even distribution of g is assumed

$$\psi(g) = \left\{ \begin{array}{ccc} \frac{1}{2} & \text{if} & g^2 \leq 1 \\ 0 & \text{if} & g^2 > 1 \end{array} \right\}.$$

The bank optimizes by solving the following Kuhn Tucker equation[7].

$$\max_{K,D,R} LL = r_l K - r_d D - r_d(p_f - 1) D \frac{1}{4} [R - 1]^2 + \varrho \left[(1 - R)\,D - \left(1 + \frac{f}{\phi}\right) K \right]$$

Two regimes result[8]. In the first regime, the interbank frictions depicted by $p_f < 2\frac{r_l}{r_d\left(1+\frac{f}{\phi}\right)} + 1$ are low and do not induce reserve holdings but simply a higher loan-deposit spread to account for the illiquidity risk. Banks will then require a loan-deposit spread of

$$\frac{r_l}{r_d} = \left(1 + \frac{f}{\phi}\right) + (p_f - 1)\frac{\left(1 + \frac{f}{\phi}\right)}{4}. \tag{5.11}$$

If the interbank frictions are larger $p_f \geq 2\frac{r_l}{r_d\left(1+\frac{f}{\phi}\right)} + 1$, it becomes optimal for banks to hold some reserves in order to diminish the likelihood of illiquidity cost realization. In this case the spread is

$$\frac{r_l}{r_d} = \left(1 + \frac{f}{\phi}\right) \sqrt{p_f - 1}. \tag{5.12}$$

---

[7]

$$\begin{aligned} E[\pi_B] &= r_l K - r_d D - r_d(p_f - 1) \int_R^1 D\,(g - R)\,\frac{1}{2} dg \\ &= r_l K - r_d D - r_d(p_f - 1) \left| \frac{1}{4} D\,(g - R)^2 \right|_R^1 \\ &= r_l K - r_d D - r_d(p_f - 1) \left[\frac{1}{4} D\,(1 - R)^2 - \frac{1}{4} D\,(R - R)^2 \right] \end{aligned}$$

[8] $D > 0$ and $K > 0$ is assumed as the model would otherwise be trivial.

The conditions are in line with zero profits.
Equilibrium on the credit market requires that the supply of bank credit (K) equals the credit demand for the research wage bill $(wL_{R\&D})$.

$$K = wL_{R\&D} \tag{5.13}$$

Note that while the wage bill is a periodic flow, the supply of credits consists of a flow and a stock. The stock consists of old credits which are revolved. The research sector (borrower) is thereby left with patent fees net of interest repayment. However, due to rising productivity (for positive growth), this amount is not sufficient to cover the present wage bill. Therefore, a positive net credit flow $\left(\dot{K}\right)$ is required.

5.1.5 Household

The representative household strives to maximize its utility. A CRRA utility function is assumed $\int_0^\infty \frac{c_t^{1-\theta}-1}{1-\theta} e^{\rho t} dt$ and the budget constraint is given by

$$\dot{D}_t = D_t r_d + w_t L_B + w_t L_{R\&D} + w_t L_{x_t} + (1-\alpha) A_t x_t^\alpha - c_t \tag{5.14}$$

The aggregate income flow consists of interest income for past deposits, labor income of bank, research, and final good sector employees, and the "profit transfer" from the final good sector. This income can be consumed or saved on deposits. Optimization results in the familiar Euler equation with ρ denoting the time preference, and θ denoting the reciprocal of the elasticity of substitution.

$$\frac{\dot{c}_t}{c_t} = \frac{r_d - \rho}{\theta} \tag{5.15}$$

Full employment of the fixed labor supply (L) requires that the available labor is allocated toward the intermediate good sector, the R&D sector and the banking sector.

$$L = L_x + L_{R\&D} + L_B \tag{5.16}$$

5.2 Steady State Solution and Comparative Statics

The steady state output growth is a function of research effort, as the steady state intermediate input is constant. By combining the final good production function (5.1), the technology growth rate (5.8) , and $\dot{x} = 0$, the steady state growth rate is depicted by[9]

$$\frac{\dot{y}}{y} = \lambda L_{R\&D} \ln \gamma, \tag{G}$$

Quadrant I in Figure 5-2 shows this typical positive relationship between research efforts and growth of endogenous growth models[10].

Quadrant II depicts the credit market. Instead of r_l-K, the diagram is depicted in terms of the spread $\frac{r_l}{r_d}$ and credit financed labor units $\frac{K}{w} = L_{R\&D}$. The reason is that the steady state credit equilibrium is rising and thus not suitable for graphical representation. The credit demand curve (CD) results from the research first order condition (5.9) including equilibrium in the intermediate good and patent market (5.2) , (5.6), (5.5) , and (5.7) as well as labor market (5.13) , (5.16) , and deposit market (5.15). Further, the steady state conditions $\omega_{i+1} = \omega_i$ with the "productivity-adjusted wage rate" $\omega_i \equiv \frac{w_i}{A_i}$ (Aghion and Howitt 1998), $L_{R\&D_{i+1}} = L_{R\&D_i}$ and $\frac{\dot{c}}{c} = \frac{\dot{y}}{y}$ were used. The detailed solution is shown in the Appendix 5.A.2.

$$\frac{r_l}{r_d} = \lambda\gamma \frac{\left[\frac{1}{\alpha} - 1\right] \left[L - \left(1 + \frac{f}{\phi}\right) K/w\right]}{\theta\lambda (\ln \gamma) K/w + \rho + \lambda K/w} \tag{CD}$$

9

$$\begin{aligned} \ln y_t &= \ln A_t + \alpha \ln x_t \\ \frac{\dot{y}}{y} &= \frac{\dot{A}}{A} = \lambda L_{R\&D} \ln \gamma \end{aligned}$$

10

$$\lambda L_{R\&D} \ln \gamma = \lambda \frac{K}{w} \ln \gamma$$

The creditmarket equilibrium (5.13) is used to depict growth as a function of credit in human capital units.

The credit demand given by Equation CD is non-negative in the relevant area and decreasing in the quantity at a decreasing rate.
The credit supply is given by the first order conditions (5.11, 5.12) of the banking sector and fully elastic at the banks optimal loan / deposit spread.

$$\frac{r_l}{r_d} = \left\{ \begin{array}{cc} \left(1+\frac{f}{\phi}\right) + (p_f - 1)\frac{\left(1+\frac{f}{\phi}\right)}{4} & \text{iff } p_f < 2\frac{r_l}{r_d\left(1+\frac{f}{\phi}\right)} + 1 \\ \left(1+\frac{f}{\phi}\right)\sqrt{p_f - 1} & \text{iff } p_f \geq 2\frac{r_l}{r_d\left(1+\frac{f}{\phi}\right)} + 1 \end{array} \right\} \tag{CS}$$

Quadrant III shows the determination of the optimal bank loan-deposit spread. It is a positive function of the exogenous penalty factor (p_f) which is a proxy for interbank frictions. Without interbank frictions, only the costs of screening credit applicants is of importance which mirrors the result of King and Levine (1993). However, once interbank frictions arise, i.e. if the penalty factor is larger than one ($p_f > 1$), banks will require a higher spread $\frac{r_l}{r_d}$ in order to cover expected illiquidity costs. These costs are realized if and only if there are net deposit outflows that are not covered by reserves. Interbank refinancing with asymmetric information thereby becomes more costly.
As can be seen in Figure 5-2, the spread initially increases linear with the penalty factor but later at a decreasing rate[11]. This is caused by reserve optimization of banks. If the expected marginal costs of illiquidity are below the marginal gross profit of intermediation, lending is preferred over reserves. Once the marginal illiquidity costs are higher, reserves are held in order to decrease the likelihood of illiquidity costs to be realized. The equilibrium in the credit market determines the research efforts and thus growth.

The comparative statics are explained using this graphical representation. Higher interbank friction (p_f) increase the optimal credit supply spread (5.11, 5.12)

[11] The critical penalty factor at which the banks are induced to hold reserves can be found by substituting the optimal spread into the side conditions.

$$\begin{array}{ll} R = 0 \Leftrightarrow & p_f < 2\frac{\left(1+\frac{f}{\phi}\right)+(p_f-1)\frac{\left(1+\frac{f}{\phi}\right)}{4}}{\left(1+\frac{f}{\phi}\right)} = 2\left(1+(p_f-1)\frac{1}{4}\right) \Rightarrow p_f < 5 \\ R \geq 0 \Leftrightarrow & p_f \geq 2\sqrt{p_f - 1} + 1 \Rightarrow p_f \geq 5 \end{array}$$

The slope is constant for the case without reserves $\partial\frac{r_l}{r_d}/\partial p_f = \left(1+\frac{f}{\phi}\right)/4$ and decreases once reserves are held $\partial\frac{r_l}{r_d}/\partial p_f = \left(1+\frac{f}{\phi}\right)/2\sqrt{p_f-1}$. The overall function is continuous.

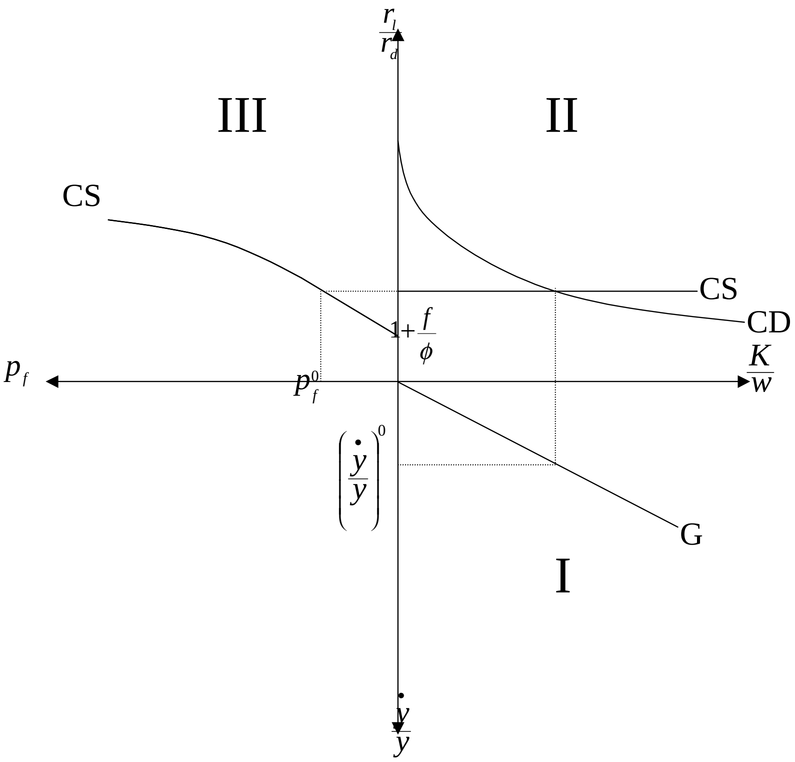

Figure 5-2: Interbank Frictions and Growth

as can be seen in Figure 5-3. As the credit demand is elastic, the equilibrium credit-financed research decreases and dampens the growth rate. Note that sufficiently high finance frictions in combination with a high preference for current consumption result in zero credits and thus zero growth[12].

Besides the interbank friction, the loan-deposit spread must also cover the screening costs $\left(\frac{f}{\phi}\right)$. It rises with the marginal labor effort requirement for screening (f) and decreases with the fraction (ϕ) of creditworthy applicants. The latter results from the fact that the burden of screening falls upon successful applicants. If their fraction increases, the costs can be distributed over a larger number and the lending spread for the single loan decreases. A rise in these screening costs $\left(\frac{f}{\phi}\right)$ also increases the credit supply spread (CS), due to an upward shift of the optimal CS schedule in Quadrant III. However, since each credit-financed employee in the research sector requires screening,

[12] The credit demand becomes nil at $\frac{r_L}{r_d} = \lambda\gamma\frac{\left[\frac{1}{\alpha}-1\right]L}{\rho}$.

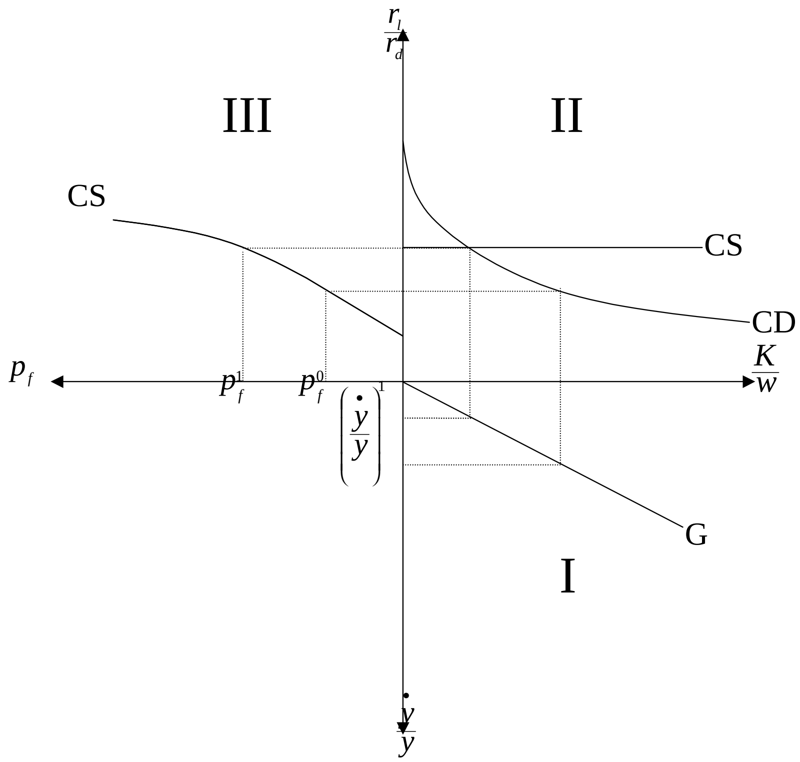

Figure 5-3: Effect of Increased Interbank Frictions

the total labor requirement per researcher $\left(1 + \frac{f}{\phi}\right)$ rises, which ceteris paribus increases the wage rate and thus decreases the demand for credit financed researchers (CD). Both effects decrease the equilibrium credit finance of research and the growth rate.

The positive effect upon CD of an increase in the labor endowment L is the well-known scale effect. More labor allows for more researchers and thus innovation, because technological progress is a function of absolute labor input in research[13].

5.3 Central Bank

A slight alteration to the above model enables a positive analysis of interbank settlement and bank monitoring by central banks. Since all transferred

[13] With a further extension of the model, such a scale effect can be eliminated.

deposits remain within the banking sector, the deposit gap of one bank is balanced by the 'excessive' deposits of another.
On an aggregate level this is a zero sum situation. If a central bank guarantees for interbank credit or supplies the required funds (demands excessive funds), the individual banks would not increase their required spread in excess of $1+\frac{f}{\phi}$. Two potential problems arise. Firstly, such a central bank must be trusted by all banks. Secondly, the central bank must be able to suppress moral hazard of banks at low costs, i.e. individual banks must not be tempted to go easy on screening.
In the real world, central banks obtain trust by building a reputation, acquiring collateral by mandatory reserves, and having the power to tax (inflation). The second problem is diminished by the right for disclosure, banking licensing and economies of scale. The right for disclosure of the monetary authority is more advanced than the rights of the public. Thus, the central bank gets a much better insight. Public disclosure cannot be as extensive, as it may reveal too much information to competitors. Further, it is stated that some ambiguity may prevent banking crises. If the central bank can withdraw banking licences, it can threat cheating banks more effectively than other lenders. Economies of scale can be realized as all auditing is bundled, which allows for specializing and avoids the double coincidence of monitoring.

In the model, these ideas can be implemented by introducing a mandatory reserves fraction $\bar{R}$ to be held at the central bank[14]. The optimization problem of the representative bank simplifies to

$$\max_{K,D} LL = r_l K - r_d D + \varrho \left[\left(1 - \bar{R}\right) D - \left(1 + \frac{f}{\phi}\right) K \right],$$

and the spread (CS) changes to[15]

$$\frac{r_l}{r_d} = \frac{1 + \frac{f}{\phi}}{1 - \bar{R}}.$$

[14]It is assumed that the reserves are simply stored as collateral at the central bank. An alternatively interpretation is that they are used to finance monitoring by the central bank. Both choices have the advantage that reserves rise with the balance sheet of banks, as collateral requirements and monitoring costs would do.

[15]The first order conditions for K and D are $r_l = 1 + \frac{f}{\phi}$ and $r_d = 1 - \bar{R}$.

This setup is more likely to be preferable to the unregulated solution the higher the central bank's reputation and monitoring technology and interbank information asymmetries[16]. In contrast to the usual argument where reserve requirements are seen as additional costs of intermediation and thus growth diminishing (Becsi and Wang 1997), reserve requirements can increase efficiency and growth in this model. However, the critical element is not the withdrawal of reserves, but their use by the central bank to guarantee settlement. A rise in reserves requirements ceteris paribus still dampens growth.

5.4 Interbank Market Financial Liberalization

As in the case of a central bank devoted to market efficiency, large international banks have a high reputation and thus generate little to no information costs when absorbing interbank funds. Even if the credibility of international banks is not based on reputation but collateral, this collateral is not taken from the domestic market. Thus, it is likely that international banks will have an effect on market efficiency that is similar to that of an active central bank. Due to its international experience and superior information technology, the international bank can also screen and monitor interbank lending at lower information costs.

In the model, interbank intermediation via international banks will decrease the interbank penalty rate ρ_b. Banks will hold less reserves and require a lower spread. The increasing efficiency of the intermediation process will foster growth. The presence of international banks in the interbank market is not necessarily a threat for smaller domestic banks. In fact, there is a chance for complementary specialization in the banking sector. International banks with superior screening technology for financial firms would improve efficiency in the interbank market segment of the financial system, while domestic banks could use their knowledge of domestic borrowers in the screening and retail banking process.

[16] More precisely, the required mandatory reserve fraction needs to be $\frac{1}{1-\bar{R}} < \sqrt{p_f - 1}$ for $p_f \geq 5$ or $\frac{1}{1-\bar{R}} < 1 + (p_f - 1)\frac{1}{4}$ for $p_f < 5$.

5.5 Summary and Discussion

The model developed in this chapter departs from the known literature in two respects. Firstly, it allows for non-idiosyncratic liquidity risk. In order to examine banks' behavior regarding their own liquidity risk, it has to be avoided that this risk can be perfectly diversified. The second departure is the acknowledgment of informational frictions between banks. Therefore, liquidity shortages in one bank cannot costlessly be balanced by excess liquidity in another bank. Interbank credits are assumed to come at a cost, similar to screening and monitoring in the previous literature. This combination of liquidity risk and costly interbank credits induces banks to hold reserves, for exactly the same reasons households have been holding reserves in Bencivenga and Smith (1991).

The results are twofold. Firstly, the model supplies a theoretical motivation for the use of interbank spreads as a proxy and a causal factor for the loan-deposit spread. Secondly, the model implies the possibility for growth-enhancing interventions. While government interventions are unlikely to improve the problems of informational asymmetries at the individual borrower-lender level, it is possible to diminish information inefficiencies at the interbank level. The monetary authority can offer an interbank settlement system with a lower spread, if its reputation is superior to the single bank's reputation. However, to realize a net gain in efficiency and growth, the costs of banks moral hazard must remain below the gains of the intervention. Similarly, financial liberalization can improve the interbank market.

Since the model builds upon that of King and Levine (1993), it shares with it most of the shortcomings. As shown by Galetovic (1994), the unambiguous positive growth effect of improved financial intermediation becomes ambiguous once the bank also lends to the non-innovative sectors. Though, due to the focus upon interbank frictions, the model is more robust. There is no reason to believe that the alleviation of interbank friction changes the structure of banks' asset portfolios. When the structure remains, total loans increase due to less reserves, and the R&D sector can attract at least as many resources as before.

In the following paragraphs the assumption of bank-dependent R&D firms is discussed in greater detail. If R&D firms could substitute bank loans against other finance (e.g. market-finance) costlessly, the impact of interbank frictions would be dampened or, in the case of perfect substitutes, nullified. Since this assumption is so vital, according theoretic and empirical literature is presented. Most of literature is related to the so-called "bank-lending channel", which also uses bank-dependence as a vital prerequisite. The basic idea behind the bank-lending channel (e.g. Kashyap, Stein and Wilcox, 1993; Bernanke and Gertler, 1995; Ashcraft, 2001) is that tight monetary policy, will cause a decreases in banks' loan supply and aggregate activity. The underlying assumptions are that tight monetary policy will reduce reserves and thus deposits, and banks do not have a perfect substitute for the latter. Similar to the liquidity model, this causes a backward shift in the loan supply curve. The connection to economic activity is achieved by assuming that firms do not have perfect substitutes for bank finance[17].

Section 2.2.3 already highlighted banks' superior ability to screen and monitor borrowers as a theoretical rational for bank finance. Banks' monitoring ability can also be used to explain firm dependence upon bank loans.
If the borrower invests his own wealth (net worth) in the project, there is an incentive for honesty as the lender would claim it (collateral), if the borrower defaults. Since banks' have better monitoring capacities than other market participants, they require ceteris paribus less collateral than the market. This situation is modeled via a two-period principal-agent equilibrium model by Holmstrom and Tirole (1997). They assume that only banks can monitor the investment outcome. The result is that firms need a higher net worth ratio if they want to obtain market finance, compared to bank finance. Thus, there are some firms which are bank-dependent.
Repullo and Suarez (2000) extend this concept by developing a model which endogenizes the fraction of bank-dependent firms and unconstrained borrowers that choose bank finance. They assume that monitoring is costly if risk neutral borrowers divert funds for private uses . The moral hazard problem results in

[17]Ben Bernanke, the new chairman of the Federal Reserve Bank, stated that the bank lending channel is of less importance now (Mishkin 1995, p. 7).

incentive constraints that are a function of the borrowers' net worth ratio and the financing costs. Credit applicants that cannot provide the minimum net worth ratio are credit rationed. Again, banks are assumed to be better monitors, and thus the threshold net worth ratio is higher for market finance than for bank loans.

Empirically the existence of bank-dependent firms is undisputed. However, there is no consensus about the extent of bank-dependency, nor about the macroeconomic importance of a bank-lending effect.
Bernanke (1993) uses the findings of Fama (1985) and James (1987) that bank borrowers carry the burden of the 'reserve tax' as an indication for the existence of bank-dependent firms. The reasoning is that debtors, who could perfectly substitute bank loans with other sources of finance, would simply circumvent the tax burden.
A more commonly used approach is to cluster firms into supposedly bank-dependent and unconstrained firms, and to test which group is stronger affected by monetary policy. Such an approach already includes the bank-lending channel assumption that bank loan supply decreases due to monetary tightening. One characteristic for the clustering is firm size. There is support for the hypothesis that the impact of monetary policy is relatively stronger on small firms (e.g. Gilchrist and Zakrajsek, 1995; Oliner and Rudebusch, 1996; Bernanke, Gertler and Gilchrist, 1996).

Subsuming it can be said that the assumption of bank-dependent firms is reasonable, especially for small firms. If these are additionally the source for technology progress, interbank frictions are highly relevant for economic growth.

5.A Appendix

5.A.1 Appendix 1

For $g > R$ the bank saves interest payments on the lost deposits $r_d g D$. However it must pay for the covered $(r_d R D)$ and the uncovered $(r_p (g - R) D)$ interbank credits. Thus the profits are

$$\begin{aligned}
& r_l K - r_d D + r_d g D - r_d R D - r_p (g-R) D \\
= \; & r_l K - r_d D + r_d D (g-R) - r_p D (g-R) \\
= \; & r_l K - r_d D - r_d (p_f - 1) D (g-R)
\end{aligned}$$

when the penalty is linear to the interests $r_p = r_d p_f$.

5.A.2 Appendix 2

The monopoly intermediate good producer maximizes his profit with regard to the demand of the final good producer. The price and the inverse of the price elasticity can be derived from the first order condition of the final output producer (5.2):

$$\frac{\partial p_i}{\partial x_i} = (\alpha - 1) \alpha A_i x_i^{\alpha-2}$$

Using this result in the first order condition of the intermediate good producer (5.6) gives the Cournot equilibrium of intermediate goods:

$$\begin{aligned}
w_i &= \left[(\alpha - 1) \alpha A_i x_i^{\alpha-2} \right] x_i + \alpha A_i x_i^{\alpha-1} \\
&= \alpha^2 A_i x_i^{\alpha-1} \\
x_i &= \left(\frac{\alpha^2 A_i}{w_i} \right)^{\frac{1}{1-\alpha}} \qquad (5.17)
\end{aligned}$$

The intermediate good producers' monopoly profit (5.5) at equilibrium quantity (5.17) and price (5.2) can then be written

$$\begin{aligned}
\pi_i &= p_i(x_i) x_i - w_i x_i \\
&= \left[\alpha A_i \left(\frac{\alpha^2 A_i}{w_i} \right)^{\frac{1}{1-\alpha}(\alpha-1)} \right] \left(\frac{\alpha^2 A_i}{w_i} \right)^{\frac{1}{1-\alpha}} - w_i \left(\frac{\alpha^2 A_i}{w_i} \right)^{\frac{1}{1-\alpha}} \\
&= \left(\frac{\alpha A_i}{w_i} \left(\frac{\alpha^2 A_i}{w_i} \right)^{-1} - 1 \right) w_i \left(\frac{\alpha^2 A_i}{w_i} \right)^{\frac{1}{1-\alpha}} \\
\pi_i &= \left[\frac{1}{\alpha} - 1 \right] w_i \left(\frac{\alpha^2 A_i}{w_i} \right)^{\frac{1}{1-\alpha}}
\end{aligned}$$

Since the value V_{i+1} is needed, the innovation counter in (5.7) is increased by 1 as well.

$$\pi_{i+1} = \left[\frac{1}{\alpha} - 1\right] w_{i+1} \left(\frac{\alpha^2 A_{i+1}}{w_{i+1}}\right)^{\frac{1}{1-\alpha}}. \tag{5.18}$$

Equilibrium on the patent market is given by (5.7) and (5.9), and π_{i+1} can be substituted by the above result (5.18)

$$\begin{aligned}
w_i \frac{r_l}{r_d} &= \lambda \frac{\pi_{i+1}}{r_d + \lambda L_{R\&D_{i+1}}} \\
w_i \frac{r_l}{r_d} &= \lambda \frac{\left[\frac{1}{\alpha} - 1\right] w_{i+1} \left(\frac{\alpha^2 A_{i+1}}{w_{i+1}}\right)^{\frac{1}{1-\alpha}}}{r_d + \lambda L_{R_{i+1}}} \\
w_i \frac{r_l}{r_d} &= \lambda \frac{\left[\frac{1}{\alpha} - 1\right] A_{i+1} \frac{w_{i+1}}{A_{i+1}} \left(\frac{\alpha^2 A_{i+1}}{w_{i+1}}\right)^{\frac{1}{1-\alpha}}}{r_d + \lambda L_{R_{i+1}}} \\
\frac{w_i}{A_i} \frac{r_l}{r_d} &= \lambda \frac{\left[\frac{1}{\alpha} - 1\right] \frac{A_{i+1}}{A_i} \frac{w_{i+1}}{A_{i+1}} \left(\frac{\alpha^2 A_{i+1}}{w_{i+1}}\right)^{\frac{1}{1-\alpha}}}{r_d + \lambda L_{R_{i+1}}} \\
\omega_i \frac{r_l}{r_d} &= \lambda \frac{\left[\frac{1}{\alpha} - 1\right] \gamma \omega_{i+1} \left(\frac{\alpha^2}{\omega_{i+1}}\right)^{\frac{1}{1-\alpha}}}{r_d + \lambda L_{R\&D_{i+1}}}
\end{aligned}$$

Here, the following identities were used $A_{i+1} = \gamma A_i$ and $\omega_i \equiv \frac{w_i}{A_i}$, which describes the "productivity-adjusted wage rate" (Aghion and Howitt 1998). The steady state requires that $\omega_{i+1} = \omega_i$ and $L_{R\&D_{i+1}} = L_{R\&D_i}$ whereby the above equation simplifies to

$$\frac{r_l}{r_d} = \lambda \frac{\left[\frac{1}{\alpha} - 1\right] \gamma \left(\frac{\alpha^2}{\omega}\right)^{\frac{1}{1-\alpha}}}{r_d + \lambda L_{R\&D}}. \tag{5.19}$$

The labor market equilibrium (5.16), including the equilibrium labor demand by the banking sector (5.13) and the intermediate good producer (5.17), can be written

$$
\begin{aligned}
L &= L_x + L_{R\&D} + L_B \\
&= L_x + L_{R\&D} + \frac{K}{w}\frac{f}{\phi} \\
&= \left(\frac{\alpha^2}{\omega}\right)^{\frac{1}{1-\alpha}} + L_{R\&D} + L_{R\&D}\frac{f}{\phi} \\
&= L_{R\&D}\left(1+\frac{f}{\phi}\right) + \left(\frac{\alpha^2}{\omega}\right)^{\frac{1}{1-\alpha}} \qquad (5.20)\\
\left(\frac{\alpha^2}{\omega}\right)^{\frac{1}{1-\alpha}} &= L - L_{R\&D}\left(1+\frac{f}{\phi}\right). \qquad (5.21)
\end{aligned}
$$

The productivity-adjusted wage rate was used in the formulation of x (5.17) and the since the research sector is the only credit receiver, $\frac{K}{w} = L_{R\&D}$. Using the labor market equilibrium, the optimal consumption path, and the steady state condition $\frac{\dot{c}}{c} = \frac{\dot{y}}{y} \implies r_d = \theta\lambda L_{R\&D}\ln\gamma + \rho$ the productivity adjusted credit demand $L_{R\&D} = K/w$ (5.13) is depicted by

$$
\begin{aligned}
\frac{r_l}{r_d} &= \lambda\frac{\left[\frac{1}{\alpha}-1\right]\gamma\left[L - L_{R\&D}\left(1+\frac{f}{\phi}\right)\right]}{\theta\lambda L_{R\&D}\ln\gamma + \rho + \lambda L_{R\&D}} \\
\frac{r_l}{r_d} &= \lambda\gamma\frac{\overbrace{\left[\left[\frac{1}{\alpha}-1\right]\left[L - \left(1+\frac{f}{\phi}\right)K/w\right]\right]}^{\pi_x/w}}{\theta\lambda\left(\ln\gamma\right)K/w + \rho + \lambda K/w}. \qquad (5.22)
\end{aligned}
$$

Chapter 6

Endogenous Growth and Banks' Solvency Risk

> "The essential function of credit ... consists in enabling the entrepreneur to withdraw the producers' goods which he needs from their previous employments, by exercising a demand for them, and thereby to force the economic system into new channels. ... The entrepreneur is never the risk bearer. ... The one who gives the credit comes to grief if the undertaking fails." Schumpeter ([1912], 1934, pp. 106, 137)

Banks are special. Besides all the various functions that have been described in Chapter 2, banks are also very easily distinguished from other firms by their balance sheet. On their asset side, machinery, buildings and other tangible assets that are important in regular firms, account for only a negligible fraction (Table 2.1, page 8). Most assets of banks are financial, i.e. loans granted to a third party. Also on their liability side they are distinct. Equity capital is such a small source of finance that it hardly accounts as a real source of finance at all. Therefore, some authors have omitted bank capital from their analysis of bank behavior (Hart and Jaffee 1974, p. 130).

However, it can be argued that bank capital's function is to serve as a buffer against insolvency risk esteeming from the variance of asset returns (O'Hara 1983), rather than serving as an important source of finance. Such an interpretation is consistent with the function of banks in transforming risky assets into risk-free deposits. This buffer mechanism is distinct from the notion that banks diminish risk by better diversification, which has been highlighted by most of the literature.

The prolonged Japanese downturn and the Asian Crisis have drawn attention to the buffer role of bank capital and its interdependency with economic growth. For example in Japan negative shocks reduced banks' profitability and equity. In order to reduce the exposure to insolvency risk, banks curtailed their lendings and may have thereby accelerated the economic downturn (e.g., Bernanke 1983; Bayoumi and Towe 1998; Kanaya and Woo 2000; Country Profile Japan 2003).

Additionally, the monetary transmission literature also highlights the importance of banks in general, i.e. the bank-lending channel (Bernanke and Blinder 1988), and specifically the importance of bank capital, the so-called "bank-capital channel" (e.g., Stiglitz 1999; Kishan and Opiela 2000; Aikman and Vlieghe 2004; Gambacorta and Mistrulli 2004). The bank-capital channel literature argues that tight monetary policy reduces bank capital. The reason for this can be seen in the maturity mismatch which causes banks to be sensitive to interest rate changes. The liability side is financed short-term and cost of funds immediately increase, while the return on the asset side (long-term) cannot be adjusted as rapidly (Repullo and Suarez 2000). Banks, wanting to maintain their capital ratios, curtail lending, whereby bank-dependent firms suffer financing problems.

Despite these strong indications of interdependencies between bank capital as a risk buffer and economic activity, bank capital has not yet been embedded into a general equilibrium endogenous growth model. Such a formalization, however, is a prerequisite for the understanding of possible economic mechanisms and according policy recommendations.

Therefore, this chapter provides two formal models explaining a causal link between bank capital and economic growth. Here the focus is upon the banking activity of transforming risky assets into risk-free deposits, using bank capital for intertemporal smoothing of occasional debt defaults. An endogenous growth model is altered to accommodate two types of agents.

In the first model, the agents differ only by their risk aversion and time pref-

erence. Besides clarifying the interdependencies between bank capital and economic growth this model is very well suited to explain the coexistence and determinants of bank and market finance.
The second model assumes that regular households cannot directly finance firms and must use the bank as an intermediary. Both models share the basic idea that banks are risk averse, and their joint elements are discussed in the following.

Considering that the idea of banks as savings allocator and risk bearers originates from Schumpeter, and Schumpeterian growth models have been formalized (Aghion and Howitt, 1992), implementing risk averse bankers into their model is an obvious task. As discussed in Subsection 3.2.3 the original Aghion and Howitt growth model uses the expected net present value of a monopoly licence as incentive for innovation activities (Table 3.1, page 44). They assume households with linear utility functions, in other words risk neutral households. In such a setup, risk transfer is useless.
Without considering banks, Wälde (2002) examines the effect of households risk aversion and altered the Aghion and Howitt (1992) model elegantly by assuming tangible R&D output. Successful research accrues in the form of a prototype machine which embodied technology is a public good. Wälde is thereby able to solve the dynamics and to explain economic cycles via stochastic innovation successes that induce a reallocation of productive resources.

The endogenous growth model used in this chapter is a variation of Aghion and Howitt's (1992) Schumpeterian growth model, and Romer's (1986) AK model. Similar to the Schumpeterian model, there are two sectors. The first is a risk-free production sector that takes technology as given, and produces deterministically. The second is an innovative sector that produces stochastic technology improvements. The denotation "innovative sector" instead of "R&D sector" has been chosen to clarify the difference in the incentive for technology improvements. The model differs from the standard Schumpeterian model insofar as the incentive to employ resources in the innovative sector is potentially higher productivity, rather than a resulting technology asset and a monopoly position. Technology improvements themselves are considered pure externalities, as in the AK model. Yet, they are produced with a risky tech-

nology, as in the aforementioned variation of Wälde (2002).
It is assumed that the workforce does not accept uncertain wages, and that the innovative sector requires external finance of its wage bill. Thereby, the availability of finance determines the labor allocation towards innovative production and thus technology growth similar to King and Levine (1993).

For bank capital to gain importance as a buffer against insolvency, one initially must answer the question: Why should the banker even hold bank capital as a buffer? The literature provides three different answers.
Firstly, the Basel Accord simply forces the banker to maintain capital of at least 8% of risk weighted assets. This is an institutional arrangement, and if it is incentive compatible with its goal to diminish the risk of insolvency is fiercely disputed in the literature[1]. Further, this explanation is not consistent with the fact that banks' capital in most G-10 countries exceeds the regulatory capital adequacy ratio (Brealey 2001, p. 149). Therefore, capital regulations are not considered in the following sections.
Secondly, once bankruptcy is costly, the expected costs can be diminished via bank capital due to the according decrease in the likelihood of insolvency. Similarly, an already higher risk of insolvency may be costly, for example due to credit rating downgrades (Brealey 2001, p. 149) which might increase the cost of funds.
Thirdly, if the banker is risk averse and liability is unlimited, capital is held to diminish the insolvency risk. Bankruptcy cost and risk aversion will cause very similar reactions by bankers. The main formal difference is that bankruptcy costs are initially monetary in the budget constraint, and are translated into forgone utility for the optimal decision, whereas risk aversion is an intrinsic result of the utility function.

The newly developed model assumes that the representative banker is risk averse as state for example by O'Hara (1983) and Stiglitz (1999). She chooses her assets (loans) as well as her liabilities (deposits) via a portfolio decision.

[1] For example Santos (1999) shows that bank capital regulation improves bank's stability. In contrast, Blum (1999) has shown that banks are induced to take more risk. The reason is the increased value of bank equity, which is an incentive for risk taking, in order to increase future equity. Empirical support for the adverse effect of banking regulation is provided by González (2005).

Such behavior has already been examined by Pyle (1971), Hart and Jaffee (1974), and Neuberger (1991, 1993), however only within a partial, static model. Since the new models differ in bank behavior, further discussion of the literature follows within the corresponding sections.

6.1 Banks' Solvency Risk, with Heterogenous Risk Aversion

The model developed in this section assumes as few constraints on the financing choice as possible. Finance is supplied by two types of agents that differ in their risk aversion. The agent with low risk aversion chooses risky investment in excess of her wealth and covers the financial gap by short selling risk-free deposits to the highly risk averse agent. Thus, the low risk averse agent is denoted as 'banker' and the high risk averse agent is denoted as 'household'. This idea is adopted from Neuberger (1991) and offers an endogenous explanation for banking activities in the sense of risk shifting. The more the agents differ in respect to their risk aversion, the more risk will be shifted towards the bank via deposit short selling and saving respectively. However, not all risk will be shifted, so that direct bank finance and indirect market finance coexist in this model.

Thereby, an immediate result of the model is that differences in the risk aversion of citizens may explain why some economies rely on bank–finance, while others rely more heavily on market-finance (e.g., Germany versus USA, Allen and Gale 1995). It is noteworthy that the model does not require transaction costs or asymmetric information to obtain this result.
Further, technology-dependent wages in the final good sector imply a ratchet effect, if the technology does not depreciate (e.g., knowledge). In combination with financial asset fluctuation, this may explain prolonged setbacks of technology progress following a negative economic shock.
Finally, the model shows that, contrary to intuition, a decreasing steady state interest rate spread can be associated with lower economic growth. The risk averse household reacts to the decreasing spread with an overproportionate portfolio shift away from market investment, towards safe but low yielding

deposits. A decreasing return on wealth outweighs increased savings, whereby wealth accumulation and economic growth settle at a lower steady state growth rate.

The following subsection introduces the endogenous growth model[2] including portfolio optimizing banks. Subsection 6.1.2 provides the solution to the model and discusses the comparative statics as well as the dynamic analysis. Subsection 6.1.3 discusses potential policy implications and concludes.

6.1.1 The Model

The model depicts a closed economy. The two factors of production are labor and technology knowledge, which resembles a public good. Output is produced by a risk-free production process in the final good sector, and a risky production process in the innovative sector. The latter offers higher average returns and increases the level of available technology as an externality (Figure 6-1). There are two[3] types of agents, which differ only in their risk aversion and time preference. Both supply labor inelastically. They optimize via their savings and portfolio choice.
The risky asset is the wage bill of the innovative sector, while the safe asset will be shown to evolve endogenously via the portfolio choices. Figure 6-1, depicts the situation, where risk aversions are sufficiently heterogenous to induce the low risk averse agent (banker) to short sell a safe asset (deposits) and lend to the risky innovative sector. The high risk averse agent (household) thereby has the choice of saving in deposits (safe) and in direct market finance (risky).

The Final Good Sector

In the final good sector existing technology[4] (A) is combined with labor input (L_S) to produce output (y_S). This output is also the numeraire of the whole model. To keep things simple, the production function is assumed linear in

[2] A table of the variables and parameters is supplied in Appendix 6.A.1.
[3] The results of the model are not affected if a continuum of risk averse agents is assumed.
[4] To simplify the notation, the time index is attached to the variables only if absolutely necessary.

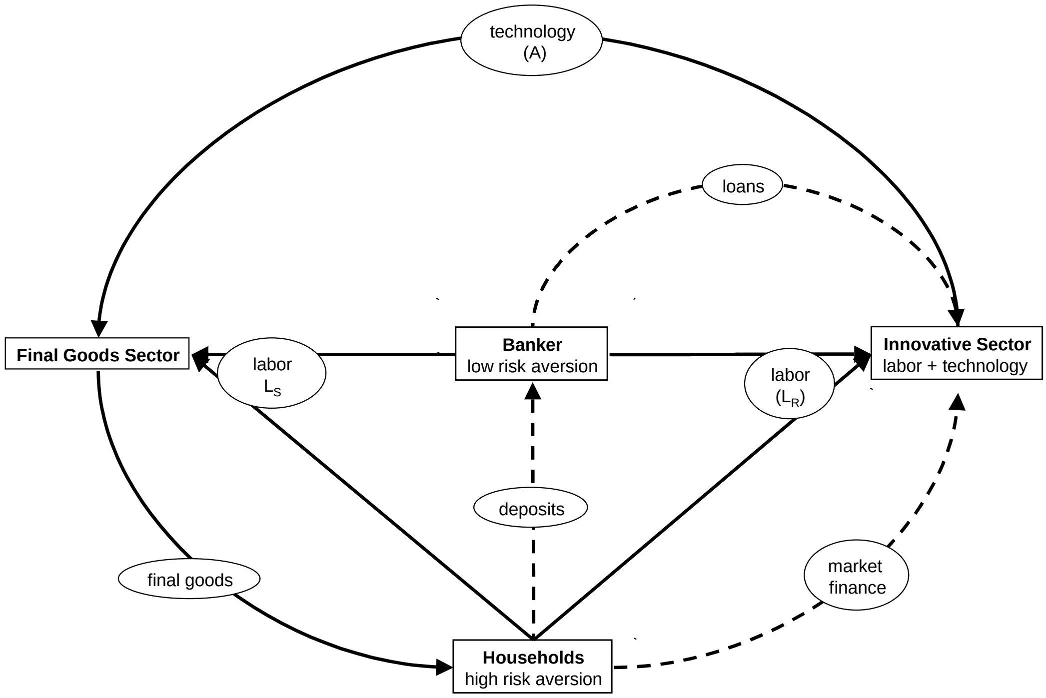

Figure 6-1: Coexistence of Bank and Market Finance

labor. With a constant labor force economic growth thus requires technology improvements.

$$y_S = AL_S \tag{6.1}$$

Profit maximization equates wage (w), with the marginal product of labor which, in this simplified case, is the technology level A.

$$w = A \tag{6.2}$$

Improvements in technology are assumed to be an externality of 'innovative production'.

The Innovative Production Sector

An alternative use of labor (L_R) is to combine it with new ideas to attempt new production technologies. However, this attempt is risky insofar as output

(y_R) obeys a Poisson process q.

$$y_R = \left\{ \begin{array}{ccc} \vartheta A L_R & \text{if} & dq = 0 \\ \vartheta A L_R - \beta A L_R & \text{if} & dq = 1 \end{array} \right\} \tag{6.3}$$

This innovative production requires an 'investment' in the extent of the wage bill wL_R. Applying the equilibrium wage rate (6.2), it can be seen that the stochastic return on the investment K is $dK(t) = (\vartheta K(t) - K(t))\,dt - \beta K(t)dq$. If the project has been successful $dq = 0$, and the risky rate of return is $r_R \equiv \vartheta - 1$. An unsuccessful attempt is formally described by[5] $dq = 1$ and causes a fraction $\beta \in [0,1]$ of the initial investment to be lost. The remaining fraction $(1-\beta)$ can be interpreted as collateral (Neuberger 1991, p. 287). The likelihood of innovative production to fail is given by the Poisson arrival rate λ.

The technology knowledge obtained during this innovative production process is a public good and, as such, enhances the technology stock as an externality:

$$dA = Af(L_R)dt - Af(L_R)dq \tag{6.4}$$

Technology growth is thus, similar to Romer (1990), a function of labor allocated towards a certain sector. Additionally, it is stochastic as in Aghion and Howitt (1992), however the incentive to allocate resources to this sector is the expectation of higher productivity, rather than a resultant monopoly position. The monopoly setup is avoided, because the present value of monopoly profits can only be calculated for the steady state, whereby dynamic analysis is excluded. Wälde (2002) solved the monopoly issue for his model, maintaining creative destruction, by assuming that the result of - and incentive for - research is a tangible prototype machine. In order to avoid an additional state variable (capital) in the present model, the output of 'research' has been altered to final goods, whereby technological progress becomes a pure externality

[5] Instead of working with upwards jumps due to a success in research (e.g. Aghion and Howitt, 1998; Wälde, 1999 and 2002) this model use downwards jumps in case of a failing innovative investments. The important characteristic that new technologies cannot be produced deterministically remains. However, the downward jump allows the interpretation of the innovative investment as a risky loan. This enables the utilization of existing literature and methods for banking activity and portfolio optimization.

as in Romer (1986). The economic concept that technological progress results from entrepreneurs diverting resources from known production processes, in an attempt to earn extra profits, remains.

Similar to Schumpeter's ([1912], 1934) concept of an entrepreneur who does not bear the economic risk of new ventures, the factor labor does not accept uncertain wages. Thereby, financiers who outlay the 'investment' of the wage bill, and bear the down- and upside risk of innovative production, must be found.

The Low Risk Averse Agent: Banker

This subsection describes, in detail, the behavior of the representative agent, with relatively low risk aversion. It demonstrates under which conditions she will become active in the banking activity of investing in risky assets in excess of her (equity) capital. The financial gap is closed by short selling safe deposits, whereby risk is transferred from the relative high risk averse agent to the banker. Bank equity is used to smooth the stochastic fluctuations of the risky asset.

The representative risk averse banker maximizes utility from consumption $u(c_b)$. To allow for constant steady state leverage, constant relative risk aversion is required $u(c_b) = \frac{1}{\gamma_b} c_b^{\gamma_b}$ (Hakansson 1996, p. 917). The objective function with ρ_b denoting the personal discount rate of the banker is

$$\int_t^{\infty} e^{-\rho_b s} u(c_b(s)) ds.$$

The banker's intertemporal budget constraint is the following stochastic differential equation

$$dE = (r_R \omega_b E + r_D(1 - \omega_b)E - c_b)\, dt - \beta \omega_b E dq. \tag{6.5}$$

The banker is thereby modeled as portfolio manager, who can invest a fraction (ω_b) of her equity (E) in the innovative production sector at the risky return (r_R) and a fraction $(1 - \omega_b)$ in risk-free deposits, with the rate of return r_D.

Risk averse portfolio optimizing bank managers have already been examined within a partial static model by Pyle (1971), and Hart and Jaffee (1974). It can be argued that bank equity is held as a buffer, reducing the risk of bankruptcy over time. O'Hara (1983) extended the portfolio choice with a retained earnings choice, in the form of optimal consumption. The incentive for the manager to retain some profits instead of consuming them is the risk of bankruptcy, which will cost her her job (O'Hara 1983, p. 131). The consumption choice c_b in the intertemporal budget constraint (6.5) can thus be interpreted as retained earnings choice, and further depicts banks' reliance upon retained earnings to increase equity. For simplicity sake, it has been assumed that the banker acts as if she is fully liable[6].

Similar continuous time stochastic portfolio and consumption optimization problems have also been examined by Merton (1969, 1971), Neuberger (1991), and Sennewald and Wälde (2005, p. 17).

Applying the Bellman Principal of Optimality, the objective function of the banker can be written (see Appendix 6.A.1)

$$0 = \max_{\omega_b, c_b} \left\{ \begin{array}{c} u(c_b(t)) - \rho_b J^* + J_E^* \left(r_R \omega_b E + r_D (1 - \omega_b) E - c_b \right) \\ + \lambda \left[J^* \left(E - \beta \omega_b E \right) - J^* \left(E \right) \right] \end{array} \right\}, \tag{6.6}$$

where $J^*(E) \equiv \int_0^\infty e^{-\rho_b s} u \left(c_b(s), s \right) ds$ is the present value of optimized lifetime consumption for time $t = 0$. From the according first order conditions, the optimal portfolio and consumption choices follows. The optimal portfolio choice is (see Appendix 6.A.1)

$$\omega_b^* = \left[1 - \left(\frac{\lambda \beta}{r_R - r_D} \right)^{\frac{1}{1 - \gamma_b}} \right] \frac{1}{\beta}, \tag{6.7}$$

with $1 - \gamma_b \in [0, 1]$ denoting the Pratt (1964) measure of relative risk aversion, and λ denoting the Poisson arrival rate, i.e. the likelihood of an asset default. For positive risky investment the expected rate of return on risky investments must exceed the safe rate of return $r_R - \lambda \beta > r_D$ in order to compensate for the utility loss due to the default risk. To allow for a useful equilibrium, it is assumed that r_R is sufficiently high to fulfill this inequality. According to intuition, higher leverage requires a higher risk premium $(r_R - r_D)$, decreased

[6] Issues of portfolio managing banks with limited liability within a partial equilibrium context are discussed by Gollier, Koehl and Rochet (1997).

risk, i.e. lower likelihood of default λ, higher collateral $(1-\beta)$, or decreased risk aversion[7].

High leverage is typical for a bank. Thus, it is assumed that the banker's risk aversion is sufficiently small[8]

$$1-\gamma_b < \frac{\ln\left(\frac{\lambda\beta}{r_R-r_D}\right)}{\ln(1-\beta)} \Leftrightarrow \omega_b^* > 1 \tag{6.8}$$

to induce risky investment in excess of her own capital. Therefore, the banker allocates 'loans' to the innovative production sector and finances the resultant gap by short selling the safe asset as deposits. Risk aversion and positive collateral ensures that the bank remains solvent even in the case of loan default[9]. Hence, bank deposits are, in fact, safe assets from the viewpoint of other agents in the economy.

The optimal consumption to equity ratio $\tilde{c}_b$ is given by (see Appendix 6.A.1)

$$\tilde{c}_b \equiv \frac{c_b}{E} = \frac{\rho_b + \lambda - \gamma_b\left(\frac{r_R-r_D}{\beta} + r_D\right) - (1-\gamma_b)\,\lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}}}{1-\gamma_b}. \tag{6.9}$$

The consumption choice is included to allow for optimal endogenous savings i.e., in the case of the bank, optimal retained earnings. This consumption ratio is increases in the personal discount rate ρ_b, and for the banker[10] also in r_D. The latter can be understood by acknowledging that r_D is a cost factor for the bank and reduces the mean rate of return on equity. Therefore, the incentive to retain profits is reduced and it is optimal to substitute current consumption for future consumption.

The High Risk Averse Agent: Regular Household

The representative household differs from the banker only in its risk aversion and time preference. Besides simplifying the setup, the rationale for this symmetry is to show that heterogenous preferences suffice to explain the co-

[7] See appendix 6.A.1 for the formal derivatives.
[8] See appendix 6.A.1.
[9] See appendix 6.A.1.
[10] $\partial(\tilde{c}_b)/\partial r_D = \frac{\gamma_b}{1-\gamma_b}(\omega_b^*-1) > 0$, see appendix 6.A.1.

existence and different reliance upon bank versus market finance observed in the real world.

The household's objective function is

$$\int_t^\infty e^{-\rho_h i} u(c_h(i)) di.$$

Again the instantaneous utility function is assumed CRRA: $u(c) = \frac{1}{\gamma_h} c_h^{\gamma_h}$, with $(1-\gamma_h)$ denoting the relative risk aversion of the household. The intertemporal budget constraint is

$$dW = (r_R \omega_h W + r_D (1-\omega_h) W - c_h)\, dt - \beta \omega_h W dq, \tag{6.10}$$

where W denotes household wealth and ω_h is the fraction of wealth allocated towards the risky investment. The household is optimizing via its consumption (savings) choice c_h and portfolio choice ω_h. The optimization problem is according to the aforementioned optimization of the banker, and the optimal portfolio and savings choices are

$$\omega_h^* = \left[1 - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_h}}\right] \frac{1}{\beta}, \tag{6.11}$$

$$\tilde{c}_h \equiv \frac{c_h}{W} = \frac{\rho_h + \lambda - \gamma_h \left(\frac{r_R - r_D}{\beta} + r_D\right) - (1-\gamma_h)\, \lambda \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma_h}{1-\gamma_h}}}{1-\gamma_h}. \tag{6.12}$$

With an expected positive risk premium $r_R - \lambda\beta - r_D > 0$, it is always optimal to invest at least some wealth into the risky asset $\omega_h > 0$. For the household r_D increases the return on wealth and thus decreases the optimal consumption to wealth ratio. A high relative risk aversion $1 - \gamma_h > \ln\left(\frac{\lambda\beta}{r_R - r_D}\right) / \ln(1-\beta)$ is typical for households, and ensures that only a small fraction of wealth is invested in the risky asset. It is assumed that labor income must be instantaneously consumed (c_L) and is not part of the optimization problem. This assumption is necessary, because otherwise the consumption and portfolio choice is influenced by the net present value of future labor income (Sennewald and Wälde 2005, p. 17), whereby the model could have been solved only for the steady state.

Markets

The wage bill in the innovative sector must be balanced by the risky investment of the representative banker and household.

$$wL_R = \omega_b E + \omega_h W \tag{6.13}$$

Equilibrium in the deposit market is given by the balance of the household's deposit investment and bank's deposit short selling.

$$(1 - \omega_h)W = -(1 - \omega_b)E \tag{6.14}$$

The fixed labor supply L is allocated via the labor market towards risky innovative production and risk-free production.

$$L = L_R + L_S \tag{6.15}$$

6.1.2 Solution

The equilibrium interest rate r_D^*, and thus the spread $r_R - r_D^*$, are determined by the deposit market equilibrium (6.14) including the optimal portfolio choices of the banker and the household (6.7, 6.11)[11].

$$\frac{E}{W} = -\frac{(1 - \omega_h^*(r_D^*))}{(1 - \omega_b^*(r_D^*))} \quad \text{and} \quad \frac{\partial r_D^*}{\partial \frac{E}{W}} > 0 \tag{6.16}$$

A relative increase in bank equity to household wealth implies ceteris paribus a relative increase in the bank's deposit short selling to household deposit demand. The deposit interest rate rises and balances the supply and demand of deposits, as the banker will decrease her leverage (6.7) and thus her need for short selling, while the household will increase its wealth allocation towards deposits (6.11). For notational convenience r_D^* and $\omega_i^*(r_D^*)$ are used in the following equations, keeping in mind their dependency upon the equity to wealth ratio E/W.

By applying the optimal leverage (6.7) and consumption ratio (6.9) in the

[11]See appendix 6.A.1.

intertemporal budget constraint (6.5) the motion of bank equity is derived[12]:

$$\frac{dE}{E} = \left[\frac{r_R}{\beta} - \rho_b - \lambda + (1 - 1/\beta)\, r_D^*\right] / (1 - \gamma_b)\, dt - \beta \omega_b^* dq \tag{6.17}$$

Accordingly, the motion of household wealth is determined (6.26, 6.11, 6.12):

$$\frac{dW}{W} = \left[\frac{r_R}{\beta} - \rho_h - \lambda + (1 - 1/\beta)\, r_D^*\right] / (1 - \gamma_h)\, dt - \beta \omega_h^* dq \tag{6.18}$$

The growth rates of bank equity and household wealth can be depicted in a growth rate - deposit rate diagram. Figure 6-2 shows the deterministic component of the stochastic differential equations (6.17) and (6.18), i.e. the growth rates for times without default $dq = 0$. The situation of default $dq = 1$ is discussed in the dynamics section. Both growth rates are decreasing in r_D although at different slopes.

For the bank the negative slope is intuitive, since liability costs increase in r_D, whereby the return on equity decreases. Further, lower returns decrease the incentive to retain profits[13].

For the household the economic intuition is less straightforward: The return on deposits increases, which induces a portfolio shift towards safe deposits, away from the high yielding risky investment. Risk aversion causes this shift to outweigh the positive impact upon deposit earnings so that the return on wealth decreases. As opposed to the bank, the household's saving out of wealth is increasing in r_D[14], whereby the negative impact upon the wealth accumulation is dampened. The bank's rate of equity accumulation is therefore more sensitive to changes in the deposit rate than the household's rate of wealth accumulation.

The technology growth rate depends upon the labor allocated to the innovative production sector which in itself depends upon the wage rate and financial funds allocated to this sector. Since there is no intrinsically risk-free asset in the economy, all financial savings end up in the innovative sector as depicted in Figure 6-1. Analytically, the deposit market equilibrium (6.14) nets the

[12] See appendix 6.A.1.
[13] See appendix 6.A.1.
[14] See appendix 6.A.1.

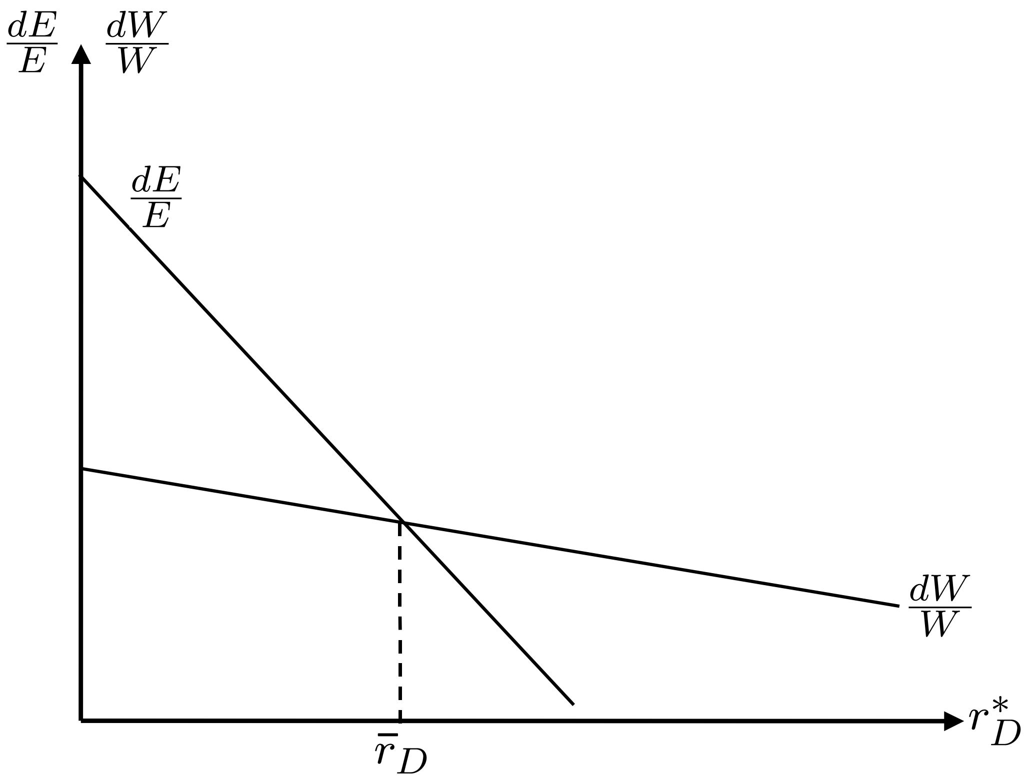

Figure 6-2: Steady State of Equity and Wealth Accumulation

safe investment of households with the 'negative' safe investment of the bank: $(1-\omega_h)W = -(1-\omega_b)E \Rightarrow W + E = \omega_b E + \omega_h W$.
These financial resources divided by the equilibrium wage rate (6.2) gives the equilibrium labor allocation (6.13) towards the innovative sector $L_R = (W+E)/A$. The result can be used in (6.4) to depict the equilibrium technology growth rate

$$\frac{dA}{A} = f\left(\frac{W+E}{A}\right)dt - f\left(\frac{W+E}{A}\right)dq. \qquad (6.19)$$

These three stochastic differential equations (6.17, 6.18, 6.19) fully describe the model. It can be seen that ongoing technology growth requires household wealth and bank equity accumulation and that fluctuations in the accumulation feed back to technology growth. However, fluctuations of technology growth do not have an impact upon the deterministic component of the wealth and equity growth rate. This makes the dynamics traceable and is a result of the assumption that labor income does not enter the portfolio and savings choice. Before proceeding to the dynamics, the model is solved for the steady state and the comparative statics are discussed.

Steady State and Comparative Statics

In the steady state all state variables grow at the same rate. The growth rates of equity (6.17) and wealth (6.18) unambiguously determine the steady state deposit rate $\bar{r}_D$, and thus the steady state equity to wealth ratio (6.16), as shown in Figure 6-2. Steady state technology growth requires that technology A grows at the same rate as equity E and wealth W (6.19). Due to the focus of this section, the discussion of comparative statics is limited to the 'individual' parameters which alter the financial decisions, namely the relative risk aversions $(1-\gamma_h,\ 1-\gamma_b)$ and time preferences $(\rho_h,\ \rho_b)$, which affect the accumulation schedules in Figure 6-2. The results are subsumed in Table 6.1 and discussed in the following.

Parameter Change	Immediate Response	Market Impact	Intermediate Response	Steady State Growth Effect
$\rho_h \uparrow$	$\frac{c_h}{W}\uparrow$, $\frac{dW}{W}\downarrow$, $\frac{E}{W}\uparrow$	$r_D \uparrow$	$\omega_h \downarrow$, $\frac{dW}{W}\downarrow$ $\omega_b \downarrow$, $\frac{dE}{E}\downarrow$	$\frac{\dot{A}}{A}\downarrow$
$\rho_b \uparrow$	$\frac{c_b}{E}\uparrow$, $\frac{dE}{E}\downarrow$, $\frac{E}{W}\downarrow$	$r_D \downarrow$	$\omega_h \uparrow$, $\frac{dW}{W}\uparrow$ $\omega_b \uparrow$, $\frac{dE}{E}\uparrow$	$\frac{\dot{A}}{A}\uparrow$
$(1-\gamma_h)\uparrow$	$\omega_h \downarrow$, $\frac{dW}{W}\downarrow$, $\frac{E}{W}\uparrow$	$r_D \uparrow$	$\omega_h \downarrow$, $\frac{dW}{W}\downarrow$ $\omega_b \downarrow$, $\frac{dE}{E}\downarrow$	$\frac{\dot{A}}{A}\downarrow$
$(1-\gamma_b)\uparrow$	$\omega_b \downarrow$, $\frac{dE}{E}\downarrow$, $\frac{E}{W}\downarrow$	$r_D \downarrow$	$\omega_h \uparrow$, $\frac{dW}{W}\uparrow$ $\omega_b \uparrow$, $\frac{dE}{E}\uparrow$	$\frac{\dot{A}}{A}\uparrow$

Table 6.1: Comparative Statics for Section 6.1

An increase in the household's time preference ρ_h, decreases its willingness to save, and thus shifts the dW/W curve downwards. The according decrease of household's deposit supply raises the equilibrium interest rate r_D^*, whereby the accumulation of equity decreases. Wealth accumulation also decreases, despite the household's willingness to save, because the rising risk-free rate lures households away from the high-yielding risky investment. The overall effect is a decrease in steady state growth.

Whilst an increase in the bank's time preference ρ_b also shifts down the dE/E curve, it causes an increase in the steady state growth. The bank is less inclined to retain profits and the resulting decrease of deposit short selling causes the equilibrium deposit rate r_D^* to decrease (6.16). Accumulation increases because the lower r_D^* not only raises the profitability of equity as well as that of wealth, but even overcompensates for the loss in retained earnings and savings respectively.

An increase in the banker's relative risk aversion $(1-\gamma_b)$ has a similar impact. However this occurs via the leverage (portfolio) choice rather than the retained earnings choice (Figure 6-3). The new line dE_1/E_1 is less steep and the banker immediately cuts her deposit short selling, whereby the equilibrium interest rate is decreasing. As before, this raises the profitability and accumulation of equity, wealth and the steady state growth rate.

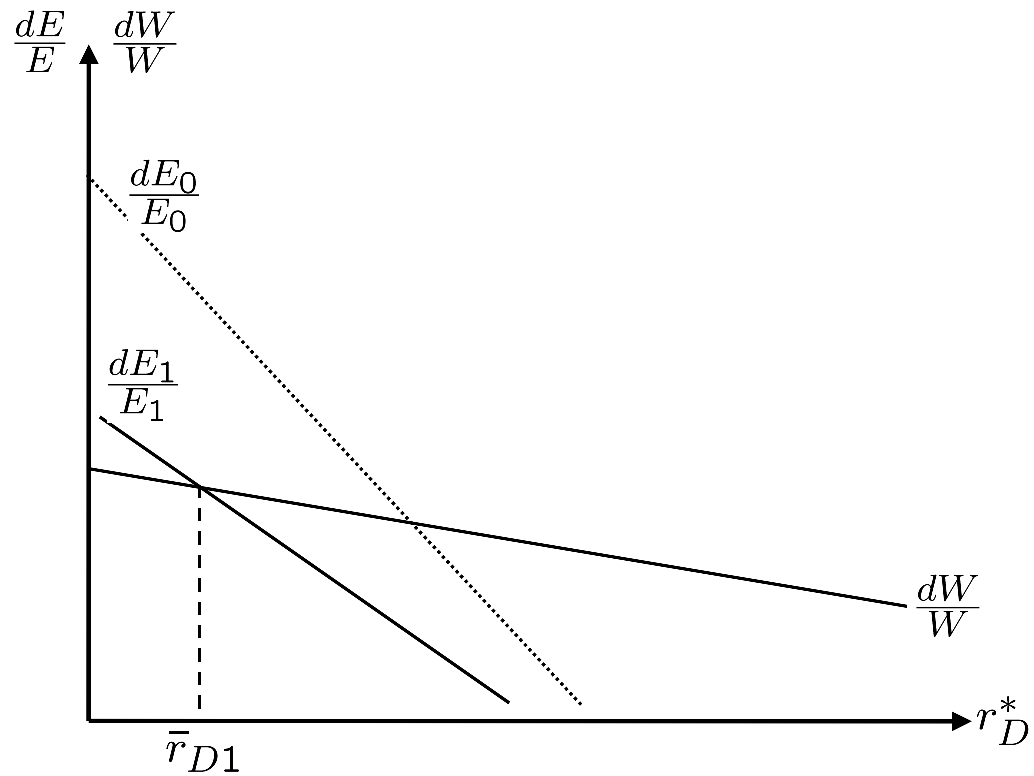

Figure 6-3: Comparative Statics for Increased Banker's Risk Aversion

Dynamics

The economic system is stable as equity grows faster than wealth if the deposit rate is falling short of its steady state level (Figure 6-4). Further, the deposit rate itself is rising in the equity-wealth fraction (6.16) and vice versa. The technology growth rate (6.19) adjusts to the steady state growth of equity and wealth, since the above steady state technology growth increases wages faster than available finance; therefore labor employment in the innovative sector and accordingly technology growth decrease, and vice versa.

The following paragraph illustrates the dynamics and economic intuition of the model for the negative realization of the Poisson process ($dq = 1$).
Lending to the innovative sector is risky as the process of innovative production is not always successful. If the production is unsuccessful ($dq = 1$), loans default and the financiers can recover only a fraction $(1 - \beta)$ of their initial outlays thus suffering a loss. From the accumulation equations (6.17 and 6.18) it can be seen that the bank's equity growth rate is affected worse than the household's wealth growth rate ($\beta\omega_b^* > \beta\omega_h^*$), since the banker chooses a much riskier portfolio. The "post-default" deposit rate r_{DC} falls short of the steady state rate. The reason lies in the relative shortfall of bank equity, whereby accepting the now relatively large supply of deposits is equivalent to increasing leverage. This high leverage is accepted by the bank only at a higher interest rate spread. The bank balance sheet thus becomes riskier, and expected bank profits and equity accumulation increase. As previously noted, a lower deposit rate also spurs the household's wealth accumulation. The equity-wealth ratio and thus the deposit rate tend towards their steady state values (Figure 6-4 and 6-5).
The impact of a substantial shock (low level of collateral $1-\beta$) upon technology is depicted by Figure 6-6. The levels have been drawn arbitrarily and the focus is upon the slopes, which equal the growth rates of the subsequent variables. Bank equity (E) takes the deepest dip, but recovers at the fastest rate. Since technology is assumed to be non-tangible, as for example knowledge, it usually does not decline. However, with a sufficiently negative shock upon equity and wealth, total finance does not suffice to attract the pre-default level of labor towards the innovative sector.

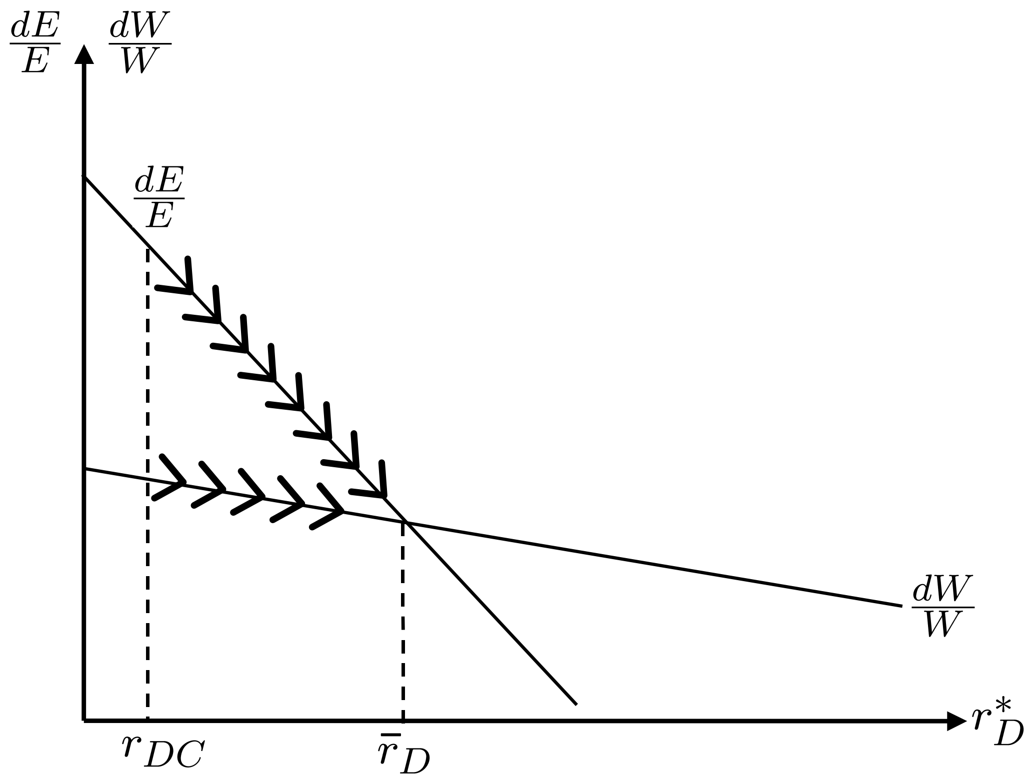

Figure 6-4: "Post-Shock" Transitional Dynamics

Labor productivity and thus wages in the risk-free sector do not adjust downwards, whereby more labor is allocated into this risk-free, 'non-innovative' sector. As a result the technology growth rate diminishes. Even if equity and wealth were to recover to their pre-default levels, the assets do not suffice to finance the former level of employment in the innovative sector, as the technological progress achieved in the meantime has raised the equilibrium wage rate. The impact of temporary shocks upon technology growth can thereby be prolonged.

6.1.3 Summary and Discussion

This section has integrated the function of banks, transforming risky credits, by guaranteeing with their own equity, into safe deposits, in an endogenous growth model. Bank behavior and equity thereby immediately gain importance. The

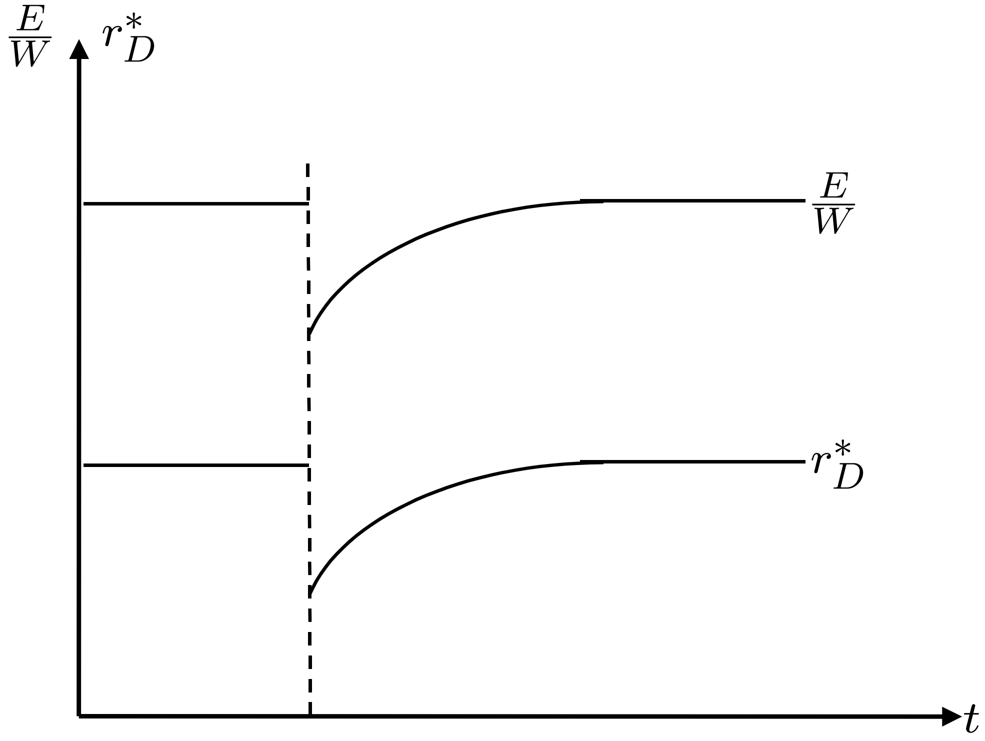

Figure 6-5: Dynamics of Relative Bank Capital and the Interest Rate Spread

main results can be summarized as follows:

The model explains differing financial structures through the portfolio choices of the bank and the household. The household is investing in deposits as a safe asset, while the banker is short selling deposits in order to finance risky investments in excess of her capital. The higher (lower) the risk aversion of the household (bank), the more funds will be channeled indirectly via the bank instead of the financial market.

Another finding is that a narrowing interest rate spread does not necessarily result in higher growth rates. This surprising result stems from the household's opportunity to invest in risk-free deposits as well as in risky direct investments. Risk aversion implies an overproportionate household portfolio shift towards the low-yielding deposits, as an reaction to the narrowing spread. Thereby, the average return on the portfolio, savings and also wealth accumulation decrease. The deposit rate continues to rise, until the new, lower steady state growth

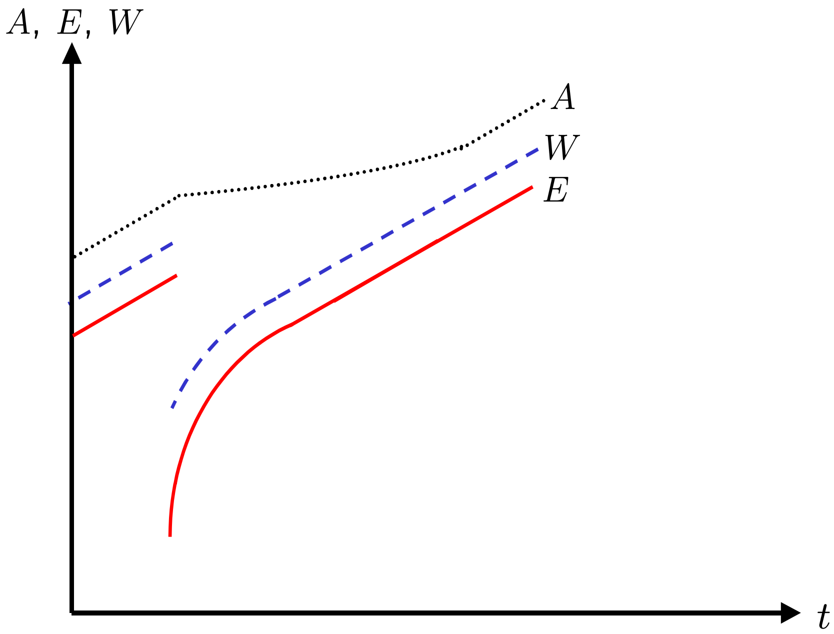

Figure 6-6: Dynamics of Bank Equity, Wealth, and Technology

is reached. It is important to note that this is not a market failure, as the household trades off wealth growth in favor of safety.

The dynamics following an endogenous loan default are intuitive. Due to their leverage, banks suffer overproportionately. There is an initially wide, but then narrowing interest rate spread.

An exception is the prolonged recovery period of the technology growth rate. The reason for this prolongation is a ratchet effect of technology upon wages. Technology progress is always non-negative and thus is increasing labor productivity and wages in the risk-free sector. Therefore, the recovery of financial resources are not sufficient to achieve the pre-shock employment in the innovative sector. Additional equity and wealth must be accumulated in order to finance the wage bill which has in the meantime increased.

What are the implications of these results for potential policy interventions on the financial sector?

Since there is no market failure in the financial sector, the model implies that

a hands-off policy will maximize welfare. For example, the model implies that minimum bank capital regulations are not required as bankers will act sufficiently prudent. However, this finding was derived under the assumption of full liability of bankers. With limited liability the banker might choose to 'overinvest' in risky assets (gamble for redemption) once the capital ratio has fallen below a certain threshold (Gollier, Koehl and Rochet 1997). In this case, minimum capital requirements or increasing the personal liability of bank managers is useful.
The model also relates to the debate of market versus bank finance and casts doubt on some previously recommended policies. To be exact, there is a base to foster market finance by policy interventions because bank-based economies are associated with underdeveloped financial markets. In contrast, the new model shows that bank finance and a low growth regime can be the optimal result, of a society with relatively risk averse households.

The main departure from the literature is the assumption of undiversifiable risk. Opposed to King and Levine (1993) this model explicitly excludes any diversification. The reason is to grasp the certainly existing residual risk. The model could be extended to allow imperfect diversification, whereby economies of scale would also imply concentration in the banking sector. Such a situation and the impact upon growth of improved diversification has been examined by Blackburn and Hung (1998). In the present analysis, this additional effect would have increased the interdependencies and substantially distracted from the issue at hand. Further, the main results would remain.
The assumption of highly risk averse households that shift risk upon banks is consistent with Merton's (1995) statement that "[c]ustomers who hold the intermediary's liabilities are identified by their strict preference to have the payoffs on their contracts as insensitive as possible to the fortunes of the intermediary itself" (Merton 1995, p. 34).
Furthermore, the implicit assumption that banks rely upon their retained earnings to increase their bank capital is used in the literature (Van Den Heuvel, ed 2001).

The dynamics of the model are consistent with real world observations. As predicted by the model (Figure 6-5), bank capital also has an empirically sig-

nificant affect upon the interest rate spread. The spread rises with decreasing bank capital and vice versa even if borrowers' and banks' characteristics are controlled for (Hubbard, Kuttner and Palia 1999). Further, banks' dislike to assume solvency risk during contractionary phases is indicated by the fact that not only the loan-deposit spread increases, but also the use of collateral.
In the model defaulted loans are immediately written-off. In the real world, the balance sheet value (book value) of capital can differ from the real capital ratio if non-performing loans are not written-off immediately. Ingves (2003) identifies the large fraction of non-performing loans that have remained on the Japanese banks' balance sheets as a source for the prolonged stagnation. His hypothesis is fully consistent with the model. The implicitly low capital ratio hampers the risk averse bank to grant risky loans. An extension of the model would show that postponing the depreciation of non-performing loans would worsen the situation even further. The immediate write-off causes banks to grant few, but new loans. If banks try to increase, or maintain their capital ratio by curtailing new loans, only the old non-performing loans remain on their asset side. There will then be hardly any income on the asset side and bank capital recovers very slowly.

6.2 Banks' Solvency Risk, with Bank-Dependence

For technical reasons, labor income has been excluded from the savings and portfolio choice in the previous model. However, labor income is certainly an important variable regarding the optimization of the life-time consumption choice of regular households. For bank managers it can be argued that labor income is of less importance regarding their optimization of the bank portfolio. In this section bankers, and households are distinguished by their choices and not only by their preferences. To be exact, the representative risk averse banker is limited to portfolio optimization, while the representative household is limited to its' consumption decision.

As in the previous model, labor and technology are the only available resources and technology growth is a function of labor allocated to an innovative sector. Again, Wälde's (2002) concept of tangible output as an incentive for risky investment is adopted. The technology is altered by assuming that the output follows a Wiener process instead of a Poisson process. Thereby, it will be shown that the qualitative result of bank behavior does hold for different stochastic processes. Market finance is excluded by assumption, and all savings are channeled via the bank towards the innovative sector.

Despite these simplifications, the model solution proves to be more complex than in the previous model. The source of this complexity is the indirect inclusion of technology in the optimization choice.

6.2.1 The Model

In this model, technology growth is an externality from labor employed in a risky production sector. Households are assumed to demand certain wages and to accumulate risk-free deposits exclusively. The risk averse banker optimizes her capital ratio and uses the wage bill in the innovative sector as an asset. Finance available to the risky sector is thus a function of deposits, bank equity and banks' portfolio optimization. Since wages grow with technology, constant labor allocation requires an according growth in finance to be sustainable.

The Standard Production Sector

In the standard production sector, existing technology (A) is combined with labor input (L_S) to produce output (y_s). The whole model is denominated in these output units.

$$y_S = AL_S \tag{6.20}$$

Since labor is the only input factor, profits are $\pi_S = AL_S - wL_S$ with w denoting the wage rate. Profit maximization implies that the firm will demand labor until the marginal cost of employment (w) equals the marginal product of labor (A)

$$w = A. \tag{6.21}$$

Output growth therefore requires technological progress. This progress is an externality of 'innovative production'.

The Innovative Production Sector

An alternative use for labor (L_R) is to combine it with new ideas, in order to attempt new production technologies

$$y_R = (1 + x)\, AL_R. \tag{6.22}$$

However, this attempt is risky insofar as x is generated by a Wiener process[15] $xdt \equiv adt + \sigma dz$ with mean a and variance σ^2. A realization of $x < -1$ implies that the outcome of the new production attempt is not only zero, but that additional damage has occurred. Even if such a situation is realistic (e.g., nuclear energy), it is not further examined and it is assumed that the mean a is sufficiently large and σ small enough to ensure that $x < -1$ is of no practically relevance. The technological knowledge obtained during this innovative production process is nonrival and by assumption nonexcludable, and thus enhances the technology stock as an externality $\dot{A} = (1 + x)\, Af(L_R)$[16]. Here $x < -1$ is economically infeasible, as existing knowledge/technology cannot be destroyed by regular economic activities.

$$\frac{\dot{A}}{A} = (1 + x)\, f(L_R) \tag{6.23}$$

The difference between this and the previous model is the use of the Wiener instead of the Poisson process. While the Wiener process is a better approximation to investments in innovative production, which can result in surprisingly high returns, the Poisson process is better suited to depict the default versus non-default state of loans. Expected profits are $\varepsilon\,[\pi_R] = (1 + a)\, AL_R - wL_R$. Again the factor labor is not willing to accept risky wages, whereby the wage bill needs to be credit financed. The required risky investment is thus the wage bill wL_R. Applying the equilibrium wage rate (6.21), the (expected)

[15] Despite its poor approximation "of actual returns in a world of limited liability", the normal distribution assumption "is most widely used" (Hakansson 1996, p. 918).

[16] Whether the externality is stochastic or deterministic is a matter of taste. Stochastic technology growth is easily explained by more or less successfully new production attempts. Deterministic knowledge growth can also be justified by the fact that even failed attempts generate some knowledge.

profit function can be rewritten

$$\frac{\varepsilon\left[\pi_R\right]}{wL_R} = a.$$

Hereby, it can be seen that a is the mean rate of return of financing the wage bill in the innovative sector.

Bank

The representative banker is modeled as a portfolio manager (Pyle 1971 and Hart and Jaffee 1974) in the simplest variation, who can invest a fraction (ω_b) of his equity (E) in the innovative production sector at the stochastic return (x), and a fraction $(1-\omega_b)$ in risk-free deposits (D) with the rate of return r. The return on bank equity, in other words bank profit $\pi_b = x\omega_b E + r(1-\omega_b)E$, is a random function due to the uncertain return on the risky investment. The variance of the return on equity is $\omega_b^2\sigma^2$ and, due to the leverage, much higher than the variance of the risky asset, whereby the risk of insolvency increases. In order to include banks' risk aversion in a simply manner, it is assumed that the banker maximizes utility from equity $u\left(E\right)$ as if she were fully liable. As before, constant steady state leverage requires a constant relative risk aversion utility function. The banker maximizes the expected present value of lifetime utility considering her personal discount rate ρ_b. The objective function is thus

$$\int_t^\infty e^{-\rho_b \tau} u(E(\tau)) d\tau$$

and the side condition, in other words the intertemporal budget constraint, with fully retained earnings is equivalent to the motion of equity

$$\dot{E} = x\omega_b E + r(1-\omega_b)E. \qquad (6.24)$$

This setup is a simplified version of Merton's (1969) famous portfolio model. The solution in the form of the optimal portfolio choice is (see Appendix 6.A.2)

$$\omega_b^* = \frac{(a-r)}{\sigma^2\left(1-\gamma_b\right)}, \qquad (6.25)$$

with $1-\gamma_b$ denoting the Arrow-Pratt measure of risk aversion. According to economic intuition, the risk averse banker is only willing to increase his exposure to risk if the risk premium $(a-r)$ is increasing or riskiness (σ^2) of the risky asset itself is decreasing. Further, a more risk averse banker $(1-\gamma_b)\uparrow$ is less willing to invest in risky assets.
Applying ω_b^* in the equity motion Equation (6.24) gives a parabola[17] in the equity motion - deposit rate plane with the slope $1-2\omega_b^*$. Though, it can be shown that only the decreasing arm is of interest. Banking activity is characterized by short selling of deposits. This is the case if the banker chooses to invest in the innovative production sector in excess of her equity, i.e. $\omega_b > 1$. In other words, banking activity takes place as long as the slope of the $\dot{E}/E$ line in Figure 6-7 is smaller than -1. The number of representative bankers is normalized to one.

Household

The representative household strives to maximize lifetime utility, considering his personal time preference ρ. The objective function is

$$\int_0^\infty e^{-\rho t} u(c(t))dt.$$

$u(c) = \frac{1}{\gamma}c^\gamma$ is the instantaneous utility function and assumed CRRA. By assumption, deposits are the only asset the household can accumulate. Therefore, the intertemporal budget constraint is given by

$$\dot{D} = rD + wL - c. \tag{6.26}$$

[17]

$$\dot{E}/E = r^2 \frac{1}{\sigma^2(1-\gamma_b)} + r\left(1 - \frac{x+a}{\sigma^2(1-\gamma_b)}\right) + \frac{xa}{\sigma^2(1-\gamma_b)}$$

See appendix 6.A.2 for the derivation. The slope in a growth - interest rate diagram is

$$\frac{\partial\left(\frac{\dot{E}}{E}\right)}{\partial r} = \frac{2r}{\sigma^2(1-\gamma_b)} + 1 - \frac{x+a}{\sigma^2(1-\gamma_b)} = 1 - \frac{x+a-2r}{\sigma^2(1-\gamma_b)},$$

which is on average $1-2\omega_b^*$.

The household earns labor income (wL), and interest income (rD) from deposit savings. Income that is not consumed (c) is accumulated as deposit savings. The solution to this problem via Hamiltonian is the well-known Ramsey rule[18]

$$\frac{\dot{c}}{c} = \frac{r-\rho}{1-\gamma}. \tag{6.27}$$

Again, the number of representative households is normalized to one.

Markets

Since market finance has been excluded from the analysis, external finance of the innovative sector wage bill is covered by the according risky investment of the bank

$$wL_R = \omega_b E. \tag{6.28}$$

For the same reason, households' savings are equal to banks' short selling of risk-free assets

$$D = -(1-\omega_b)E. \tag{6.29}$$

The inelastic labor supply of households is allocated to the risky innovative sector and the risk-free final good sector

$$L = L_R + L_S. \tag{6.30}$$

6.2.2 Solution

In equilibrium all markets will clear in accordance with the optimal choices of the economic agents. The solution is described by the equilibrium motion of deposits (D), bank equity (E), technology (A), and consumption (c).
The deposit market clearing interest rate r^*, results from the deposit market equilibrium (6.29) in combination with the optimal leverage of the bank

[18] See appendix 6.A.2 for the derivation.

(6.25)[19].

$$r^* = a - \left(\frac{D}{E} + 1\right)\sigma^2\left(1 - \gamma_b\right)$$

Applying this result and (6.25) and (6.29) to the bank equity motion Equation (6.24) results in the motion Equation for bank capital[20]

$$\dot{E} = \left(\frac{D^2}{E} + D\right)\sigma^2\left(1 - \gamma_b\right) + \left(x - a\right)D + xE. \tag{6.31}$$

The Ramsey rule including the market clearing interest rate gives the motion of consumption

$$\dot{c} = \frac{a - \left(\frac{D}{E} + 1\right)\sigma^2\left(1 - \gamma_b\right) - \rho}{1 - \gamma}c. \tag{6.32}$$

Deposits are accumulated according to the budget constraint of the household (6.26) including the equilibrium interest rate and wage rate (6.21).

$$\dot{D} = aD - \left(\frac{D}{E} + 1\right)\sigma^2\left(1 - \gamma_b\right)D + AL - c \tag{6.33}$$

For technology growth the allocation of labor to innovative production is decisive. The total 'financial' resources allocated to this sector (6.29 and 6.28) divided by the equilibrium wage rate (6.21) yields this amount and can be used in (6.23)[21].

$$\dot{A} = \left(1 + x\right)Af\left(\frac{D + E}{A}\right) \tag{6.34}$$

These four differential equations describe the dynamics of the model. Before proceeding to the analysis of the dynamic characteristics, the model is solved for the steady state and the comparative statics are discussed.

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[19] The deposit market equilibrium (6.29) can be rewritten $\omega_b^* = 1 + D/E$ and thus

$$\begin{aligned}\frac{D}{E} + 1 &= \frac{\left(a - r^*\right)}{\sigma^2\left(1 - \gamma_b\right)} \\ r^* &= a - \left(\frac{D}{E} + 1\right)\sigma^2\left(1 - \gamma_b\right)\end{aligned}$$

[20] See appendix 6.A.2.

[21] $\dot{A} = \left(1 + x\right)Af\left(\left(\frac{D}{E} + 1\right)\frac{E}{A}\right)$

Steady State and Comparative Statics

In the steady state all growth rates are equivalent. The growth rates of bank equity and consumption are both functions of bank leverage (D/E). For the economic intuition it is advantageous to use the intermediate solutions with the deposit interest rate. The consumption growth rate (6.27) is linear increasing in r, while the equity growth rate is a parabola[22].

$$\frac{\dot{E}}{E} = r^2 \frac{1}{\sigma^2 (1-\gamma_b)} + r\left(1 - \frac{x+a}{\sigma^2 (1-\gamma_b)}\right) + \frac{xa}{\sigma^2 (1-\gamma_b)} \tag{6.35}$$

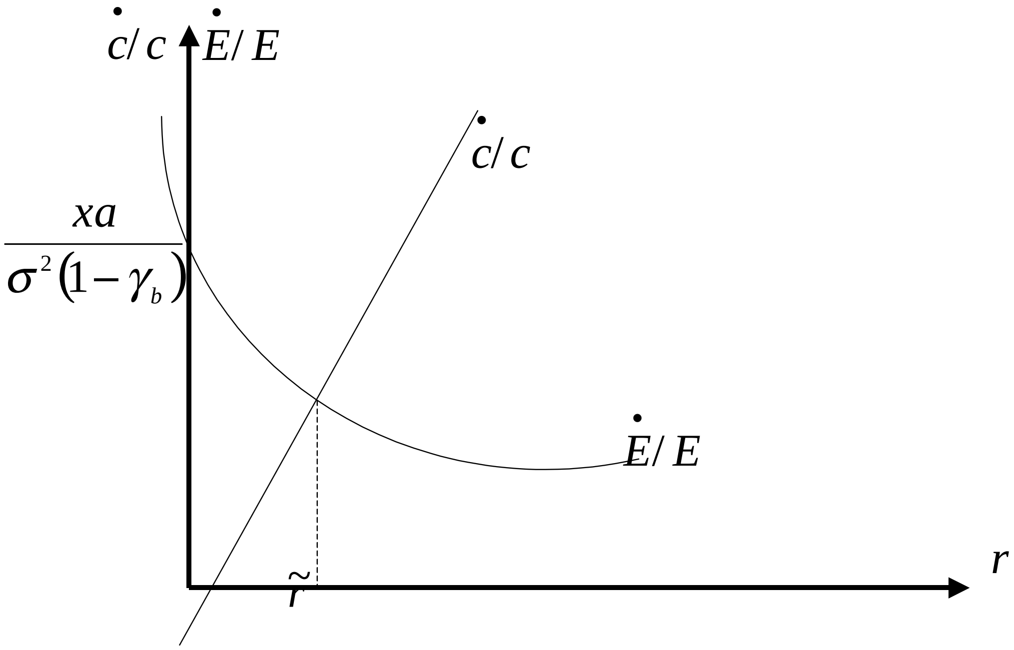

Figure 6-7: Bank Equity Motion and Ramsey Rule

[22]The abscissa is crossed at $xa/\sigma^2(1-\gamma_b)$ the turning point is at $r = \frac{x+a-\sigma^2(1-\gamma_b)}{2}$. The maximum interest rate still allowing financial intermediation is $\bar{r} = a - \sigma^2(1-\gamma_b)$.

In Section 6.2.1 it has already been indicated that only the decreasing branch is relevant for this model, i.e. the relevant steady state solution is at the lower r^*[23].

$$\tilde{r} = \frac{(\gamma_b \sigma^2 + x + a)}{2} - \sqrt{\frac{(\gamma_b \sigma^2 + x + a)^2}{4} - \sigma^2 \rho - ax}$$

The comparative statics for the 'bank' parameters a, $1 - \gamma_b$, and σ^2 can be best seen by their impact upon the $\dot{E}/E$ schedule by examining Figure 6-7. (6.35). Note that the growth rate of equity is also the return on equity, since all profits are retained by assumption.

Higher mean return on the risky investment (a) provides an incentive for the bank to increase its activity in the risky sector and also increases the mean rate of return on equity[24]. The $\dot{E}/E$ schedule shifts outwards (see Figure 6-8). The deposit market equilibrium with higher equity growth can only be maintained with a higher interest rate, in order to induce increased deposit accumulation by the households. The according postponement of consumption is depicted by the rising consumption growth rate. The increase in savings and risky investment changes the labor allocation in favor of the innovative sector, and technology growth also rises. Further, the variance of bank equity ($\omega^2 \sigma^2$) rises with leverage. This will presumably induce increased volatility of economic growth as well.

Similar to an increase in the risky return, a decrease in risk (σ^2) and decrease in the banker's risk aversion ($1 - \gamma_b$) will also shift the $\dot{E}/E$ schedule outwards[25]. High leverage for risky investment becomes more attractive, and the banker increases her leverage. The economy adjusts to the new situation in the aforementioned way.

To subsume, increasing leverage of banks raises available finance for innovative production. Thereby, more labor is allocated to the innovative sector, and economic growth is fostered.

The parameters affecting the household have the standard impact via the Ramsey rule. An increase in the personal discount rate (ρ) and risk aversion ($1 - \gamma$)

[23] See appendix 6.A.2.

[24] $\frac{\partial \dot{E}/E}{\partial a} = \frac{x-r}{\sigma^2(1-\gamma_b)} > 0$ the expected value is $\frac{a-r}{\sigma^2(1-\gamma_b)} = \omega_b$.

[25] See appendix 6.A.2.

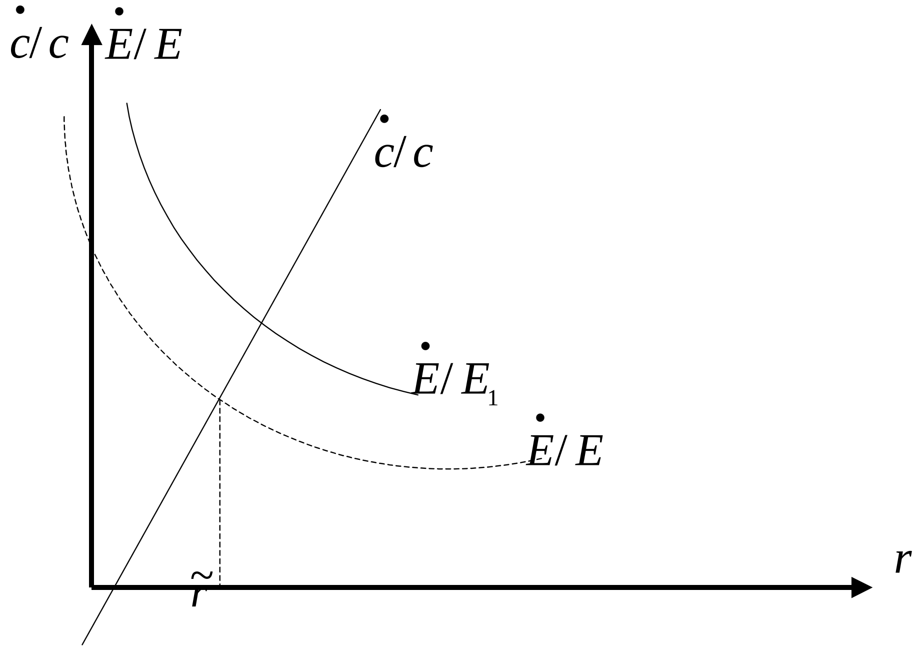

Figure 6-8: Comparative Statics of "Bank Parameters"

decreases the household's willingness to save. This implies ceteris paribus rising interest rates which depress banks' profitability and leverage choice and thus growth.

Dynamics

Unfortunately the interdependencies of the differential equations obstruct the reduction to two differential equations in two variables and thus inhibit a graphical analysis. The stability of the linearized system can only be determined by the Jakobian matrix (J). For simplicity the technology externality was assumed to be a linear function of L_R.

$$J = \begin{pmatrix} -\left(\frac{D^2}{E^2}\right)\sigma^2\left(1-\gamma_b\right)+x & 0 & \left(2\frac{D}{E}+1\right)\sigma^2\left(1-\gamma_b\right)+\left(x-a\right) & 0 \\ \frac{\left(\frac{D}{E^2}\right)\sigma^2(1-\gamma_b)}{1-\gamma}c & \frac{a-\left(\frac{D}{E}+1\right)\sigma^2(1-\gamma_b)-\rho}{1-\gamma} & \frac{-\left(\frac{1}{E}\right)\sigma^2(1-\gamma_b)}{1-\gamma}c & 0 \\ \left(\frac{D^2}{E^2}\right)\sigma^2\left(1-\gamma_b\right) & -1 & a-\left(2\frac{D}{E}+1\right)\sigma^2\left(1-\gamma_b\right) & L \\ \left(1+x\right)f' & 0 & \left(1+x\right)f' & 0 \end{pmatrix}$$

Already the sign of the trace is cumbersome to determine but can be negative[26], whereby a necessary condition for stability (Gandolfo 1997, p. 254) is fulfilled.

6.2.3 Summary and Discussion

In the endogenous growth model presented in this section, the representative banker plays a key role for growth. She optimizes her balance sheet in accordance with her risk and return preference. By assumption the average return on risky loans was an exogenous parameter, whereby the banker's preference for leverage affects the loan-deposit spread via endogenous deposit interest rates. Since market finance has been excluded from the analysis, all wealth is channeled via the bank to the innovative sector to meet the wage bill of innovative production. On the balanced growth path bank equity and consumption grow at equal rates. Therefore, the bank's risk aversion and the resulting equilibrium deposit interest rate determines the growth rate of consumption, deposits, equity, and technology.

The comparative statics are in line with intuition. For example, a decrease in risk aversion induces the banker to increase her leverage and thereby profits and equity growth. This effect is dampened by the rising deposit rate that is required to induce higher deposit accumulation (savings). Besides the growth rates, the volatility is rising as well.

The separation of the accumulation (household) and the portfolio (bank) decision, makes the intermediate results of the model very traceable. However, some important questions remain open. Presumably the dynamics will depict a financial accelerator. Periods with low successes of the innovative sector

[26] See appendix 6.A.2.

decrease bank-equity overproportionately due to the bank's leveraged position. The negative shock upon bank-equity should feedback upon finance of innovation and technology growth and vice versa. However, despite simplifying assumptions the dynamic system remains four-dimensional and cannot be analyzed graphically. Additionally, the numerous interdependencies disable a useful formal analysis and economic interpretation.

6.3 Discussion

This chapter has formalized Schumpeter's hypothesis of the bank as primary risk bearer of risky innovation activities. The banker has been assumed to be risk averse, whereby the stock of bank equity gained importance for the bank's loan decision and economic growth. In the following, similarities and differences with the related literature and between the two models are discussed. Further, the assumptions are more in-depth motivated.

The model variations are most closely related to Neuberger's (1991) and Wälde's (1999, 2002) models.
Neuberger also models portfolio optimization of a risk averse banker. Risk averse households optimize via their continuous time portfolio and consumption decisions. Without financial intermediaries, the household can invest in firm equity (Wiener process) and firm lending (Poisson process). The combination of firm collateral and bank equity can results in risk-free deposits. Bankers are assumed to be less risk averse than the 'regular' household and insure with their equity and borrowers' collateral against deposit default. "Thus, there is scope for financial intermediaries with low risk aversion to foster capital accumulation by attracting risk-free deposits which they use to invest in risk-bearing loans." (Neuberger 1991, p. 284)
However, unlike the models developed in this thesis, Neuberger limits her analysis to the steady state of a partial model with zero growth. Hence, she does not (need to) solve for the retained earnings, and there is no capital accumulation in her model. In contrast to her presumption, the model in Section 6.1 shows that capital accumulation can even decrease with increasing risk insurance via banks' risk-free deposits.

Wälde (1999 and 2002) uses endogenous growth models including a Poisson process to describe Schumpeterian business cycles. He has integrated risk averse households with a portfolio and savings choice in an endogenous growth model. The risk-free asset is real capital and the risky asset is R&D investment. Since capital accumulation decreases the marginal return of capital, the risky R&D investment becomes relatively more profitable over time.
In his model there is no interior solution to the portfolio problem, i.e. households either invest in capital accumulation or in R&D. Further, he assumes that a new technology implies creative destruction in the sense that a large fraction of old capital (embodying old technology) becomes obsolete. This decrease in capital increases the marginal return of capital, and households switch towards capital accumulation. The alternation between these two regimes (accumulation and R&D) results in growth cycles, which are the focus of Wälde's articles. Banks are not considered in his models. Including banks and allowing for an interior solution would imply that capital accumulation also becomes risky, due to the chance of creative destruction. Therefore, his model has not been used for such an extension.

The two new model variations integrate risk in different way. The first model variation uses a Poisson process, while the second uses a Wiener process.
With the focus upon banks, the Poisson process has the advantage that it is the market standard for modelling loan default risk (Sandow, Friedman, Gold and Chang 2003). Further, the risk of a Poisson process cannot be diversified within a sector, i.e. the volatility is not decreasing by granting more research credits (Olkin, Gleser and Derman 1994, p. 599). Increasing the amount of researchers is increasing the likelihood of research success but not decreasing its volatility. The realized amount of defaults approaches the expected amount of defaults only over long periods of time (Olkin et al. 1994, p. 326). Diversification can only be achieved by financing research in different directions, i.e. several independent growth ladders. Due to the law of large numbers, in each moment in time, innovation will occur on at least one ladder.
The second model variation employs a Wiener process. This has the advantage, that it better depicts the downside and upside risk of innovation. In the model, the bank participated in the upside risk, i.e. the bank is rather a residual

claimant than a lender. This is a simplification, in order to avoid stochastic profits without downside risk, and the according incentive problems, for the innovative producer.

Risk has been relevant, because the agents were assumed to be risk averse. Risk aversion can be modeled via the so-called mean, variability approach and the above used expected utility approach. Both approaches are fundamentally different and match only for the case of quadratic utility function and if the distribution of the random term is two-parametric. However, if utility is quadratic in income, with decreasing marginal utility, a point will be reached where additional income will decrease utility. Thus, Hirshleifer states that quadratic utility function are "unacceptable"(Hirshleifer 1989, p. 80) even as an approximation when dealing with risky portfolios and this is especially true for growth models with increasing income.

The comparative statics of the two model variations differ substantially. In the first model variation a decrease in the banker's risk aversion decreases growth, while in the second model variation it increases growth. In both model variations a less risk averse banker wishes to increase his leverage. Besides increasing the loans (which are fully elastically demanded in both model variations), the banker needs to attract more deposits and thus raises the deposit rate. The different growth effects can be seen in the contrasting effect of rising deposit rates upon the household's average return on savings and accumulation choice. Comparing Figure 6-3 with Figure 6-8 it can be seen that dW/W and $\dot{c}/c$ schedule have opposing slopes. In the second model variation the increase of the deposit interest rate also increase the average return on savings and thus induces more savings, i.e. accumulation. The economy gets onto a steeper growth path. This contrasts to the first model variation, where the rising deposit interest rate induces an overproportionately portfolio shift away from high yielding risky investments. Thereby, the average return and thus the accumulation decreases. This forces the economy on a less steep growth path.

The question remains, which of the two model variations is more realistic? Both models are highly stylized. On the one hand the first model has less restrictive assumptions regarding the financial system, as it allows for market finance as well as bank finance. On the other hand, the second model includes labor income in the optimization choice, whereby savings are not restricted to wealth. Presumably, the comparative statics of the first model variation would change significantly if one allows for an alternative low risk use of financial capital. In that case the lower risk aversion of the banker would increase the allocation of finance to R&D, and this increase may not be outweighed by decreasing asset accumulation of households. Thereby, the comparative statics of the two models would not contrast.

Therefore, the strength of the model variations should be seen in their explanatory value for certain real world observations.

For example Hubbard et al. (1999) find some support for the assumption that (small) firms are bank-dependent and that bank equity capital affects the loan supply of banks, which matches the second model variation. The coexistence bank and market finance, as well as the typical development of the spreads can be explained by the first model variation.

6.A Appendix

6.A.1 Banks' Solvency Risk, with Heterogenous Risk Aversion

A	Level of technology
y_s	Output final good sector
w	Wage rate
L_s	Labor final good sector
L_R	Labor innovative sector
y_R	Output innovative sector
K	Financial investment in innovative sector
c_b, (c_h)	Consumption bank (household)
E	Bank Equity
ω_b, ω_h	Fraction of risky investment
r_D	Deposit rate of return
W	Household wealth
$\tilde{c}_b$, $(\tilde{c}_h)$	$\frac{c_b}{E}$, $\left(\frac{c_h}{W}\right)$
c_L	Instantaneously consumed labor income

Table 6.2: Variables for Section 6.1

r_R	Risky rate of return
$1-\beta$	Collateral fraction
q	Poisson process
λ	Poisson arrival rate
$1-\gamma_b$, $(1-\gamma_h)$	Relative risk aversion bank (household)
ρ_b, (ρ_h)	Personal discount rate bank (household)
L	Total labor supply

Table 6.3: Parameters for Section 6.1

Appendix Equations (6.6)**,** (6.7) **and** (6.9)

The solution for the stochastic portfolio and savings (retained earnings) optimization is obtained by applying Bellman's Principle of Optimality, the change-of-variables formula, and an educated guess (Sennewald and Wälde 2005, p. 2). Similar continuous time stochastic portfolio and consumption optimization problems have been examined by Merton (1969, 1971) and Neuberger (1991).

Defining the so-called value function $J(E(t),t)$ as maximized expected lifetime utility

$$J(E(t),t) \equiv \max_{\omega_b,c_b} \varepsilon_t \int_t^{\infty} e^{-\rho_b \tau} u(c_b(\tau))d\tau$$

and applying the Bellman's Principle of Optimality, the objective equation can be rewritten:

$$\begin{aligned} J(E(t),t) \equiv \max_{\omega_b,c_b} \varepsilon_\tau & \left\{ \int_t^{t+dt} e^{-\rho_b \tau} u(c_b(\tau))d\tau + \int_{t+dt}^{\infty} e^{-\rho_b \tau} u(c_b(\tau))d\tau \right\} \\ = \max_{\omega_b,c_b} \varepsilon_t & \left\{ e^{-\rho_b t} u(c_b(t))dt + J\left(E+dE, t+dt\right) \right\} \\ 0 = \max_{\omega_b,c_b} \varepsilon_t & \left\{ e^{-\rho_b t} u(c_b(t))dt + J\left(E+dE, t+dt\right) \right\} - J(E(t),t) \\ 0 = \max_{\omega_b,c_b} \varepsilon_t & \left\{ e^{-\rho_b t} u(c_b(t))dt + dJ(E,t) \right\} \end{aligned}$$

The integral for infinitesimal small increments of time ($dt \to 0$) has been solved via the mean value theorem[27]. It is assumed that J is a continuously differentiable function of E and t. Applying the Ito's lemma for Poisson processes[28] the change of the value function[29] is (Sennewald and Wälde 2005, p. 4):

$$\begin{aligned} dJ(E,t) &= \left[J_t + J_E * dE\right]dt + \left[J\left(E - \beta\omega_b E, t\right) - J\left(E,t\right)\right]dq \\ &= \left[J_t + J_E * \left(r_R \omega_b E + r_D(1-\omega_b)E - c_b\right)\right]dt \\ &\quad + \left[J\left(E - \beta\omega_b E, t\right) - J\left(E,t\right)\right]dq \end{aligned}$$

[27] The mean value theorem is (Stöcker 1993, p. 487)

$$\int_a^b f(x)g(x)dx = f(c)\int_a^b g(x)dx \qquad c \in [a,b].$$

Using $a=t$, $b=t+dt$, $f(x)=e^{-\rho_b \tau}u(c_b(\tau))$, $g(x)=1$, $\tau = x$, and $c=t$ the solution is

$$\begin{aligned} \int_t^{t+dt} e^{-\rho_b \tau} u(c_b(\tau))d\tau &= e^{-\rho_b t} u(c_b(t)) \int_t^{t+dt} 1 d\tau \\ &= e^{-\rho_b t} u(c_b(t))\left|\tau\right|_t^{t+dt} \\ &= e^{-\rho_b t} u(c_b(t))\left(t+dt-t\right) \end{aligned}$$

[28] "Given a Poisson stochastic differential equation: $dx = adt + bd\pi$. Let $f(x,t)$ be a continuously differentiable function of x and t. Then $df = (f_t + af_x)dt + (f(x_t+b,t) - f(x_{t,}t))\,d\pi$" (www.stanford.edu/~japrimbs/01-Math(f).ppt, 11.02.06)

$dE = dx$ is the stochastic differential equation, $J(E,t)$ is the differentiable function, the deterministic part of dE is a, while the stochastic part is b.

[29] dE is taken from (6.5). The notation is $J_t \equiv \partial J/\partial t$ and $J_E \equiv \partial J/\partial E$.

The intuition is that with $dq = 0$ no jump occurs and the change results from the deterministic derivatives for the two arguments (E, t). However, with $dq = 1$ the additional downwards jump $(-\beta\omega_b E)$ has to be considered. Since the change of utility and not equity itself is important for the agent, $J(E - \beta\omega_b E, t) - J(E, t)$ has to be used. The probability of the Poisson jump to occur is $\varepsilon dq = \lambda dt$ (Aghion and Howitt 1998, p. 55). Thus, the Bellman equation can be rewritten:

$$0 = \max_{\omega_b, c_b} \left\{ \begin{array}{c} e^{-\rho_b t} u(c_b(t))dt + [J_t + J_E * (r_R \omega_b E + r_D(1-\omega_b)E - c_b)]\, dt \\ + [J(E - \beta\omega_b E, t) - J(E, t)]\, \lambda dt \end{array} \right\}$$
$$= \max_{\omega_b, c_b} \left\{ \begin{array}{c} e^{-\rho_b t} u(c_b(t)) + J_t + J_E * (r_R \omega_b E + r_D(1-\omega_b)E - c_b) \\ + [J(E - \beta\omega_b E, t) - J(E, t)]\, \lambda \end{array} \right\}$$

The objective function can be further simplified by defining $J^*(E(t), t) \equiv e^{\rho_b t} J(E(t), t)$, whereby J^* becomes independent of time[30] $J^*(E(t), t) = J^*(E(t))$ and $J_t = -\rho_b e^{-\rho_b t} J^*(E)$ (Merton 1969, p. 252).

$$0 = \max_{\omega_b, c_b} \left\{ \begin{array}{c} e^{-\rho_b t} u(c_b(t)) - \rho_b e^{-\rho_b t} J^* + e^{-\rho_b t} J^*_E * (r_R \omega_b E + r_D(1-\omega_b)E - c_b) \\ + [e^{-\rho_b t} J^*(E - \beta\omega_b E) - e^{-\rho_b t} J^*(E)]\, \lambda \end{array} \right\}$$
$$0 = \max_{\omega_b, c_b} \left\{ \begin{array}{c} u(c_b(t)) - \rho_b J^* + J^*_E * (r_R \omega_b E + r_D(1-\omega_b)E - c_b) \\ + \lambda [J^*(E - \beta\omega_b E) - J^*(E)] \end{array} \right\} \qquad (6.6)$$

The first order conditions are:

$$J^*_E * (r_R E - r_D E) + \lambda J^*_{E-\beta\omega^*_b E} * (-\beta E) = 0$$

$$u' = J^*_E \qquad (6.36)$$

30

$$J^*(E, t) \equiv e^{\rho_b t} J(E, t) = e^{\rho_b t} \int_t^\infty e^{-\rho s} u(c_b(s), s)\, ds$$
$$= \int_t^\infty e^{-\rho_b (s-t)} u(c_b(s), s)\, ds$$
$$= \int_0^\infty e^{-\rho_b s} u(c_b(s), s)\, ds = J^*(E)$$

In order to find a closed form solution, the form of the value function has to be guessed (Sennewald and Wälde 2005, p. 15). I follow Merton (1969, p. 250) guessing that the value function is of the same form as the instantaneous utility function $J^*(E) = \frac{b(t)}{\gamma_b} E^{\gamma_b}$ and thus

$$J_E^*(E) = b(t) E^{\gamma_b - 1}. \tag{6.37}$$

With this guess the optimal fraction of risky investment can be identified by the first order condition for ω_b^*.

$$\begin{aligned}
J_E^* * (r_R E - r_D E) + \lambda J_{E-\beta\omega_b^* E}^* * (-\beta E) &= 0 \\
b(t) E^{\gamma_b - 1} (r_R E - r_D E) + \lambda b(t) (E - \beta \omega_b^* E)^{\gamma_b - 1} (-\beta E) &= 0 \\
(r_R - r_D) + \lambda (1 - \beta \omega_b^*)^{\gamma_b - 1} (-\beta) &= 0 \\
\frac{r_R - r_D}{\lambda \beta} &= (1 - \beta \omega_b^*)^{\gamma_b - 1} \\
\left(\frac{r_R - r_D}{\lambda \beta} \right)^{\frac{1}{\gamma_b - 1}} &= 1 - \beta \omega_b^* \\
\left[1 - \left(\frac{\lambda \beta}{r_R - r_D} \right)^{\frac{1}{1 - \gamma_b}} \right] \frac{1}{\beta} &= \omega_b^* \qquad (6.7)
\end{aligned}$$

Using the guess in the first order condition of consumption (6.36) gives $b^{\frac{1}{\gamma_b - 1}}$ as consumption to equity ratio.

$$\begin{aligned}
c_b^{\gamma_b - 1} &= b(t) E^{\gamma_b - 1} \\
b^{\frac{1}{\gamma_b - 1}} &= \frac{c_b}{E} \qquad (6.38)
\end{aligned}$$

The ratio itself can be calculated by using the objective function (6.6) in combination with the equations (6.38) and (6.37) (Merton 1969; Sennewald and

Wälde 2005).

$$
\begin{aligned}
0 &= u(c_b^*(t)) - \rho_b J^* + J_E^* * (r_R\omega_b^* E + r_D(1-\omega_b^*)E - c_b^*) + \lambda \left[J^*\left(E - \beta\omega_b^* E\right) - J^*\left(E\right)\right] \\
&= \frac{1}{\gamma_b}\left[b^{\frac{1}{\gamma_b-1}}E\right]^{\gamma_b} - \rho_b \frac{1}{\gamma_b} bE^{\gamma_b} + bE^{\gamma_b-1}\left(r_R\omega_b^* E + r_D(1-\omega_b^*)E - b^{\frac{1}{\gamma_b-1}}E\right) \\
&+ \lambda\left[\frac{1}{\gamma_b} b\left(E - \beta\omega_b^* E\right)^{\gamma_b} - \frac{1}{\gamma_b} bE^{\gamma_b}\right] \\
&= \frac{1}{\gamma_b} b^{\frac{\gamma_b}{\gamma_b-1}-1} - \rho_b\frac{1}{\gamma_b} + r_R\omega_b^* + r_D(1-\omega_b^*) - b^{\frac{1}{\gamma_b-1}} + \lambda\frac{1}{\gamma_b}\left[(1-\beta\omega_b^*)^{\gamma_b} - 1\right]
\end{aligned}
$$

$$
\begin{aligned}
b^{\frac{1}{\gamma_b-1}}\left(1 - \frac{1}{\gamma_b}\right) &= -\rho_b\frac{1}{\gamma_b} + r_R\omega_b^* + r_D(1-\omega_b^*) + \lambda\frac{1}{\gamma_b}\left[(1-\beta\omega_b^*)^{\gamma_b} - 1\right] \\
b^{\frac{1}{\gamma_b-1}} &= \frac{-\rho_b + \gamma_b r_R\omega_b^* + \gamma_b r_D(1-\omega_b^*) + \lambda\left[(1-\beta\omega_b^*)^{\gamma_b} - 1\right]}{\gamma_b - 1} \\
&= \frac{-\rho_b + \gamma_b\left(r_R - r_D\right)\omega_b^* + \gamma_b r_D + \lambda\left[\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}} - 1\right]}{\gamma_b - 1} \\
&= \frac{-\rho_b + \gamma_b\frac{r_R-r_D}{\beta}\left[1 - \left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{1}{1-\gamma_b}}\right] + \gamma_b r_D + \lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}} - \lambda}{\gamma_b - 1} \\
&= \frac{-\rho_b - \lambda + \gamma_b\left[\frac{r_R-r_D}{\beta} - \frac{r_R-r_D}{\beta}\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{1}{1-\gamma_b}}\right] + \gamma_b r_D + \lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}}}{\gamma_b - 1} \\
&= \frac{-\rho_b - \lambda + \gamma_b\left[\frac{r_R-r_D}{\beta} - \lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}}\right] + \gamma_b r_D + \lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}}}{\gamma_b - 1} \\
&= \frac{-\rho_b - \lambda + \gamma_b\left[\frac{r_R-r_D}{\beta} - \lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}}\right] + \gamma_b r_D + \lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}}}{\gamma_b - 1}
\end{aligned}
$$

$$
\frac{c_b}{E} = \frac{\rho_b + \lambda - \gamma_b\left(\frac{r_R-r_D}{\beta} + r_D\right) - (1-\gamma_b)\lambda\left(\frac{\lambda\beta}{r_R-r_D}\right)^{\frac{\gamma_b}{1-\gamma_b}}}{1-\gamma_b} \tag{6.9}
$$

Appendix Characteristics of ω_b^*

Higher leverage is induced by a higher risk premium $(r_R - r_D)$:

$$\omega_b^* = \left[1 - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}}\right]\frac{1}{\beta}$$
$$\frac{\partial\omega_b^*}{\partial\left(r_R - r_D\right)} = \left[\frac{1}{1-\gamma_b}\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}-1}\frac{\lambda\beta}{\left(r_R - r_D\right)^2}\right]\frac{1}{\beta} > 0,$$

decreased risk, i.e. lower likelihood of default λ

$$\frac{\partial\omega_b^*}{\partial\lambda} = \left[-\frac{1}{1-\gamma_b}\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}-1}\frac{\beta}{r_R - r_D}\right]\frac{1}{\beta} = -\frac{1}{1-\gamma_b}\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}-1}\frac{1}{r_R - r_D} < 0,$$

and higher collateral $(1-\beta)$

$$\frac{\partial\omega_b^*}{\partial\beta} = \left[-\frac{1}{1-\gamma_b}\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}-1}\frac{\lambda}{r_R - r_D}\right]\frac{1}{\beta} - \left[1 - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}}\right]\frac{1}{\beta^2} < 0.$$

For risky investment to be considered by risk averse agents, its expected rate of return must exceed the safe rate of return $r_R - \lambda\beta > r_D$. It is assumed that this condition always holds, whereby $\ln\left(\lambda\beta/r_R - r_D\right) < 0$. Therefore, bank leverage is decreasing in the banker's risk aversion:

$$\frac{\partial\omega_b^*}{\partial\left(1-\gamma_b\right)} = -\frac{1}{\beta}\left[\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}}\left(-\frac{1}{\left(1-\gamma_b\right)^2}\right)\ln\left(\frac{\lambda\beta}{r_R - r_D}\right)\right] < 0$$

Appendix Side Condition (6.8)

A necessary condition for banking activity is sufficiently low risk aversion. The required level is derived in the following.

$$\omega_b^* > 1 \Leftrightarrow \left[1 - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}}\right]\frac{1}{\beta} > 1$$

$$1 - \beta > \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_b}}$$

$$\ln(1-\beta) > \frac{1}{1-\gamma_b}\ln\left(\frac{\lambda\beta}{r_R - r_D}\right)$$

$$1 - \gamma_b < \frac{\ln\left(\frac{\lambda\beta}{r_R - r_D}\right)}{\ln(1-\beta)} \ (> 0) \tag{6.8}$$

The sign changes direction because $\ln(1-\beta) < 0$. The whole term is positive since $\ln\left(\frac{\lambda\beta}{r_R - r_D}\right) < 0$. Since the calculations for the bank and household are alike the index i represents b and h, respectively. The impact of r_D upon ω_i is according to intuition negative for households and banks.

$$\frac{\partial\omega_i^*}{\partial r_D} = \left[-\frac{1}{1-\gamma_i}\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}-1}\frac{\lambda\beta}{(r_R - r_D)^2}\right]\frac{1}{\beta}$$

$$= \left[-\frac{1}{1-\gamma_i}\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}}\frac{1}{(r_R - r_D)}\right]\frac{1}{\beta} < 0$$

Appendix Proof that Bank's Deposit are Risk-Free

The solvency constraint in case of loan default is:

$$E + r_R E\omega_b^* - \beta\omega_b^* E + r_D E(1 - \omega_b^*) > 0$$

$$1 + r_R\omega_b^* - \beta\omega_b^* + r_D(1 - \omega_b^*) > 0$$

$$1 - \beta\omega_b^* + (r_R - r_D)\omega_b^* + r_D > 0$$

From the first order condition (6.7) it can be seen that $\beta\omega_b^* < 1$, whereby the solvency constraint always holds.

Appendix $\partial\left(\tilde{c}_i\right)/\partial r_D$

The reaction of the consumption ratio following a change in r_D is dependent upon the risk aversion.

$$\begin{aligned}
\tilde{c}_i &= \frac{\rho_i + \lambda - \gamma_i\left(\frac{r_R - r_D}{\beta} + r_D\right) - (1-\gamma_i)\,\lambda\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma_i}{1-\gamma_i}}}{1-\gamma_i} \\
\frac{\partial\left(\tilde{c}_i\right)}{\partial r_D} &= \frac{-\gamma_i\left(\frac{-1}{\beta} + 1\right) - (1-\gamma_i)\,\frac{\gamma_i}{1-\gamma_i}\lambda\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma_i}{1-\gamma_i}-1}\frac{\lambda\beta}{\left(r_R - r_D\right)^2}}{1-\gamma_i} \\
&= \frac{-\gamma_i\left(\frac{-1}{\beta} + 1\right) - (1-\gamma_i)\,\frac{\gamma_i}{1-\gamma_i}\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}-2}\frac{\lambda\lambda\beta}{\left(r_R - r_D\right)^2}}{1-\gamma_i} \\
&= \frac{\gamma_i\frac{1}{\beta} - \gamma_i - \gamma_i\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}}\frac{1}{\beta}}{1-\gamma_i} \\
&= \frac{-\gamma_i + \gamma_i\left[1 - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}}\right]\frac{1}{\beta}}{1-\gamma_i} \\
&= \frac{\gamma_i}{1-\gamma_i}\left(\omega_i^* - 1\right)
\end{aligned}$$

This term is positive for the bank ($i = b$) and negative for the household ($i = h$). An increase in the interest rate changes the relative price of current versus future consumption in favor of future consumption from the households point of view. This is the substitution effect. However increased lifetime income due to rising interest income can induce the household to decrease savings (income effect). For the bank the effects have opposing signs, because the deposit rate is a cost and not return factor for the banker.

Accordingly, the sign is unambiguous for the mean rate of return of the risky investment, which increases returns for households as well as banks.

$$
\begin{aligned}
\frac{\partial\left(\tilde{c}_i\right)}{\partial r_R} &= \frac{-\gamma_i \frac{1}{\beta} - \left(1-\gamma_i\right) \lambda \frac{\gamma_i}{1-\gamma_i} \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma_i}{1-\gamma_i}-1} \frac{-\lambda\beta}{\left(r_R-r_D\right)^2}}{1-\gamma_i} \\
&= \frac{-\gamma_i \frac{1}{\beta} - \gamma_i \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}-2} \frac{-\lambda^2\beta}{\left(r_R-r_D\right)^2}}{1-\gamma_i} \\
&= \frac{-\gamma_i \frac{1}{\beta} - \gamma_i \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}} \frac{1}{\beta}}{1-\gamma_i} \\
&= \frac{-\gamma_i \frac{1}{\beta} \left(1 - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}}\right)}{1-\gamma_i} \\
&= -\frac{\gamma_i \omega_i^*}{1-\gamma_i} < 0
\end{aligned}
$$

Appendix

The commodity market clears in a Walrasian manner.

$$
\begin{aligned}
y_S + y_R &= AL_S + \left(1 + r_R\right) AL_R - \beta AL_R dq \\
&= wL + r_R w L_R - \beta w L_R dq \\
&= wL + r_R \left(\omega_b E + \omega_h W\right) - \beta \left(\omega_b E + \omega_h W\right) dq \\
&= wL + r_R \omega_b E - \beta \omega_b E dq + r_R \omega_h W - \beta \omega_h W dq \\
&= c_L + c_b + c_h + dE + dW
\end{aligned}
$$

The equations have been used in the following order: 6.1 + 6.3, 6.2, 6.15, 6.13, 6.5 and 6.10, where the equality of bank's deposit cost and household's deposit return was utilized.

Appendix Equation (6.16)

The deposit market equilibrium balances the safe investment choice of the household and (short selling) of the bank. It can be used to write the equity/wealth ratio as a function of the deposit rate r_D and vice versa.

$$\begin{aligned}\left(1-\omega_h^*\right)W &= -\left(1-\omega_b^*\right)E \\ \frac{E}{W} &= -\frac{\left(1-\omega_h^*\right)}{\left(1-\omega_b^*\right)}\end{aligned} \tag{6.16}$$

Using the implicit function theorem, it can be shown that the deposit rate is rising in the equity/wealth fraction:

$$\begin{aligned}0 &= \frac{E}{W} + \frac{\left(1-\omega_h^*\right)}{\left(1-\omega_b^*\right)} \\ \frac{\partial r_D}{\partial \frac{E}{W}} &= -\frac{1}{\left[\frac{\left(-\frac{\partial \omega_h^*}{\partial r_D}\right)\left(1-\omega_b^*\right)-\left(1-\omega_h^*\right)\left(-\frac{\partial \omega_b^*}{\partial r_D}\right)}{\left(1-\omega_b^*\right)^2}\right]} \\ &= -\frac{\left(1-\omega_b^*\right)^2}{\left(-\frac{\partial \omega_h^*}{\partial r_D}\right)\left(1-\omega_b^*\right)-\left(1-\omega_h^*\right)\left(-\frac{\partial \omega_b^*}{\partial r_D}\right)} > 0 \ \text{ if } \ 1-\omega_b^* < 0\end{aligned}$$

Appendix Equation (6.17) **and** (6.18)

Using the optimal leverage (6.7, 6.11 respectively) and consumption ratio (6.9, 6.12) in the intertemporal budget constraint (6.5, 6.10) the equity and wealth growth rates can be depicted as functions of the deposit rate r_D. Since the calculations for the bank and household are alike I represents E or W and i represents b and h. The stochastic part $\beta\omega_i^* dq$ is also a function of r_D, but since it cannot be further simplified it is not substituted.

$$\frac{dI}{I} = \begin{pmatrix} (r_R - r_D)\left[1 - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}}\right]\frac{1}{\beta} + r_D \\ -\frac{\rho_i + \lambda - \gamma_i\left(\frac{r_R - r_D}{\beta} + r_D\right) - (1-\gamma_i)\lambda\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma_i}{1-\gamma_i}}}{1-\gamma_i} \end{pmatrix} dt - \beta\omega_i^* dq$$

$$= \begin{pmatrix} (r_R - r_D)\frac{1}{\beta} - \left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{1}{1-\gamma_i}}(r_R - r_D)\frac{1}{\beta} + r_D \\ -\frac{\rho_i + \lambda - \gamma_i\left(\frac{r_R - r_D}{\beta} + r_D\right) - (1-\gamma_i)\lambda\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma_i}{1-\gamma_i}}}{1-\gamma_i} \end{pmatrix} dt - \beta\omega_i^* dq$$

$$= \begin{pmatrix} \frac{(1-\gamma_i)\left(\frac{(r_R - r_D)}{\beta} + r_D\right)}{1-\gamma_i} - \lambda\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma}{1-\gamma_i}} + \lambda\left(\frac{\lambda\beta}{r_R - r_D}\right)^{\frac{\gamma}{1-\gamma_i}} \\ -\frac{\rho_i + \lambda - \gamma_i\left(\frac{r_R - r_D}{\beta} + r_D\right)}{1-\gamma_i} \end{pmatrix} dt - \beta\omega_i^* dq$$

$$= \left(\frac{(1-\gamma_i)\left(\frac{(r_R - r_D)}{\beta} + r_D\right) - \rho_i - \lambda + \gamma_i\left(\frac{r_R - r_D}{\beta} + r_D\right)}{1-\gamma_i}\right) dt - \beta\omega_i^* dq$$

$$= \left(\frac{\frac{(r_R - r_D)}{\beta} + r_D - \rho_i - \lambda}{1-\gamma_i}\right) dt - \beta\omega_i^* dq$$

6.A.2 Banks' Solvency Risk, with Bank-Dependence

Appendix

By assumption the banker derives utility straight from equity. $u(E) = \frac{1}{\gamma_b}E^{\gamma_b}$ is the instantaneous utility function. In the following it is important to acknowledge that equity is a function of time $E(t)$. Equity develops according to

$$\begin{aligned} dE &= r(1-\omega_b)E(t) + x\omega_b E(t) \\ &= ((a-r)\omega_b E(t) + rE(t))\,dt + \sigma\omega_b E(t)dz \end{aligned}$$

where dz describes the Wiener process. Defining $J(E(t), t)$ as maximized expected lifetime utility

$$J(E(t), t) \equiv \max_{\omega_b} \varepsilon_t \int_t^{\infty} e^{-\rho_b i} u(E(i))di$$

and applying the Bellman's Principle of Optimality, the objective equation can be rewritten

$$\begin{aligned} J(E(t),t) &\equiv \max_{\omega_b} \varepsilon_t \left[\int_t^{t+dt} e^{-\rho_b i} u(E(i))di + \int_{t+dt}^{\infty} e^{-\rho_b i} u(E(i))di \right] && (6.39) \\ &= \max_{\omega_b} \varepsilon_t \left[e^{-\rho t} u(E(t))dt + J\left(E+dE, t+dt\right) \right] \\ 0 &= \max_{\omega_b} \varepsilon_t \left[e^{-\rho t} u(E(t))dt + dJ(E,t) \right] && (6.40) \end{aligned}$$

However, because the term $\varepsilon_t dJ$ is a function of the stochastic E, the Ito's lemma for Wiener process[31] has to be applied (Ingersoll 1987, pp. 348): $dJ = J_t dt + J_E \left((a-r)\omega_b E_t + rE_t\right) dt + \frac{1}{2}\left(\sigma\omega E\right)^2 J_{EE} dt$. The objective function can be further simplified by defining $J^*(E(t),t) = e^{\rho_b t} J\left(E(t),t\right)$,whereby J^* becomes independent of time[32] $J^*(E(t),t) = J^*(E(t))$ (Merton 1969, p. 252).

$$\begin{aligned} 0 &= \max_{\omega_b} \varepsilon_t \left[\begin{array}{c} e^{-\rho_b t} u(E(t))dt + \rho_b e^{-\rho_b t} J^* dt + e^{-\rho_b t} J_E^* \left((a-r)\omega_b E(t) + rE(t)\right) dt \\ +\frac{1}{2}\left(\sigma\omega E(t)\right)^2 e^{-\rho_b t} J_{EE}^* dt \end{array} \right] \\ &= \max_{\omega_b} \left[u(E(t)) - \rho_b J^* + J_E^* \left((a-r)\omega_b E(t) + rE(t)\right) + \frac{1}{2}\left(\sigma\omega_b E(t)\right)^2 J_{EE}^* \right] \end{aligned}$$

The first order condition is thus

$$\begin{aligned} 0 &= J_E^*(a-r)E(t) + \sigma^2 \omega_b E(t)^2 J_{EE}^* \\ \omega_b &= -\frac{(a-r)}{\sigma^2} \frac{J_E^*}{E(t) J_{EE}^*}. \end{aligned}$$

[31] "Given a stochastic differential equation: $dx = adt + bdz$. Let $f(x,t)$ be a twice continuously differentiable function of x and t. Then $df = (f_t + af_x + \frac{1}{2}b^2 f_{xx})dt + bf_x dz$" (www.stanford.edu/~japrimbs/01-Math(f).ppt, 11.02.06)

[32]

$$\begin{aligned} J^*(E,t) &= e^{\rho_b t} J(E,t) = e_t^{\rho_b t} \int_t^{\infty} e^{-\rho_b s} u\left(E(s),s\right) ds \\ &= \int_t^{\infty} e^{-\rho_b (s-t)} u\left(E(s),s\right) ds \\ &= \int_0^{\infty} e^{-\rho_b s} u\left(E(s),s\right) ds = J^*(E) \end{aligned}$$

Guessing that $J^*(E)$ has the same functional form as $u(E)$ and later is CRRA with the Arrow-Pratt measure of risk aversion $(1-\gamma_b)$ the optimal portfolio satisfies[33]

$$\omega_b^* = \frac{(a-r)}{(1-\gamma_b)\,\sigma^2}.$$

Appendix

$$\begin{aligned}
\dot{E}/E &= x\omega_b^* + r(1-\omega_b^*) \\
&= x\frac{(a-r)}{\sigma^2(1-\gamma_b)} + r\left(1 - \frac{(a-r)}{\sigma^2(1-\gamma_b)}\right) \\
&= x\frac{(a-r)}{\sigma^2(1-\gamma_b)} + r - \frac{(ar-r^2)}{\sigma^2(1-\gamma_b)} \\
&= \frac{xa - xr - ar + r^2}{\sigma^2(1-\gamma_b)} + r \\
&= r^2\frac{1}{\sigma^2(1-\gamma_b)} + r\left(1 - \frac{x+a}{\sigma^2(1-\gamma_b)}\right) + \frac{xa}{\sigma^2(1-\gamma_b)}
\end{aligned}$$

Appendix

$$\begin{aligned}
H &= \frac{c_t^{\gamma}-1}{\gamma}e^{-\rho t} + \lambda\left[D_t r + w_t L_t - c_t\right] \\
H_c &= c_t^{\gamma-1}e^{-\rho t} - \lambda = 0 \\
&\Rightarrow\ -\frac{\dot{\lambda}}{\lambda} = -(\gamma-1)\frac{\dot{c}}{c} + \rho \\
H_{D_t} &= \lambda r = -\dot{\lambda} \\
&\Rightarrow\ -\frac{\dot{\lambda}}{\lambda} = r
\end{aligned}$$

33

$$\begin{aligned}
J^*(E(t)) &= \frac{1}{\gamma_b}E(t)^{\gamma_b} \\
\frac{J_E^*}{E(t)J_{EE}^*} &= \frac{E(t)^{\gamma_b-1}}{E(t)\,(\gamma_b-1)\,E(t)^{\gamma_b-2}} \\
&= -\frac{1}{(1-\gamma_b)}
\end{aligned}$$

Appendix

$$
\begin{aligned}
y_S + y_R &= AL_S + AL_R + xAL_R \\
&= wL + xwL_R \\
&= wL + x\omega_b E \\
&= wL + \pi_b - r\left(1-\omega_b\right)E \\
&= wL + \dot{E} + rD \\
&= \dot{D} + c + \dot{E}
\end{aligned}
$$

The equations have been used in the following order: 6.20 + 6.22, 6.21, 6.30, 6.28, 6.24, 6.29 and finally 6.26.

Appendix

$$
\begin{aligned}
\dot{E} &= x\omega_b^* E + r^*(1-\omega_b)E = \left[\left(x - r^*\right)\omega_b^* + r^*\right]E \\
&= x\left(\frac{D}{E}+1\right)E + r^*(-\frac{D}{E})E = x\left(\frac{D}{E}+1\right)E + r^*(-D) \\
&= x\left(\frac{D}{E}+1\right)E + \left(a - \left(\frac{D}{E}+1\right)\sigma^2\left(1-\gamma_b\right)\right)(-D) \\
&= x\left(D+E\right) - aD + \left(\frac{D^2}{E}+D\right)\sigma^2\left(1-\gamma_b\right) \\
&= \left(\frac{D^2}{E}+D\right)\sigma^2\left(1-\gamma_b\right) + \left(x-a\right)D + xE
\end{aligned}
$$

Appendix

$$
\begin{aligned}
\frac{r^{*}-\rho}{1-\gamma} &= r^{2}\frac{1}{\sigma^{2}\left(1-\gamma_{b}\right)}+r\left(1-\frac{x+a}{\sigma^{2}\left(1-\gamma_{b}\right)}\right)+\frac{xa}{\sigma^{2}\left(1-\gamma_{b}\right)} \\
r^{*} &= r^{2}\frac{1}{\sigma^{2}}+r\left(\left(1-\gamma_{b}\right)-\frac{x+a}{\sigma^{2}}\right)+\frac{xa}{\sigma^{2}}+\rho \\
0 &= r^{2}\frac{1}{\sigma^{2}}+r\left(\left(-\gamma_{b}\right)-\frac{x+a}{\sigma^{2}}\right)+\frac{xa}{\sigma^{2}}+\rho \\
0 &= r^{2}+r\left(-\gamma_{b}\sigma^{2}-x-a\right)+xa+\rho\sigma^{2} \\
r_{1,2} &= -\frac{-\left(\gamma_{b}\sigma^{2}+x+a\right)}{2}\pm\sqrt{\left(\frac{-\left(\gamma_{b}\sigma^{2}+x+a\right)}{2}\right)^{2}-\sigma^{2}\rho-ax} \\
\tilde{r} &= \frac{\left(\gamma_{b}\sigma^{2}+x+a\right)}{2}-\sqrt{\frac{\left(\gamma_{b}\sigma^{2}+x+a\right)^{2}}{4}-\sigma^{2}\rho-ax}
\end{aligned}
$$

The side condition for a real number solution of the root is

$$
\frac{\left(\gamma_{b}\sigma^{2}+x+a\right)^{2}}{4}-\sigma^{2}\rho-ax>0.
$$

Appendix

$$
\begin{aligned}
\frac{\partial\dot{E}/E}{\partial\sigma^{2}} &= \frac{-2}{\sigma}r^{2}\frac{1}{\sigma^{2}\left(1-\gamma_{b}\right)}-\frac{-2}{\sigma}r\frac{x+a}{\sigma^{2}\left(1-\gamma_{b}\right)}+\frac{-2}{\sigma}\frac{xa}{\sigma^{2}\left(1-\gamma_{b}\right)} \\
&= \frac{-2}{\sigma}\left[r^{2}\frac{1}{\sigma^{2}\left(1-\gamma_{b}\right)}-r\frac{x+a}{\sigma^{2}\left(1-\gamma_{b}\right)}+\frac{xa}{\sigma^{2}\left(1-\gamma_{b}\right)}\right] \\
&= \frac{-2}{\sigma}\left[r\frac{r-a}{\sigma^{2}\left(1-\gamma_{b}\right)}+x\frac{a-r}{\sigma^{2}\left(1-\gamma_{b}\right)}\right] \\
&= \frac{-2}{\sigma}\left(x-r\right)\frac{a-r}{\sigma^{2}\left(1-\gamma_{b}\right)}<0
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial\dot{E}/E}{\partial\left(1-\gamma_{b}\right)} &= -r^{2}\frac{1}{\sigma^{2}\left(1-\gamma_{b}\right)^{2}}+r\frac{x+a}{\sigma^{2}\left(1-\gamma_{b}\right)^{2}}-\frac{xa}{\sigma^{2}\left(1-\gamma_{b}\right)^{2}} \\
&= \frac{ra-r^{2}}{\sigma^{2}\left(1-\gamma_{b}\right)^{2}}-x\frac{a-r}{\sigma^{2}\left(1-\gamma_{b}\right)^{2}} \\
&= -r\frac{a-r}{\sigma^{2}\left(1-\gamma_{b}\right)^{2}}-x\frac{a-r}{\sigma^{2}\left(1-\gamma_{b}\right)^{2}}<0
\end{aligned}
$$

Appendix

$$
\begin{aligned}
T &= -\left(\frac{D^2}{E^2}\right)\sigma^2\left(1-\gamma_b\right)+x+\frac{a-\left(\frac{D}{E}+1\right)\sigma^2\left(1-\gamma_b\right)-\rho}{1-\gamma}+a \\
&\quad -\left(2\frac{D}{E}+1\right)\sigma^2\left(1-\gamma_b\right) \\
&= -\left[\frac{D^2}{E^2}+2\frac{D}{E}+1\right]\sigma^2\left(1-\gamma_b\right)+x+\frac{a-\left(\frac{D}{E}+1\right)\sigma^2\left(1-\gamma_b\right)-\rho}{1-\gamma}+a \\
&= -\left[\frac{D}{E}+1\right]^2\sigma^2\left(1-\gamma_b\right)+x+\frac{a-\left(\frac{D}{E}+1\right)\sigma^2\left(1-\gamma_b\right)-\rho}{1-\gamma}+a \\
&= -\left[\omega\right]^2\sigma^2\left(1-\gamma_b\right)+x+\frac{a-\left(\omega\right)\sigma^2\left(1-\gamma_b\right)-\rho}{1-\gamma}+a \\
T &= -\frac{\left[a-r\right]^2}{\sigma^2\left(1-\gamma_b\right)}+x+\frac{r-\rho}{1-\gamma}+a
\end{aligned}
$$

Chapter 7

Conclusion

The general presumption that banks and their decisions are vital for economic growth is confirmed by the economic literature. This thesis extends this literature by focusing upon bank behavior in regard to liquidity and solvency risk.

Firstly, the relevant growth literature has been reviewed to identify a useful framework for extension. It has been shown that endogenous growth models are the only type which allow for a persistent impact of endogenous choices upon steady state growth. However, in the growth literature, it is fiercely disputed whether endogenous growth models are a realistic simplification of the real world. Therefore, it is also shown that endogenous growth models are a sufficient proxy to the real world.
This is in line with the finance-growth literature which mainly uses AK-type, Romer-type, and Schumpeterian growth models to explain the impact of banks upon economic growth.
In AK models the growth rate is driven by capital accumulation. However, empirical studies offer more support to a link between financial development and allocation of capital as the source of growth. Therefore, Romer and Schumpeterian growth models, in which capital allocation drives growth, fit the empirics better.

The literature utilizes banks' ability to produce information via screening and monitoring, and to diminish liquidity and default risk for the households. The reduction of risk is achieved via diversification on banks' balance sheets. With the exception of Ennis and Keister (2003), and Blackburn and Hung (1998), the literature assumes that banks can perfectly diversify any risk. Therefore, risk is of no importance for banks' decisions and economic growth.

Though, such full diversification is not realistic. In the real world, financial intermediaries do face liquidity risk as well as undiversifiable solvency risk. Therefore, the assumption of perfect risk diversification has been eased in this thesis. Suitable models to analyze banks' behavior regarding risk and its impact upon economic growth have been developed in Chapter 5 and 6.

Liquidity risk of banks has been included in a Schumpeterian growth model by acknowledging that bank customers use their deposits for transfers. Although, deposit transfers remain within the banking system, individual banks can experience a stochastic net outflow of deposits. If the resulting 'deposit gap' is not covered by reserves, the bank must liquidate long-term loans or use an interbank credit to balance the outflow.
The cost of liquidating long-term assets is prohibitively high, whereby, the focus is upon interbank credits. Since banks are opaque, these interbank credits are only available at a 'penalty rate'. Illiquidity, thereby becomes costly and banks optimize reserve holdings to diminish expected illiquidity costs.
Reserves and expected illiquidity costs increase the loan-deposit spread, similar to a tax on banking activity. A high spread decreases the net present value of credit financed research and development (R&D). Therefore, less resources are allocated to R&D and the growth rate decreases.

Inclusion of solvency risk is a natural extension of the Schumpeterian growth model, since R&D is an intrinsically risky process, and already Schumpeter ([1912], 1934) noted that it requires financiers willing to bear this risk. In Chapter 6 banks were assumed to be risk averse in order to model a positive role of bank equity capital. Bank equity capital serves as a buffer against credit defaults and allows the bank to offer safe deposits to even more risk averse households. Two model variations have been introduced.
The first model variation allows for the coexistence of banks and financial markets. It is assumed that the banker and the households differ only in their preferences. Four insights have been derived. Firstly, the more heterogenous

the risk aversions the more bank-based the economy will be. Secondly, the growth rate does not depend upon the bank- versus market-finance choice, but rather the combination of preference. This is in line with the empirical findings that neither system is superior. Thirdly, the model replicates and explains the stylized facts that decreasing bank equity is associated with increasing spreads and low economic growth. The intuition is that stochastic R&D success implies stochastic loan defaults. Compared to the wealth loss of households, banks suffer an overproportionate loss in equity because of their high leverage. Therefore, households' deposit savings will be relatively high. By accepting this relatively high amount of deposits, the bank is increasing its leverage. The bank is only willing to accept the according solvency risks at an increased loan-deposit spread. Less finance will be available for R&D, whereby, less resources are allocated to this sector. The growth rate is dampened. Fourthly, following debt defaults, the growth rate remains low for a prolonged period of time. The reason is that sufficient financial savings have to be accumulated to finance the wage bill of the R&D sector while the slow technology growth continuous to increase the wage rate. In other words, the recovery of wealth and bank equity to the former level is insufficient to finance the former R&D workforce.
The second model variation excludes market finance from the analysis. Thereby, banks' willingness to assume risk is directly related to the deposit rate, and loans available for R&D. Decreasing banks' risk aversion allows for higher deposit rates, which induce households to increase savings. More labor can be allocated to R&D, whereby, the growth rate increases.

Clearly, the theoretical models developed in this thesis, depict a highly stylized picture of the real world. One must thus be very careful when deriving policy options from them.
The negative growth impact of interbank information frictions can be alleviated, if the central bank acts as a 'bank of banks'. It is likely that the central bank has a better insight of banks' creditworthiness. Further, the central bank can economize on reserve holdings. Alternative to central bank intervention, financial liberalization and inclusion of foreign banks can improve the efficiency of the interbank market. If foreign banks' reputation or screening technology is superior, they can assume a role similar to the central bank.

The solvency models have explained the difference between market-based and bank-based financial systems via the preferences of the population. Often bank-based systems are associated with insufficiently developed financial markets and there is a tendency to foster market finance. If, in fact, the financial market is underdeveloped, such a policy may be useful. However, if the reason for bank-based finance was heterogeneity of the preferences, policy intervention in favor of market finance would distort the financing decisions and decrease welfare accordingly.

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