Discussion Paper No. 02-74

Research and Development: Financial Constraints and the Role of Public Funding for Small and Medium-sized Enterprises

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Non–technical summary

This paper presents microeconometric evidence on financing difficulties of research and development activities. In comparison to existing studies for Germany, there are basically three new features in this paper: first, this study focuses on small and medium–sized enterprises with 500 employees at most (SME) while other authors have used samples of larger firms. Second, previous studies are conditional on R&D–performing firms and neglect the circumstance that a large share of smaller firms do not conduct any R&D activities due to the lack of financial resources. In this case, non–R&D–performing firms, and the endogeneity of their decision, are explicitly taken into account. Third, special attention is paid to a comparison of Eastern and Western Germany, and to the public R&D funding already provided by government in both regions. In Eastern Germany, R&D activities are extensively subsidized in order to accelerate the transformation process from a planned economy to a market economy. It is questionable whether these governmental actions alleviate financial constraints significantly.

In the empirical section of the paper, censored regression models are estimated. It turns out that it is important to take non–R&D performing firms into account when SME are considered. Firms may be completely deterred from R&D by the lack of capital instead of just spending less but a positive amount for R&D. Western German SME are financially constrained in their R&D activities by both internal and external resources. Another important factor in explaining different levels of R&D expenditures are public R&D subsidies. Publicly funded firms exhibit higher R&D expenditures than other firms. In Eastern Germany, no external financial constraints for R&D are present. The results suggest that R&D in Eastern Germany is to a large extent driven by public subsidies since the German re–unification in 1990 and that the usual financial market mechanisms are repealed with respect to R&D in this region.

Although the estimation results show that public funding is the driving force for R&D in Eastern Germany, one may question whether the high level of public R&D funding leads to a corresponding innovation success in terms of market shares and sales of new products in many of these publicly funded firms.

Research and Development: Financial Constraints and the Role of Public Funding for Small and Medium–sized Enterprises[1]

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Abstract

This paper presents microeconometric evidence on financing contraints for research and development activities in German small and medium–sized firms (SME). Special attention is paid to the role of public R&D subsidies. For this purpose SME in Western and Eastern Germany are compared because these regions are very different in their supply of public R&D funding. It turns out that Western German SME are financially constrained in their R&D activities by both internal and external resources. In Eastern Germany, firms are not sensitive to external constraints, possibly due to high public R&D subsidies. The results suggest that R&D in Eastern Germany is to a large extent driven by public subsidies since the German re–unification in 1990 and that the usual financial market mechanisms are repealed with respect to R&D in this region.

Keywords: Research and development, financial constraints, public funding, SME, censored regression models

JEL–Classification: C24, O31, O38

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1 Introduction

Different theoretical arguments point out that investment in research and development (R&D) activities is different from investment in capital goods and underinvestment in R&D may occur. Since Nelson (1959) and Arrow (1962), it is known that with respect to R&D market failures occur. On one hand, innovations are expected to generate positive external effects, but firms can only appropriate private returns and therefore will only launch privately profitable innovation projects. As there may be projects that would have positive benefits to society, but do not cover the private cost, firms are reluctant to invest and the quantity of innovations is below the socially desirable level. Another reason which increases the likelihood of underinvestment is also described by Arrow (1962) and is due to information asymmetries: When the innovation investor and financier are different, an additional gap exists between the private rate of return and the cost of capital. Often there is a (large) difference between the rate of return required by a firm investing its own funds and the required rate by external investors. Hall (2002) surveys the literature on this topic and reviews several studies from different countries.[2] The asymmetric information problem refers to the following fact: The inventor usually has a better information on the innovation project, e.g. on the likelihood of success. In this case, financing for R&D fits in Akerlof's (1970) famous 'market for lemons' framework. The investors have difficulties to distinguish good projects from 'lemons' and do therefore charge a lemons' premium for R&D which will be higher than that for capital investment.[3] In this context, an additional reason for financial constraints, especially in small and medium–sized enterprises (SME) is sunk costs: Banks and other debt–holders prefer to use physical assets to secure loans and are reluctant to lend when the project involves substantial R&D investment. Assets whose value in an alternative use is almost as high as in their current use are more suited to the governance structures associated with debt. Alderson and Betker (1996) find that liquidation costs and R&D are positively correlated across firms. The entry barrier of sunk costs can be expected to represent a bigger problem the smaller the firms are.

As a result, those arguments justify governmental interventions in the market for R&D. While the positive external effects are usually considered

[2]See this survey for a lot of further of references on the topic. The present study is not intended to provide a comprehensive discussion on the existing literature dealing with financial constraints but focuses on the empirical analysis.

[3]See Hall (2002) for further arguments on market failures for R&D financing.

when public funding for basic research, state–of–the–art technologies or possible future key technologies, is the topic of interest, the second argument on the wedge between internal and external cost of capital is used as a rationale for supporting activities of SME. Especially SME may be completely deterred from undertaking R&D projects because internal funds are often scarce, and capital from private investors external to the firm is expensive when the investment, like risky R&D projects, is difficult to collaterize. Public R&D subsidies represent a cheap external resource for the financing of R&D and an opportunity to reduce sunk costs and therefore enhance the probability of an implementation of R&D activities in SME.

This paper presents an empirical analysis which investigates whether financial constraints are present in SME and whether public R&D subsidies are able to alleviate these constraints in a sample of firms from the German manufacturing sector. In comparison to existing studies on Germany, there are basically three new features in this paper:

- It focuses on SME while other authors have used samples of large firms.
- Previous studies are conditional on R&D–performing firms and neglect the circumstance that a large share of smaller firms do not conduct any R&D activities due to the lack of financial resources. In this case, non–R&D–performing firms, and the endogeneity of their decision, are explicitly taken into account.
- Special attention is paid to a comparison of Eastern and Western Germany, and to the public R&D funding already provided by government in both regions. In Eastern Germany, R&D activities are extensively subsidized in order to accelerate the transformation process from a planned economy to a market economy. It is questionable whether these governmental actions alleviate financial constraints significantly.

The following section describes some background on financial constraints for R&D. Existing empirical studies for Germany which test for financial constraints are taken into account for the subsequent empirical analysis. The third section describes the special situation in Germany with respect to R&D subsidies: on one hand, the western part, as industrialized and well developed region since the mid of the last century, and, on the other hand, the eastern regions which can be seen as transition economy since the German re–unification in 1990. A comparison of both situations motivates the following econometric section. The empirical approach is outlined below and after a description of the data, the estimation results are discussed. The conclusion summarizes the empirical findings and suggests further research.

2 Brief review of the literature

R&D activities may be regarded as investment into a firm's knowledge capital and therefore insights from studies on physical investment are important. In several studies, estimations of R&D investment equations are compared with investment in physical assets. Investment in intangible assets like R&D tends to be both more risky and harder to collaterize than investment in physical assets. Therefore, it is more likely that financial constraints for R&D occur. As most of the literature is already reviewed in Hall (2002), I mainly refer to three existing studies using German data (Harhoff, 1998; Bond et al., 1999; and Haid/Weigand, 2001), in order to describe which kind of empirical work on financial constraints for R&D has already been conducted for Germany and to explain what is new in this study.[4] The main results of Hall's survey can be summarized as follows: small and start–up firms in R&D–intensive industries face a higher cost of capital than larger firms. In contrast, the financing gap for large firms is harder to establish, but it seems clear that these firms prefer internally generated funds for R&D investment. Moreover, Hall states that public policies for R&D funding deserve further study. For those reasons, this study focuses on SME and takes the public funding explicitly into account.

Since the study of Fazzari et. al (1988), econometric studies use to test for financial contraints by investigating two (or more) different regimes of the economy: On one hand, a regime of unconstrained firms is defined. These are expected to be able to raise funds for any investment and therefore the spending should not be sensitive to the availability of internal funds, e.g. shocks in cash flow. On the other hand, the potentially constrained firms should exhibit a significant relationship between investment and the availability of financial resources.[5] In the context of R&D and the literature

[4]Only the most recent paper of Haid and Weigand (2001) is not included in Hall's survey.

[5]This approach has been critized by Kaplan and Zingales (1997) who doubt that investment–cash flow sensitivities provide useful measures of financing constraints. However, Fazzari et al. (2000) reply that the Kaplan–Zingales operational definition of the absence of financing constraints and their empirical approach are inappropriate. Kaplan and Zingales (2000) disagree with the comment of Fazzari et al. and in conclusion several questions about both approaches remain unsolved. This paper paper as most other studies follows Fazzari et al.

on Germany, the regimes are classified by firm size, where constraints would be expected for smaller firms, by countries (Germany and the UK) and by governance structures (owner–controlled versus manager–controlled):

Harhoff (1998) compares R&D and investment in physical assets of German manufacturing firms. He considers three different models: an accelerator model, an error correction model and Euler equations (see Harhoff, 1998, for a description of these models). The sample is split at the median of firm size measured by sales (in the initial year). A combination of econometric results for the three models applied and additional evidence from survey data yields the following conclusions: Harhoff finds weak effects of cash flow on R&D for small and large firms and positive cash flow effects on investment in physical assets for small firms. The survey evidence suggests that small firms have a higher probability of being constrained, ceteris paribus.

Bond et al. (1999) also compare R&D and investment but consider two countries: Britain and Germany. The British financial system is seen to be less conducive to long–term investment than the German system, due to different circumstances. One reason, among others, is a more concentrated share ownership in Germany which may mitigate asymmetric information and conflicts of interest between shareholders and managers. In Germany, banks are often present in large firms' supervisory boards, and thus asymmetric information between borrowers and lenders is reduced (see Bond et al., 1999, for further information). Bond et al. mention that a few previous studies suggest that company R&D spending is sensitive to cash flow, but the results are often weak. They attribute this result to two key features of R&D investment: establishing a R&D program involves significant sunk costs, and large fluctuations in the level of spending in existing research activities are very costly because a lot of R&D spending is wages of R&D staff. As these are usually high–skilled workers, large hiring, firing and training costs are incurred. For these reasons, "financial constraints may manifest themselves more in the decision to set up R&D facilities, rather than in decisions about the year to year levels of spending in existing research programmes." (Bond et al., 1999, p. 3) Therefore, the R&D participation decision is separately taken into account by a cross–sectional Probit estimation. Moreover, the relationship between fixed investment and cash flow is investigated for R&D performing and non–R&D performing firms. The results of their empirical analysis can be summarized easily: In Germany, cash flow is not informative at all. In Britain, cash flow influences investment in physical assets but not R&D. However, R&D participation is significantly correlated with cash flow in Britain but not in Germany. Additionally, for the UK the ratio of debt to capital has a significantly negative coefficient. Therefore, Bond et al. conclude that UK firms are more likely to be affected by financing constraints. "UK firms face a higher wedge between the costs of external and internal finance than German firms. Thus they are more cautious about undertaking long–term commitments to R&D projects [...] and those British firms that choose to do R&D are a self–selected sample with 'deep pockets', for whom financial constraints are less likely to be binding." (Bond et al., 1999, p. 36)

Haid and Weigand (2001) also compare R&D and investment. They bring arguments from innovation studies and from the literature on corporate finance and governance together: They take different governance structures into account and split their sample into a manager–controlled and an owner–controlled regime. Splitting by size into large and smaller firms is also considered. Haid and Weigand distinguish internal and external funding constraints. As measures of external financing, a ratio of debt to total liabilities and the change of bank loans to total liabilities are used. They use a panel of 106 large and medium–sized German firms, which reported R&D investment from 1987 to 1993. In contrast to Bond et al., Haid and Weigand identify constraints for R&D and investment by both internal and external funds: Owner–controlled firms are constrained in both R&D and investment in physical assets by the availability of internal and external funding. However, no such constraints occur in manager–controlled firms.

There are two studies using German data which are worth noting in this context, although R&D is not considered but only investment in physical assets: Audretsch and Elston (2001) analyze the role of firm size in more detail. The sample is split in four different size classes where the smallest group refers to firms with 500 or less employees. This study uses a more representative sample of the German economy than the three studies cited above, because there only very large firms were considered. However, the mean in the smallest group is still 310 employees which is much larger than most firms in the economy. Audretsch and Elston find that medium–sized firms, defined as firms with a number of employees between 500 and 5500, are more constrained than smaller and larger companies.

Janz (1997) uses Euler equation models to analyze the investment behavior of large German companies. He does not explicitly test for financial constraints but studies investment behavior and investigates why the Euler equation approach often fails to explain firm behavior. Janz uses an interesting econometric technique: Instead of splitting the sample into different firm groups a–priori, he applies a robust generalized method of moments (GMM) for panel data to detect 'outliers': If firms act in heterogeneous markets and face other competitive pressure, or suffer from financial constraints, for example, they possibly behave differently from others. Therefore, Janz applies a robust GMM estimator which allows to detect outliers, i.e. some firms that engage in markets with perfect competition and others with monopolistic structures, in his case. He concludes that the neoclassical paradigm is suitable for explaining the behavior of the mass of firms but the firms are too heterogeneous to be described by a single model. As reasons for the failure of such investment models are unknown a–priori, robust GMM allows to identify these on the basis of the data. For example, Janz (1997) shows that outliers turn out to represent changes of firms' location or takeovers. Although this methodology cannot be applied in this paper due to data limitations, it could be a useful approach to study financial constraints in the future, too.

The new features of this study are the comparison of Eastern and Western Germany. This is motivated in the following section. Moreover, this study focuses exclusively on SME, i.e. only firms with at most 500 employees are considered. This is new for Germany because all other studies on R&D in this context have used samples of large firms (even if the sample are sometimes split into 'smaller' and 'larger' firms): The mean of the number of employees in former studies on R&D and financial constraints in Germany is 15,006 in Harhoff (1998), 16,538 in Bond et al. (1999) and 25,545 in Haid and Weigand (2001). These large firms may not be the best candidates for studies on financial constraints. The huge size of the firms considered could be an explanation for the weak, or heterogenous, results on cash flow sensitivity which are used to identify ficancial constraints. Finally, in this study the non–R&D–performing firms are taken explicitly into account because, as Harhoff (1998) and Bond et al. (1999) already point out, one hypothesis is that smaller firms are often completely deterred from any R&D activity instead of just spending less but positive amounts on R&D.

3 R&D in Eastern and Western Germany in the 1990s

In Germany, many public R&D policies focus on the five states ("Länder") of the former German Democratic Republic. The aim is to foster innovation activities in Eastern Germany. Innovations are expected to increase productivity growth in these underdeveloped parts of the country. Since the German re–unification in 1990, the vast majority of firms in Eastern Germany has been newly founded. Therefore they are smaller than Western German firms on average, and a large share of those is struggling to survive. In the 1990s, the still underdeveloped infrastructure and, additionally, the breakdown of the eastern European markets possibly have hampered a positive development of Eastern Germany. The lack of large manufacturing plants is often believed to cause a poor economic performance of this area.

The federal government has tried to compensate for these disadvantages by offering specific R&D subsidies for Eastern German firms: first, all public R&D programmes have been opened for Eastern German applicants after the re–unification, and firms from the five new states received a preferential treatment. Second, special R&D policy schemes have been launched exclusively for Eastern Germany and, third, a special venture capital program has been designed. Those components of federal R&D policy were supplemented by additional programs initiated by the states.

Table 1 shows the total innovation expenditure in both regions: while Western Germany contributes 52 Billion Euro in 1998, Eastern Germany spends about 4 Billion. As Eastern Germany is much smaller than the western part, a comparison at the firm level is necessary: It turns out that the 'average Eastern German manufacturer' spends less on innovation compared to the Western German average (about two thirds of the Western German average). This result is, of course, partly due to a smaller average firm size in Eastern Germany. In contrast, the share of R&D performing firms is larger than in Western Germany, as is the share of firms that receive public funding for R&D. As Table 1 shows, 41% of all Eastern German firms are performing own internal R&D activities in 1998 while in Western Germany only 31% do so. With respect to public funding of R&D, this relation is not surprising: One third of all Eastern firms receive funding for R&D activities from public resources, while only 8% are recipients in Western Germany in 1998 (see Table 1).

Table 1:
Innovation expenditure, R&D–performing firms and public R&D funding in German manufacturing[a]

	1994	1996	1998
Innovation expenditure in Billion Euro[b]			
Western Germany	42.7	47.0	51.8
Eastern Germany	3.7	2.4	3.9
Average innovation expenditure per firm in Thousand Euro[b]			
Western Germany	699	861	956
Eastern Germany	439	307	635
Share of R&D–performing firms (in %)			
Western Germany	28	39	31
Eastern Germany	39	48	41
Share of firms receiving public R&D funding (in %)			
Western Germany	7	6	8
Eastern Germany	27	34	33

[a] Shares adjusted by sampling weights; "R&D–performing" refers to firms conducting own internal R&D projects.
[b] "Innovation expenditure" is defined according to the OSLO–Manual (Eurostat/OECD 1997)
Source: Mannheim Innovation Panel

The question arises how public funding of R&D activities affects the usual market mechanisms at work. Are the financial constraints for such activities significantly reduced? Perhaps the usual capital market mechanisms are repealed with respect to R&D in Eastern Germany? This makes a comparison of Eastern and Western Germany an interesting task: It allows to investigate how public policies affect the level of investment in R&D activities and how usual market mechanisms are influenced. The description of the Eastern German situation shows that it is very important to take public resources into account when financial constraints for R&D are analyzed.

In addition, survey evidence suggests that it is important to take non–R&D performing firms into account, too, especially in case of SME. Lacking financial resources may impede any kind of R&D activity in SME rather than reducing the level of R&D investment (see Table 2). In Eastern Germany, more firms indicate financial constraints concerning R&D than in Western Germany. From the group of firms with more than 500 employees, a larger share reports financing difficulties in both Eastern and Western Germany. This is not surprising because limited financial resources are endogenous to R&D: firms that are innovating and doing research intensely will clearly reach their limits more likely than companies that conduct less R&D activities (or only occasionally). However, it is interesting that a large part of hampered firms does not conduct any R&D activities. Especially, in Western Germany 42% of small firms reporting the lack of financial resources for innovation projects, are deterred from own R&D activities. This effect is bigger for the small firms than for the larger ones in both Eastern and Western Germany. The results in Table 2 point again to the importance of public R&D subsidies in Eastern Germany: While more Eastern German firms report the lacking of financial resources than those in the western part, this result turns when current R&D activities are taken into account. More Western German companies do not perform R&D if they face financial constraints. This emphasizes the role of public funding in Eastern Germany has to be taken into account because it seems that public policy schemes could crucially alleviate financing difficulties for SME.

Table 2:
The lack of financial resources as obstacle for innovation (in 1998)[a]

Firms reporting a lack of financial resources for innovation (in %)		
	Western Germany	Eastern Germany
Large firms	9	25
SME	6	13
Out of those: Share of firms which did not conduct any R&D project (in %)		
	Western Germany	Eastern Germany
Large firms	14	3
SME	42	28

[a] Shares adjusted by sampling weights; SME have 500 employees or less, large firms have more than 500.
Source: Mannheim Innovation Panel

4 Empirical Study

R&D is modeled as a function of firms' knowledge stocks, the internal and external funding opportunities, public funding, and of other control variables:

$$\text{R\&D} = f(\text{knowledge stock, internal resources, external resources, public R\&D funding, firm size, sectoral and time controls}).$$

The interpretation of estimation results is in the spirit of Fazzari et al. (1988): The sample is split in Eastern and Western German firms. If the R&D expenditure of one group of firms is sensitive to a measure, e.g. to external funding resources, while R&D of the other group is not, it is concluded that constraints are present for the firms being sensitive to that particular measure. For comparison, I additionally estimate an equation for the investment in physical assets

$$\text{INV} = f(\text{capital stock, internal resources, external resources, firm size, sectoral and time controls}).$$

The following subsection describes the data used and how the considered variables are operationalized. Subsequently, the estimation results are discussed.

4.1 Data and Empirical Considerations

The data used are taken from three different databases: the Mannheim Innovation Panel (MIP), a database of Creditreform and another one of the "Deutsches Patent- und Markenamt" (DPMA) which is the German patent office.

Most information is from the MIP which is an annual German innovation survey conducted since 1992 by the Centre for European Economic Research (ZEW) on behalf of the German Federal Ministry of Education and Research (BMBF). This study uses three waves on manufacturing firms from 1995, 1997 and 1999, i.e. the data refer to the years 1994, 1996 and 1998. These particular waves are selected because information on public innovation funding is available. Additionally to the MIP, data reflecting the availability of external financial resources, i.e. a credit rating index from the Creditreform database, is used. Creditreform is the largest German credit rating agency. Moreover, patent applications are extracted from the database of the DPMA. Comprehensive information on patenting activity in Germany is available since 1980. Firms included in the MIP are searched in the DPMA database by text–fields of name and location of the applicant. Different entities of all included firms back to 1992 are considered. For the time before 1992, there is no information on different entities available, which may yield a downward bias of counts in the years before 1992. In the case of SME, and especially Eastern German firms, this bias should be small, however, because the majority of those firms did not exist before 1992.

As the analysis focuses on small and medium–sized firms, i.e. the sample is restricted to firms with 500 employees at most. A sample of 1,306 observations on Western German firms and of 672 observations on Eastern German firms of the manufacturing sector can be used. Descriptive statistics of all variables used are presented in Table 3.

The recent empirical literature on financial constraints, typically uses a GMM estimator suggested by Arellano and Bond (1991) for dynamic panel data models and its extensions, e.g. Arellano and Bover (1995) or Blundell and Bond (1998). This is not possible in this study for two reasons: On one hand, the term 'innovation panel' is misleading. Most of the firms are only observed once (see Table 9 in the appendix B) and thus the available information is only cross–sectional. It is not possible to apply the kind of dynamic models used in the recent literature. On the other hand, these dynamic panel data models cannot be used for limited dependent variables, which is the case in this study. For these two reasons, only cross–sectional estimations of censored regression models with pooled data are carried out. However, the empirical specification is related as close as possible to the other studies. Lagged explanatory variables, if available, are considered to avoid endogeneity.

The dependent variable is the log of R&D expenditure at the firm level, $\ln(R\&D_{it})$.[6] The share of firms with positive R&D expenditure is about 50% in both regions.[7] R&D expenditures are deflated by a weighted price index of producer goods, wages and investment goods. The weights take into account the industry–specific R&D composition of material cost, staff cost and investment (Source: Wissenschaftsstatistik, 1999). For comparison, the gross investment into capital, $\ln(INV_t)$, is also considered. INV_t is deflated by the price index for investment goods.

The lagged amount of physical assets $\ln(A_{t-1})$ is used to control for size effects. The squared value, $(\ln(A_{t-1}))^2$, is included to allow for a possible non–(log)linear relationship. The lag is obtained by the perpetual inventory method $A_t = (1 - \delta_j)A_{t-1} + INV_t$. It follows that

$$A_{t-1} = (1 - \delta_j)^{-1}(A_t - INV_t).$$

A_t and INV_t is available in the sample and δ_j is the industry–specific rate of depreciation. This is calculated from the full sample of the MIP, where currently nine waves are available, and enough repeated observations of firms are included to calculate at least industry–specific depreciation rates. A_t is deflated by the price index for investment goods.

[6]For convenience, I drop the index i in the following. All variables are at the firm level.

[7]Note that the figures in Table 1 refer to firms which conduct own internal R&D projects but the R&D expenditure in this sample also includes research external to the firm (e.g. contracted out). Therefore the share of firms with positive R&D expenditure is larger in the sample used. Moreover, the statistics in Table 1 are population weighted while the description of the sample is not.

Table 3:
Descriptive statistics[a]

	Mean	Std. Dev.	Min.	Max.
		Western Germany		
Employees$_t$	142.342	128.075	2	500
$R\&D_t$	.256	.658	0	8.050
INV_t	.862	1.507	0	21.664
A_{t-1}	6.059	9.887	.008	111.074
PS_{t-1}	3.211	13.924	0	237.539
MP_{t-1}	.581	.494	0	1
CR_{t-1}	202.191	55.809	110	600
PCM_t	.276	.139	.002	.798
PF_t	.120	.325	0	1
		Eastern Germany		
Employees$_t$	92.152	92.475	2	460
$R\&D_t$	.155	.442	0	5.889
INV_t	.767	1.636	0	17.931
A_{t-1}	4.969	8.995	.009	91.848
PS_{t-1}	1.368	6.118	0	88.165
MP_{t-1}	.741	.438	0	1
CR_{t-1}	243.390	54.564	135	600
PCM_t	.258	.150	.002	.813
PF_t	.408	.492	0	1

[a] Observations: 1,306 in Western Germany and 672 in Eastern Germany.

As control variable for the size of knowledge capital, the R&D stock is usually constructed from a time series of R&D expenditures. However, this is not possible in this paper due to the cross–sectional structure of the innovation data. Therefore, the stock of patents (PS_t) is considered as knowledge stock (cf. OECD, 1994, for a comprehensive discussion on the use of patents as science and technology indicators). On one hand, the R&D stock is a more general measure of knowledge and it is known that patent counts underestimate the innovation potential of firms because not every research result is patented due to limitations in patentability of new knowledge and firms' preference for secrecy and lead time advantage as protection for intellectual property (see e.g. for the United States: Levin et al., 1987, Cohen et al., 2000; or for Germany: König and Licht, 1995). On the other hand, R&D may be a noisy measure of innovation potential because not every research activity must be successful and lead to usable results for the firm. If patents are considered as a measure for the knowledge stock, one issue should be clarified: One could choose either patent applications or patents granted. In Germany, the number of patent applications in 1999 (2001) are, for example, 61,283 (64,151) but the granted patents are only 15,008 (14,707) (Source: German Patent Office, 2000, 2001). Therefore, using only patent grants as a measure of knowledge stocks would cause a severe downward bias. Moreover, patent applications will be closer to the time of original knowledge production, but the time lag between patent applications and grants may be large. Therefore, I prefer to use the stock of patent applications instead of patents granted because it indicates a stock of useful research results, at least from the particular firm's point of view. Even if a number of filed patents are not granted, the technological knowledge behind them could be used for the development of innovative processes and products. The merging of the DPMA database with the MIP provides a series of the number of patent applications per year for the firms included in the sample since 1980. The stock of applications is calculated by the perpetual inventory method as

$$PS_t = (1 - \delta)PS_{t-1} + PA_t.$$

PA_t is the number of patent applications in period t and δ is the annual depreciation of knowledge capital which is set to 0.15 (see also Hall, 1990). As the patent series is available since 1980 and the sample under consideration begins in 1994, the starting value PS_{1980} is set to zero for all firms. The bias possibly emerging from this assumptions vanishes over the years due to depreciation and should be negligible in the 1990's.[8]. Of course, not every firm has filed a patent: 42% (26%) of Western (Eastern) German firms in the sample have a patent stock larger than zero. The average patent stock of firms with at least one application in the period under review is 7.6 (5.1) in Western (Eastern) Germany. The patent stocks in Eastern Germany are obviously smaller because most firms did not exist until the German re–unification in 1990. The patent stock enters the regressions as the lagged ratio to assets, $\ln(PS_{t-1}/A_{t-1})$, to avoid collinearity due to firm size. As this variable is in logs, the non–patenting firms would have missing values in logarithmic specification. Therefore, these missings are set to the minimum of non–missing values in the data. A dummy variable MP_{t-1} indicates if a firm is not patenting and captures the resulting bias of the transformation of the stock variable.

The financing hierarchy suggests that firms prefer to use internal financial resources first. The internal finance portion is cash flow (with constant marginal cost). When internal finance is exhausted, firms turn to debt finance which may be more costly when capital markets are imperfect. (See

[8]If a patent has been filed jointly by two or more applicants, the application is counted for both of them because the knowledge behind the patent should be available to each of the applicants.

Fazzari et al., 2000). There are several arguments why debt finance is subject to increasing marginal cost (see Carpenter and Petersen, 2002): First, the probability of financial distress rises with the degree of leverage. Second, moral hazard increases with leverage. Third, especially small firms whose assets are firm specific or intangible to a large fraction, e.g. in high–tech industries, face high costs for debt finance, because the value of knowledge capital as collateral is limited. Both resources, internal and external, are taken into account. However, it is not possible to calculate cash flow with the data available. The firms in the sample are SME and almost all are unquoted and are not obliged to publish account data. Such information as given in balance sheets is not surveyed in the MIP. However, as proxy for internal funds available, a kind of price–cost margin can be calculated as

$$PCM_t = \frac{\text{sales}_t - \text{staff cost}_t - \text{material cost}_t}{\text{sales}_t}.$$

This formula goes back to Ravenscraft (1983). Unfortunately, this variable cannot be lagged due to the cross–sectional structure of the innovation survey. In other studies, the R&D expenditures are sometimes added back to cash flow because R&D is an expense (see e.g. Harhoff, 1998). However, R&D is not completely an expense: according to the Wissenschaftsstatistik (1999), which is the largest German survey on R&D activities, about 62% of R&D expenditures in the manufacturing sector are wages, 31% are material costs and 7% are investment. Therefore, only the wages and the material costs are added back to PCM. The information of the Wissenschaftsstatistik is used on a two digit industry level, where the share of investment within R&D ranges from 1.5% to 27.2%. Sales are deflated by an industry–specific price index of producer goods, staff cost by the price index of wages in manufacturing and material cost by the price index of producer goods.

The measure reflecting external financing constraints is a lagged credit–rating index (CR_{t-1}). Firms which have bad credit ratings will clearly have higher costs for raising external capital than others. Moreover, such firms will need a collateral to obtain additional external funds, at all. If external financing contraints are present, the estimated coefficient should be significantly different from zero. The credit rating index ranges from 100 to 600 where 100 represents the best rating and 600 the worst. Thus, the expected sign is negative, i.e. the better the rating, the more able is a firm to acquire (cheap) external funds and the more R&D it will perform.

As already discussed, the most important variable for the comparison of Eastern and Western Germany is the receipt of public subsidies for R&D. A dummy variable indicates whether a firm has received public funding (PF_t). Public innovation programs offer a reduction of possible financial constraints, and are expected to enlarge the innovative activities in the economy.

4.2 Estimation Results

OLS regressions are carried out for the firms with positive R&D expenditure (column I in the regression tables). As non–R&D–performing firms are also taken into account in this study, the application of censored regression models is necessary. Therefore, Tobit models are estimated (col. II in following tables; see the appendix A for a description of the estimated models). First, the assumption of homoscedasticity is maintained. As heteroscedasticity in the Tobit model implies not only biased standard errors but also inconsistent estimates of the coefficients, tests of heteroscedasticity are essential. Lagrange multiplier tests on (group–wise) multiplicative heteroscedasticity are performed with industry dummies, size dummies and time dummies (see Greene 2000, p. 913–914). As the assumption of homoscedasticity is rejected in all regressions, heteroscedastic models are estimated, where the variance is modeled as function of the 13 industry dummies, five size dummies and two time dummies (col. III in the regression tables). As the coefficients of the Tobit model do not allow for a direct interpretation, marginal effects of the explanatory variables on the observed dependent variable (col. IV) are computed at the sample means on basis of the heteroscedastic Tobit model (see appendix A.1 for the formula).

Table 4 displays the estimation results on R&D expenditures of Western German SME. Firm size has the expected positive effect on R&D expenditures. The marginal effect (col. IV) shows that the effect of size is larger when all firms are considered rather than only R&D–performing firms (col. I). This is also supported by the measure of knowledge capital: firms with a larger ratio of patent applications to physical assets are spending more on R&D activities.

Table 4:
Western Germany: Estimation of R&D equation[a]

	Dependent variable: $\ln(R\&D_t)$			
	I OLS[b]	II Homoscedastic Tobit	III Heteroscedastic Tobit [c]	IV Marginal Effects[d]
$\ln(A_{t-1})$	.651***	1.827***	1.708***	1.017
	(.053)	(.207)	(.191)	
$(\ln(A_{t-1}))^2$	-.003	-.103*	-.076	-.045
	(.017)	(.056)	(.054)	
$\ln(PS_{t-1}/A_{t-1})$	.237***	.849***	.752***	.448
	(.042)	(.163)	(.146)	
MP_{t-1}	.442**	-.314	-.723	-.431
	(.197)	(.709)	(.667)	
$\ln(PCM_t)$	.254***	1.385***	1.270***	.756
	(.088)	(.285)	(.274)	
$\ln(CR_{t-1})$	-.394*	-1.723**	-1.973**	-1.175
	(.215)	(.800)	(.775)	
PF_t	.382***	4.592***	3.948***	2.351
	(.122)	(.512)	(.473)	
Constant term	-.505	.548	-.788	
	(1.215)	(4.393)	(4.624)	
log–likelihood	—	-2,525.36	-2,497.05	
R^2	0.4279	—	—	
nobs	672	1,306	1,306	

[a] Standard errors in parentheses; ***(**;*) report a 1% (5; 10%) level of significance; all estimations include 13 industry dummies and 2 time dummies.
[b] Only R&D performing firms. Standard errors are heteroscedastic–consistent.
[c] Heteroscedasticity term includes industry dummies, time dummies and size dummies.
[d] Marginal effects are based on the heteroscedastic Tobit model and are calculated at the sample means of the explanatory variables.

The internal resources measured by PCM are highly significant and firms are sensitive to external funding constraints: firms with a bad credit rating do less R&D, which leads to the conclusion that external capital is an additional source for innovation activities in Western German SME. Moreover, public funding is significantly positive at the 1% level in all regressions. The difference between the subsample of R&D–performing firms (col. I) and the full sample (col. IV) show that generally the effects are underestimated when the R&D status is not taken into account.

The estimation for R&D expenditures in Eastern Germany shows interesting differences. While Western German firms seem to be constrained by both internal and external financing resources, no impact of the credit rating can be identified for the Eastern ones. Moreover, the impact of PCM is smaller in Eastern Germany. Besides firm size, only the public funding dummy is significantly different from zero. The estimated coefficient and the marginal effect at the sample mean is roughly twice as high in Western Germany. The Eastern German firms seem not to be financially constrained by external resources, because the public policy schemes repeal the mechanisms of financial markets. On one hand, this result is positive because the public R&D programs seem to foster innovation. Firms which would possibly not be able to conduct innovation activities due to the lack of internal and external financial opportunities are enabled to create their own technological knowledge stock and may reach a critical mass of absorptive capacity for future research projects. On the other hand, it is questionable if it should be the government's aim to wipe out market solutions. Perhaps a lot of R&D performed in Eastern Germany does not lead to successful products or processes.

Table 5:
Eastern Germany: Estimation of R&D equation[a]

	Dependent variable: $\ln(R\&D_t)$			
	I OLS[b]	II Homoscedastic Tobit	III Heteroscedastic Tobit [c]	IV Marginal Effects[d]
$\ln(A_{t-1})$	.717***	.735**	.843***	.512
	(.130)	(.324)	(.276)	
$(\ln(A_{t-1}))^2$	-.017	-.087	-.073	-.044
	(.031)	(.071)	(.070)	
$\ln(PS_{t-1}/A_{t-1})$	.190*	-.200	-.052	-.032
	(.112)	(.280)	(.236)	
MP_{t-1}	.266	-1.856	-1.080	-.656
	(.419)	(1.174)	(.993)	
$\ln(PCM_t)$	-.184*	.288	.447**	.272
	(.101)	(.253)	(.226)	
$\ln(CR_{t-1})$	.253	-.008	-.014	-.008
	(.328)	(1.060)	(.859)	
PF_t	.524***	8.067***	8.174***	4.968
	(.196)	(.445)	(.416)	
Constant term	-5.656***	-10.657*	-11.290**	
	(1.876)	(5.929)	(4.853)	
log–likelihood	—	-1,135.69	-1,106.63	
R^2	0.3640	—	—	
nobs	336	672	672	

[a] Standard errors in parentheses; ***(**;*) report a 1% (5; 10%) level of significance; all estimations include 13 industry dummies and 2 time dummies.
[b] Only R&D performing firms. Standard errors are heteroscedastic–consistent.
[c] Heteroscedasticity term includes industry dummies, time dummies and size dummies.
[d] Marginal effects are based on the heteroscedastic Tobit model and are evaluated at the sample means of the explanatory variables.

The results of the regressions are fairly stable over subsamples. Tables 6 and 7 present results of analogous estimations for firms with less than 200 employees. The effects of financial factors remain significantly different from zero and the marginal effects are similar, when smaller firms in Western Germany are considered (Table 6). The public funding is also important for the smaller firms which is in line with the hypothesis that public policy schemes are an important stimulus for the R&D status of small firms. Participating in a public policy scheme may serve as some kind of certification: In case of this 'governmental approval' of the research carried out in the firm, the gap due to asymmetric information between the external investors and the firm is perhaps reduced and additional external financing resources become available.

Table 6:
Western Germany: Estimation of R&D equation[a]
— Firms with less than 200 employees —

	Dependent variable: $\ln(R\&D_t)$			
	I OLS[b]	II Homoscedastic Tobit	III Heteroscedastic Tobit [c]	IV Marginal Effects[d]
$\ln(A_{t-1})$	.477***	1.261***	1.110***	.515
	(.066)	(.311)	(.295)	
$(\ln(A_{t-1}))^2$	.024	-.250***	-.240***	-.111
	(.024)	(.087)	(.084)	
$\ln(PS_{t-1}/A_{t-1})$	.127**	.556**	.526**	.244
	(.061)	(.265)	(.253)	
MP_{t-1}	.072	-1.442	-1.427	-.662
	(.230)	(1.010)	(1.103)	
$\ln(PCM_t)$	.266**	1.478***	1.556***	.722
	(.117)	(.391)	(.386)	
$\ln(CR_{t-1})$	-.383	-2.499**	-3.155***	-1.464
	(.313)	(1.165)	(1.177)	
PF_t	.290*	5.586***	5.013***	2.327
	(.174)	(.720)	(.687)	
Constant term	-1.411	3.900	-4.677	
	(1.802)	(6.355)	(7.080)	
log–likelihood	—	-1,582.76	-1,566.71	
R^2	0.3688	—	—	
nobs	400	913	913	

[a] Standard errors in parentheses; ***(**;*) report a 1% (5; 10%) level of significance; all estimations include 13 industry dummies and 2 time dummies.
[b] Only R&D performing firms. Standard errors are heteroscedastic–consistent.
[c] Heteroscedasticity term includes industry dummies, time dummies and size dummies.
[d] Marginal effects are based on the heteroscedastic Tobit model and are evaluated at the sample means of the explanatory variables.

In Eastern Germany, the results are also similar between the full sample and the sample of small firms. The public funding dummy and PCM are significantly different from zero while CR is not. This points to the hypothesis that possibly too much public funding is offered in Eastern Germany, because no financial constraints for R&D due to the lack of external resources can be found.

Table 7:
Eastern Germany: Estimation of R&D equation[a]
— Firms with less than 200 employees —

	Dependent variable: $\ln(R\&D_t)$			
	I OLS[b]	II Homoscedastic Tobit	III Heteroscedastic Tobit [c]	IV Marginal Effects [d]
$\ln(A_{t-1})$	.472***	.290	.572*	.313
	(.156)	(.369)	(.315)	
$(\ln(A_{t-1}))^2$	-.004	-.045	-.011	-.006
	(.035)	(.091)	(.089)	
$\ln(PS_{t-1}/A_{t-1})$	-.001	-.541	-.184	-.101
	(.142)	(.327)	(.283)	
MP_{t-1}	-.398	-3.106	-1.618	-.884
	(.499)	(1.335)	(1.125)	
$\ln(PCM_t)$	-.011	.626**	.730***	.399
	(.097)	(.287)	(.255)	
$\ln(CR_{t-1})$	-.021	.282	-.063	-.034
	(.362)	(1.185)	(.913)	
PF_t	.521**	8.186***	8.430***	4.605
	(.221)	(.499)	(.453)	
Constant term	-3.867*	-11.521*	-10.777***	
	(2.069)	(6.610)	(5.175)	
log–likelihood	—	-922.76	-896.466	
R^2	0.3374	—	—	
nobs	269	582	582	

[a] Standard errors in parentheses; ***(**;*) report a 1% (5; 10%) level of significance; all estimations include 13 industry dummies and 2 time dummies.
[b] Only R&D performing firms. Standard errors are heteroscedastic–consistent.
[c] Heteroscedasticity term includes industry dummies, time dummies and size dummies.
[d] Marginal effects are based on the heteroscedastic Tobit model and are evaluated at the sample means of the explanatory variables.

In Table 8 the results of estimations on the determinants of investment are displayed. These regressions are analogous to the R&D equation, but the measures of innovation are not meaningful (knowledge stock and the dummy on public R&D funding) and therefore left out. In Western Germany, the results are similar to the R&D equation. Firm size has a strong positive effect. Moreover, investment is sensitive to resources of internal and external funding. Those firms with low cash flow or a bad credit rating invest less than others. In Eastern Germany, the regressions are not very informative. Besides size, only the credit rating is weakly significant in the regression. One reason may be the absence of a dummy variable which captures public subsidies for investment in physical assets. Subsidies of such kind are also present in Germany, but are not as extensive as R&D subsidies (in relation to overall investment and R&D expenditure).

Table 8:
Estimation of investment equations[a]

	Dependent variable: $\ln(INV_t)$			
	I	II	III	IV
	OLS[b]	Homoscedastic Tobit	Heteroscedastic Tobit [c]	Marginal Effects [d]
	Western Germany			
$\ln(A_{t-1})$	.711***	.952***	.889***	.889
	(.022)	(.041)	(.053)	
$(\ln(A_{t-1}))^2$	.004	-.026	-.066***	-.066
	(.009)	(.017)	(.017)	
$\ln(PCM_t)$	.065	.194**	.151***	.151
	(.047)	(.087)	(.067)	
$\ln(CR_{t-1})$	-.703***	-1.041***	-.600***	-.600
	(.154)	(.268)	(.192)	
Constant term	2.000**	3.502**	1.909*	
	(.837)	(1.461)	(1.053)	
log–likelihood	—	-2,791.54	-2,532.61	
R^2	0.5224	—	—	
nobs	1,245	1,306	1,306	
	Eastern Germany			
$\ln(A_{t-1})$	.739***	.882***	.795***	.795
	(.035)	(.053)	(.057)	
$(\ln(A_{t-1}))^2$	.016	-.002	-.015	-.015
	(.014)	(.023)	(.021)	
$\ln(PCM_t)$	-.026	.017	-.002	-.002
	(.074)	(.097)	(.080)	
$\ln(CR_{t-1})$	-.716**	-.930**	-.707*	-.707
	(.325)	(.418)	(.369)	
Constant term	2.324	3.281	2.457	
	(1.779)	(2.314)	(2.042)	
log–likelihood	—	-1,391.76	-1,284.81	
R^2	0.4501	—	—	
nobs	652	672	672	

[a] Standard errors in parentheses; ***(**;*) report a 1% (5; 10%) level of significance; all estimations include 13 industry dummies and 2 time dummies.
[b] Only firms with positive investment. Standard errors are White–heteroscedastic consistent.
[c] Heteroscedasticity term includes industry dummies, time dummies and size dummies.
[d] Marginal effects are based on the heteroscedastic Tobit model and are evaluated at the sample means of the explanatory variables.

In appendix A.2, I present additional estimates of a simultaneous estimation of the R&D and investment equation. A possible correlation of disturbances among equations is exploited to gain efficiency. Although a significant correlation of error terms is found, the results of the separate equations are confirmed and the additional regressions are relegated to the appendix therefore.

5 Conclusion

This paper presents an empirical investigation of possible financing constraints in SME in Germany. Both R&D expenditure and investment in physical assets were considered. It turns out that Western Germany firms are sensitive to both internal and external funding constraints. Another important factor in explaining different levels of R&D expenditures are public R&D subsidies. Publicly funded firms exhibit higher R&D expenditures than other firms. In Eastern Germany, no external financial constraints for R&D are present. The estimation results show that public funding is the driving force for R&D in Eastern Germany. The financial markets mechanisms are repealed by public R&D subsidies and do not have a significant impact on the R&D activities of Eastern German firms. The results are fairly stable over subsamples: The estimation of the R&D equation for firms with less than 200 employees confirm the previous conclusions. The results on investment are similar to R&D in Western Germany. The firms are sensitive to internal and external financing constraints. In Eastern Germany, the results are not very informative but the coefficient of lacking external resources differs significantly from zero.

It is important to note that the inclusion of a measure of public subsidies is essential if firms' R&D expenditures are analyzed in Germany. However, the estimated coefficient is possibly too large due to problems of sample selection: Firms with a higher propensity for innovation will select themselves into the public programs. As the evaluation of the impacts was not the central topic of this paper, the selection problem is not taken into account here. The problem, "how much the subsidized firms would have spent on R&D if they had not received public funding" is a classical evaluation question. This has already been addressed by Czarnitzki (2001) and Almus and Czarnitzki (2002) for Eastern Germany. Both studies find that the public funding does not crowd–out the private investment in R&D. Subsidies are positive stimulus for innovation activities in Eastern Germany. However, one may question whether the high level of public R&D funding leads to a corresponding innovation success in terms of market shares and sales of new products in many of these publicly funded firms.

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Appendix A.1: The Tobit model

Let c be the censoring point (from below in this case), y_i^* the dependent variable of a latent model and y_i the observed values. The formulation of the regression model is

$$y_i^* = \beta'\mathbf{x_i} + \varepsilon_i, \qquad i = 1, \ldots, N \tag{1}$$

where

$$y_i = \begin{cases} y_i^* & \text{if} \quad y_i^* > c, \\ c & \text{if} \quad y_i^* \leq c, \end{cases} \tag{2}$$

and $y^* \sim N[\mu, \sigma^2]$. β is the vector of parameters to be estimated, x_i is the set of regressors and ε_i denotes the error term. The log likelihood for this censored regression model is

$$\begin{aligned} \ln L \quad = \quad & \sum_{y_i > c} -\frac{1}{2}\left[\ln(2\pi) + \ln\sigma^2 + \frac{(y_i - \beta'\mathbf{x_i})^2}{\sigma^2}\right] \\ & + \sum_{y_i \leq c} \ln\left[\Phi\left(\frac{c - \beta'\mathbf{x_i}}{\sigma}\right)\right], \end{aligned} \tag{3}$$

where Φ denotes the cumulative density function of the standard normal distribution. If heteroscedasticity is present, the variance is modeled as

$$\sigma_i^2 = \sigma^2 \exp(\alpha'\mathbf{w_i}), \tag{4}$$

where α denotes the vector of parameters and $\mathbf{w}_i$ is the set of explanatory variables causing heteroscedasticity. In the heteroscedastic model, σ in the log likelihood function above is simply replaced by σ_i.

Note that using logs of y_i in estimations would cause missing values for the censored observations if $c \leq 0$ which is true in the case considered here. Therefore, the censored observations are set to the minimum (observed) value of $\ln y_i^*$. The same rule applies to c, of course. The only problem arising from the transformation is that the estimate of the constant term in $\mathbf{x_i}$ is biased.

Marginal effects are calculated at the sample means of the explanatory variables as (see e.g. Greene 2000, p. 909)

$$\frac{\partial E(\bar{y}_i|\bar{\mathbf{x}}_\mathbf{i})}{\partial \bar{\mathbf{x}}_\mathbf{i}} = \hat{\beta}\text{Prob}(\bar{y}_i^* > c) = \hat{\beta}\left[1 - \Phi\left(\frac{c - \bar{\mathbf{x}}_\mathbf{i}\hat{\beta}}{\hat{\sigma}}\right)\right]. \tag{5}$$

Appendix A.2: Simultaneous estimation of two Tobit equations

Additionally to the estimations presented in section 4, a simultaneous estimation of R&D and investment has been carried out. In this case, a possible correlation among disturbances can be exploited to gain efficiency. Let y_{i1}^* and y_{i2}^* be the two dependent variables of the latent model. c_1, c_2 are the corresponding censoring limits (from below) and y_{i1}, y_{i2} are the observed values. The econometric model is (Gourieroux, 2000, chapter 9, has a good overview on systems of simultaneous equations with limited dependent variables, or see Maddala, 1983, chapter 7):

$$\begin{aligned} y_{1i}^* &= \beta_{\mathbf{1}}'\mathbf{x_{1i}} + \varepsilon_{1i}, \qquad i = 1, \ldots, N \\ y_{2i}^* &= \beta_{\mathbf{2}}'\mathbf{x_{2i}} + \varepsilon_{2i}, \qquad i = 1, \ldots, N \end{aligned} \tag{6}$$

where

$$y_{1i} = \begin{cases} y_{1i}^* & \text{if} \quad y_{1i}^* > c_1, \\ c_1 & \text{if} \quad y_{1i}^* \leq c_1, \end{cases} \qquad y_{2i} = \begin{cases} y_{2i}^* & \text{if} \quad y_{2i}^* > c_2, \\ c_2 & \text{if} \quad y_{2i}^* \leq c_2. \end{cases} \tag{7}$$

Assuming that the dependent variables are jointly normally distributed, $(y_1^*, y_2^*) \sim N_2[\mu_1, \sigma_1^2, \mu_2, \sigma_2^2, \rho]$, leads to the likelihood function L which is composed of four parts defined by the different parameter regimes. Let

$$\eta_k = \frac{y_{ki} - \beta_{\mathbf{k}}'\mathbf{x_{ki}}}{\sigma_k}, \quad \text{with} \quad k = 1, 2,$$

and L_1 be the first regime where both dependent variables are non–censored ($L_1 : y_k = y_k^*,\ k = 1, 2$). In this case, the likelihood is just the density of the bivariate normal distribution:

$$L_1 = \prod_{\substack{y_1 = y_1^* \\ y_2 = y_2^*}} \left(2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}\right)^{-1} \exp\left[-0.5\frac{(\eta_1^2 + \eta_2^2 - 2\rho\eta_1\eta_2)}{1-\rho^2}\right] \tag{8}$$

In the case where one variable is censored ($y_2 = c_2$) while the other is not ($y_1 = y_1^*$), the contribution to the likelihood function is (see Gourieroux 2000, p. 227)

$$L_2 = \prod_{\substack{y_1 = y_1^* \\ y_2 = c_2}} \sigma_1^{-1}\phi(\eta_1)\,\Phi\left(\frac{c_2 - \beta_{\mathbf{2}}'\mathbf{x_{2i}} + \rho\frac{\sigma_2}{\sigma_1}(y_{1i} - \beta_{\mathbf{1}}'\mathbf{x_{1i}})}{\sigma_2\sqrt{1-\rho^2}}\right), \tag{9}$$

where ϕ denotes the density function of the standard normal distribution. L_3 is the corresponding case of $y_1 = c_1$ and $y_2 = y_2^*$.

In the fourth regime both variables are censored ($y_1 = c_1$ and $y_2 = c_2$):

$$L_4 = \prod_{\substack{y_1 = c_1 \\ y_2 = c_2}} \Phi_2 \left(\frac{c_1 - \beta_1' \mathbf{x_{1i}}}{\sigma_1}; \frac{c_2 - \beta_2' \mathbf{x_{2i}}}{\sigma_2}; \rho \right), \tag{10}$$

where Φ_2 is the cumulative density function of the bivariate standard normal. Consequently, the likelihood function to be maximized is

$$L = \prod_{\substack{y_1 = y_1^* \\ y_2 = y_2^*}} L_1 \prod_{\substack{y_1 = y_1^* \\ y_2 = c_2}} L_2 \prod_{\substack{y_1 = c_1 \\ y_2 = y_2^*}} L_3 \prod_{\substack{y_1 = c_1 \\ y_2 = c_2}} L_4 \tag{11}$$

The estimation of this model is difficult in the case considered here, because there are only few observations of y_2 (the investment) which are censored. Hence the optimization does not converge well. To estimate both equations simultaneously, I have reduced the maximization problem: y_2 is treated as a continuous variable without censoring. This should not harm the results in this case, but makes the simultaneous estimation of both equations possible. The likelihood function then reduces to

$$L = \prod_{\substack{y_1 = y_1^* \\ y_2 = y_2^*}} L_1 \prod_{\substack{y_1 = c_1 \\ y_2 = y_2^*}} L_3 \tag{12}$$

Instead of estimating ρ directly, a parameter λ is estimated to ensure that the correlation is restricted to the interval $(-1; 1)$: $\rho = (2/\pi) \arctan(\lambda)$. The estimation confirms the results of the single equation models presented in the text.

Table 9:
Simultaneous Estimation of R&D and investment equations[a]

	Western Germany		**Eastern Germany**	
	Dependent variable:			
	$\ln(R\&D_t)$	$\ln(INV_t)$	$\ln(R\&D_t)$	$\ln(INV_t)$
$\ln(A_{t-1})$	1.776***	.916***	.797**	.858***
	(.202)	(.038)	(.316)	(.050)
$(\ln(A_{t-1}))^2$	-.088	-.008	-.077	.001
	(.055)	(.016)	(.070)	(.021)
$\ln(PS_{t-1}/A_{t-1})$	.691***	—	-.179	—
	(.162)		(.276)	
MP_{t-1}	-.731	—	-1.706	—
	(.684)		(1.157)	
$\ln(PCM_t)$	1.393***	.195**	.372	.026
	(.281)	(.085)	(.252)	(.092)
$\ln(CR_{t-1})$	-2.040***	-1.007***	-.356	-.862**
	(.775)	(.251)	(1.05)	(.389)
PF_t	4.116***	—	7.917***	—
	(.520)		(.444)	
Constant term	1.901	2.733**	-8.796	2.596
	(4.253)	(1.378)	(5.860)	(2.162)
λ $[\rho]$[b]	.605*** [.346]		.424*** [.255]	
	(.160)		(.122)	
log–likelihood	-5,274.34		-2,505.49	
nobs	1,306		672	

[a] Standard errors in parentheses; ***(**;*) report a 1% (5; 10%) level of significance; Both equations include 13 industry dummies and 2 time dummies.
[b] $\rho = (2/\pi)\arctan(\lambda)$. This transformation is made to ensure that the determinant of the covariance matrix is positive, i.e. $0 < \rho < 1$.

Appendix B: Panel structure

Most firms in the sample are only observed once: this concerns 77% of firms in Western Germany and 69% in Eastern Germany. Therefore the data are pooled and only cross–sectional estimators are applied in this study.

Table 10:
Panel structure

Western Germany					
Observed pattern					
1994	1996	1998	Frequency	Percent	Cumulative
	X		310	30.2	30.2
X			294	28.7	58.9
		X	185	18.1	77.0
	X	X	104	10.2	87.1
X	X		60	5.9	93.0
X	X	X	45	4.4	97.4
X		X	27	2.6	100.0
			1025	100.0	

Eastern Germany					
Observed pattern					
1994	1996	1998	Frequency	Percent	Cumulative
X			145	29.4	29.4
	X		103	20.9	50.2
		X	93	18.8	69.0
	X	X	56	11.3	80.4
X	X		52	10.5	90.1
X	X	X	25	5.1	96.0
X		X	20	4.1	100.0
			494	100.0	