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Collaborative R&D as a Strategy to Attenuate Financing Constraints

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Non-technical summary

Underinvestment in research and development (R&D) due to financing constraints may result in a slowdown in productivity growth and consequently have particularly detrimental effects on technological progress, economic development and competitiveness. The question how firms encounter and deal with such constraints is a crucial one in economic analysis that has, however, received little attention so far.

Firms may develop strategies to attenuate the constraint for instance by creating signals to lenders and investors, finding ways to reduce resource requirements and to exploit economies of scale and scope in R&D. We argue in this article that collaborative R&D may not only increase incentives for investing in R&D by alleviating market failures stemming from incomplete appropriability of returns to R&D investment, but it may also be beneficial with respect to market failures associated with the financing of R&D.

R&D collaboration serves as such a quality signal to investors if the partner firm or institution possesses properties that increase the confidence with respect to successful projects outcomes. Being selected as desired collaboration partner is a quality signal in the sense that it is awarded by the partner. The partner is likely to be less prone to information asymmetries as he is engaged in related or complementary activities that allow a much more accurate assessment of the R&D project's value than one made by a financial institution, for instance. In addition to the signaling effect, collaboration may simply reduce the riskiness of the R&D endeavor by the realization of scope economies that also reduce the amount of funds that needs to be raised. Firms may for instance have an incentive to source (complementary) knowledge from collaboration partners, to reduce the resources needed to build-up that knowledge on their own. Since R&D often exhibits economies of scale it might well be that only a consortium of firms has the necessary resources both financially and physically to undertake the larger, more complex, and more expensive research projects and synergetic effects and risk pooling can broaden the research horizon of collaborating firms. Strategic R&D collaboration may thus be especially useful in the early stages of an R&D project, in particular in the research phase, when uncertainty and information asymmetries are high.

Using firm-level panel data from the region of Flanders in Belgium and distinguishing between R&D and pure research projects, we find that collaborative research alleviates liquidity constraints. While we do not find such an effect of science-collaboration for R *and* D investment, looking at pure research investments shows that collaboration with science does indeed reduce the sensitivity of such research investment to internal funds. Moreover, we observe alleviating effects from horizontal collaboration for both for R *and* D as well as pure research investments. Vertical collaboration with customers or suppliers on the contrary has no such alleviating effects.

Das Wichtigste in Kürze

Finanzierungrestriktionen stellen eine wesentliche Einschränkung für Investitionen in Forschung und Entwicklung (FuE) dar und können folglich zu Verzögerung des technologischen Fortschritts und der ökonomischen Wettbewerbsfähigkeit führen. Die Frage wie Unternehmen Finanzierunsrestriktionen zu mindern und zu umgehen versuchen, ist daher von entscheidender Bedeutung. Dennoch hat dieser Aspekt in der empirischen Forschung bisher nur wenig Beachtung gefunden.

Betroffene Unternehmen können Strategien entwickeln, um Finanzierunsrestriktionen für ihre FuE Aktivitäten entgegen zu wirken. Beispiele dafür sind die Aussendung von Qualitätssignalen an Banken und Investoren, die Schaffung von Wegen zur Reduzierung der erforderlichen Ressourcen, sowie die Ausschöpfung von Möglichkeiten zur Realisierung von Skalenerträgen. Mit Hilfe gemeinschaftlicher FuE können Unternehmen diese Ziele erreichen.

Mit dieser Studie leisten wir daher einen Beitrag zum Verständnis der Rolle von FuE-Zusammenarbeit zur Verminderung von Finanzierungsrestriktionen. Wir untersuchen dabei, ob FuE-Kooperationen nicht nur durch die Internalisierung von positiven Externalitäten von FuE Anreize für Investitionen in die Schaffung von Wissen verstärken, sondern auch durch eine positive Signalwirkung und eine Begrenzung des mit den FuE-Projekten verbundenem Risikos die Auswirkungen von Finanzierungsrestriktionen mindert. FuE-Zusammenarbeit stellt ein Qualitätssignal dar, wenn der Kooperationspartner Eigenschaften besitzt, die das Vertrauen in den Erfolg der gemeinsamen Projekte steigert. Zur Zusammenarbeit ausgewählt worden zu sein, stellt somit ein Signal dar, das vom FuE-Partner verliehen wird. Dieser verfügt potentiell über bessere Fachkenntnisse und kann daher die Erfolgsaussichten und das Risiko genauer einschätzen als Banken oder externe Investoren. Strategische FuE-Kooperation ist daher möglicherweise gerade in den frühen Stadien von FuE-Projekten von besonderer Bedeutung wenn Informationasymmetrien und Unsicherheit sehr groß sind.

Die Ergebnisse auf Basis von Paneldaten aus dem flämischen Teil der OECD FuE-Erhebung zeigen, dass gemeinschaftliche Forschung in der Tat Finanzierungsrestriktionen mindert. Während wir für gemeinsame F *und* E mit wissenschaftlichen Einrichtungen keinen derartigen Effekt finden, zeigt sich eine deutlich reduzierte Abhängigkeit der Forschungsausgaben von intern verfügbaren Mitteln für reine Forschungsprojekte. Im Gegensatz dazu, wirkt sich horizontale Zusammenarbeit, sowohl auf Forschung als auch auf FuE im Allgemeinen, positiv aus. Vertikale Zusammenarbeit bei FuE, auf der anderen Seite, hat keinen derartigen Effekt.

Collaborative R&D as a Strategy to Attenuate Financing Constraints*

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Abstract

The ability of firms to establish R&D collaborations that combine resources, exploit complementary know-how, and internalize R&D externalities has been shown to be of high importance for the successful creation and implementation of new knowledge. We argue in this article that collaborative R&D may not only be beneficial in terms of appropriability of returns to R&D investment, access to the partner's knowledge base and the exploitation of scale and scope in R&D, but that it may also be a strategy to cope with financing constraints for R&D. Studying panel data we show that collaboration with science alleviates liquidity constraints for research. Horizontal collaboration reduces liquidity constraints for both research as well as R and D. Vertical collaboration has no such effects.

Keywords: Collaborative Research, Industry-Science Links, Research and Development, Liquidity Constraints, Innovation Policy

JEL-Classification: O31, O32, O38

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1 Introduction

The role of research and development (R&D) for promoting economic growth has long been emphasized in economic research (see e.g. Solow, 1957 and Jones, 1995). At the firm level, R&D has been recognized as important input factor to industrial production and studies have shown that the impact of R&D on productivity is substantial (Griliches, 1986; Griliches and Mairesse, 1984; Hall and Mairesse, 1995; and Hall *et al*., 2010). The successful creation of new knowledge and hence firm performance, however, has also been shown to often depend on the firms' engagement in collaborative R&D that combines resources, exploits complementary know-how, and internalizes R&D externalities (Teece, 1992; Shan *et al*., 1994; Das *et al*., 1998; Baum *et al*., 2000; Rothaermel, 2001; Dussauge *et al.*, 2002; Hemphill and Vonortas, 2003; Rothaermel and Deeds, 2004; Powell and Grodal, 2005; Sampson, 2007).

Previous research pointed to the positive effects of collaboration on R&D through the internalization of knowledge spillovers (Katz, 1986; d'Aspremont and Jacquemin, 1988; Kamien *et al*., 1992; Cassiman and Veugelers, 2002), the acquisition of new technological capabilities (Kogut, 1988; Hamel, 1991; Mody, 1993; Mowery *et al*., 1996, and the positive incentives for internal R&D stemming from the building of absorptive capacities needed to fully benefit from the collaboration (Dyer and Singh, 1998; Kamien and Zang, 2000; Leahy and Neary, 2007).

We argue in this article that collaborative R&D may not only be beneficial in terms of improving the appropriability of returns to R&D, knowledge exchange and exploitation of scale and scope in R&D, but that R&D collaborations may also constitute a strategy to cope with financing constraints for R&D. While a considerable strand of literature stressed the problems related to financing R&D activities (see Hall and Lerner, 2010 for a review), the effect of research collaboration as an attenuation strategy has not been subject to much analysis in the literature so far. This article aims to fill this gap by studying the role of vertical and horizontal R&D collaborations as well as of collaborative research with universities and public research centers on financing constraints for R&D. Using firm-level panel data from the region of Flanders in Belgium, we argue that the motivation for firms to engage in collaborative R&D differs with types of partners and that the distinct cooperation modes differ with respect to their impacts on financing constraints for R&D.

Previous empirical research stressed the relevance of financing constraints particularly for industrial research, thus for the 'R' component of R&D (Kamien and Schwartz, 1978, Czarnitzki *et al*., 2011). Research differs from development activities not only in its nature since it is used as an informational input into subsequent inventive activities, but ‘R’ and ‘D’ projects also differ with respect to important factors like, originality, knowledge depth and market proximity (Karlsson *et al*., 2004). What is more, research units are often organizationally separated from development units within the same company (Mansfield *et al*., 1971; Karlsson *et al*., 2004). Finally, characteristics usually attributed to R&D in general such as the intangibility and uncertainty of its outcome are very likely to be more applicable for ‘R’ than for ‘D’.

Distinguishing between R&D and pure research projects and measuring financial constraints by the sensitivity of such expenditures to available internal funds, the results show that collaborative research with science alleviates liquidity constraints. While we do not find such an effect of science-collaboration for R *and* D investment, looking at pure research investments shows that collaboration with science does indeed reduce the sensitivity of such research investment to internal funds. Moreover, we observe alleviating effects from horizontal collaboration for both for R *and* D as well as pure research investments. Vertical collaboration with customers or suppliers on the contrary has no such alleviating effects.

This article proceeds as follows. Section 2 outlines the motivation for this research as well as the conceptual framework of our analysis. Section 3 describes the data. The econometric model specifications are described in section 4. Section 5 presents the results of the econometric analysis before we conclude in section 6.

2 Financing constraints and incentives for R&D collaboration

2.1 Financial constraints and the nature of R&D

Previous literature supported the conjecture that capital market imperfections, in particular information asymmetries, affect lending and investment decisions of firms (Leland and Pyle, 1977; Stiglitz and Weiss, 1981; Myers and Majluf, 1984). In the case of investments in R&D, information asymmetries may be particularly severe. Complexity, specificity and outcome uncertainty of such projects may make it extraordinarily difficult (not only) for outsiders to judge the expected return (Anton and Yao, 2002). The uncertainty is aggravated if firms are reluctant to reveal details of the projects to potential investors fearing that too much information could leak out to competitors (Bhattacharya and Ritter, 1983).

Besides information asymmetries, R&D has another distinct feature when compared to investment into physical assets. The primary output of R&D is new knowledge that is often tacit and naturally intangible. Thus R&D investment provides a very low inside collateral value which makes raising funds externally more costly for R&D projects than for other types of investments (Arrow, 1962; Berger and Udell, 1998; Harhoff, 1998). Thus, firms willing to pursue an ambitious R&D agenda may face serious difficulties to attract external investors or to obtain bank loans and may therefore pile up cash to finance their R&D. This leads to a trade-off between investing in current R&D projects and retaining cash for future ones (Levitas and McFadyen, 2009).

Besides the opportunity costs of holding cash, firms unable to save-up the required resources may have to constrain their research to currently available funds, postpone or abandon projects that they would otherwise have conducted if additional (external) financing was available. This reduces incentives to invest in research projects and may bring overall industrial R&D in the economy below socially optimal levels.

2.2 Incentives to collaborate

An important issue that has not been studied as extensive as the demonstration of the existence of financial constraints so far (see e.g. Hall and Lerner, 2010; Hottenrott and Peters, 2012 for recent surveys of the literature) is how firms counter such constraints on their R&D activities. Constrained firms may develop strategies to attenuate the resource limitation for instance by finding ways to reduce resource requirements through exploiting economies of scale and scope in R&D, but also by creating signals to lenders and investors. R&D collaboration and alliances that comprise many different constellations of bilateral or multilateral agreements among firms may serve such purposes.

Previous literature on R&D partnerships, mostly located in the management literature, identified a whole set of incentives for firms to participate in collaborative R&D (see Hagedoorn *et al*., 2000 for a review). First, collaboration may simply reduce the riskiness of the R&D endeavor by the realization of scope economies that broaden the effective scope of projects or reduce the amount of funds needed to finance a given set of projects. Collaborating firms may also be able to undertake more R&D projects at the same time and thereby increase the overall probability of success of their R&D efforts (Kotabe and Swan, 1995). Second, firms may have an incentive to source (complementary) knowledge from collaboration partners in order to reduce the resources needed to build-up that knowledge on their own. Moreover, a simple cost sharing argument has for instance been put forward by Harrigan (1988), Mowery (1988), and Link and Bauer (1989) and Hagedoorn (1993, 2002). Since R&D often exhibits economies of scale, it might well be that only a consortium of firms has the necessary resources both financially and physically to undertake the larger, more complex, and more expensive research projects (Pisano, 1991;

Hagedoorn and Schakenraad, 1990a,b). Jorde and Teece (1990) and Teece (1992) consequently argue that R&D collaboration is especially attractive when key know-how is widely dispersed among different organizations.

Access to external complementary physical assets, resources and capabilities may also facilitate better exploitation of the firms' own resource base achieving a competitive advantage. Additionally, joint R&D can broaden the research horizon of collaborating firms enabling them to obtain leading-edge positions in relevant technology areas that they would not be able to achieve without external competencies (Nelson, 1991). A number of studies have therefore pointed to the use of collaborative R&D to access tacit knowledge that allows firms to acquire particular technology-based capabilities from partner firms (Kogut, 1988; Hamel, 1991; Mowery *et al*., 1996, 1998).

Further, it is often hypothesized that research projects involving a high uncertainty of outcome are preferably conducted within research consortia as this allows pooling and spreading the risk. R&D alliances may therefore be a device that reduces uncertainty in the overall technological strategy of the firms involved (Porter and Fuller, 1986; Harrigan, 1988; Tether, 2002; Letterie *et al*., 2008).

Collaborative R&D has therefore been seen as a strategy not only to cope with but also benefit from radical technological change (Teece, 1992; Hill and Rothaermel, 2003). Strategic R&D collaboration may thus be especially useful in the early stages of an R&D project, in particular in the research phase, when uncertainty and information asymmetries are high.

So far hardly discussed in the literature is the idea that collaborative R&D provides a quality signal to outside parties like banks and investors if the partner firm or institution possesses properties that increase the confidence with respect to successful projects outcomes. As stressed by a considerable strand of literature including Gulati (1995), Eisenhardt and Schoonhoven (1996), Dyer and Singh (1998), Stuart (1998), Ahuja (2000) and Park *et al.* (2002), firms must possess resources that make them attractive targets for potential collaboration partners. Being selected as desired collaboration partner is consequently a quality signal in the sense that it is awarded by the partner. The partner is likely to be less prone to information asymmetries than other financiers as the partner organization is typically engaged in related or complementary activities that allow a much more accurate assessment of the R&D project's value. Li *et al.* (2008) show that the more radical a R&D alliance in terms of new technological knowledge, the more likely it is that partners are "friends" rather than strangers. This moreover suggests that considerations with regard to protecting the firms' own valuable resources are taken into account when selecting a partner which in turn increases appropriability of returns to R&D.

To sum up, being aware of the benefits from collaborative R&D in the before mentioned dimensions and given the strong signal from being involved in such collaborations, banks and investors may be more willing to provide funds for R&D performing firms. Collaborative R&D may therefore constitute a strategy that attenuates liquidity constraints for the firms' R&D efforts.

2.3 Collaboration and liquidity constraints

While the organizational forms of the collaborative R&D, partnerships and alliances as well as their benefits for productivity, innovation performance and firm growth, have been subject to extensive investigation in the economics as well as in the strategic management literature (see e.g. Hagedoorn and Narula, 1996; Hagedoorn *et al*., 2000; and Caloghirou *et al*., 2003 for surveys of this literature), rather little attention has been paid to the role of such activities in mitigating liquidity constraints.

There are two noteworthy exceptions. Lerner *et al*. (2003) find that small U.S.-based biotechnology firms appear to fund their R&D through alliances with larger firms when financial market conditions are disadvantageous. Instead of raising equity through the capital markets such firms negotiate R&D collaboration agreements that assign the 'bulk of the control' and hence, the financial burden, to the larger partner. Interestingly, they find that these agreements are often renegotiated once financial market conditions improve. Lerner *et al*.'s results suggest that small biotech firms deliberately use collaborative R&D to circumvent financial constraints. Again for a sample of young U.S.-based biotechnology firms Gulati and Higgins (2003) test whether being involved in a strategic alliance partnership affects the initial public offering (IPO) success of these firms. Unlike for partnerships with venture capital (VC) firms during "cold markets", they find however no such beneficial effects from alliances with major pharmaceutical and/or healthcare firms. In such cases being involved in collaborative research with very asymmetric partners may - instead of suggesting high quality - signal the prospect or threat of being taken over by a larger firm sooner or later. This supports the findings by Mitchell and Sign (1996) who provide evidence for circumstances under which businesses using collaborative relationships are sometimes susceptible to being acquired by other firms.

More recently, Levitas and McFadyen (2009) who also study biotechnology firms in the U.S., find that the nature of the collaboration matters. Certain alliance activities - in particular with the aim of "exploitation" - provide important signaling mechanisms and thus lower the firms' need to hold liquid assets to finance their R&D activities. Levitas and McFadyen argue that exploitation alliances attenuate financing constraints as they 'generally couple one firm's technology with the complementary assets (e.g. distribution, manufacturing) of a partner to incrementally extend the scope of an existing technology'. Thus, such alliances, unlike exploration alliances, have the objective to and are designed such that they yield marketable outcomes soon.

Implicitly referring to the role of R&D collaboration for the mitigation of financing constraints, Veugelers (1997) observes that new technology-based firms are more likely to engage in collaborative R&D with larger firms because of abundant internal R&D budgets of these partners. Also Park *et al*. (2002) who study strategic alliances of semiconductor start-ups do not only find that firms use strategic alliances as a mechanism to adapt to market uncertainties, but also that in relatively stable markets "resource-poor" firms are more likely form such alliances.

Findings by Tether (2002) who reports that R&D cooperation is mostly the domain of firms pursuing radical innovations rather than incremental innovations, are also in line with our reasoning. Recent research has shown that financing constraints for more radical R&D, involving more fundamental research, are more severe as compared to routine R&D and product development (Czarnitzki and Hottenrott 2011, Czarnitzki *et al*., 2011). If firms pursuing a radical R&D strategy are more likely to face binding financial constraints, these firms may have a strong incentive to alleviate the constraints on their R&D by engaging in collaborative R&D. The benefits from collaborating may outweigh the cost of setting-up such collaborations for these firms.

In this article, we present an empirical framework that adds to existing research in several dimensions. First, we distinguish between total R&D and 'research investments' as part of total R&D, as research as compared to development is more uncertain in terms of outcome and is more difficult to appropriate. Secondly, we differentiate between collaboration partners such as universities or other public research institutions and vertically or horizontally related firms. Thus, we argue in this article that the motivation for firms to engage in collaborative R&D differs between types of partners and that the diverse cooperation modes have different impacts on financing constraints for R&D.

2.4 Collaboration modes and their effects

Besides reporting a substantial increase in the establishment of research partnerships over time (Hagedoorn, 2002), previous research on R&D collaboration has also argued that different types of R&D cooperation serve different purposes (Belderbos *et al*., 2004a,b). Based on these arguments we hypothesize that different collaboration modes are likely to affect financing conditions differently. More precisely, we expect horizontal collaboration to provide a different signal compared to vertical partnerships. Collaborative R&D with universities and research centers may likewise only be useful for certain types of R&D projects or at stages of the R&D process that are closer to science than to the market.

By far most attention in the literature has been attributed to horizontal collaboration. The key aspect in the economics literature is the existence of knowledge spillovers between competing firms that, in the absence of cooperation, involuntarily occur as one firm invests in R&D and thereby increases the knowledge stock of the other firm. R&D collaboration between horizontally related firms allows internalizing these knowledge spillovers and reduces the disincentive effect for R&D investments. Thus, firms benefit from collaborating through internalization of technological spillovers which eliminates the free-rider problem within the group of collaborating firms. (e.g. Jorde and Teece, 1990; Kamien *et al*., 1992; Suzumura, 1992; Leahy and Neary, 1997; Amir *et al*., 2003).

The strategic management literature has additionally stressed that R&D collaboration increases voluntary knowledge transfers, facilitates organizational learning and increases efficiency (Kogut, 1988; Hamle, 1991; Mody, 1993; Mowery *et al*., 1996; Mayer and Teece, 2008). By capturing tacit knowledge from the partner, collaborating firms may have access to new technologies faster and more directly, opening up technological opportunities that benefit the overall innovation performance of these firms (see e.g. Das *et al*., 1998; Rothaermel, 2001; Gomes-Casseres *et al*., 2006). Moreover, in case of horizontally collaborating firms, beneficial effects from pooling complementary assets and skill may therefore be particularly high. Horizontal collaboration may also not only motivated by securing the relative market positions, but also by the prospect to share costs by pooling resources effectively (Harrigan, 1988; Mowery, 1988; Link and Bauer, 1989; Hagedoorn, 1993, 2002; Das and Teng, 2000), or by advantages stemming from the joint implementation of industry standards and from participation in government subsidy programs (Nakamura, 2003). Finally, horizontal R&D collaboration may create a source of competitive advantage vis-à-vis competing firms outside the consortium. All these attributes of horizontal R&D collaboration may add to the signaling value in addition to the mere selection as collaboration partner.

Vertical forms of technology partnerships have been of key interest in the early contributions to the literature on R&D collaboration which especially stressed the transaction cost argument (see e.g. Williamson, 1985; Teece, 1986). As pointed out by Hagedoorn (1993), joint R&D with suppliers generally aims at enhancing efficiency in the production process through cost-reducing process innovations or the improvement of the quality of inputs. Vertical collaboration with customers, on the other hand, is usually thought of as being a source of ideas and of reducing risk when introducing a new product to the market (von Hippel, 1988)[1]. While the former arguments suggest rather indirect effects on financing conditions for R&D via anticipated efficiency improvements by the bank or investor, the latter argument of reduced risk related product development suggests beneficial effects for financing development activities rather than alleviating constraints on research.

Collaborative research with universities or public research institutions has again distinct benefits. Technological innovation has become increasingly complex and multidisciplinary not last through the emergence of "science-based technologies" such as biotechnology. It is usually alleged that collaboration with science concerns rather basic research projects that generate or exchange original and new knowledge compared to 'business-only' R&D projects. Collaborative R&D with scientific institutions may thus provide important knowledge inputs and organizational advantages that reduce the risk for firms to engage in R&D that aims at expanding in new technology fields. This implies that firms may seek such collaboration for fundamental, long-term and therefore often strategic R&D projects (Tether, 2002; Monjon and Waelbroeck, 2003).

Hall *et al*. (2003) conduct a survey-based study of research projects having universities as research partners within the US ATP program. They argue that universities are involved in such projects that apply "new science", i.e., firms seek for expertise to absorb results of basic research. The role of the university may be a translation of basic science into applicable technology for selected problems. Veugelers and Cassiman (2005) using Belgian Community Innovation Survey (CIS) data show that firms that are impeded by high cost of innovation are often attracted by government subsidized cost-sharing within public-private partnerships. In addition, larger firms are more likely to collaborate with universities than smaller firms indicating that some minimum absorptive capacity is needed for fruitful collaboration. These results thus suggest that (basic)

[1] These arguments are in line with the work by Fritsch and Lukas (2001) who find that collaboration with suppliers is rather associated with process innovation while product innovation is usually the motivation for collaboration with customers. Thus, vertical collaboration seems to be designed such that it matches the firms' product and process innovation strategies. Belderbos *et al*. (2006) study performance effects of simultaneous engagement in R&D cooperation with different partners (competitors, clients, suppliers, and universities and research institutes) and find that customer cooperation helps to increase market acceptance and diffusion of product innovations but also enhances the impact of competitor and university cooperation.

research is particular difficult to finance and that it may benefit from collaborative research with science more than later stages of the innovation process, such as (less basic and less risky) development projects.

2.5 Empirical strategy

We build on previous studies on financing constraints for investment going back to the seminal work by Fazzari *et al*. (1988). Their methodology suggests detecting financial constraints by analyzing the firms' investment sensitivities to available financial resources, usually measured by cash flow. Excess sensitivities are interpreted as indirectly reflecting the firms' lack of access to the credit market. In order to observe more than an average effect, samples are usually split into potentially constrained and unconstrained firms or the focus is directed at a particular group of firms a priori. This empirical testing strategy has subsequently been applied to investment in R&D (see e.g. Bond and Van Reenen, 2007 for a survey of the literature.)

In line with this approach, we expect a positive relationship between firms' liquidity and the firms' expenditures on R&D if firms face binding financial constraints in the credit market. More precisely, we expect the sensitivity of R&D to internal liquidity to also depend on collaboration. If collaborating firms show lower sensitivities on average, we interpret this as an 'alleviation effect' that reduces the firms' dependency on internal funds for their R&D. Instead of estimating separate equations for collaborating and non-collaborating firms, we estimate different slope coefficients for each group.

The 'alleviation effect' may work through distinct mechanisms depending on the type of R&D the firms is conducting, i.e. more (basic) 'R'esearch vs. rather applied 'D'evelopment, as well as on the type of collaboration partner. We address these issues in a framework that allows us to analyze these differences in detail. While we expect collaborative R&D between firms to reduce financial constraints for R&D in general, we hypothesize that collaboration with universities may have higher beneficial effects especially for research projects as compared to more applied development projects.

3 Data and econometric framework

3.1 Data

The data for the following analysis stems from the Flemish part of the EUROSTAT/OECD R&D survey. The survey is harmonized across OECD countries and is conducted every second year in order to derive the corporate R&D statistics for the OECD's Main Science and Technology

Indicators. The survey is particularly directed at R&D-active companies. Our analysis is based on four consecutive waves of the R&D survey data covering the period from 2000 until 2007. Each wave provides information on firm level data for two years. The survey data provides detailed information on general firm characteristics as well as details on the firms' R&D activities.

In order to construct financial indicators we supplemented this data with information on the firms' financial background with data drawn from the BELFIRST database which is provided by *Bureau van Dijk*. Moreover, we supplement the panel data with information on public R&D project funding that has been provided by IWT Flanders, which is the innovation and technology policy agency of the Flemish government that is responsible for innovation subsidies to firms.

The sample comprises firms that were observed at least twice in the reference period as we estimate panel data models that allow controlling for unobserved heterogeneity. On average, we observe each firm about 4 times in the panel. After the elimination of observations with missing values in the variables of interest, the final sample consists of 3,462 unique firm-year observations referring to 904 different firms in manufacturing industries and business services.[2]

3.2 Variables

According to the definition of the OECD Frascati Manual (1993, 2002) which sets out guidelines for collecting and interpreting R&D statistics, the term R&D covers three activities: basic research, applied research and experimental development. Basic and applied research activities comprise 'experimental or theoretical work undertaken primarily to acquire *new knowledge* of the underlying foundation of phenomena and observable facts', with or without a particular application or use in view. Development activities are rather 'systematic work, drawing from *existing knowledge* gained from research and/or practical experience, which is directed to producing new materials, products or devices […]' (OECD, 2002, p.30). The survey provides information not only about aggregate R&D spending, but also about pure research spending as defined above. The following analysis makes use of this distinction. First, we analyze firms' total internal R&D expenditure (*R&D*), and then we zoom in on the component of research expenditure (*RESEARCH*) as dependent variable.

Additionally, each wave of the survey asked firms to indicate if they had been engaged in collaborations that aimed either at *joint generation of technological knowledge* or at the *exchange*

[2] Table A.1 in the appendix provides details on the distribution of firms across industries.

of technological knowledge. Firms were asked to specify the type(s) of partner(s) with whom they collaborated: universities, research centers, suppliers, customers or other firms including competitors. If a firm had collaborated with any of these types of partners, we define a dummy variable (*COLLAB*). Additionally, we derive three dummy variables from the information on the type of collaboration partner. The first summarizes collaboration with universities and public research centers into one category that we label 'science collaboration' (*COLLAB_SCIENCE*). Collaboration with customers and suppliers, i.e. vertical collaboration, is summarized in the dummy variable *COLLAB_VERT* and horizontal collaboration, i.e. with other firms such as competitors, is captured by the dummy variable *COLLAB_HORI*.

Next, we define variables for the capital structure of the firms in our sample from balance sheet information accounted according to local Belgian GAAP. If external financing for R&D is constrained, firms engaging in R&D may have to rely to a larger extent on internal financial resources than firms that mainly invest in capital goods (e.g. Himmelberg and Petersen, 1994; Carpenter and Petersen, 2002; Chiao, 2002). Theoretical and empirical literature has illustrated that firms foremost use internal funds to finance innovation projects as compared to debt indicating such a gap in the cost of capital (see Hall and Lerner, 2010 for a review). At the same time, internal financial resources are affected by the firms' debt payment obligations. The higher the obligations relative to the internal funds of the firm, the less liquidity remains for activities that have to be financed internally such as R&D. Thus, increases in firms' levels of debt may put pressure on the firm to use its cash flow to service interest and repayment at the expense of long-term investments such as R&D (Hall, 1990; Long and Ravenscraft, 1993; Bhagat and Welch, 1995). Moreover, high leverage may reduce access to further credit due to increasing default risk. Therefore we control for internal liquidity as well as debt.

We employ the firms' stock of working capital as a measure of operating liquidity to overcome limitations of cash flow as indicator for firms' liquidity as suggested by Hall and Kruiniker (1995).[3] Working capital is used by firms for day-to-day financial operations and is therefore an important indicator of the firms' liquidity. By retaining cash inflows, firms accumulate the financial funds needed for investment as reflected in the stock of working capital. Thus, unlike

[3] The appropriateness of cash flow as an indicator for the availability of internal funds and the interpretation of sensitivity of R&D investment to changes in cash flow has been seriously questioned in the literature (Hao and Jaffe, 1993; Hall and Kruiniker, 1995; Kaplan and Zingales, 1997, 2000). Especially in the case of large firms, free cash flow levels may be determined by accounting as well as dividend policies aimed at mitigating moral hazard problems (Jensen, 1986).

cash flow, it accounts for the option to stock up cash in one period for investment in the next one. The advantage of working capital over cash flow is therefore that it is an accumulation rather than a flow parameter. Although working capital is affected by cash flow, working capital is a more precise liquidity indicator when it comes to investment decisions as it also includes not only cash holdings but also other assets that can relatively easy be converted into cash.

For the purpose of the following analysis, we measure working capital (*WCAP*) as the net amount of short term assets, i.e. the difference between current assets minus current liabilities of a firm. The higher the value for *WCAP* the more secured is a firm's liquidity and accordingly its financial flexibility. This variable can take positive or negative values. A positive working capital means that short term liabilities are covered by current assets (cash, accounts receivable and inventory) whereas a negative working capital indicates that a firm's current assets are not sufficient to cover its current liabilities.

In addition, we use firm's debt as further variable controlling for credit market access. The overall liabilities of the firm (*DEBT*) consist of current liabilities payable within one year and non-current liabilities payable later than one year. As common in the financial constraints literature, we scale the dependent variables as well as *WCAP* and *DEBT* by firms' assets (see e.g. Fazzari *et al.*, 1988, Fazzari and Petersen, 1993; Harhoff, 1998). We use lagged tangible assets (*K)* calculated as the value of a firm's total fixed assets minus current assets and financial assets (that were already captured by *WCAP*), goodwill and other intangible assets.

We also control for firm-level characteristics such as firm size, group membership and age of the firm. Larger firms may be able to realize economies of scope when conducting research and development activities. Therefore we include the log of the firms' tangible assets ln*(K)* as well as its squared value $[\ln(K)]^2$. The dummy variable *GROUP* taking the value 1 if a firm belongs to a group (0, otherwise) controls for different governance structures. Group members may conduct more R&D activities since firms associated with a group can make use of intra-firm spillovers, internalise externalities as well as fund R&D from intra-group sources. To control for age-related effects, since younger and newly established firms may invest relatively more into research and development than older firms, we also use the log of age, ln*(AGE)*. We also allow for a non-(log)-linear relationship by including $[\ln(AGE)]^2$.

Finally, business cycle effects are captured by including a set of time dummies, and 16 sector dummies on basis on the European standard industry classification (NACE) are included to control for different technological opportunities reflected by sectoral differences in the propensity to engage in R&D as well as in its intensity.

As a robustness check that we describe in more detail below, we control for the receipt of public subsidies for R&D (*SUB*). In the models on *RESEARCH*-expenditure we control for whether the firm received a subsidy particularly for basic or strategic research (*R_SUB*).

All monetary variables are measured in thousands of Euros and in prices of the year 2000 which have been adjusted using the GDP deflator. To avoid a simultaneity bias which can arise if there are feedback effects from the dependent variable to current explanatory variables, we use lagged values of *all* time variant explanatory variables (except *AGE*).[4]

Table 1 shows descriptive statistics for all variables used in the models that we will describe in more detail in the following section. Average R&D expenditures are around 3 million Euros for each firm per year where roughly two thirds are spent for development and one third for research.

40% of the firms collaborated at some point in some form during our panel period. 29% of those collaborations had universities or research centres as partners. In 31% of the cases collaborative research involved ‘vertical partners’ like customers or suppliers. Other firms such as competitors were collaborative partners in 12% of the cases.[5] Firms were often engaged in several research partnerships with different partners in the same year or switched partners over time. 54% had scientific and vertical partners and 23% had been collaborating with horizontal as well as science partners. 12% of the collaborating firms had vertical as well as horizontal research partners.

On average, liabilities amount to about 66 million Euros and working capital to almost 13 million. The median values, however, are much lower for both (about 5 million € for *DEBT* and about 2 million for *WCAP*). Firms hold on average tangible assets of about 16 million Euros. Note, that also here the median value is much lower. Firms in our sample have about 270 employees on average. However, the size distribution of firms is skewed and at the median the number of employees is only 58. The sample comprises very young firms of 2 years as well as established firms of up to 125 years of business activity. The average firm age is about 26 years. 60% of the firms in our sample are part of a group.

As mentioned above, we use subsidy information as an additional control in a robustness check. 22% of the firms received a project-based R&D subsidy in any of the years between 2000 and

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[4] We employ a 2-period lag for *DEBT* as it is measured at the end of the year *t*-2, and its signal to lenders becomes effective in *t*-1. Thus, this 2-period lag indicates access to external funding in *t*-1 when also the available working capital is measured.

[5] See Table A.1 for frequencies of collaboration modes in different industries. The original data provided information on collaboration with universities and research centers separately (23% and 21%, respectively. 29% had either one or the other partner) and vertical research collaboration distinguished customers (24%) and suppliers (22%).

2007. Only 7% received a subsidy that was granted for project that explicitly aimed at basic and strategic research.

Table 1: Descriptive statistics (3,462 obs.)

Variable	**Unit**	**Median**	**Mean**	**Std. Dev.**	**Min**	**Max**
$R\&D_{i,t}$	*million €*	0.15	2.85	18.51	0	471.35
thereof $RESEARCH_{i,t}$	*million €*	0.03	1.08	7.45	0	217.58
SUB_{it}	*dummy*	0	0.22	0.41	0	1
R_SUB_{it}	*dummy*	0	0.07	0.25	0	1
Collaboration:						
COLLAB	*dummy*	0	0.40	0.49	0	1
COLLAB_SCIENCE	*dummy*	0	0.29	0.45	0	1
COLLAB_VERT	*dummy*	0	0.31	0.46	0	1
COLLAB_HORI	*dummy*	0	0.12	0.32	0	1
$DEBT_{i,t-2}$	*million €*	5.10	66.14	314.4	0.01	7,764.43
$WCAP_{i,t-1}$	*million €*	2.06	12.67	43.18	-155.02	634.90
$K_{i,t-1}$	*million €*	1.43	16.05	85.14	0.01	1,805.05
$EMP_{i,t-1}$	*headcount*	58	272.31	748.55	1	11,575
$AGE_{i,t}$	*years*	19	25.80	19.22	2	125
$GROUP_i$	*dummy*	1	0.59	0.49	0	1

Note: time and industry dummies omitted. Note that we use the variables in monetary units measured in thsd. EUR in the regression analysis. For better readability, we present them in millions in this table. See Table A.3 in the Appendix for correlations between the variables.

4 Econometric analysis

We estimate censored panel regression models as not all of our firms in the sample perform R&D in each period. Especially small firms may conduct R&D only on an irregular basis. In particular, we estimate random effects models that can be written as

$$y_{it} = \max\left(0, x_{it}\beta + c_i + u_{it}\right), \quad i = 1,2,\ldots,N, \quad t = 1,2,\ldots,T$$
$$u_{it} \mid x_i, c_i \sim N\left(0, \sigma_u^2\right) \qquad (1)$$

where y denotes the dependent variable, x the set of regressors, c a firm-specific time-constant effect, and u the usual random error term. The parameters to be estimated are denoted by the vector β. We first estimate the model as random effects Tobit that requires the assumption that c and x are uncorrelated (see Wooldridge, 2002: 540-541, for further technical details).[6] Second,

[6] Note that it is not useful to estimate a fixed effects Tobit model, as the maximum likelihood estimator is not consistent (see e.g. Cameron and Trivedi, 2005).

we follow Wooldridge (2002) and relax the assumption of uncorrelatedness between *x* and *c* by modifying the model. If $c_i = \psi + \bar{x}_i \xi + a_i$, we can write

$$y_{it} = \max\left(0, \psi + x_{it}\beta + \bar{x}_i\xi + a_i + u_{it}\right)$$

(2) with

$$u_{it} \mid x_i, a_i \sim N\left(0, \sigma_u^2\right),$$
$$a_i \sim N\left(0, \sigma_a^2\right).$$

The appropriateness of the Wooldridge model, i.e. whether or not the assumption of uncorrelatedness between the firm-specific effect and the regressors is not valid, will be tested by the joint significance of the *x*-variables' "within" means.

Turning to the key ingredient of our analysis, it is essential to note that we use the collaboration dummies (as described before) to estimate two separate slope parameters for *WCAP*. On the one hand, we estimate a coefficient for the research-collaborating firms (*WCAP*COLLAB_X*). And on the other hand, a separate slope for the firms that did not collaborate *[WCAP*(1-COLLAB_X)]* is estimated. *COLLAB* denotes the aggregate collaboration dummy and *COLLAB_X* (*X = SCIENCE, VERT or HORI*) the individual collaboration modes.

We expect that the non-collaborating firms are financially constrained, and thus a positive and significant coefficient estimate. If collaboration alleviates financial constraints and thus reduces the sensitivity of expenditures to availability of internal funds, the slope for the collaborating firms should be smaller or even insignificant. That is, firms show no or less sensitivity to their internal funds.

We estimate separate models for our two dependent variables of interest. The basic model for R&D investment is specified as:[7]

(3)
$$\frac{R\&D^*_{it}}{K_{it}} = \beta_0 + \beta_1 \frac{DEBT_{i,t-2}}{K_{i,t-1}} + \beta_2 \frac{WCAP_{i,t-1}}{K_{i,t-1}} \times COLLAB_{i,t-1} + \beta_3 \frac{WCAP_{i,t-1}}{K_{i,t-1}} \times \left(1 - COLLAB_{i,t-1}\right) + \beta_4 COLLAB_{i,t-1}$$
$$+ \beta_5 \ln K_{i,t-1} + \beta_6 \left(\ln K_{i,t-1}\right)^2 + \beta_7 \ln AGE_{i,t} + \beta_8 (\ln AGE_{i,t})^2 + \beta_9 GROUP_i + \sum_{k=10}^{25} \beta_k IND_{ik} + \sum_{s=26}^{34} \beta_s t_s + c_i + u_{it}$$

and

[7] Although the model contains a time-invariant firm-specific effect we also include the time-invariant regressors *GROUP* and the industry dummies, as the firm-specific effect is treated as a random component in the estimation. Including time invariant regressors are used to decrease the error term variance (see Wooldridge, 2002: 541).

(4) $$\frac{R\&D_{it}}{K_{it}} = \begin{cases} \frac{R\&D^{*}_{it}}{K_{it}} & \text{if } x_{it}\beta + c_i + u_{it} > 0 \\ 0 & \text{otherwise} \end{cases}.$$

5 Estimation results

First, we estimate a specification of the model as described in equation (3) employing the information of whether the firm was engaged in any form of research collaboration (*COLLAB*). We estimate separate models for R&D expenditures and *RESEARCH* expenditures and present first the results of the random effects panel estimation (columns 2 and 3 of Table 2) and then the modification of the estimator as suggested by Wooldridge (columns 4 and 5 of Table 2).

A test on joint significance of the within firm means of the regressors shows that the random effects assumption of no correlation between the explanatory variables and the firm-specific effect is violated in the standard random-effects Tobit model. Therefore, we only discuss the Wooldridge version relaxing this assumption in more detail.

We find that the coefficient of working capital is not significant for the collaborating firms [$(WCAP_{i,t-1} / K_{i,t-1})*COLLAB_{i,t-1}$] but that it is significantly different from zero for the non-collaborating firms [$(WCAP_{i,t-1} / K_{i,t-1})*(1- COLLAB_{i,t-1})$] in the R&D equation. In previous studies, this would have been interpreted as financial constraints being present for non-collaborating firms and as non-binding financial constraints for R&D collaborators. However, a test on whether the two coefficients are significantly different from each other does not reveal that the Null hypothesis of the coefficients being equal can be rejected (see Table 2).[8] Therefore, we cannot unambiguously conclude on the presence of financial constraints in the R&D equation. If, we, however, turn to the results concerning the research investment as part of the total R&D spending, we find more refined evidence. In the equation using *RESEARCH* as dependent variable, the *WCAP* coefficient for the non-collaborating firms is almost as twice as high as for collaborating firms. Here this difference in slopes is also significantly different from zero. We thus conclude that collaborating firms are less constrained in their research investments than firms that conduct research activities individually without involving external partners. This points to both effective risk pooling and bundling of knowledge which may avoid duplicate research and thus wasting financial resources.

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[8] Note that this is also confirmed in the standard random effects estimation.

Note that we also ran the regression models using the expenditure for *DEVELOPMENT* instead of research as the complement in total R&D spending. There we never found any significant result concerning the *WCAP* variable (the results are not presented in detail in the paper). Thus, firms seem to be financially constrained for research expenditure, but not for development activities where the underlying inventions are possibly already secured by intellectual property rights, and the inventive process is already closer to an innovation and thus the market, that is, the uncertainty on returns might be significantly lower at this stage of the inventive process and firms may be able to raise capital in the credit market easier than for pure research activities.

The coefficient of the collaboration dummy itself is positive and significant at the 1% level in all regressions. This result is in line with the theoretical industrial organization literature on knowledge spillovers which predicts that collaborating firms will invest more into R&D than non-collaborating firms in the presence of knowledge spillovers. We can thus indirectly conclude that knowledge spillovers are present and that these collaborations trigger additional investments in the economy.

The other controls are also in line with our expectations. For both the total R&D investment and for *RESEARCH*, we find that debt is negatively significant. We interpret this as indication that a higher default risk due to higher levels of debt reduces the likelihood of potential investors to provide further capital for R&D investment. Additionally, higher levels of debt imply a liquidity outflow to serve creditors which reduces funds available for R&D.

Furthermore, we find a non-linear relationship between the dependent variables and firm size as measured by ln*K*. Note that the estimated coefficients suggest a U-shape relationship between the dependent variable and ln*K*. A closer look at the data reveals, however, that the extreme value of the curve is roughly at the 95th percentile of the ln*K* distribution. We thus find basically a downward sloping curve, that is, the investment intensity declines as firm size increases.

Firms that are part of a company group invest significantly more on R&D compared to stand-alone ventures. In the Wooldridge specification of the model, the age of the firms is significant. *R&D* is increasing with the maturity of the firm, while *RESEARCH* spending follows an inverted U-shape, i.e. it decreases after having reached a maximum at about 11 years of business activity.

Table 2: Estimation results from Tobit regressions (3,462 obs. of 904 firms) on *R&D* and *RESEARCH* expenditures per unit tangible assets (*K*)

	Random-Effects Estimator		Wooldridge Estimator	
Variable	**R&D**	**RESEARCH**	**R&D**	**RESEARCH**
$DEBT_{i,t-2} / K_{i,t-1}$	-0.006 **	-0.004 ***	-0.011 ***	-0.011 ***
	(0.002)	(0.001)	(0.003)	(0.001)
$(WCAP_{i,t-1} / K_{i,t-1})*COLLAB_{i,t-1}$	0.105 ***	0.051 **	0.080	0.088 ***
	(0.048)	(0.020)	(0.054)	(0.027)
$(WCAP_{i,t-1} / K_{i,t-1})*(1-COLLAB_{i,t-1})$	0.148 ***	0.119 ***	0.119 **	0.153 ***
	(0.032)	(0.016)	(0.047)	(0.023)
$COLLAB_{i,t-1}$	2.725 ***	1.330 ***	2.715 ***	1.323 ***
	(0.389)	(0.191)	(0.389)	(0.189)
$ln(K_{i,t-1})$	-4.542 ***	-1.646 ***	-4.982 ***	-1.350 ***
	(0.469)	(0.232)	(0.732)	(0.361)
$[ln(K_{i,t-1})]^2$	0.246 ***	0.098 ***	0.262 ***	0.071 ***
	(0.031)	(0.015)	(0.047)	(0.023)
$ln(AGE_{i,t-1})$	1.328	-0.208	9.262 **	10.222 ***
	(1.617)	(0.801)	(4.314)	(2.041)
$[ln(AGE_{i,t-1})]^2$	-0.274	-0.038	-1.453	-2.108 ***
	(0.274)	(0.136)	(1.103)	(0.530)
$GROUP_i$	2.061 ***	0.333	1.912 ***	0.281
	(0.427)	(0.213)	(0.435)	(0.215)
Joint sig. of time dummies $\chi2$ (7)	9.73	23.66***	10.23	13.36*
Joint sig. of ind. dummies $\chi2$ (15)	34.48***	17.51	34.52***	19.26
Test of $\beta_2 = \beta_3$ $\chi2$ (1)	0.85	8.69***	0.71	8.06***
Joint sig. of within means $\chi2$ (6)	-	-	14.80**	89.73***
Log-Likelihood	-10,505.29	-7,206.52	-10,497.95	-7,163.93
ρ	0.303	0.350	0.296	0.347
# of censored obs	531	1,033	531	1,033

Notes: Standard errors are in parentheses. *** (**, *) indicate a significance level of 1% (5%, 10%). All models include an intercept, time and industry dummies (not presented). Coefficients of variables' within means in Wooldridge model are omitted from the table. The value of ρ indicates the share of the total variance which is due to the cross-sectional variation.

5.1 Distinguishing between collaboration partners

In a next step of our analysis we investigate which particular forms of research collaboration or more precisely, collaboration with which partner contribute to the 'alleviation effect' with regard to financial constraints. We estimate three distinct models for collaborative research with *SCIENCE*, with *VERTICAL* and with *HORIZONTAL* partners for both dependent variables (*R&D, RESEARCH*). As we did with the general collaboration dummy in the models discussed above, we interact *WCAP* now with the collaboration dummies *COLLAB_SCIENCE*, *COLLAB_VERT*, *COLLAB_HORI*, respectively. Table 3 depicts the results from this exercise.[9] While the collaboration dummies and the control variables and show similar patterns across all specifications, we find interesting differences between collaboration partners with respect to the sensitivity to internal funds of the collaborating firms. Columns 2 and 3 show the results for collaborative research with universities or research centers. The coefficients of *WCAP* do not differ significantly between the two groups of collaborating and non-collaborating firms when total R&D spending is considered. In the equation using *RESEARCH* as dependent variable, we find that the slope for science-collaborators is significantly smaller than for firms that do not collaborate with science. Thus, having collaborated with science appears to alleviate financing constraints for research projects, while it does not for development projects. These results point to the conclusion that firms engage in collaboration with science when projects that concern more fundamental R&D (in our setting rather research than experimental development) are undertaken. These results are in line with Hall *et al*. (2003) who found for the US ATP program that projects undertaken with science tackle problems that are more basic and more fundamental than others. Here we conformingly find that indeed such collaborations reduce the sensitivity of research investments to internal financial resources.

The results for the models including the interaction term for vertical collaboration show that such collaborative research has no 'alleviation effect' on either R&D in general or *RESEARCH* in particular.[10] Interestingly, horizontal collaboration (columns 6 and 7 of Table 3) appears to reduce sensitivity to internal funds not only for research, but also for R&D projects in general. Horizontal collaboration may therefore provide a stronger signaling value with respect to the potential benefits arising from such collaboration for both R&D in general and, interestingly, also for pure research projects. The quality signal may stem from the high potential between competitors to pool their (complementary) skills. Further, as firms can share costs of R&D equipment and labor problems of indivisibility may be reduced. Finally, the exploitation of economies of scale and the elimination of R&D duplication may increase the profitability of any

[9] As we found the relaxation of the assumption that *x* and *c* are correlated to be important, we will discuss the results of the Wooldridge specification in the following (Table 3). The results for the random effects estimator can be found in Table A.2 in the Appendix.

[10] We also tested the models with separate dummy variables for collaborations with universities and research centers and obtained similar results. Estimating the models with the collaboration dummy for vertical partners separately for customers and suppliers, we find like with the joint variable, insignificant interaction terms for both types of vertical collaboration.

R&D effort also leading to a more effective signaling value in horizontal as compared to vertical collaboration.

5.2 Robustness check: controlling for subsidies

As a robustness check we also control for the receipt of public subsidies. The subsides considered here are mission-orientated direct R&D grants distributed by IWT, by far the most important source of public funding for corporate R&D in Flanders. The IWT subsidy data has the feature that the projects are categorized into those that aim at basic research and others that are more focused on experimental development. In our sample, 22% of the firms received a project-based R&D subsidy in any of the years between 2000 and 2007. Only 7% received a subsidy that was granted for project that explicitly aimed at basic and strategic research.

It is interesting to control for the subsidy receipt, as projects conducted within R&D consortia are often preferred over individually conducted projects by a single firm, as public agencies intend to increase knowledge spillovers within the economy, and thus social welfare. Therefore, the effects found for the collaboration dummies could be confounded with subsidy receipts (see Czarnitzki, 2006, Czarnitzki *et al*., 2011, for studies on financial constraints and subsidies).

We specify the model as before but just add an R&D subsidy dummy (*SUB*) to the R&D equation. In order to avoid simultaneity bias, we also lag this indicator by one period. The equation for *RESEARCH* is specified analogously, but we control for research subsidies (*R_SUB)* instead for subsidies in general.

As the regression results show, subsidies increase spending on R&D as intended. Similarly we find that pure research subsidies also increase research investment in the equation that is only considering *R* instead of R&D. It is noteworthy that the findings on the subsidy dummy should be interpreted with some care. It is known that firms may self-select themselves into subsidy schemes (see e.g. the survey by David *et al*., 2000) and thus we may overestimate the effect of *SUB* and *R_SUB* although our panel regressions control for unobserved heterogeneity among firms and that should take care of the potential selection bias to a certain extent. As can be seen in Table 4, the results on the collaboration variable reported earlier also hold when we control for the subsidy receipt.

Table 3: **Wooldridge model estimation results** (3,462 obs. of 904 firms) on expenditures per unit tangible assets (*K*)

	SCIENCE COLLABORATION		***VERTICAL COLLABORATION***		***HORIZONTAL COLLABORATION***	
Variable	**R&D**	**RESEARCH**	**R&D**	**RESEARCH**	**R&D**	**RESEARCH**
$DEBT_{i,t-2} / K_{i,t-1}$	-0.011***	-0.011***	-0.011***	-0.011 ***	-0.011 ***	-0.011 ***
	(0.003)	(0.001)	(0.003)	(0.002)	(0.003)	(0.002)
$(WCAP_{i,t-1} / K_{i,t-1})*COLLAB_{i,t-1}$	0.108*	0.073**	0.104*	0.117 ***	-0.089	-0.012
	(0.061)	(0.030)	(0.061)	(0.030)	(0.076)	(0.040)
$(WCAP_{i,t-1} / K_{i,t-1})*(1-COLLAB_{i,t-1})$	0.106**	0.146***	0.104**	0.134 ***	0.129 ***	0.147 ***
	(0.045)	(0.022)	(0.045)	(0.022)	(0.045)	(0.022)
$COLLAB_{i,t-1}$	2.800***	1.286***	2.729***	1.357 ***	2.577 ***	0.998 ***
	(0.421)	(0.204)	(0.414)	(0.200)	(0.560)	(0.270)
$\ln(K_{i,t-1})$	-4.966***	-1.335***	-5.070***	-1.426 ***	-4.840 ***	-1.315 ***
	(0.729)	(0.361)	(0.723)	(0.361)	(0.735)	(0.362)
$[\ln(K_{i,t-1})]^2$	0.259***	0.069***	0.268***	0.076 ***	0.251 ***	0.068 ***
	(0.047)	(0.023)	(0.047)	(0.023)	(0.048)	(0.023)
$\ln(AGE_{i,t-1})$	9.930**	10.266***	8.461*	9.032 ***	7.785 *	9.565 ***
	(4.315)	(2.044)	(4.301)	(2.035)	(4.307)	(2.034)
$[\ln(AGE_{i,t-1})]^2$	-1.614	-2.113***	-1.219	-2.021 ***	-1.115	-1.928 ***
	(1.102)	(0.531)	(1.099)	(0.528)	(1.104)	(0.529)
$GROUP_i$	1.956***	0.297	1.932***	0.282	2.008***	0.330
	(0.433)	(0.215)	(0.435)	(0.214)	(0.439)	(0.215)
Joint sig. of time dummies χ^2 (7)	9.47	10.64	9.19	12.04*	11.75	9.01
Joint sig. of ind. dummies χ^2 (15)	35.48***	19.77	33.84***	19.33	32.61***	18.77
Test of $\beta_2 = \beta_3$ $\chi2$ (1)	0.01	7.73***	0.00	0.39	9.81***	18.26***
Joint sig. of within means $\chi2$ (6)	14.74**	89.04***	15.14**	89.02***	14.25**	90.45***
Log-Likelihood	-10,498.19	-7,168.43	-10,497.44	-7,161.55	-10,513.95	-7,176.78
ρ	0.295	0.350	0.298	0.347	0.309	0.355
# of censored obs.	531	1,033	531	1,033	531	1,033

Notes: Standard errors are in parentheses. *** (**, *) indicate a significance level of 1% (5%, 10%). All models include an intercept, time and industry dummies (not presented). Coefficients of variables' within means are omitted from the table. The value of ρ indicates the share of the total variance which is due to the cross-sectional variation. Coefficients of variables' within means in Wooldridge model are omitted from the table.

Table 4: **Wooldridge model estimation results** (3,462 obs. of 904 firms) on expenditures per unit tangible assets (*K*)

	SCIENCE COLLABORATION		***VERTICAL COLLABORATION***		***HORIZONTAL COLLABORATION***	
Variable	**R&D**	**RESEARCH**	**R&D**	**RESEARCH**	**R&D**	**RESEARCH**
$DEBT_{i,t-2} / K_{i,t-1}$	-0.010***	-0.011***	-0.011***	-0.011 ***	-0.010 ***	-0.011 ***
	(0.003)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)
$(WCAP_{i,t-1} / K_{i,t-1})*COLLAB_{i,t-1}$	0.110*	0.074**	0.107*	0.117 ***	-0.079	-0.009
	(0.061)	(0.030)	(0.061)	(0.030)	(0.076)	(0.040)
$(WCAP_{i,t-1} / K_{i,t-1})*(1-COLLAB_{i,t-1})$	0.106**	0.147***	0.104**	0.135 ***	0.129 ***	0.148 ***
	(0.045)	(0.022)	(0.045)	(0.022)	(0.045)	(0.022)
$COLLAB_{i,t-1}$	2.586***	1.280***	2.567***	1.351 ***	2.446 ***	0.976 ***
	(0.428)	(0.204)	(0.416)	(0.200)	(0.559)	(0.270)
$SUB_{i,t-1}$	1.019**		1.206***		1.458 ***	
	(0.398)		(0.393)		(0.393)	
$R\_SUB_{i,t-1}$		0.708**		0.679 **		0.680 **
		(0.327)		(0.327)		(0.327)
$\ln(K_{i,t-1})$	-5.023***	-1.360***	-5.137***	-1.449 ***	-4.944 ***	-1.338 ***
	(0.729)	(0.361)	(0.730)	(0.361)	(0.734)	(0.361)
$[\ln(K_{i,t-1})]^2$	0.263***	0.071***	0.272***	0.078 ***	0.258 ***	0.069 ***
	(0.047)	(0.023)	(0.047)	(0.023)	(0.048)	(0.023)
$\ln(AGE_{i,t-1})$	9.674**	10.356***	8.310*	10.021 ***	7.708 *	9.651 ***
	(4.317)	(2.045)	(4.303)	(2.036)	(4.309)	(2.034)
$[\ln(AGE_{i,t-1})]^2$	-1.566	-2.141***	-1.204	-2.048 ***	-1.104	-1.954 ***
	(1.102)	(0.531)	(1.098)	(0.528)	(1.102)	(0.529)
$GROUP_i$	1.957***	0.302	1.937***	0.285	2.007 ***	0.333
	(0.432)	(0.215)	(0.432)	(0.214)	(0.436)	(0.215)
Joint sig. of time dummies χ^2 (7)	9.69	11.02	9.49	12.41*	11.64	9.31
Joint sig. of ind. dummies χ^2 (15)	34.28***	18.90	32.58***	18.60	31.28***	18.07
Test of $\beta_2 = \beta_3$ $\chi2$ (1)	0.01	7.71***	0.00	0.46	8.91***	17.78***
Joint sig. of within means $\chi2$ (6)	13.94**	88.52***	14.27**	88.57***	12.96**	89.91***
Log-Likelihood	-10,494.92	-7,166.20	-10,492.76	-7,159.50	-10,507.08	-7,174.77
ρ	0.290	0.348	0.290	0.345	0.298	0.353
# of censored obs.	531	1,033	531	1,033	531	1,033

Notes: Standard errors are in parentheses. *** (**, *) indicate a significance level of 1% (5%, 10%). All models include an intercept, time and industry dummies (not presented). Coefficients of variables' within means are omitted from the table. The value of ρ indicates the share of the total variance which is due to the cross-sectional variation. Coefficients of variables' within means in Wooldridge model are omitted from the table.

6 Conclusion and discussion

Underinvestment in R&D due to financing constraints may result in a slowdown in productivity growth and consequently have particularly detrimental effects on technological progress and economic development. The question how firms encounter such constraints is therefore a crucial one that has, however, received little attention so far. Our results suggest that collaborative R&D may be one way of firms to mitigate the detrimental effects of constrained access to financial resources for their R&D. Collaborative R&D may not only help firms to absorb knowledge spillovers from their partners, facilitate organizational learning and allow higher degrees of efficiency in the R&D process that reduce risk and provide effective insurance against technological and market uncertainty. Moreover it may provide a positive signal to potential investors and banks about the quality and the expected success of the project. Our results show that collaborative research alleviates liquidity constraints especially for investment in research. We do, however, find interesting differences in the effects between the different collaboration partners. While we do not find such an effect of science-collaboration for R *and* D investment (as compared to research only), we do observe alleviating effects from horizontal collaboration for both pure research investment as well as for R *and* D. Vertical collaboration with customers or suppliers, on the contrary, has no such alleviating effects.

Horizontal collaboration may therefore provide a stronger signaling value with respect to the potential benefits arising from such collaboration for both R&D in general and, interestingly, also for pure research projects. Pooling of complementary skills, the exploitation of economies of scale and the elimination of R&D duplication as well as reduced problems of indivisibility as firms can share costs may thus be more effective in horizontal as compared to vertical collaboration.

In the recent past, industry-science collaborations have attracted increased attention of both academics and policy makers. It is generally believed that an enhanced knowledge and technology transfer from science to industry via collaborative research also contributes to the long-run innovativeness and thus competitiveness of the business sector (Salter and Martin 2001 for a review). Our results confirm the importance of such alliances by explicitly pointing to the implications of such collaborative research for financing of research projects. While (basic) research had been identified as a main driver of productivity at the firm level (Mansfield 1980, Griliches 1986), basic research suffers from worse appropriability conditions than other projects, i.e. spillovers are larger. In addition, the argument by Arrow (1962) that "basic research, the output of which is used as an informational input into other inventive activities, is especially *un*likely to be rewarded" may increase firms' incentives for research collaboration in order to attenuate such constraints.

Aggarwal and Hsu (2009) show that firms' appropriation environment and their governance capabilities both influence the choice of partners for R&D collaboration. This underpins our results that different collaboration modes serve different purposes for instance at different stages of the R&D process. Firms may thus align their alliance portfolio also to technological needs as well as to prospects about a potential signaling value to outside parties. Moreover, next to different *modes* of collaboration they can choose between different *forms* of collaborative R&D, i.e. licensing relationships, equity alliances and other contractual specifications. Unfortunately these aspects are beyond the scope of our analysis: Future research should address the differences in the forms of collaboration for the link between liquidity constraints and collaboration addressed in this study.

Future research would also benefit from studying the nature of the R&D collaboration in greater detail as research partnerships can take plenty of forms and contractual arrangements (Hagedoorn *et al.*, 2000). For instance, it is certainly interesting to study the differences between research joint ventures - that usually involve knowledge sharing between firms within joint research labs - and R&D collaboration that mainly aims at the exchange of know-how, but not its joint generation. Moreover, the role of intellectual property (IP) has not been discussed in the present study. As the exchange of IP is often central in collaborative R&D, plays a crucial role for incentives to invest in R&D and may be in many cases the only 'tangible' outcome of R&D this important aspect should be given attention to in future analysis on this issue.

Finally, we would like to point out that the presented analysis has some limitations. First, our panel structure that is highly unbalanced and did not allow us to estimate dynamic specifications that are theoretically founded models of investment behavior (see e.g. Wooldridge, 2005 and Bond and Van Reenen, 2007 for an overview). Modeling the initial condition and including a lagged dependent variable would require at least 4 consecutive observations per firm to conduct a meaningful estimation. As our panel is not only unbalanced but has also gaps (as the firms did not necessarily respond to the surveys in adjacent years), we found it impossible to estimate a dynamic model.

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Appendix

Table A.1: **Industry classifications**

Industry	**NACE rev. 2008**	**Description**	**Frequency**	**%**	***SCIENCE COLLABORATION***	***VERTICAL COLLABORATION***	***HORIZONTAL COLLABORATION***
1	10, 11, 12	Food and Tobacco	242	6.99	33.47	28.93	13.22
2	13, 14, 15	Textiles, Clothing and Leather	213	6.15	28.17	30.52	7.98
3	16, 31	Wood and Furniture	117	3.38	12.82	17.95	7.69
4	17, 18	Paper	118	3.41	25.42	27.12	9.32
5	19, 20	Chemicals	268	7.74	37.69	39.18	8.96
6	21	Pharmaceuticals	68	1.96	19.12	14.71	8.82
7	22	Rubber and Plastic	153	4.42	18.30	32.68	7.84
8	24, 25, 33	Metal	295	8.52	29.15	30.17	12.20
9	27, 28	Machines and Equipment	424	12.25	30.42	33.02	9.67
10	26	ICT	262	7.57	40.08	38.17	22.14
11	29, 30	Transport	105	3.03	26.67	31.43	18.10
12	41	Building and Construction	105	3.03	26.67	15.24	10.48
13	1, 5, 23, 37, 35, 32	Miscellaneous Industries	209	6.04	22.97	26.79	10.53
14	45, 46, 47, 49, 55, 58	Commerce and Transport	212	6.12	31.13	27.83	14.62
15	59, 64, 68, 69, 71 - 79	Other Services	450	13.00	29.56	33.56	13.11
16	61, 62	Software Development and Communication	221	6.38	24.89	30.32	10.86
			3,462	**100.00**	**29.06**	**30.73**	**11.90**

Table A.2: **Random-effects estimation results** (3,462obs. of 904 firms) on expenditures per unit tangible assets (*K*)

	SCIENCE COLLABORATION		***VERTICAL COLLABORATION***		***HORIZONTAL COLLABORATION***	
Variable	**R&D**	**RESEARCH**	**R&D**	**RESEARCH**	**R&D**	**RESEARCH**
$DEBT_{i,t-2} / K_{i,t-1}$	-0.006**	-0.005***	-0.006**	-0.004 ***	-0.006 **	-0.004 ***
	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
$(WCAP_{i,t-1} / K_{i,t-1})*COLLAB_{i,t-1}$	0.135***	0.040	0.128**	0.076 ***	-0.056	-0.043
	(0.049)	(0.025)	(0.051)	(0.025)	(0.068)	(0.037)
$(WCAP_{i,t-1} / K_{i,t-1})*(1-COLLAB_{i,t-1})$	0.133***	0.114***	0.134***	0.103 ***	0.152 ***	0.111 ***
	(0.030)	(0.015)	(0.030)	(0.015)	(0.029)	(0.014)
$COLLAB_{i,t-1}$	2.569***	1.290***	2.573***	1.389 ***	2.477 ***	0.961 ***
	(0.428)	(0.206)	(0.416)	(0.202)	(0.558)	(0.273)
$SUB_{i,t-1}$	1.076***		1.257***		1.518 ***	
	(0.398)		(0.393)		(0.392)	
$R\_SUB_{i,t-1}$		0.742**		0.712 **		0.727 **
		(0.331)		(0.331)		(0.331)
$\ln(K_{i,t-1})$	-4.470***	-1.602***	-4.536***	-1.651 ***	-4.578 ***	-1.677 ***
	(0.466)	(0.232)	(0.467)	(0.229)	(0.469)	(0.232)
$[\ln(K_{i,t-1})]^2$	0.238***	0.094***	0.244***	0.098 ***	0.248 ***	0.101 ***
	(0.031)	(0.015)	(0.031)	(0.015)	(0.031)	(0.015)
$\ln(AGE_{i,t-1})$	1.671	-0.145	1.297	-0.236	1.254	-0.305
	(1.606)	(0.801)	(1.604)	(0.796)	(1.616)	(0.800)
$[\ln(AGE_{i,t-1})]^2$	-0.325	-0.050	-0.269	-0.037	-0.257	-0.023
	(0.272)	(0.136)	(0.272)	(0.135)	(0.274)	(0.136)
$GROUP_i$	2.097***	0.355*	2.075***	0.335	2.154***	0.393 *
	(0.424)	(0.214)	(0.424)	(0.212)	(0.427)	(0.213)
Joint sig. of time dummies χ^2 (7)	9.88	18.83***	8.80	23.25***	11.46	17.25**
Joint sig. of ind. dummies χ^2 (15)	33.95***	17.32	32.20***	16.79	31.28***	16.63
Test of $\beta_2 = \beta_3$ $\chi2$ (1)	0.00	7.69***	8.80	1.06	8.91***	16.89***
Log-Likelihood	-10,501.817	-7,208.218	-10,499.825	-7,201.494	-10,513.534	-7,217.395
ρ	0.296	0.351	0.296	0.349	0.303	0.356
# of censored obs.	531	1,033	531	1,033	531	1,033

Notes: Standard errors are in parentheses. *** (**, *) indicate a significance level of 1% (5%, 10%). All models include an intercept, time and industry dummies (not presented. The value of ρ indicates the share of the total variance which is due to the cross-sectional variation.

Table A.3: **Correlation matrix** (3,462obs. of 904 firms)

		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*I1*	*12*	*13*	*14*
1	*R&D*	1													
2	*RESEARCH*	0.7902	1												
3	*SUB*	0.1787	0.1625	1											
4	*R_SUB*	0.2336	0.1533	0.4085	1										
5	*COLLAB*	0.1290	0.0994	0.2801	0.1037	1									
6	*COLLAB_SCIENCE*	0.1287	0.1204	0.3278	0.1175	0.7823	1								
7	*COLLAB_VERT*	0.1181	0.1113	0.2198	0.0986	0.8142	0.6009	1							
8	*COLLAB_HORI*	0.1512	0.1247	0.1217	0.0736	0.4493	0.3935	0.3275	1						
9	*DEBT*	0.3767	0.3185	0.1714	0.1591	0.1422	0.1814	0.1144	0.1071	1					
10	*WCAP*	0.3156	0.1875	0.2225	0.1402	0.1677	0.2027	0.1479	0.1718	0.7095	1				
11	*K*	0.1289	0.1218	0.0516	0.0362	0.1041	0.1404	0.0879	0.0741	0.4281	0.3145	1			
12	*EMP*	0.4627	0.3723	0.2095	0.1629	0.1752	0.2258	0.1748	0.1652	0.5683	0.6323	0.3766	1		
13	*AGE*	0.1990	0.1093	0.0315	0.0546	0.0272	0.0694	0.0521	0.0336	0.2307	0.2982	0.0827	0.3230	1	
14	*GROUP*	0.1168	0.1062	0.0835	-0.0006	0.1321	0.1234	0.1341	0.1163	0.1522	0.2049	0.0644	0.2284	0.1281	1