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# Firm characteristics and the cyclicality of R&D investments

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The aim of this study is to combine micro-aspects of firm behavior with macro aspects of business development and identify market conditions (e.g. price competition) and firm characteristics (e.g. type of R&D partners) that enable a firm to have a pro-cyclical, anti-cyclical, or non-systematic R&D investment behavior. The empirical results confirm to large extent a series of hypotheses as to innovation-relevant firm characteristics that underline the three different behavior categories and allow us to make profiles of the three types of R&D behavior.

**JEL classification:** E32, L23, O31.

## 1. Introduction

There is some theoretical consent (see Bernanke and Gertler, 1989, Barlevy, 2007) and some empirical evidence (see Guellec and Ioannidis, 1999; Mairesse et al., 1999; Rammer et al., 2004; Quyang 2011a) that R&D investment expenditures of firms are pro-cyclical, i.e. they are increasing in the business upswing, and they are decreasing in the business downturn. However, there are also some theoretical arguments as well as some anecdotical evidence that firms show an anti-cyclical R&D investment behavior. Such investment behavior is advantageous not only for the respective firm but also for the economy as a whole, as anti-cyclical investment behavior might mitigate the negative implications of the cyclical movement of the economy such as strong employment fluctuation.

Therefore, there is scope for an analysis that takes as starting point a picture of real situations that is more heterogeneous than that prescribed in the "pure"

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pro-cyclical or "pure" anti-cyclical point of view. Hence, it is the aim of this study to combine micro-aspects of firm behavior with macro-aspects of business development and identify market circumstances (e.g. competition) and firm characteristics (e.g. type of R&D partners) that enable a firm to have an anti-cyclical or unsystematic R&D investment behavior.

To explain pro- or anti-cyclical R&D behavior, we have to take into account two diverging forces, namely, (i) demand aspects (see Filippetti and Archibugi, 2011) and (ii) the "opportunity cost" aspect. As R&D investments are predominantly financed through the cash-flow of a firm, which is expected to fluctuate pro-cyclically with demand, we would expect a pro-cyclical R&D investment behavior as well. If the "opportunity cost" aspect prevails, we would expect the contrary; firms would make use of lower production costs in recessions and would intensify their R&D investments. As a consequence, this would not only make R&D activities cheaper but also increase the probability to market new products in the business upswing, when markets are in general more receptive for new products. Hence, our theoretical notions are around these two aspects, and we want to figure out under which circumstances firms are able to follow the opportunity cost approach and when financial restrictions are likely to be dominant and firms show pro-cyclical R&D investment behavior.

Based on firm-level panel data for manufacturing firms in Switzerland comprising three waves (2002, 2005, 2008) of the Swiss Innovation Survey and aggregated yearly data (three-digit level) for the business cycles development in Switzerland (1999–2009), we could identify important firm characteristics and market conditions that are responsible for anti-cyclical R&D investment behavior of firms. In sum, we could learn that firms can benefit from low opportunity costs through anti-cyclical R&D investments (compared with unsystematic R&D investment behavior) if they have a relatively large sales share of R&D expenditures, if they have external R&D relationships, if they are not exposed to intensive price competition (e.g. operating in international market niches), if they belong to high-tech industries, and if they are relatively large. If we compare anti-cyclical firms with pro-cyclical firms, at least three factors are important. Anti-cyclical firms have larger sales shares of R&D investments, they are less frequently cooperating with universities, and they are not exposed to intensive price competition.

From a policy point of view, the results indicate that innovation policy can contribute to mitigate the cyclical fluctuation of R&D investments through considering the just mentioned factors in their promotion activities. This would not only help firms make use of lower opportunity costs at recessions but also contribute to dampen the overall business fluctuation.

The article is organized as follows. Section 2 summarizes the most important findings in the existing literature and introduces our theoretical framework and subsequent hypotheses. Section 3 discusses the data. Section 4 presents the main facts with respect to R&D and the business cycle development in Swiss manufacturing in the period 1999–2009. Section 5 discusses the empirical setting. Section 6 presents the results and Section 7 concludes.

## 2. Literature review and hypotheses

The literature on the relationship between innovation activities and business cycle development is comprehensive. In what follows, we want to identify important firm-level and industry-level factors that explain pro-cyclical or anti-cyclical behavior with respect to R&D investment.

### *2.1 Theoretical arguments and evidence in favour of pro-cyclical behavior*

#### 2.1.1 The argument of the dominant role of demand factors

Although Schmookler (1966) emphasized demand-side factors as important driving factors for innovation activities, Schumpeter (1942) emphasized supply-side factors. It appears that both components are important (see Arvanitis and Hollenstein, 1994, for evidence for Switzerland). If we think of great technological inventions, such as biotechnology and nanotechnology, or important elements of Information and Communication Technology (e.g. World Wide Web, personal computers), it is clear that they caused a bunch of follow-on innovations that have created promising markets. Following Schmookler (1966), such innovations are more likely if the economy is booming, and they are less likely if demand is shrinking. In case innovation activities are predominantly financed by cash-flow, innovation activities are likely to be pro-cyclical. Geroski and Glegg (1997) found a positive relationship between demand and major innovations (or patents), but a less clear link between R&D investment and demand, as the fluctuations of R&D investments are limited by high adjustment costs.[1] Also Piva and Vivarelli (2007, 2009) found a significant demand-pull effect for innovations if companies are liquidity constrained. For Switzerland, especially, the development of export markets (demand) show a positive relationship with innovation success of Swiss firms (see Woerter and Roper, 2010).

Quyang (2011b) develops a simple model showing that higher persistence of R&D investment raises the cyclical response in innovation's marginal expected return, which in turn reduces the dominance of marginal opportunity cost (see further later in the text), and therefore drives R&D pro-cyclical. The theoretical argument is supported by empirical evidence based on a panel of US industries in the period 1958–1998.

[1] Geroski and Walters (1995) found that innovation activities are pro-cyclical. However, Collins and Yao (1998) showed that the Granger-causality test in Geroski and Walters (1995) shows some flaws. Collins and Yao (1998) used a VAR model and could not find any causality between innovation and business cycle based on the same data set as Geroski and Walters (1995).

#### 2.1.2 The financial restraints argument

Hall (1992) found a positive elasticity between R&D investments and cash-flow, controlling, among other factors, also for demand; she concludes that financial restraints rather than demand fluctuation prevent firms from R&D investments. Himmelberg and Petersen (1994) also found good reasons that cash-flow is important for R&D investments. They stated that earlier studies did not find an effect of internal finance on R&D investments, as they predominantly looked at large firms. Large firms are less likely to be financially constrained compared with smaller firms. They themselves investigated small high-tech firms. Also, Blundell et al. (1999) argued that internal sources of funding are of particular importance for investments in R&D. Mairesse et al. (1999) emphasized that causality between cash-flow and R&D investments goes both ways. This suggests that both pre-innovation rents as well as post-innovation rents are important for R&D investments. Huergo and Moreno (2011) found that R&D investments are directly linked to past firm performance. As both internal finance and firm performance are likely to be pro-cyclical, R&D investments are expected to be pro-cyclical as well. Lerner (2010: 30) concludes based on the results of several studies that "Anglo-Saxon" economies are more sensitive or show a greater responsiveness of R&D to cash-flow than then economies of continental European countries. This greater responsiveness of R&D may arise because they are financially constrained in the sense that they view external financial resources as expensive (high expectations of rates of returns from investors). In Germany, the correlation between cash flow and R&D investments seems to be stronger for smaller firms compared with larger ones. Rammer et al. (2004) stated for Germany that SMEs are stronger affected by business cycle fluctuations than larger firms. However, the R&D expenditures of SMEs show a more moderate reaction on turnover than large firms. Some rigidity on the R&D employment level may be responsible for this observed effect, as a further reduction of R&D activities—that are already on a low level—could mean to shut down R&D.

#### 2.1.3 The role of the "sunk cost" character of R&D investment

The outcomes of R&D activities are not a product that can be easily traded. To some extent they are "sunk" investments, and they cannot be sold easily until they resulted in a product. It is also costly to stop a project and continue it at a later moment. Research knowledge has tacit components; it roots in the mind of single researchers. If they leave the firm, the knowledge is gone too. This may be especially true for firms with a few specialized researchers. Hence, R&D expenditures are expected to fluctuate less with the business cycle than sales of innovative products. Nevertheless, Guellec and Ioannidis (1999) based on industry-level data as well as Rammer et al. (2004) based on firm-level data found a positive relationship between turnover (sales) and R&D expenditures. Also Mairesse et al. (1999) stated a positive relationship between market growth and R&D expenditures. This may be due to the cash-flow effect. Cash-flow plays an important role for R&D investments.

#### 2.1.4 The information asymmetry argument

Arrow (1962) has already used R&D investments as an example for moral hazard, as the output of R&D activities can never be predicted from the input (see Arrow, 1962: 172). Furthermore, there is greater information asymmetry between potential investors and researchers. It should be easier for researchers to assess the likelihood of technological success of R&D projects compared with investors, as the latter lack detailed information and experience with respect to the research processes. Therefore, it is difficult for investors to distinguish good from bad projects ("lemon problem"). In case the information asymmetry is too great, a market for R&D investments may disappear at all. Information asymmetry is expected to fluctuate with the business cycle (see Bernanke and Gertler, 1989). The information asymmetry or principle-agent problem is alleviated if the net worth of the borrower increases, as financial distress causes higher agency costs. As borrowers' net worth is pro-cyclical, there will be a decline in agency costs in booms and an increase in recessions. The pro-cyclicality of agency costs tends to make external R&D investments pro-cyclical as well.

These theoretical findings were confirmed by Aghion et al. (2008) for France. The authors argued that information asymmetries prevented French firms from increasing their investments in business downturn.

### *2.2 Arguments and evidence in favor of anti-cyclical behavior*

#### 2.2.1 The opportunity cost argument

It is expected that costs for labor and other input factors for R&D activities would be high in a booming phase of an economy and low in a recession phase. Hence, opportunity costs are lower in recessions, and firms would benefit if they could shift resources to R&D activities. If the economy improves and demand increases, firms could launch the new products and benefit from these investments. Aghion and Saint-Paul (1998) stated that R&D activities would be anti-cyclical if costs are pro-cyclical. Also, Barlevy (2007) argued that based on opportunity costs consideration, rational firm behavior would cause R&D to be anti-cyclical. Rafferty and Funk (2004) found that opportunity-cost effects are more likely for firms with large R&D budgets.

#### 2.2.2 The argument of rent displacement

Rent displacement refers to the fear that introducing a new innovation will displace earnings from existing products. As earnings of existing products are expected to be low in recessions, or even to dry up, resistance to introduce newer products or new versions of existing products may be lower (see Geroski and Glegg, 1997). Thus, it should be easier to introduce innovations toward the end of recessions or the beginning of the upswing. This would make innovation activities anti-cyclical.

### 2.2.3 The role of technological opportunities

Firms are doing research in different technological fields. Some of them are fields with greater potential—so-called high-technological opportunity fields; others show a lower potential—so-called low-technological opportunity fields. Brouwer and Kleinknecht (1999) argued that innovators in high-opportunity fields have fewer problems with demand shocks or with financing R&D activities in recessions than innovators in fields with a low potential. They assume that this is related to market power, as they found little effects for firms that concentrate their R&D in certain technological fields (e.g. information technology, new materials technology, or biotechnology). However, technological opportunities are likely to be strongly related with R&D effort. Dugal and Morbey (1995) found that firms with larger R&D investments are suffering less from sales declines during recessions than firms with small R&D investments. They found that >70% of firms that spent >5% of their sales in R&D experienced even a sales increase in recession. Tang (2002) analysed this issue at country level and found that technical process reduces growth volatility. However, also "competitive effect" could be possible, as Rammer et al. (2004) found for Germany that a change in world-wide research intensity of an industry has a negative effect on R&D expenditures of German firms in those technology fields. This means that R&D dynamics in Germany took place in industries that are not characterized through a strong increase in international R&D.

### 2.2.4 The role of R&D collaborations

R&D collaboration could decrease the fixed costs for R&D projects, as firms can make use, for example, of the technological infrastructure of the collaboration partners or they can share the "sunk costs" in developing project-specific new knowledge.[2] Consequently, R&D collaboration would increase the flexibility of R&D investments, and firms could better adapt R&D investments to their cash-flow. This would render R&D investment pro-cyclical. However, if R&D collaborations are strategically motivated aiming, for example, at investment in new promising technologies or the involvement of potential competitors in common projects, then flexibility would be decreased, as firms would fear to miss an opportunity if they reduce their investment in such collaborations in recessions, as it would be difficult to revitalize them later. Looking at Switzerland, empirical investigations show that strategic motives for R&D cooperation (such as utilization of technological synergies and access to specialized technology) have been considerably more frequent than cost motives (such as saving of R&D costs and shortening of development time) (Arvanitis, 2012). Consequently, it is likely that R&D collaboration would rather provide incentives for an anti-cyclical R&D investment behavior.

[2] We thank an anonymous referee for this suggestion.

## *2.3 The role of competition*

Competition is a further important factor for explaining pro- or anti-cyclicality of R&D investment. Starting with a Schumpeterian point of view (see Schumpeter, 1942), concentrated markets, which firms have some market power, are more likely to have internal financial means that are sufficient for financing their R&D activities than less concentrated ones. But do such firms have incentives for R&D? Lacking competitive pressure, large firms may tend to be overcautious and bureaucratic and as a consequence less innovative. Especially in "bad" times, they are likely to protect their markets rather than expand them through innovative products. This could be an argument that competition fosters innovative activities (see Geroski and Glegg, 1997). However, firms in an atomistic type of competitive environment may not have access to sufficient financial means (internal and external) for permanent R&D activities. Thus, they may also refrain from innovation activities especially in recessions, when sales and cash-flow are likely to be low. This leads us to the view that neither monopoly nor atomistic competition is likely to be the most favorable competitive environment for innovation; an oligopolistic market with a few R&D-active firms seems to be the most favorable operating field for innovative firms. In a more stylized form, we would consider an "inverted U-shape" relationship between competition and innovation performance. The findings in Aghion et al. (2005) make it plausible that R&D expenditures in oligopolistic markets are likely to remain considerably high even during recessions.

## *2.4 The role of labor costs*

Factor costs are usually higher in an expanding economy and lower during recessions. Labor costs show some special characteristics. First, labor supply is usually rather stable (or only slowly changing). A lack of skilled people could negatively affect the R&D activities of firms. Consequently, firms are motivated to "hoard" highly skilled expensive workers in recessions to have their knowledge available in the upswing.[3] In a booming economy, labor shortage and greater labor costs are more likely, and firms can switch personnel resources into more market-related activities (e.g. sales and marketing). Hence, R&D employment in the economic downturn is relatively high, whereas it is relatively low in the booming period. In sum, this would suggest an anti-cyclical R&D employment effect. However, empirically the opposite has been observed. Rammer et al. (2004) found that R&D personnel show a pro-cyclical development over time. This result suggests that liquidity constrains matter more than the opportunity of relatively cheap R&D activities. However, they also found that R&D personnel fluctuate less than R&D expenditures along a business cycle. This is related to the aforementioned argument that firms cannot afford to loose skilled people and their specific (tacit) knowledge during a recession.

[3] We thank an anonymous referee for this point.

As there is some rigidity in R&D labor fluctuations, it is unlikely that salaries would drop significantly during recessions. In contrast, sales are more volatile during a business cycle. This suggests that R&D personnel—although more expensive in expansive economies—could be financed easier in good times than in recessions. This also contributes to the pro-cyclicality of R&D employment. If labor supply is fluctuating (pro-cyclical), then Barlevy (2007) argued that R&D behavior is pro-cyclical, too, although opportunity costs would push for anti-cyclical R&D activities.

### *2.5 Summing up: resulting hypotheses*

In sum, we discussed a number of factors that have a pro-cyclical or anti-cyclical effect on R&D investments or innovative behavior. Although demand factors and cash-flow clearly work for a pro-cyclical effect of innovation behavior, opportunity costs and rent displacement are clearly anti-cyclical. High technological opportunities and more "oligopolistic" type of competition increase the R&D intensity of firms and also make R&D expenditures less dependent on fluctuating sales. Labor supply can show pro-cyclical as well as anti-cyclical effects, depending on the employment and wage flexibility of firms. If flexibility is low and sales fluctuate strongly with the business cycle, then R&D employment is likely to be pro-cyclical. Whether R&D investments or innovations are pro-cyclical or anti-cyclical depends on the just mentioned factors. As restraints in financial means are expected to affect behavior stronger than the "opportunity effect" (see Rafferty and Funk, 2008), one could expect some tendency for pro-cyclical fluctuation. However, what holds at the end is an empirical question. Based on available data and the literature, we will test empirically the following hypotheses that are derived from the discussion in Section 2:

*Anti-cyclical behavior:*

(a) A good past demand development increases the financial opportunities of firms and hence, enables firms to invest anti-cyclically in R&D (as measured by the sales share of R&D expenditures) in the future.
(b) Larger firms are more likely to finance R&D internally, and they should be less dependent on short-term market fluctuations. Hence, they are likely to exploit opportunity costs and invest anti-cyclically in R&D.
(c) External R&D cooperation increases the flexibility of R&D activities of a firm. Hence, it is expected that such firms are more likely to make use of opportunity costs. They are more likely to invest anti-cyclically in R&D.
(d) It is expected that firms with larger sales share of R&D investments would suffer less from sales declines during recessions than firms with (relatively) small R&D budgets. Hence, such firms are likely to invest anti-cyclically to make use of opportunity costs.

*Pro-cyclical behavior:*

(e) Firms with intensive price competition in their main markets are likely to have difficulties to finance their R&D, as their price-cost margins are expected to be low. In good business times, they are expected to have fewer problems to finance R&D. Hence, their investment behavior is expected to be pro-cyclical.

(f) High average personnel costs point at well-educated and experienced staff that is not easily substituted, if once they are dismissed. Hence, firms have the tendency to keep their "expensive" high-qualified R&D employees. Clearly, such personnel could be financed easier in good times than in recessions. This would point to pro-cyclicality of R&D investments. Hence, firms with great average personnel costs are likely to invest pro-cyclically.

## 3. Data

We used two sources of data for this investigation. First, we used data at industry level on the cyclical movement of business activity in the period 1999–2009 in Swiss manufacturing. These data are stemming from the monthly Swiss Business Survey (see http://www.kof.ethz.ch/en/surveys/business-tendency-surveys/manufacturing/) and were first aggregated to three-digit industry level (30 industries) and then transformed to annual data (average of monthly data). The original data at firm level are measured on a three-level ordinal scale (positive change, negative change, no change). Through the aggregation, the ordinal scale data are transformed to pseudo-metrical data. We constructed a composite indicator of business activity based on the following three single indicators of business activity: "incoming orders", "production," and "order backlog" (see Table 1).

Second, we used firm-level data of three waves (2002, 2005, 2008) of the Swiss Innovation Survey (see http://www.kof.ethz.ch/en/surveys/structural-surveys/innovation-survey/). The survey yields information on the R&D expenditures, the firm size, the employees' education level, the competition conditions (intensity of price and non-price competition), and external R&D activities such as R&D cooperation with different business partners and institutions and/or contract (external) R&D. Pooling data from two different sources and building differences of R&D expenditures and indicators for cyclical movement between two points of time led finally to a sample of 980 available observations[4] of firms with R&D activities. The basic descriptive statistics as well as the correlation matrix of the variables used in the econometric part are found in the Tables A1, A2, and A3, respectively.

[4] The calculation of the differences between the periods 2000–2002 and 2003–2005 and between 2003–2005 and 2006–2008, respectively, is based on data for 457 firms and 523 firms, respectively.

**Table 1** Definition of variables

| Variables | Definition |
|---|---|
| Dependent variables (DEP) | |
| The classification of the firms (non-systematic, anti-cyclical, pro-cyclical) was based on the *signs* of the *change* of the composite indicator of business activity and the *change* of R&D intensity between the periods 2000–2003 and 2003–2005 as well as between 2003–2005 and 2006–2008. | |
| The composite indicator of business activity was based on the following three single indicators of business activity: “incoming orders”, “production,” and “order backlog”. Monthly data of the three single indicators at firm level were used to calculate the composite indicator at a monthly basis. These monthly data were first aggregated to three-digit industry level (30 industries) and then transformed to annual data using the average of the monthly data. The original data at firm level are measured on a three-level ordinal scale (positive change; negative change; no change). Through the aggregation, the ordinal scale data are transformed to pseudo-metrical data. Concretely, we calculated the average values of the composite indicator of business activity during the three 3-year periods 2000–2002, 2003–2005, and 2006–2008). The *change* of the level of business activity at three-digit industry level was measured by the difference of the average values of the periods 2000–2002 and 2003–2005 as well as 2003–2005 and 2006–2008. | |
| The R&D intensity (R&D expenditures divided by sales) was recorded in the survey as the average value of the three 3-year periods 2000–2002, 2003–2005, and 2006–2008). The *change* of the R&D intensity was then measured by the difference of the average values of the periods 2000–2002 and 2003–2005 as well as 2003–2005 and 2006–2008. R&D intensity in the original micro data was measured in every 3-year period as an average of 3 years. | |
| The firms are broken down to groups as follows: (a) in the three groups 0, 1, and 2 (see below) and (b) in the four groups 0, 1, 2a, and 2b (where the latter two are sub-groups of group 2; see below). The multinomial variable DEP (0, 1, 2) served as dependent variable for the estimates in Table 5, the multinomial variable DEP (0, 1, 2a, 2b) for the estimates in Table 6. | |

(continued)

**Table 1** Continued

| Variables | Definition |
|---|---|
| 0: non-systematic behavior (as to R&D intensity) | This group contains firms the R&D intensity of which does not show a systematic (monotonously positive or negative) relationship to the cyclical indicator of business activity. This means that either the R&D intensity increases or decreases during a certain period, whereas the business activity indicator remains constant ("constant" includes fluctuation between −2% points and +2% points), or the R&D intensity remains constant ("constant" includes fluctuation of 0.3%), whereas the overall business situation improves or deteriorates. |
| 2: pro-cyclical behavior (as to R&D intensity) | This group contains firms for which the business activity indicator of the respective 3-digit industry and the R&D intensity change during a certain period in the *same* direction (both variables either increase or decrease) |
| 2a: pro-cyclical behavior/negative | This sub-group contains firms that behave pro-cyclical only for *negative* changes. This means that the R&D intensity decreases when the business activity indicator falls, but the R&D intensity does not increase when the business activity indicator rises. |
| 2b: pro-cyclical behavior/positive | This sub-group contains firms that behave pro-cyclical only for *positive* changes. This means that the R&D intensity increases when the business activity indicator rises, but the R&D intensity does not decrease when the business activity indicator falls. |
| 1: anti-cyclical behavior | This group contains firms for which the business activity indicator of the respective three-digit industry and the R&D intensity change during a certain period in the *opposite* direction (R&D intensity increases when the business activity indicator falls and the other way around). |
| Independent variables | |

(continued)

**Table 1** Continued

| Variables | Definition |
|---|---|
| Innovation-relevant characteristics: | |
| R&D/S | R&D intensity: R&D expenditures divided by sales |
| D | Assessment of the demand development in the past 3 years; five-level ordinal variable (1: “very weak”; 5: “very strong”) |
| FIN | Shortage of own funds; five-level ordinal variable (1: “not important”; 5: “very important”) |
| SHORT_RD | Shortage of R&D personnel; five-level ordinal variable (1: “not important”; 5: “very important”) |
| LLCOST_L | Natural logarithm of labor costs per employee |
| EXT_NET | R&D cooperation and/or contract (external) R&D (dummy variable) |
| UNIV | R&D cooperation with universities (dummy variable) |
| VERT | R&D cooperation with suppliers and/or clients (dummy variable) |
| GROUP | R&D cooperation with firms of the same group (dummy variable) |
| COMP | R&D cooperation with competitors (dummy variable) |
| IPC | Intensity of price competition; five-level ordinal variable (1: “very weak”; 5: “very strong”) |
| INPC | Intensity of non-price competition; five-level ordinal variable (1: “very weak”; 5: “very strong”). Non-price competition includes product differentiation, frequent introduction of new products, technical advance, high awareness of client needs, additional supply of services |
| FSIZE | Number of employees (in full-time equivalents) |
| HIGHTECH | Dummy variable for high-tech manufacturing (see Hatzichronoglou 1997): chemicals (NACE classification: 24), plastics (25), machinery (29), transportation vehicles (34, 35), electrical machinery (31), electronics/instruments (30, 32, 331–334) |
| TDUM_05 | Dummy variable for the year 2005 |

## 4. Empirical setting

### *4.1 Dependent variables*

We classified firms according to their R&D behavior when the level of business activity changes cyclically.[5] We distinguished three basic behavior categories: non-systematic, pro-cyclical, and anti-cyclical behavior. The group of pro-cyclically behaving firms was further broken down in two sub-categories of *asymmetric* pro-cyclical behavior: firms reacting pro-cyclically only when the economic situation (according to the business activity indicator; see Table 1) is improving (pro-cyclical positive) and firms reacting pro-cyclically only when the economic situation is deteriorating (pro-cyclical negative). Each firm in the sample was placed in one of these categories. We used the changes of R&D intensity (R&D expenditures divided by sales) as the criterion for distinguishing pro-cyclical, anti-cyclical, and non-systematic behavior. An increase of R&D intensity in boom phases or a decrease in recession phases was denoted as "pro-cyclical" behavior. A decrease in boom phases or an increase in recession phases was defined as "anti-cyclical" behavior. No change of R&D intensity over the business cycle (see Table 1 for the exact definition of "no change") was defined as "non-systematic" behavior. According to our definition, given that sales fluctuate—even if firm-specifically—with the business cycle, pro-cyclical behavior does not mean that R&D expenditures just increase or decrease with business cycle, but that they change stronger (in both directions) than sales. To take all hypothetically possible cases into consideration, in case that sales change in the opposite direction as the business cycle, R&D expenditures have to increase or decrease (less than sales) to get an increase of the R&D intensity in the boom phases and the other way around in recession phases. For anti-cyclical behavior R&D expenditures, similar arguments hold. At any rate, we need a *firm-specific* measure of R&D activity that fluctuates with the *industry-specific* measure of business cycle to be able to define cyclical behavior unequivocally.[6] The exact definition of the dependent variable is found in Table 1.

Based on this classification of cyclical behavior, we constructed two multinomial variables (DEP) that served as dependent variables of the empirical model: a first one that distinguishes three basic behavior categories (value 0: firms showing *only* non-systematic behavior; value 1: firms showing *only* anti-cyclical behavior; value 2: firms

[5] We have three single indicators (incoming orders, order backlog, and production) and one composite indicator for the business activities (business activities). To build these indicators, we calculated (like usually) the net total (difference) of the percentages of positive answers of firms and the percentages of negative answers of firms as to the relevant questions, e.g. "Did your incoming orders increase, decrease, or remain constant?"

[6] Hence, the use of the change of the value of R&D expenditures as criterion for distinguishing firm behavior over the business cycle would be arbitrary. We thank an anonymous referee for his/her remarks that helped us to clarify this point.

showing *only* pro-cyclical behavior) and a second one that takes additionally into consideration a refinement of pro-cyclical behavior (value 0 and 1 are defined as aforementioned; value 2a: asymmetric *positive*; and value 2b: asymmetric *negative* pro-cyclical behavior).

## *4.2 Independent variables*

We regressed the two multinomial variables against a vector of independent variables that allow testing the hypotheses (a) to (f) in Section 2 (see Table 1). The variable D measures past demand development; a positive sign of this variable in the estimates for anti-cyclically behaving firms is a hint that demand development might increase the financial opportunities of firms and hence enable them to invest anti-cyclically (*hypothesis a*). Additional evidence in favor of *hypothesis a* would yield a negative relationship of the variable FIN,[7] showing that lack of own financial resources can be a considerable hindrance of anti-cyclical investment in R&D. Moreover, we expect larger firms (variable FSIZE) to be able to finance R&D internally at a larger extent as smaller firms, with the consequence that they can better use opportunity costs and invest anti-cyclically in R&D (*hypothesis b*). Further, we expect anti-cyclically investing firms to use more external (innovation-relevant) knowledge (*hypothesis c*) and invest more in R&D as pro-cyclically behaving firms (*hypothesis d*). Thus, for pro-cyclically behaving firms, a positive sign of the variable EXT (or alternatively of any of the variables UNIV, VERT, GROUP, or COMP referring to different types of R&D cooperation partners) and a positive sign of the R&D/S variable, respectively, is to be interpreted as evidence supporting *hypothesis (c)* and *hypothesis (d)*, respectively.

Firms with high labor costs per employee are likely to invest pro-cyclically. Thus, we expect a positive sign of the variable LLCOST_L in the estimates for pro-cyclically behaving firms (*hypothesis e*). Firms operating under conditions of high price pressure are likely to behave pro-cyclically with respect to R&D intensity (*hypothesis f*). Thus, a positive sign of the variable IPC in the estimates for pro-cyclically behaving firms can be interpreted as evidence in favor of *hypothesis (f)*. We also include in our model a further competition variable referring to the non-price dimensions of competition (variable INPC), for which we expect the opposite sign as for price competition.[8] We also include in our model controls for the high-tech sector and the year, in which the survey has taken place.

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[7] In the questionnaire, we asked whether a firm lacks own funds for innovation activities. The firm could give an answer based on a five-point Likert-scale (1: 'not important'; 5: 'very important').

[8] IPC measures the intensity of price competition in the main sales market of a firm based on a five-point Likert scale. The question goes as follows: "Assess the intensity of competition in your main sales market according to prices and according to non-price competition dimensions (product differentiation, frequent introduction of new products, flexibility in serving customers wishes, services, technical advance)."

In sum, we estimate the following equations:

$$\begin{aligned} DEP_{it} = {} & \beta_0 + \beta_1 R\&D/S_{it-1} + \beta_2 D_{it-1} + \beta_3 FIN_{it-1} + \beta_4 LLCOST\_L_{it-1} \\ & + \beta_5 SHORT\_RD_{it-1} + \beta_6 EXT\_NET_{it-1} + \beta_7 IPC_{it-1} + \beta_8 INPC_{it-1} \\ & + \beta_9 FSIZE_{it-1} + \beta_{10} HIGHTECH_i + \beta_{11} TDUM\_05_i + e_{it} \end{aligned} \quad (1)$$

$$\begin{aligned} DEP_{it} = {} & \beta_0 + \beta_1 R\&D/S_{it-1} + \beta_2 D_{it-1} + \beta_3 FIN_{it-1} + \beta_4 LLCOST\_L_{it-1} \\ & + \beta_5 SHORT\_RD_{it-1} + \beta_6 UNIV_{it-1} + \beta_8 VERT_{it-1} \\ & + \beta_9 GROUP_{it-1} + \beta_{10} COMP_{it-1} + \beta_{11} IPC_{it-1} + \beta_{12} INPC_{it-1} \\ & + \beta_{13} FSIZE_{it-1} + \beta_{14} HIGHTECH_i + \beta_{15} TDUM\_05_i + e_{it} \end{aligned} \quad (2)$$

$DEP_{it} = \varepsilon(0,1,2)$
*or*
$DEP_{it} = \varepsilon(0,1,2a,2b)$
DEP is the multinomial dependent variable (exclusive categories) that predetermines also the econometric method to be used. We applied a multinomial probit estimator ("mprobit" procedure in STATA), at which the independent variables are lagged one period. Hence, we are estimating the relationship between the DEP (measuring how R&D intensity responses to business cycle fluctuation) in a certain period t and the firm characteristics in the period t-1. This setting prevents that our estimations are driven by endogeneity of R&D/S (reverse causality).[9] Furthermore, following Greene (2003: 727), the IIA (independence of irrelevant alternatives) rule does not apply, as we use the multinomial probit estimator.[10]

## 5. R&D and business cycle development in Swiss manufacturing 1999–2009: The main facts

The three business indicators (incoming orders, order backlog, and production) as well as the composite indicator for economic activity in the Swiss manufacturing sector in the period 1999–2009 show a strong cyclical pattern with two peaks in 2000 and 2007, respectively, and two troughs in 2002 and 2009, respectively (Figure 1). Almost all of the 30 three-digit industries considered in this study show a similar cyclical pattern. There are some exceptions (e.g. pharmaceutical industry), but they are too few to affect the overall picture.

[9] Other types of endogeneity (omitted variable bias) cannot be adequately addressed owing to the lack of instruments.

[10] We also applied a random effects multinomial logit estimator. The results are similar. However, the random effects multinomial logit model does not fulfil the IIA (independence of irrelevant alternatives) assumption.

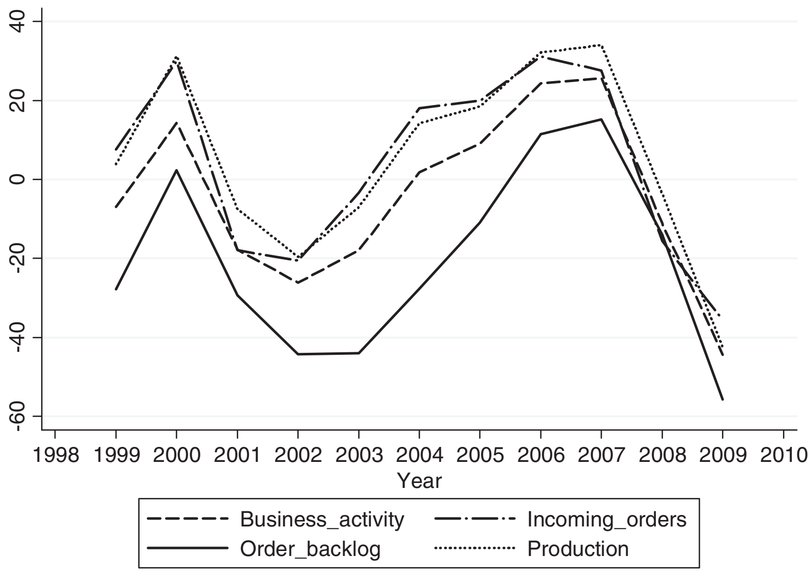


**Figure 1** Business indicators 1999–2009. Vertical axis shows the net total (difference) of percentages of firms that answered positive to the respective question (e.g. "Did your incoming orders increase, decrease or remain constant?") and percentage of firms that answered negative.

Table 2 shows the shares of firms that behave differently with respect to R&D investment when the overall business conditions change (see Table 1 for the definition of pro-cyclical, anti-cyclical, and non-systematic behavior). About 42% of all firms with R&D activities behave pro-cyclically, only 17% behave anti-cyclically, and the rest (~40%) shows no systematic behavior with respect to cyclicality. Pro-cyclically reacting firms show an asymmetric behavior. In all, 83% of them react only to *positive* changes of the overall business conditions, 17% only to *negative* changes of the overall economic activity. Economically relevant is the fact that there is considerable behavior variety (heterogeneity) in our sample that allows testing alternative hypotheses.

Table 3 shows the distribution of the various behavior categories by industry. In every industry, we found more pro-cyclical behaving than anti-cyclical behaving firms. But there are four industries, in which the group of firms with "non-systematic" behavior is the largest one: wood processing, printing, metal working, and other manufacturing, all four of them rather low-tech industries with a low R&D intensity. In two more industries are the groups of firms with "non-systematic" behavior and pro-cyclical behavior about of the same magnitude: food and glass, stone, clay, and also industries with a low R&D intensity. Finally, machinery and electronics/instruments, two of the most innovative industries in Switzerland, show relatively high

**Table 2** Business cycle and firm behavior with respect to R&D intensity

| Behavior | | *N* | Percentage share |
|---|---|---|---|
| Non-systematic | | 396 | 40.41 |
| Anti-cyclical | | 171 | 17.45 |
| Pro-cyclical | Pro-cyclical/negative | 72 | 7.35 |
| | Pro-cyclical/positive | 341 | 34.80 |
| Total | | 980 | 100 |

The calculation of the differences between the periods 2000–2002 and 2003–2005 and between 2003–2005 and 2006–2008, respectively, are based on data for 457 firms and 523 firms, respectively. See Table 1 for the definition of the variables.

**Table 3** Firms with pro-cyclical, anti-cyclical, or non-systematic behavior as to R&D intensity by industry (number of observations 2002, 2005)

| Industry | Non-systematic | Anti-cyclical | Pro-cyclical | | Total |
|---|---|---|---|---|---|
| | | | Pro-cyclical negative | Pro-cyclical positive | |
| Food, beverage, tobacco | 36 | 6 | 10 | 28 | 80 |
| Textiles | 7 | 9 | 0 | 16 | 32 |
| Clothing | 2 | 2 | 0 | 2 | 6 |
| Wood processing | 19 | 5 | 0 | 14 | 38 |
| Paper | 8 | 3 | 0 | 11 | 22 |
| Printing | 37 | 5 | 7 | 20 | 69 |
| Chemicals | 7 | 19 | 0 | 36 | 62 |
| Plastics, rubber | 38 | 4 | 0 | 10 | 52 |
| Glass, stone, clay | 22 | 7 | 0 | 15 | 44 |
| Metal | 7 | 4 | 0 | 6 | 17 |
| Metal working | 93 | 7 | 2 | 45 | 147 |
| Machinery | 54 | 37 | 34 | 60 | 185 |
| Electrical machinery | 11 | 15 | 0 | 18 | 44 |
| Electronics, instruments | 65 | 52 | 34 | 78 | 229 |
| Transportation vehicles | 6 | 3 | 1 | 3 | 13 |
| Other manufacturing | 19 | 3 | 0 | 8 | 30 |
| Total | 396 | 171 | 72 | 341 | 980 |

See Table 1 for the definition of the variables.

shares of firms with that react pro-cyclically only to negative changes of economic conditions.

## 6. Empirical results

### 6.1 Some descriptive results

Table 4 shows how the most important innovation-relevant characteristics used in this study are distributed among the three main categories of cyclical behavior and the two sub-groups of pro-cyclically behaving firms. Both price and non-price pressure is experienced primarily by firms behaving non-systematically and those with negative-pro-cyclical behavior. The latter fact is in accordance with theoretical expectation. External contacts for knowledge acquisition are more frequent for positive-pro-cyclically behaving firms than for anti-cyclically operating firms (i.e. contrary to theoretical expectation), but they are more frequent for anti-cyclically behaving firms than for those operating negative-anti-cyclically (i.e. in accordance to theoretical expectations). Thus, there is much behavior heterogeneity that has to be taken into account in the empirical analysis. A similar pattern as for the overall variable "external contacts" is found also for the single cooperation partners (universities, suppliers/clients, competitors, and firms of the same group).

### 6.2 Econometric results

The results in Table 5 (columns 2 and 4) show that in our sample, pro-cyclically behaving firms are more likely to pay higher wages (LCOST_L) and operate in markets with a high price pressure (IPC) than anti-cyclically behaving firms (reference group). Thus, the hypotheses (e) and (f) seem to be backed by the estimates. No differences between pro-cyclical and anti-cyclical behavior could be found with respect to non-price competition (INPC).

Further, we see that the likelihood of pro-cyclical behavior is related to lower R&D intensity (R&D/S), and a significantly drop in past demand development (D) is also more likely to be related to pro-cyclical rather than anti-cyclically firm behavior (see Filippetti and Archibugi, 2011). Looking at these results from the point of view of anti-cyclical behavior, it appears that the hypotheses (a) and (d), respectively, are confirmed.[11] No difference as to lack of internal financial resources (FIN) was found between pro-cyclical and anti-cyclically behaving firms. The lack of internal finance resources appears to be a problem rather for non-systematic than for anti-cyclical behavior. Hypothesis (d) receives only partly additional support by the results for the

[11] R&D has a "structural" component that tends to be rigid along the business cycle (equipment, ongoing long-term projects). However, our findings confirm hypothesis (d), which means that firms with a larger sales share of R&D investments are likely to invest anti-cyclically.

**Table 4** Firm characteristics that are relevant for innovation and anti-cyclical, pro-cyclical or non-systematic behavior as to the R&D intensity

| Firm characteristics | All firms | | Non-system. | Anti-cyclical | Pro-cyclical | |
|---|---|---|---|---|---|---|
| | | | | | Pro-cyclical negative | Pro-cyclical positive |
| (High) Intensity of non-price competition | 37.7 | of which | 34.7 | 21.1 | 9.8 | 34.4 |
| (High) Intensity of price competition | 76.3 | of which | 40.0 | 16.2 | 7.1 | 36.8 |
| External contacts (R&D cooperation and/or contract (external) R&D | 39.3 | of which | 18.4 | 28.3 | 13.0 | 40.3 |
| R&D cooperation with universities | 12.3 | of which | 15.8 | 28.3 | 10.8 | 45.0 |
| R&D cooperation with suppliers and/or clients | 16.5 | of which | 17.4 | 29.8 | 10.6 | 42.2 |
| R&D cooperation with firms of the same group | 12.0 | of which | 15.4 | 33.3 | 11.1 | 40.2 |
| R&D cooperation with competitors | 6.0 | of which | 20.3 | 27.1 | 5.1 | 47.5 |

See Table 1 for the definition of the variables. The table can be read as follows: In line 1, 37.7% of all firms are exposed to a high intensity of non-price competition. Of these 37.7%, 34.7% show a non-systematic behavior, 21.1% show a systematic behavior, and 44.2% show a pro-cyclical behavior (9.8% show a pro-cyclical negative behavior and 34.4% show a pro-cyclical positive behavior).

**Table 5** Innovation-relevant characteristics of firms with pro-cyclical, anti-cyclical or non-systematic behavior with respect to R&D intensity; manufacturing; 2000–2008

| Variable | 0: non-systematic | 2: pro-cyclical | 0: non-systematic | 2: pro-cyclical |
|---|---|---|---|---|
| R&D/S | −22.347*** (3.109) | −6.013*** (1.823) | −27.000*** (3.166) | −6.543*** (1.812) |
| D | −0.093 (0.071) | −0.174*** (0.068) | −0.120* (0.071) | −0.189*** (0.069) |
| FIN | 0.103* (0.062) | 0.016 (0.059) | 0.123** (0.062) | 0.025 (0.059) |
| LLCOST_L | 0.208 (0.258) | 0.428* (0.244) | 0.044 (0.257) | 0.413* (0.245) |
| SHORT_RD | −0.041 (0.066) | 0.042 (0.062) | −0.062 (0.065) | 0.045 (0.062) |
| EXT_NET | −1.015*** (0.174) | −0.102 (0.160) | | |
| UNIV | | | 0.574* (0.345) | 0.538* (0.292) |
| VERT | | | −0.215 (0.318) | −0.165 (0.270) |
| GROUP | | | −0.906*** (0.322) | −0.349 (0.266) |
| COMP | | | −0.278 (0.364) | −0.144 (0.302) |
| IPC | 0.159** (0.079) | 0.154** (0.075) | 0.147* (0.079) | 0.145** (0.075) |
| INPC | −0.094 (0.094) | 0.026 (0.089) | −0.137 (0.093) | 0.028 (0.088) |
| FSIZE | −0.115** (0.062) | −0.066 (0.058) | −0.170*** (0.062) | −0.065 (0.058) |
| HIGHTECH | −0.428*** (0.161) | −0.131 (0.154) | −0.431*** (0.161) | −0.132 (0.155) |
| TDUM_05 | −0.713*** (0.156) | 0.712*** (0.147) | −0.693*** (0.155) | 0.727*** (0.148) |
| Constant | −0.130 (2.889) | −4.272 (2.735) | 1.991*** (2.867) | −4.104 (2.743) |
| *N* | 980 | | 977 | |
| Wald chi2 | 281.6*** | | 260.2*** | |
| Log L | −830.6 | | −841.8 | |
| Pseudo R2 | 0.004 | | 0.006 | |

Multinomial probit estimates; reference group: 1: anti-cyclical.

***, **, and * denote statistical significance at the 1%, 5%, or 10% test level, respectively.

The results are based on data for 457 firms and 523 firms for the periods 2000–2002 and 2003–2005 and 2003–2005 and 2006–2008, respectively.

variable FIN. The variable SHORT_RD did not show any effect in all estimates in Tables 5 and 6.

We do not find any difference between anti-cyclical and pro-cyclical behavior with respect to firm size (FSIZE). Larger firms do not seem to be stronger inclined to anti-cyclical behavior than smaller ones, as it is postulated in hypothesis (b). However, this hypothesis receives some support when anti-cyclical behavior is compared with non-systematic behavior (column 1): the likelihood of behaving non-systematically is negatively correlated with firm size or the other way around the likelihood of anti-cyclical behavior is positively correlated with firm size.

According to hypothesis (c), it is expected that the acquisition of external knowledge (EXT_NET) is a characteristic for anti-cyclical investment behavior of firms.

**Table 6** Additional refinements: innovation-relevant characteristics of firms with pro-cyclical, anti-cyclical, or non-systematic behavior with respect to R&D intensity; manufacturing; 2000–2008

| Variable | 0: non-systematic | 2a: pro-cyclical-negative | 2b: pro-cyclical-positive | 0: non-systematic | 2a: pro-cyclical-negative | 2b: pro-cyclical-positive |
|---|---|---|---|---|---|---|
| R&D/S | −21.618*** (3.118) | 6.379** (2.873) | −13.378*** (2.457) | −26.000*** (3.152) | 8.434** (3.124) | −14.159*** (2.371) |
| D | −0.087 (0.071) | −0.174* (0.097) | −0.162** (0.072) | −0.112 (0.071) | −0.181* (0.099) | −0.178** (0.073) |
| FIN | 0.095 (0.062) | 0.058 (0.091) | −0.003 (0.063) | 0.113* (0.062) | 0.063 (0.092) | 0.004 (0.063) |
| LLCOST_L | 0.175 (0.258) | 1.135*** (0.430) | 0.309 (0.255) | 0.008 (0.257) | 1.140*** (0.439) | 0.272 (0.257) |
| SHORT_RD | −0.036 (0.066) | −0.078 (0.098) | 0.065 (0.065) | −0.056 (0.062) | −0.104 (0.101) | 0.075 (0.066) |
| EXT_NET | −0.995*** (0.173) | 0.019 (0.245) | −0.093 (0.172) | | | |
| UNIV | | | | 0.588* (0.345) | −0.242 (0.467) | 0.695** (0.316) |
| VERT | | | | −0.275 (0.317) | 0.088 (0.426) | −0.291 (0.295) |
| GROUP | | | | −0.866*** (0.322) | −0.284 (0.418) | −0.298 (0.290) |
| COMP | | | | −0.210 (0.364) | −1.245*** (0.566) | 0.174 (0.318) |
| IPC | 0.154** (0.079) | −0.144 (0.121) | 0.211*** (0.079) | 0.146* (0.078) | 0.240 (0.178) | 0.210*** (0.079) |
| INPC | −0.109 (0.095) | 0.209 (0.178) | −0.025 (0.092) | −0.149 (0.094) | −0.155 (0.122) | −0.023 (0.092) |
| FSIZE | −0.107* (0.062) | −0.005 (0.090) | −0.060 (0.062) | −0.163*** (0.062) | 0.038 (0.093) | −0.067 (0.062) |
| HIGHTECH | −0.434*** (0.161) | −0.076 (0.241) | −0.128 (0.161) | −0.440*** (0.160) | 0.024 (0.246) | −0.149 (0.163) |
| TDUM_05 | −0.534*** (0.157) | −14.020 (3.9E+06) | 1.393*** (0.162) | −0.519*** (0.156) | −15.896 (2.9E+07) | 1.423*** (0.163) |
| Constant | −0.187 (2.888) | −12.683*** (4.805) | −3.587 (2.863) | 2.313 (2.871) | −12.884*** (4.899) | −3.184 (2.884) |
| *N* | 980 | | | 977 | | |
| Wald chi2 | 382.8*** | | | 382.8*** | | |
| Log L | −884.0 | | | −888.7 | | |
| Pseudo R2 | 0.007 | | | 0.010 | | |

Multinomial probit estimates; reference group: 1: anti-cyclical.

***, **, and * denote statistical significance at the 1%, 5%, or 10% test level, respectively.

The results are based on data for 457 firms and 523 firms for the periods 2000–2002 and 2003–2005 and 2003–2005 and 2006–2008, respectively.

This is the case only when anti-cyclical behavior is compared with non-systematic behavior, but not when compared with anti-cyclical behavior. Hence, hypothesis (c) is only partly confirmed. There is some rather weak evidence that pro-cyclical and no-systematic behavior is related to the use of university knowledge (columns 3 and 4 in Table 5), which is contrary to hypothesis (c). The more refined results in Table 6, column 6, show that the university knowledge effect holds primarily for the positive-pro-cyclically behaving firms (see later in the text). The negative effect of EXT_NET is traced back to the use of knowledge from firms of the same firm group or firm conglomerate (GROUP).

Finally, firms in the high-tech sector of the manufacturing sector (HIGHTECH) are more likely to be found among anti-cyclically behaving firms than among non-systematically behaving firms, but no difference with respect to the affiliation to the high-tech sector was found between anti-cyclically and pro-cyclically behaving firms. The likelihood of behaving pro-cyclically has been significantly higher in the period beginning with 2005 than in the earlier period beginning with 2002, when compared with anti-cyclical behavior.

Some additional insights are gained when pro-cyclical behavior is broken down to positive-pro-cyclical behavior for firms reacting pro-cyclically only when the economic situation is improving (boom) and negative-pro-cyclical behavior for firms reacting pro-cyclically only when the economic situation is deteriorating (trough). The results in Table 6 show that the effects of demand development and R&D intensity are found for both sub-categories of pro-cyclical behavior. Thus, the hypotheses (a) and (d) are holding on a wide basis. The effect of high labor costs per employee (LLCOST_L) comes primarily from firms with a negative-pro-cyclical behavior, and the price competition effect (IPC) is traced back primarily to the positive-pro-cyclical behaving firms. Hence, these results lead to a (data-driven) refinement of the hypotheses (e) and (f), each of them holding for a specific subgroup of pro-cyclically behaving firms.

The more detailed results for various R&D cooperation partners in Table 6 (columns 5 and 6) show—as already aforementioned—a positive university knowledge effect for positive-pro-cyclically behaving firms as compared with anti-cyclically behaving firms that is contrary to theoretical expectations. Thus, the flexibility effect of R&D cooperation as postulated in hypothesis (c) does not hold for the cooperation with universities. A further result is the negative effect of horizontal R&D cooperation, which is in accordance with theoretical expectations, but it did not show with the overall variable for external knowledge EXT_NET (see Table 5, column 3).

In Table A4, we investigate R&D/S, which is an important factor for the cyclical behavior of firms, in greater detail. The results in Table 5 show a positive correlation between R&D/S and the probability for anti-cyclical R&D investments. The predicted probability of R&D/S yields some interesting further insights. The probability of anti-cyclical behavior increases steadily with increased values for R&D/S. For instance, holding other variables at their mean values, the probability of showing an anti-cyclical behavior amounts to 17%, if a firm invests 2% of its sales in R&D. If R&D/S increases to 6%, the probability for anti-cyclical behavior increases to 27%; with an R&D/S of 24%, the probability increases to 67%. Further, Table A4 shows that the probability of having non-systematic R&D investment behavior or a pro-cyclical R&D investment behavior decreases with increasing R&D/S rates. It is remarkable that the probabilities for pro-cyclical behavior start to decrease with a rather high R&D/S investment rate of 10%.

## 7. Conclusions

New elements of our analysis are as follows: (i) the identification in our data of three main types of R&D investment behavior, namely, anti-cyclical, pro-cyclical, and non-systematic with respect to the fluctuation of overall economic activity as measured by a standard composite indicator of the business conditions at industry level and (ii) the investigation of a series of hypotheses as to innovation-relevant firm characteristics that underline the three different behavior categories.

About 42% of all firms with R&D activities behave pro-cyclically, only 17% behave anti-cyclically, and the rest (~40%) shows no systematic behavior with respect to cyclicality. Economically relevant is the fact that there is considerable behavior variety in our sample that allows testing alternative hypotheses.

To this end, we analyzed a number of factors that have a pro-cyclical or anti-cyclical effect on R&D investments or innovative behavior. In sum, we found that firms can benefit from low opportunity costs through anti-cyclical R&D investments if: (i) they are confronted with stronger demand effects (compared with anti-cyclical behavior; hypothesis a); (ii) they have a relatively large sales share of R&D expenditures (hypothesis d); (iii) they have external R&D relationships (only compared with non-systematic behavior, thus only partial confirmation of hypothesis c); (iv) they have rather low average labor costs (compared with pro-cyclical behavior; hypothesis f); (v) they are not exposed to intensive price competition (e.g. because they operate in international market niches; hypothesis e); (vi) they are relatively large (hypothesis b); and (vii) they belong to high-tech industries. An additional characteristic of anti-cyclical behaving firms is that compared with pro-cyclical firms, particularly positive-pro-cyclically operating firms, they are less frequently cooperating with universities.

From a policy point of view, the results indicate that innovation policy can contribute to mitigate the cyclical fluctuation of R&D investments through considering the just mentioned factors in their promotion activities. For the specific case of R&D expenditures, we learnt that the predicted probability of an anti-cyclical behavior considerably increases at relatively high levels of sales share of R&D investments. In sum, an anti-cyclical R&D investment behavior would not only help firms make use of lower opportunity costs at recessions but also contribute to dampen the overall business fluctuation.

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## Appendix

**Table A1** Descriptive statistics

| Variable | *N* | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| D | 980 | 2.993 | 1.093 | 1 | 5 |
| FIN | 980 | 2.389 | 1.320 | 1 | 5 |
| SHORT_D | 980 | 2.240 | 1.198 | 1 | 5 |
| LLCOST_L | 980 | 11.270 | 0.313 | 8.517 | 12.432 |
| FSIZE | 980 | 4.095 | 1.364 | 0 | 8.882 |
| INPC | 980 | 3.169 | 0.855 | 1 | 5 |
| IPC | 980 | 4.049 | 0.963 | 1 | 5 |
| EXT | 980 | 0.393 | 0.489 | 0 | 1 |
| R&D/S | 980 | 0.018 | 0.038 | 0 | 0.498 |
| UNIV | 977 | 0.123 | 0.328 | 0 | 1 |
| VERT | 977 | 0.165 | 0.371 | 0 | 1 |
| GROUP | 977 | 0.120 | 0.325 | 0 | 1 |
| COMP | 977 | 0.060 | 0.238 | 0 | 1 |

**Table A2** Categorical variables and share of observations

| Variable | Proportion | Standard error | 95% confidence interval |
|---|---|---|---|
| D | | | |
| 1 | 0.097 | 0.009 | 0.078–0.115 |
| 2 | 0.240 | 0.014 | 0.213–0.267 |
| 3 | 0.306 | 0.015 | 0.277–0.335 |
| 4 | 0.288 | 0.014 | 0.259–0.316 |
| 5 | 0.069 | 0.008 | 0.053–0.085 |
| FIN | | | |
| 1 | 0.355 | 0.015 | 0.325–0.385 |
| 2 | 0.219 | 0.013 | 0.193–0.245 |
| 3 | 0.186 | 0.012 | 0.161–0.210 |
| 4 | 0.161 | 0.012 | 0.138–0.184 |
| 5 | 0.079 | 0.009 | 0.062–0.095 |
| SHORT_D | | | |
| 1 | 0.372 | 0.015 | 0.342–0.403 |
| 2 | 0.232 | 0.013 | 0.205–0.258 |
| 3 | 0.216 | 0.013 | 0.191–0.242 |
| 4 | 0.143 | 0.011 | 0.121–0.165 |
| 5 | 0.037 | 0.006 | 0.025–0.049 |
| INPC | | | |
| 1 | 0.037 | 0.006 | 0.025–0.049 |
| 2 | 0.154 | 0.012 | 0.131–0.177 |
| 3 | 0.433 | 0.016 | 0.402–0.464 |
| 4 | 0.329 | 0.015 | 0.299–0.358 |
| 5 | 0.048 | 0.007 | 0.035–0.061 |
| IPC | | | |
| 1 | 0.013 | 0.004 | 0.006–0.020 |
| 2 | 0.068 | 0.008 | 0.053–0.084 |
| 3 | 0.155 | 0.012 | 0.132–0.178 |
| 4 | 0.383 | 0.016 | 0.352–0.413 |
| 5 | 0.381 | 0.016 | 0.350–0.411 |

Number of observations 980.

**Table A3** Correlation matrix

| | D | FIN | SHORT_D | LLCOST_L | INPC | IPC | EXT | R&D/S | UNIV | VERT | GROUP | COMP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D | 1.000 | | | | | | | | | | | |
| FIN | −0.114 (0.000) | 1.000 | | | | | | | | | | |
| SHORT_D | 0.034 (0.286) | 0.168 (0.000) | 1.000 | | | | | | | | | |
| LLCOST_L | 0.059 (0.067) | −0.138 (0.000) | 0.010 (0.765) | 1.000 | | | | | | | | |
| INPC | 0.148 (0.000) | 0.009 (0.791) | 0.002 (0.940) | 0.010 (0.766) | 1.000 | | | | | | | |
| IPC | −0.041 (0.195) | 0.035 (0.276) | 0.045 (0.162) | 0.076 (0.017) | 0.004 (0.909) | 1.000 | | | | | | |
| EXT | 0.155 (0.000) | −0.114 (0.000) | 0.127 (0.000) | 0.190 (0.000) | 0.165 (0.000) | 0.022 (0.491) | 1.000 | | | | | |
| R&D/S | 0.088 (0.006) | 0.020 (0.538) | 0.084 (0.009) | 0.015 (0.640) | 0.024 (0.460) | −0.048 (0.136) | 0.346 (0.000) | 1.000 | | | | |
| UNIV | 0.118 (0.000) | −0.063 (0.048) | 0.047 (0.143) | 0.118 (0.000) | 0.070 (0.029) | 0.042 (0.189) | 0.466 (0.000) | 0.257 (0.000) | 1.000 | | | |
| VERT | 0.101 (0.002) | −0.052 (0.105) | 0.104 (0.001) | 0.132 (0.000) | 0.092 (0.004) | 0.011 (0.726) | 0.553 (0.000) | 0.252 (0.000) | 0.691 (0.000) | 1.000 | | |
| GROUP | 0.091 (0.005) | −0.073 (0.022) | 0.062 (0.051) | 0.103 (0.001) | 0.067 (0.035) | 0.017 (0.600) | 0.459 (0.000) | 0.176 (0.000) | 0.611 (0.000) | 0.635 (0.000) | 1.000 | |
| COMP | −0.018 (0.584) | −0.042 (0.186) | 0.021 (0.517) | 0.075 (0.019) | 0.060 (0.062) | 0.005 (0.884) | 0.315 (0.000) | 0.109 (0.001) | 0.342 (0.000) | 0.449 (0.000) | 0.281 (0.000) | 1.000 |

Significance levels in brackets.

**Table A4** Predicted probabilities for several R&D/S values

| R&D/S | Delta-method | | | |
|---|---|---|---|---|
| | Predicted probability | Standard error | $z$ | $P > z$ |
| OUTCOME 0 (non-systematic) | | | | |
| 0.20 | 0.380 | 0.015 | 24.89 | 0.000 |
| 0.60 | 0.223 | 0.030 | 7.48 | 0.000 |
| 1.00 | 0.109 | 0.033 | 3.29 | 0.001 |
| 1.40 | 0.042 | 0.023 | 1.81 | 0.070 |
| 1.60 | 0.013 | 0.011 | 1.12 | 0.262 |
| 2.00 | 0.003 | 0.004 | 0.75 | 0.453 |
| 2.40 | 0.000 | 0.001 | 0.53 | 0.594 |
| OUTCOME 1 (anti-cyclical firms) | | | | |
| 0.20 | 0.170 | 0.012 | 13.87 | 0.000 |
| 0.60 | 0.270 | 0.023 | 11.78 | 0.000 |
| 1.00 | 0.373 | 0.041 | 9.03 | 0.000 |
| 1.40 | 0.465 | 0.061 | 7.64 | 0.000 |
| 1.60 | 0.543 | 0.080 | 6.83 | 0.000 |
| 2.00 | 0.611 | 0.096 | 6.39 | 0.000 |
| 2.40 | 0.672 | 0.108 | 6.22 | 0.000 |
| OUTCOME 2 (pro-cyclical) | | | | |
| 0.20 | 0.450 | 0.016 | 28.67 | 0.000 |
| 0.60 | 0.506 | 0.028 | 18.24 | 0.000 |
| 1.00 | 0.519 | 0.043 | 12.17 | 0.000 |
| 1.40 | 0.493 | 0.060 | 8.18 | 0.000 |
| 1.60 | 0.444 | 0.079 | 5.63 | 0.000 |
| 2.00 | 0.386 | 0.095 | 4.05 | 0.000 |
| 2.40 | 0.328 | 0.108 | 3.04 | 0.002 |