NORGES HANDELSHØYSKOLE

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How does external technology sourcing affect internal R&D investments?

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NORGES HANDELSHØYSKOLE

Abstract

This thesis examines the relationship between internal R&D and external R&D contracting, as well as internal R&D and R&D collaboration for a comprehensive panel of Norwegian firms. Special emphasis is put on multinational firms with R&D ties with foreign affiliates within their enterprises. The data is drawn from the R&D and innovation surveys, conducted and provided by Statistics Norway. Estimating the effect of external R&D sources on internal R&D, we find that neither foreign R&D contracting nor foreign R&D cooperation within multinational enterprises affect internal R&D significantly. We find a substitutable relationship between these external R&D sources and internal R&D. Other external R&D sources are found to be positively related to internal R&D expenditures, and both complementary and substitutable relationships are found between these external R&D sources and internal R&D. We conclude that the need for absorptive capacity seems to be an underlying driver for the increase in internal R&D due to all forms of external R&D activity. Firms with multinational R&D ties seem to have high levels of internal R&D and absorptive capacity. As multinational R&D ties have substitutable properties with internal R&D, multinational R&D sourcing may lead to a displacement of domestic internal R&D activity.

Acknowledgement

We would like to thank our advisor Professor Jarle Møen for invaluable and enthusiastic guidance during the writing process. We are grateful to him for arousing our interest in R&D, help with provision of data, thorough feedback, and availability when problems arose. Finally we would like to thank Statistics Norway and Frank Foyn for access to the R&D and innovation surveys.

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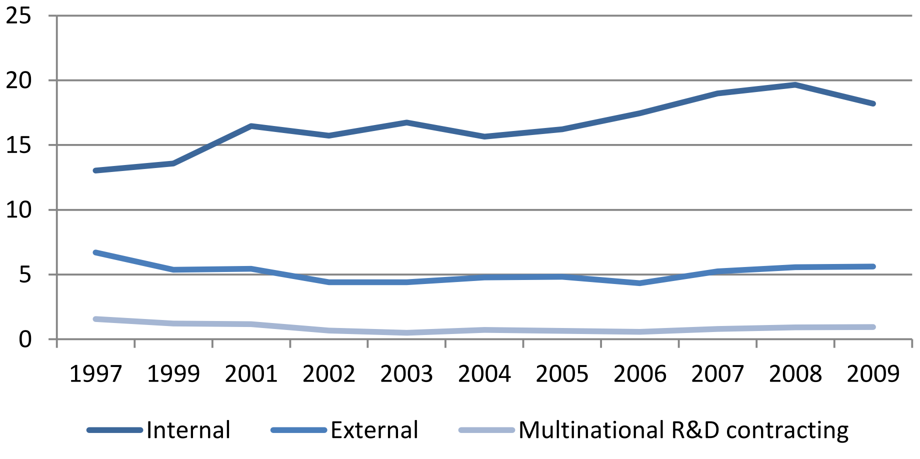
1. Introduction

1.1 Introduction

The growth of multinational enterprises in developed countries the recent decades and the following internationalization of R&D have attracted interest from academics as well as policy makers. The rise of foreign ownership shifts the strategic decision making from domestic to foreign headquarters, and may create uncertainty in future domestic employment and investment. On the other side, internationalization of R&D may increase technology sharing and dispersion, and hence promote domestic R&D investment, innovation and productivity growth.

During the last decade, internal R&D activity among Norwegian firms has increased slowly, while R&D contracting fluctuated slightly. Graph 1.1 shows an upward trend in internal R&D expenditures from 1997 to 2009. External R&D purchases were reduced in the first part of the decade, but rose slightly towards 2009. A similar pattern is seen for R&D purchased from foreign firms within the same enterprise, referred to as multinational R&D contracting..

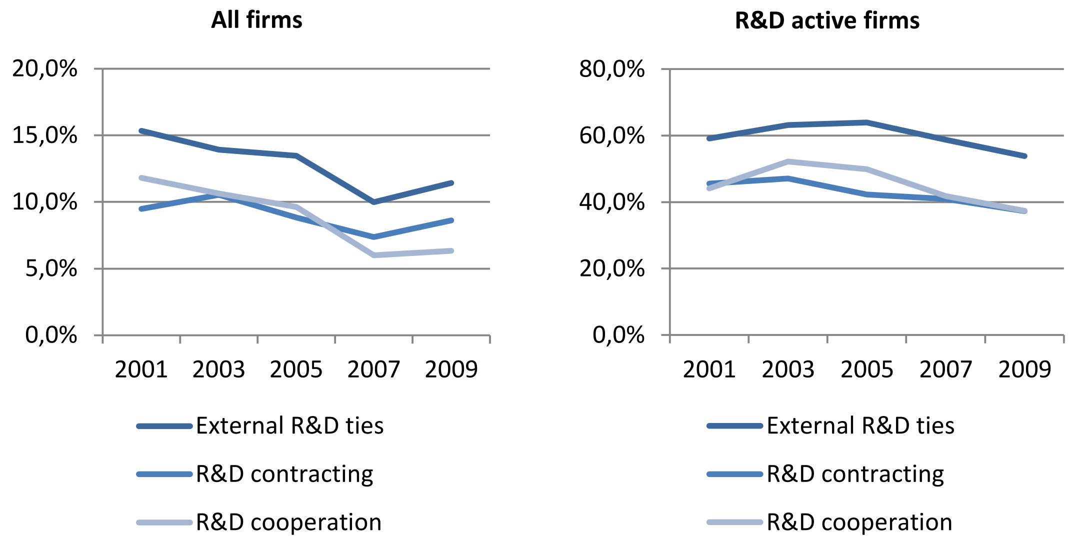
Figure 1.1: R&D expenditures. Bn. 2009NOK.



Source: R&D and innovation surveys, Statistics Norway. External multinational refers to R&D expenditures from foreign firms within the same enterprise. The survey covers all Norwegian firms with more than 50 employees, and a sample of firms with 10-49 employees. Aggregation based on weights provided by Statistics Norway. Deflation in accordance with price indices for R&D from “Indikatorrapporten”.

R&D ties with external partners seem important for R&D active firms. Around 60 percent of Norwegian multinational firms contract out R&D or cooperates in R&D, or both, seen in the right panel of figure 1.2. A small decrease in the frequency appears in the last part of the decade. For all firms, a slight reduction in the frequency of external R&D ties is seen in the left panel of same figure.

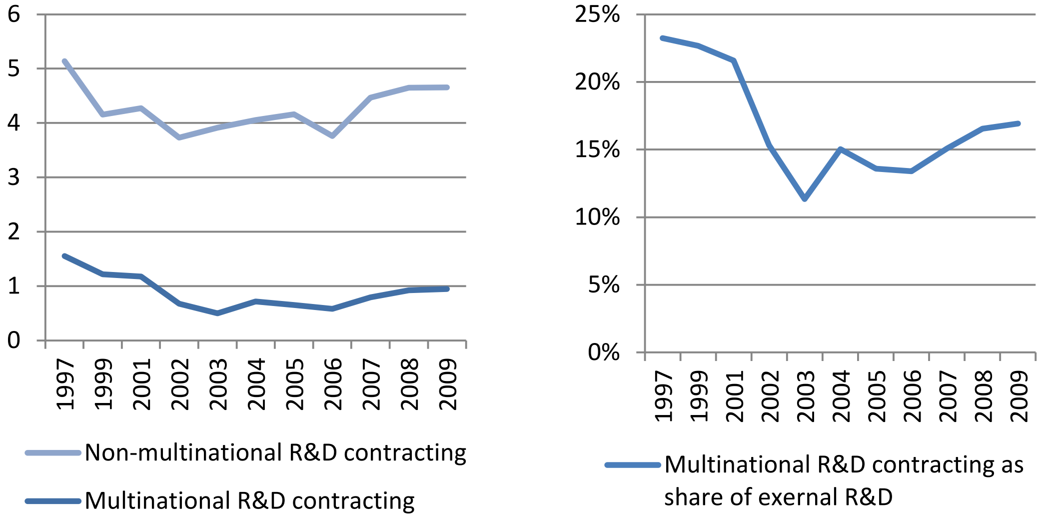
Figure 1.2: Frequency of firms with external R&D ties



Source: R&D and innovation surveys, Statistics Norway. External R&D contracting refers to buying R&D from externals. R&D cooperation refers to collaborate in R&D. R&D ties refers to either R&D contracting or cooperation, or both. The survey covers all Norwegian firms with more than 50 employees, and a sample of firms with 10-49 employees. Aggregation based on weights provided by Statistics Norway.

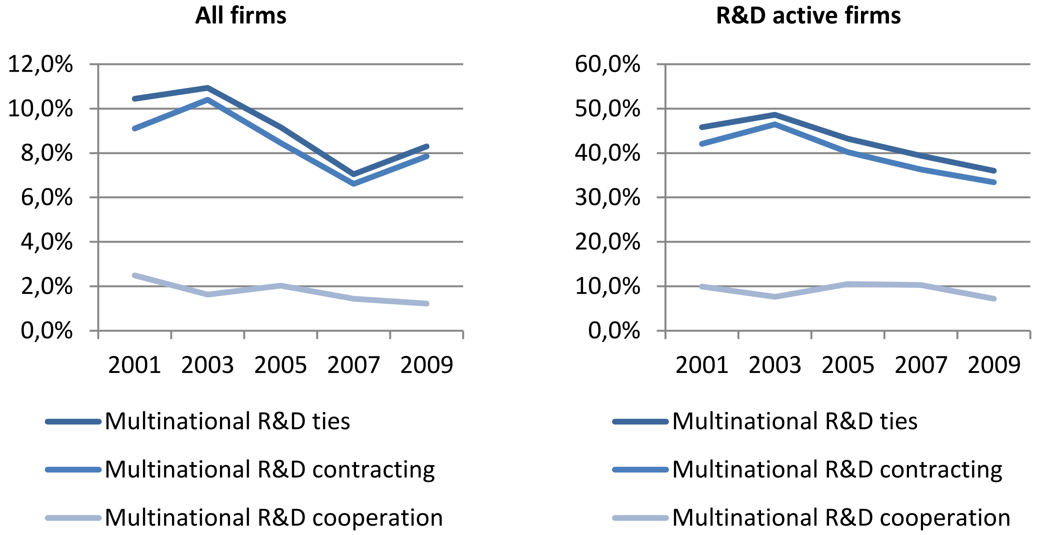
Multinational firms are thought to access foreign R&D easier. However, as figure 1.3 shows, for Norwegian multinationals there is no sign of increased inflow of foreign R&D through their multinational enterprises at the aggregate level. The Norwegian Government has established several programs in order to increase R&D activity in Norwegian firms. It also wants to attract foreign investment in R&D (St.meld. nr. 7 2008-2009:60). Firms with foreign ownership contribute a larger share of R&D expenditures. According to Statistics Norway (2009) R&D conducted by these firms constitute 30 percent of total R&D investments in Norway in 2007. Norwegian subsidiaries account for a considerable part – 30 percent – of total external R&D as well, but differ from other firms regarding sources of R&D with a more international orientation. Multinational subsidiaries have a higher propensity to acquire foreign R&D – from either within or outside the multinational enterprise – according to Statistics Norway (2009). Looking at foreign R&D acquisition from within multinational enterprises, R&D purchases from foreign firms within the same enterprise still constitute a considerable share of external R&D purchases for Norwegian firms. Figure 1.3 shows that this ratio decreased from around 23 percent in 1997 to 11 percent in 2003, before increasing slowly to 17 percent in 2009. The sharp reduction in the first part of last decade is due to a relatively larger reduction for R&D contracted out to foreign firms within the same enterprise than the reduction in R&D contracted out to other firms outside the multinational enterprise, as seen in figure 1.3. Figure 1.4 shows that firms with multinational R&D ties constituted between 11 and 7 percent of all firms, and around 40 percent of R&D active firms from 1997 to 2009. Multinational R&D collaboration seems to be far less frequent than contracting foreign R&D from same enterprise.

Figure 1.3 External R&D expenditures. Bn. 2009NOK.



Source: R&D and innovation surveys, Statistics Norway. Deflation in accordance with price indices for R&D from “Indikatorrapporten”. Multinational R&D contracting refers to R&D contracting with foreign firms within the same enterprise, while non-multinational R&D contracting refers to R&D contracting with other partners.

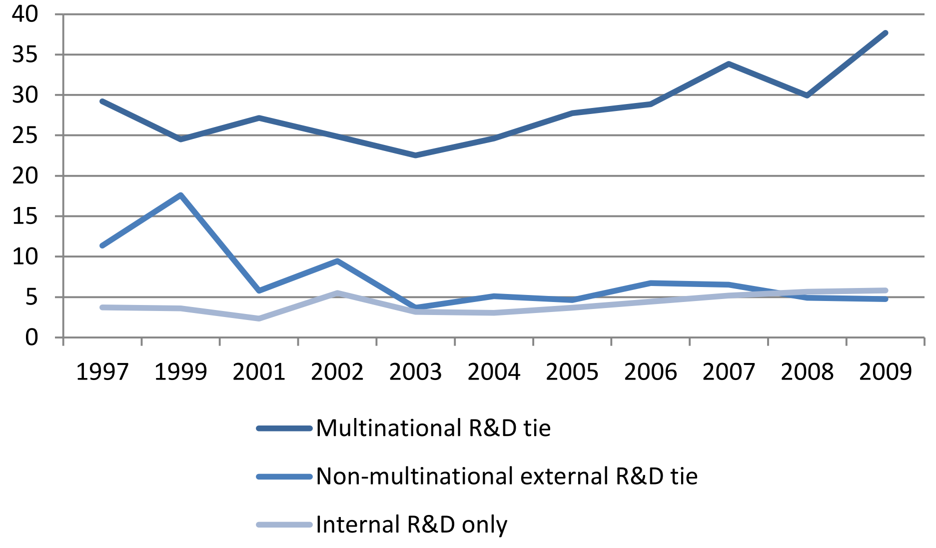
Figure 1.4: Frequency of firms with multinational R&D ties



Source: R&D and innovation surveys, Statistics Norway. Multinational R&D contracting refers to buying R&D from a foreign firm within the same enterprise. Multinational R&D contracting refers to collaborate in R&D with the same kind of firm. R&D ties refers to either multinational R&D contracting or cooperation, or both.

Firms with multinational R&D ties performs on average far more internal R&D than firms with other forms of external R&D ties, and firms only performing internal R&D. Figure 1.5 shows that firms with multinational R&D ties on average spent around 25 million NOK on internal R&D in the first half of last decade, and increased investments to 37 million NOK in 2009. Average internal R&D expenditures for firms with other forms of external R&D decreased around year 2000, then stabilized throughout the decade at approximately five million NOK per year. Average internal R&D expenditures for firms without external R&D ties fluctuated on levels somewhat below five million NOK. Norwegian subsidiaries are mainly represented among large and medium sized firms which perform more R&D than small firms according to Statistics Norway (2009). This may explain the large averages for firms with multinational R&D. However, the results are not surprising given the fact that large firms, of which a relatively large share is multinational, are found to contribute to the main share of R&D in Norway (Herstad and Nås, 2007).

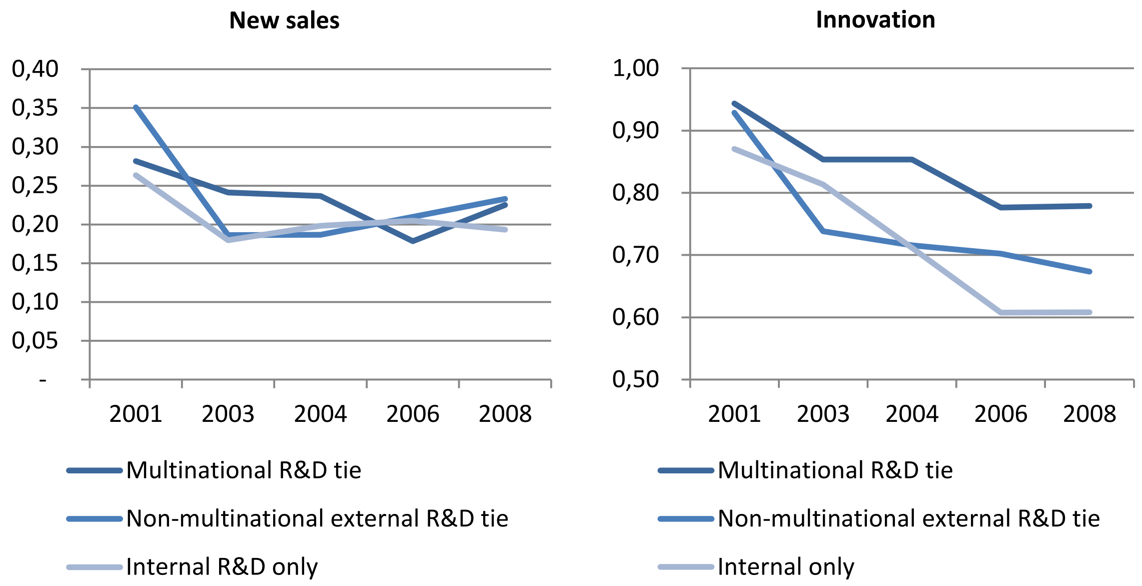
Figure 1.5: Average internal R&D expenditures. Mn. 2009NOK.



Source: R&D and innovation surveys, Statistics Norway. Multinational R&D tie refers to firms either purchasing R&D from, or collaborates in R&D with, a foreign firm within the same enterprise, or both. Non-multinational external R&D tie refers to either R&D purchasing or R&D cooperation with all other firms. Deflation in accordance with price indices for R&D from “Indikatorrapporten”.

Somewhat surprising, the descriptive statistics show only weak signs for firms with multinational R&D ties to be superior in innovativeness relative to firms with other forms of external R&D ties or firms who rely solely on conducting internal R&D. Norwegian multinationals hold an advantage in R&D by their internal access to foreign knowledge and technology within their enterprise. One should therefore expect these to be more innovative than other firms. Figure 1.6 gives no such indication when measuring innovativeness as the share of total sales attributable to new products, but a weak indication when innovativeness is measured as frequency of making process or product innovation. External R&D ties allow firms to gain access to a broader pool of resources and knowledge, possibly at a lower cost, and to share the risk of performing R&D with other R&D partners. Thus, one should expect firms with other external R&D ties to be more innovative than firms only conducting internal R&D. This does not seem to be the case for Norwegian firms as shown in figure 1.6.

Figure 1.6: Innovativeness



Source: R&D and innovation surveys, Statistics Norway. New sales refers to share of total sales attributed to new or significantly improved products the current or last two years. Innovation refers to whether or not the firm has made any process or product innovations the current or last two years. Multinational R&D tie refers to firms either purchasing R&D from, or collaborates in R&D with, a foreign firm within the same enterprise, or both. Non-multinational external R&D tie refers to either R&D purchasing or R&D cooperation with all other firms.

We examine the impact of acquiring external R&D on R&D investment in Norway. We put special emphasis on the acquisition of foreign R&D within multinational firms, and treat external R&D purchases and R&D cooperation separately. As described in the beginning of this section, internationalization of R&D by multinational enterprises may promote domestic R&D investment, innovation and productivity growth. Additional investments in internal R&D may be needed in order to absorb new technology and knowledge. Technology sharing and dispersion may improve and complement existing technology within the firms, also leading to increased investment in R&D. The high frequency and level of external R&D contracting in general should also promote technology sharing and dispersion for Norwegian firms. Hence, external R&D contracting may lead to a similar need for, and stimulus of, internal R&D investment. On the other hand, firms may use external R&D sources – from either within or outside the multinational enterprise – as a substitute for internal R&D activity. External R&D sourcing could therefore both increase and displace R&D activity in Norway.

1.2 Data

The data used in this thesis comes from R&D and innovation surveys conducted by Statistics Norway, with 49 990 observations covering R&D activity in 18,410 Norwegian firms in 1997, 1999 and 2001 – 2009. The questionnaire is answered by the majority of Norwegian firms, but the number of respondents varies from year to year[1]. The questions in the survey differ to some extent as well, however the questions of most interest are asked in all years. For our analysis we have removed all observations for firms with less than 10 employees, reducing the total number of observations to 46 792. This is in line with the guidelines proposed by SSB when working with the R&D and Innovation survey[2].

The question sheets are constructed in accordance with the data collection guidelines proposed by the Frascati-manual and the Oslo-manual. The Frascati-manual provides the basis for the part of the questionnaire concerning R&D, whereas the Oslo-manual dictates the questions relating to innovation activity.

A further presentation of the data and variables will be given in section 3.2 and 4.2.

1.3 Outline

The thesis is divided in five parts. The next section gives a summary of relevant theory and literature. In chapter 3 we investigate the effect of external R&D and R&D cooperation on internal R&D expenditures. Chapter 4 examines possible substitutability and

[1] R&D survey: All business units with 50 employees or more are asked to answer the survey in all years. For units with 10-49 employees, usually 35 % of the firms are drawn out to participate as well as units that were R&D active last survey. The data for 2006 and 2008 includes business units with 5 to 9 employees as well.
The innovation survey: All business units with 50 employees or more. In addition 35 % randomly drawn firms with 5 to 49 employees.

[2] http://www.ssb.no/foun/om.html

complementarity between internal R&D and external R&D expenditures, and internal R&D and R&D cooperation with respect to firm innovativeness. In the last section the main results will be discussed, summarized, and based on our findings conclusions will be drawn.

2. Literature: Determinants of R&D and innovation

A firm can acquire knowledge and technology skills either by conducting R&D itself or access R&D from external sources: R&D contracting; through merging or acquisition with R&D active firms; and through R&D cooperation with other firms. Determining how much to conduct internally, and how much – and from whom – to acquire externally, has been frequent subject in research. In this section, we give an outline of these determinants.

Mairesse and Mohnen (2010) give a brief outline of determinants of R&D. The effect of buying external R&D on internal R&D depends on whether the two are substitutes or complements. Substitutability is traditionally analyzed within the transaction cost framework. Complementarity became an object for R&D research first after the absorptive capacity was introduced as a concept. Market structure as determinant of R&D has been given attention in research since Schumpeter. Over the past twenty years, the effect of R&D spillovers and cooperation in R&D has also been given attention in the industrial organization economics.

2.1 Theoretics of Substitutability in R&D: The Transaction Cost Theory

The interaction between internal and external R&D was first analyzed within the framework of transaction cost theory. Under this approach, the choice of organizing R&D in the firm or buying R&D externally dependents on minimizing costs (rather than exploiting complementarities), which hence assumes substitutability between internal and external R&D[3].

[3] This is explicit in Coase (1937) who defines the determinants of the size of the firm (i.e. the tradeoff between internal organizing or external market contracting, and hence the mere existence of the firm): “It is hoped to show in the following paper that a definition of a firm may be obtained which is not only realistic in that it correspond to what is meant by a firm in the real world, but is tractable by two of the most powerful instruments of economic analysis developed by Marshall, the idea of the margin and that of substitution, together giving the idea of substitution at the margin” and “at the margin, the cost of organizing within the firm will be equal either to the costs of organizing in another firm or to the costs involved in leaving the transaction to be “organized” by the price mechanism.” Coase (1937: 386, 404)

In the process of inventing and developing new products, Williamson (1975: 177-207) describes the large firm in general as inferior to the small firm, due to organizational limits of the large firm[4]. The large firm should acquire inventions and developments from smaller firms through either external assignments or vertical integration, and thereafter finish the products for supply. Williamson (1975:205-206) favours in general vertical integration in order to overcome the potential problems of opportunistic behaviour and moral hazard between contractor and buyer. If contracting should limit the scope of opportunistic behaviour, the buyer must undertake precaution in specifying and governing the contract, especially when the transactions of innovations involve high uncertainty, are frequent and involve durable investments (Williamson 1979).

In a later paper, Williamson (1981) discusses the trade-off between buying external R&D in the market and making R&D internally, e.g. through vertical merger or acquisition. Markets enjoy certain advantages in both production and governance costs respects if the tradeable R&D is of nonspecific nature, i.e. not customized for the buyer: "Static scale economies can be more fully exhausted by buying instead of making; markets can also aggregate uncorrelated demands, thereby realizing risk-pooling benefits; and external procurement avoids many if the hazards to which internal procurement is subject", the latter referring to bureaucratic hazards (Williamson 1981: 558). On the other hand, when the tradeable R&D becomes more specific, the costs of contracting and governance for the buyer increase. Making R&D internally instead has certain advantages over the market: "First, common ownership reduces the incentives to suboptimize. Second, and related, internal organization is able to invoke fiat to resolve differences, whereas costly adjudication is needed when an impasse develops between autonomous traders. Third, internal organization has easier and more complete access to the relevant information when dispute settling is needed" (Williamson 1981: 559). Hence, for a certain level of specificity in R&D, the firm is superior to the market in procurement of R&D.

Transaction cost theory has two implications for R&D. First, the firm acquires non-specific R&D through external purchases and specific R&D through vertical merger or acquisition.

[4] The organizational limits of the large firm is attributed to large organizational and conservative bureaucratic rules which hinders the range of response to outer circumstances and innovation; limited access to venture capital; problems of providing appropriate incentives for entrepreneurs within the firm; and conflicts between parallel R&D projects (Williamson 1975: 199-203).

Second, if internal R&D is found to have positive and diminishing returns to scale, the assumption of substitutability in internal and external R&D in transaction cost theory involves that buying external R&D have negative effect of the marginal product of internal R&D.

Teece (1977) finds that enterprises which are more experienced in contracting out R&D experience lower technology transfer costs. He claims that international transfer of technology is most likely to be viable when production are of a certain scale, i.e. that it runs are long enough to allow for several R&D outsourcing contracts. These kinds of conclusions where later analyzed within the absorptive capacity framework.

2.2 Theoretics of Complementarity in R&D: Absorptive Capacity

Theory concerning absorptive capacity

The term absorptive capacity was introduced by Cohen and Levinthal (1989, 1990). Their findings suggest a dual role of R&D; R&D promotes innovation as well as playing an intermediate role in the diffusion of technology. They define absorptive capacity as a firm's ability to identify, assimilate and exploit knowledge from the environment. It relies heavily on the experience and knowledge accumulated in the firm, due to former operations and prior investments in R&D. As well as easing the learning process when conducting own R&D, the ability to identify and utilize technology originating outside the firm sets the premises for diffusion of technology and R&D cooperation. Rosenberg (1990) points out the ability to monitor research conducted elsewhere as an important determinant for firms performing basic research. Mowery and Oxley (1995) emphasize the importance of human capital, suggesting that absorptive capacity is the basic knowledge needed to deal with technology acquired outside the firm's own technology pool, whereas Zahra & George (2002) extends the concept of absorptive capacity even further, dividing the capacity in to potential and realized absorptive capacity. The potential ACAP of a firm consists of their ability to acquire and assimilate new technology, whereas the realized ACAP revolves around their ability to transform and exploit the new information. They suggest that the value created from own R&D depends on a firm's potential and realized ACAP; the potential capacity increases the firm's ability to make strategic changes and the realized capacity is what gives them a competitive advantage. See Zahra and George (2002) for a thorough review of literature and empirics concerning absorptive capacity.

Evidence for the importance of the dual role of R&D are found both at the organizational level (Cohen and Levinthal, 1990, Cockburn and Henderson, 1998), the national level (Keller, 1996) and at the industry level (Griffith et al, 2000), suggesting that the presence of intramural R&D facilitates innovation and technology transfer. Cockburn and Henderson emphasize the importance of connections with the scientific community, stating that conducting basic research within the firm is not sufficient, at least not in the pharmaceutical industry.

Examining the US pharmaceutical industry, Gambardella (1992) finds evidence supporting the importance of absorptive capacity. In his study he finds that the ability to utilize intramural R&D, as well as technology originating outside the firm, increases with the quality of the in-house R&D department. His findings suggest that diffusion of technology may be a better strategy than protection, promoting R&D collaboration. A successful innovator in his sample is not characterized by superior production of new technology per se, rather being part of a network where information flows between the participants.

When addressing the technology gap between nations, Keller (1996) stresses the importance of absorptive capacity in the case of technology transfer following a regime change in lesser developed countries. Lacking absorptive capacity in the receiving country will limit the growth associated with the increased access to technology and information, seeing that accumulated human capital is crucial for the implementation phase. In order for developing countries to fully benefit from the technological information, the human capital must accumulate at a higher rate than before the regime change.

Arora and Gambardella (1994) split the absorptive capacity in to two dimensions; ability to evaluate and the ability to utilize. The ability to utilize raises the number of innovation ventures. Firms with greater ability to evaluate are more selective and focus on fewer but more valuable linkages.

Empirics

In recent years a growing interest in possible complementarities in innovation strategies has arisen. Complementarity in innovation strategies suggest that synergy effects may exist for firms pursuing different R&D practices, i.e. implementing one of the practices yields higher marginal returns for the other and vice versa. If such a relationship exists this is in contrast with earlier literature promoting substitutability between internal R&D and R&D acquired outside the firm, theoretically anchored in transaction cost theory as described earlier. Two forms of complementarity are relevant for this paper; a) complementarity between internal R&D and various forms of R&D cooperation and b) complementarity between internal R&D and contracted R&D. Literature concerning complementarity between product and process innovation exist as well, e.g. Miravete and Parnias (2006). However, we don't differentiate between the two innovation strategies in our thesis and will not discuss this matter in depth.

Several econometric approaches are used to unveil possible complementarity. A combination of the adoption approach and the production approach is most commonly used, at least in the earliest work in the area (e.g. Arora and Gambardella, 1990; Cassiman and Veugelers, 2002a). The adoption approach checks for conditional correlation between the residuals of reduced form regressions of the different strategies and observed exogenous variables (Lokshin et al., 2007). The production approach uses the concept of supermodularity to directly test for complementarity. Different methods for testing for complementarity, and an overview of previous literature, are thoroughly described in Athey and Stern (1998). In later years as the availability of longitudinal data has increased dynamic panel data methods are used as well (e.g. Lokshin et al., 2008; Bergman, 2011).

The empirical support for complementarity is ambiguous, seeing that different R&D strategies are found to be both complementary and substitutes. Assessing four different strategies of external linkages in the biotechnology industry, Arora and Gambardella (1990) find complementarity in all cases. Veugelers (1997) finds support for complementarity between in-house and external R&D, given that the firms have an internal R&D department, underlining the need for absorptive capacity. Belderbos et al. (2008a) finds complementarity for affiliate R&D and intra-firm technology transfer from parent firm for Japanese firms. Assessing the effects of FDI in India after the reform in 1991, Sasidharan and Kathuria (2011) find that a firm's decision whether to engage in intramural R&D or not are complementary to the inflow of FDI. However, in the case of majority equity ownership they found substitutability.

Belderbos et al. (2006) examines which effects engaging in simultaneous cooperation strategies have on a firm's productivity, being the first paper who addresses possible complementarity between different R&D cooperation. Their results find support for both complementarity and substitutability between the different strategies. For large firms a strategy involving cooperation with competitors and customers turn out to be complementary. Examining the small firms in the sample cooperation with customers and suppliers are the only cooperation strategy that passes the test for complementarity. Cooperation with competitors and universities turn out to be substitutes independent of firm size, whereas cooperation with customers and suppliers, and suppliers and universities are substitutes only for small firms.

Hagedoorn and Wang (2010) explore under which conditions internal and external R&D strategies turn out to be substitutes or complementary. In their study they find that as investments in in-house R&D increases the R&D strategies are complementary, whereas lower levels of in-house R&D investments provides support for substitutability. The presence of complementarity, conditional on significantly high investments in intramural R&D are found by Belderbos et al. (2008a) as well.

Assessing the effects of FDI in India after the reform in 1991, Sasidharan and Kathuria (2011) find that a firm's decision whether to engage in intramural R&D or not are complementary to the inflow of FDI. However, in the case of majority equity ownership they found substitutability.

Schmiedeberg (2008) find weak evidence for complementarity between contracted R&D and in-house R&D. Evidence for complementarity between R&D cooperation and in-house R&D are found when the probability of patenting are used as dependent variable. However, when percentage of sales due to new products is dependent variable she finds no evidence of complementarity, which is similar to previous empirical work using new sales attributable to new products as dependent variable as well(e.g. Cassiman and Veugelers, 2002b; Love and Roper, 2001). Using comparable data to Cassiman and Veugelers (2006) she reaches different conclusions regarding internal and external R&D, which in itself is surprising.

However, she attributes the differing results to country-specific affecting the innovative behavior of the firms.

Recent work by Karin Bergman (2011) found weak evidence for complementarity analyzing a panel of Swedish manufacturing firms. However, her results showed that whether complementarity or substitutability is found are industry-sensitive. This is in line with the literature examined for this thesis, seeing that small changes in samples or models lead to different conclusions for tests of complementarity. She also provides an overview of recent empirical work concerning complementarity.

2.3 R&D, innovation and market structure: Theoretics and empirics

The literature on market structure and R&D has not returned any unique verdict on the relationship between the two. The Schumpetarian view that market competition does not provide optimal investments in R&D, and hence the optimal provision of innovation,[5] has been proved, rejected and modified. Arrow (1962) shows that the monopolist always has less incentive to innovate than competing firms, since the total gain of a given cost reduction per unit is less under monopoly than under competition. However, Arrow assumes that under monopoly only the monopolist itself can invent. Reinganum (1983) models a situation where a monopolist faces possible entrants, and assumes that both the monopolist and the entrants can engage in a given R&D project which gives considerable market power post innovation if proven successful, but that the success of the project is uncertain. She shows that the incumbent firm invests more in R&D in the presence of challengers, but less than the challengers. In an earlier article, Dasgupta and Stiglitz (1980) also emphasise the effect of competition in R&D on the level of R&D conducted. They show that under both initial

[5] When Schumpeter (1947) discusses the importance of studying the capitalistic economy as an evolving process, where the characteristics and qualities of the whole process, and not of the economy in any particular state in time, should be concerned, he states: “A system – any system, economic or other – that at every given point of time fully utilizes its possibilities to the best advantage may yet in the long run be inferior to a system that does so at no given point of time, because the latter’s failure to do so may be a condition for the level of speed of lung-run performance.” (Schumpeter 1947: 83)

competition and initial monopoly in the product market, competition in R&D increases the level of R&D conducted in each firm. Further, each firm tries to outperform the other firms by conducting more and more R&D, leading to an excessive level of R&D expenditure in equilibrium. Concerning these findings, it is not the degree of competition in the market of present products, but the market of future products, that affects the level of R&D; it is not price and quality competition on existing products, but rather competition in introducing new products that matters[6].

Empirically, the threat of losing market power has been proven a motive for conducting more R&D in the presence of entrant challengers in a study of British manufacturing firms by Blundell et al. (1999). They also find that market share is positively related to innovation. Performing continuous R&D is also found to be important (Mairesse and Mohnen, 2010).

The presence of R&D spillovers also affects the level of R&D conducted. As will be emphasized in the literature section on cooperation, R&D spillovers have negative impact on the level of R&D conducted. This effect is increasing in the degree of spillovers and the number of competitors; a firm will limit the leakage of R&D to its competitors by simply reducing R&D. On the other hand, in the absence of spillovers, Sah and Stiglitz (1987) show that the total level of R&D conducted is invariant to the number of competing firms in the industry. This naturally involves that the change in R&D conducted per firm is negatively proportional to the number of firms in the industry. A further overview of the literature on market structure, R&D and innovation is given by e.g. Kamien and Schwartz (1975) and van Cayseele (1998).

2.4 R&D, innovation and M&A: Empirics

Regarding the effect of international M&A, it is not the multinationality that affects the level of conducted R&D per se; it is rather the changes in the conditions of conducting R&D pre-

[6] a parallel to Schumpeter (1947: 84): "… in capitalist reality as distinguished from its textbook picture, it is not that kind of [price] competition which counts, but the competition from the new commodity, the new technology, the new source of supply, the new type of organization – competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms, but at their foundations and their very lives."

and post-M&A that makes the difference. Research on the effect of M&A on R&D and innovation has largely been analyzed within the theoretical frameworks presented in this literature section: M&A may generate scale and scope economies in R&D, and create synergies in R&D in the new firm in the case of complementarity in R&D; M&A may reduce competition which again may impact R&D and innovation decisions; and in the case of substitutability in R&D between the two former firms, R&D may be concentrated in the most R&D efficient firm (Bertrand, 2009). In this section, we therefore only present empirical results on the effect of M&A on R&D.

Regarding the growth in Japanese foreign investment in the United States in the early 1990's, Kogut and Chang (1991) find that Japanese foreign investments are more likely to occur in U.S. industries with intensive R&D expenditures, and that the likelihood decreases as R&D intensity grows in Japanese industries. They suggest that Japanese foreign direct investment in R&D intensive industries are motivated by acquisition of technology and knowledge. In a later study of 32 Japanese and American companies, Kuemmerle (1999) comes to a similar conclusion in an examination of factors determining whether firms seek to augment, as the opposite to exploit, the knowledge stock of their foreign affiliates. He finds that the propensity to make R&D augmenting investment in an affiliate abroad rises with the quality of the human resource pool in the industry of the foreign affiliate, as well as with the R&D intensity in the home country of the affiliate. Firms are less likely to invest in augmenting R&D, and hence more likely to invest in exploiting R&D, as the relative attractiveness of the country market, measured as GNP in foreign country relative to GNP in home country, increases. Hence, these firms are motivated by utilizing R&D spillovers in foreign countries and as the quality of these spillovers increase, these firms are more likely to invest in R&D augmentation abroad.

With respect to the industrial organization literature, Ekholm and Hakkala (2007) analyze the impact of R&D spillovers on R&D and production localization in a two-country (one small and one large country), two-factor (unskilled and skilled labour) and two-good model. The unskilled workers produce a homogenous good, while the high skilled workers are engaged in R&D and produce a differentiated high-tech good. In the case of large spillovers in R&D, the equilibrium outcome of the model is when the firm locates production of the differentiated high-tech good, including the R&D activity, in the smallest country. This is because there are fewer high skilled workers able to absorb the spillovers in the smallest country.

After the wave of M&A and leverage buy-outs (LBOs) in the 1980's, several studies on the effects of M&A and LBOs were carried out. Lei and Hitt (1995) argue that M&A and LBOs bring along complex changes within the firm which make external knowledge sourcing attractive relative to internal R&D activity. Prolonged R&D outsourcing reduces the base of human capital and skills, i.e. its absorptive capacity, and hence its ability to utilize new knowledge and technologies, reducing its competitiveness on the long run.

Gupta and Govindarajan (2000) find that acquired subsidiaries have higher knowledge inflows from parent corporations than greenfield subsidiaries, and attribute the difference to higher absorptive capacity in acquired subsidiaries. On the contrary, they do not find any significant difference between acquired and greenfield subsidiaries in knowledge outflows to parent corporations. The results suggest that a subsidiary's absorptive capacity only increases its disposition to acquire, and not disperse, knowledge.

In a study of cross-border and domestic M&A in OECD-countries between 1990 and 1999, Bertrand and Zuniga (2006) find that outward cross-border M&A had a positive effect on R&D expenditures, while inward cross-border M&A and domestic M&A had a negative effect. The results are valid across high, medium and low-technology industries. They suggest that domestic M&A partners do not seem to be looking for R&D efficiency as a motive for M&A, while domestic firms, on the other hand, seek to exploit complementarity in R&D with foreign M&A partners. Their results may also indicate substitutability in internal and external R&D between domestic M&A partners.

Regarding geographical limitations of access knowledge and technology through spillovers, some studies have examined foreign direct investment as a strategy for easier access. Griffith et al. (2006) examines the impact of spillovers acquired by UK firm inventors located in US and UK respectively. Productivity gains due to these spillovers were significantly higher for inventors located in the US than UK inventors. The authors attribute the difference to the larger size of the US, relative to the UK, R&D stock, and suggest that firms should locate more inventors in the US in order to access larger R&D spillovers. Keller (2002) finds evidence for geographical limits of R&D spillovers. In a sample of OECD countries between

1970 and 1995, he finds that foreign spillovers are declining in distance to a major technology-producing country[7]. In a more limited sample of Japanese and U.S. firms, Branstetter (2001) comes to a similar conclusion. He finds that knowledge spillovers are of an intranational, rather than international, character for these geographically isolated developed countries.

Addressing the fear of knowledge sourcing of domestic target firms by a foreign acquirer, Bertrand et al. (2008) show that, in a theoretical oligopoly model, foreign acquirers must increase R&D investment in target firm post acquisition. Rival firms will increase R&D investment post acquisition and outdo the target firm unless its R&D is expanded. For target firm, some studies find a positive effect of acquisition on R&D activity. Bandick, Görg and Karpaty (2010) find that R&D expenditures increase after a foreign takeover in a study of Swedish firms. Sadowski and Sadowski-Rasters (2006) reach a similar conclusion. In a study of Dutch manufacturing firms, they find that foreign subsidiaries have higher innovation activity, and are more likely to develop new products than domestic firms. However, in a study of German firms, Stiebale and Reize (2008) estimate a lower propensity to perform innovation activities and reduced level of R&D expenditures among firms acquired by foreign enterprises. Bertrand (2009) finds, on the other hand, that the acquisition of French firms by foreign enterprises increases internal and external R&D, and also the propensity to collaborate in R&D with external partners.

Ito and Wakasugi (2007) examine the R&D activities in Japanese overseas subsidiaries. They find that subsidiaries in countries with high frequency of high-skilled labour force (measured as the ratio of researchers to the whole population) drive the parent company to increase the R&D activity in the subsidiary. Erken and Kleijn (2010) reach the same conclusion in a large panel of OECD-countries between 1990 and 2004. Shimizutani and Todo (2008), also studying determinants of foreign R&D investment in Japanese overseas subsidiaries, differentiate between basic R&D and R&D aimed at development/design at the subsidiary. They find that basic R&D activity in subsidiary is increasing in the ratio of R&D to GNP in subsidiary country. No relationship between R&D aimed at development/design and R&D level in subsidiary country is found. The authors suggest that subsidiaries increase

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[7] These are France, Germany, Japan, U.K. and U.S.

their absorptive capacity in countries with high R&D activity, in order to gain from spillovers. R&D aimed at development/design is found to be positively dependent on the R&D intensity (R&D to sales ratio) of the parent.

For the acquirer, the effect on own internal R&D is ambiguous. Desai, Foley and Hines (2008) find that foreign investment that is triggered by foreign economic growth is associated with growing capital accumulation, employment compensation, R&D, and exports in home firm. Todo and Shimizutani (2008) find that overseas R&D expenditures aimed at the utilization and acquisition of foreign advanced knowledge have a positive impact on the productivity growth of the parent firm, in a study of Japanese multinational enterprises. However, they find no evidence of increased marginal effect of internal R&D on productivity growth due to the overseas subsidiaries' R&D, and suggest that overseas R&D is a substitute rather than complement. Hamida and Piscitello (2010) also find a positive impact of R&D investment in subsidiaries on parent productivity growth among Swiss multinationals.

Firms may access technology and knowledge from other externals. Cruscuolo, Haskel and Slaughter (2005) find that multinational firms tend to exhibit higher productivity than their purely domestic counterparts. They attribute much of the difference to the fact that multinationals acquire more knowledge from external partners; it is not only that they are multinational that makes these firms more innovative per se. Collaboration with suppliers, customers, universities and own enterprise contribute to a large part of the innovation difference.

Examining acquisition motives of high tech companies in the electronic design automation, biotech and semiconductor industry, Wagner (2007) finds that, except for the biotech industry, R&D intensity of the acquirer is insignificantly associated with numbers of acquisitions. He suggests that these companies do not seek to substitute away R&D from itself to the target firm. Rather, high financial leverage (total assets to equity) and high sales seem to be conditions for acquisition in these industries. For the biotech industry, Wagner finds weak evidence for a negative relationship between R&D intensity of the acquirer and number of acquisitions, indicating a motive for R&D substitution.

Analyzing R&D localization decisions, Belderbos et al. (2008b) set up a two-country model with two competing firms, one technology leader and one technology laggard, with headquarters located in one country and a subsidiary in the other country. Assuming that spillovers do not cross borders, increased spillovers reduce R&D activity in the subsidiary of the technology leader. The efficiency of technology transfer between parent company and subsidiary is positively related to concentration of R&D in the headquarter country. The efficiency of technology transfer is associated with high absorptive capacity, indicating that higher absorptive capacity of a subsidiary reduce the subsidiary's share of R&D activity of the enterprise. In the case of strong technological leadership, increased product market competition induces the leader to increase R&D abroad, in order to capture market share.

2.5 Cooperation in R&D: Theoretics and empirics

Veugelers (1998:2) summarizes motives and problems of R&D allying: Sharing of costs and risks; access to the partners' know-how; utilization of potential economies of scale in R&D; utilization of synergies between internal and external R&D; monitoring of R&D activities of the competitors and influence competition; access to public subsidies, and influence industrial, trade or competition policy as potential motives. Potential problems are: start-up investments; coordination and agency costs of running the cooperation; asymmetric information; and lack of ability to control information flows between partners.

In our consideration of the nature of R&D cooperation, we follow Belderbos et al. (2004a) and differentiate three types of cooperation partners: (i) horizontal cooperation, involving cooperation with competitors on the output market; (ii) vertical cooperation, involving cooperation with suppliers or customers; and (iii) institutional cooperation, involving cooperation with independent research institutions and universities.

Horizontal cooperation

Cooperation between competitors has been analyzed under the framework of Industrial Organization Theory (IO). IO models compare scenarios of R&D cooperation with scenarios of R&D competition. In these multiple-stage models, firms typically first decide whether or not to participate in a cooperative R&D agreement, the firms then decide the level of R&D

activity and – finally – output in the product market is chosen. The models assume that R&D leads to a reduction in unit costs of production. In these models, the implication of horizontal R&D cooperation on the level of R&D conducted and on final output depends on initial market structure and the level of initial spillovers from R&D.

Katz (1986) shows that, in a model where several firms interact, horizontal R&D cooperation favours the level of R&D conducted if the firms operate in independent product markets, if their products are imperfect substitutes, or if there is R&D spillovers in the absence of cooperation. Under initially restricted R&D spillovers and high degree of product market competition, the model predicts that firms find it in their collective interest to use a cooperative agreement to restrict the level of R&D conducted.

Modelling a Cournot duopoly, D'Aspremont and Jacquemin (1988) show that the level of total R&D will be higher under R&D cooperation compared to non-cooperation. The difference is attributed to internalization of R&D externalities, i.e. spillovers. The difference is even found to be greater if the firms also collude in output given a certain level of spillovers, which is explained by the firms' ability to capture more of the surplus created by their research and hence make more R&D under absence of competition. De Bondt and Veugelers (1991) refine the model, and show that above a certain level of spillovers, coordination of R&D between two firms with differentiated substitutes result in more R&D investments compared to a non-coordination situation. If the spillovers are too small, or if the products are complements rather than substitutes, the effect of R&D cooperation on R&D investment is negative. This is also consistent with Atallah (2002). Kamien et al (1992) extend the model by D'Aspremont and Jacquemin (1988) by including several firms (i.e. opening for the possibility of both duopoly and oligopoly) and heterogeneity in products. Their model predicts that R&D activity is negatively related to spillovers within an R&D cooperative if (i) the firms compete with homogeneous products and spillovers are small initially or (ii) the products are heterogeneous and spillovers are large initially. When the products are homogeneous, a firm benefits from cost reduction by increasing their own profit at the expense of its competitors[8]. When spillovers within the cooperative are below a certain level, the R&D efforts of the firm will induce a larger unit cost reduction for the firm

[8] Cf. the implications of a unit cost reduction for one firm in a Cournot duopoly.

relative to its competitors, resulting in increasing profits for the firm. If spillovers increase, the incentive to conduct R&D reduces as the competitors increase their unit costs reduction relative to the firm. The incentive to cooperate also weakens. As for heterogeneous products, a unit cost reduction for one firm increases profits for all firms[9]. But, if spillovers become sufficiently high, the unit costs of the less and most cost efficient firms converge. A further increase in spillovers within the cooperative, reduce the profits for the most cost efficient firms, and hence reducing their incentive to conduct R&D and collaborate in R&D. The theoretical predictions are largely supported by Kaiser (2002) in an empirical study considering cooperation between firms in the German service sector.

Vertical cooperation

In the context of transaction cost theory, Pisano (1990) and Teece (1992) describes vertical cooperation as a hybrid between hierarchical and market transactions, superior to both hierarchical organization and markets if R&D can be effectively governed by contracts. In transaction cost theory, cost reduction has been seen as a major motive for vertical cooperation (Belderbos et al. 2004a).

Within the IO literature, Atallah (2002) models two firms competing in the output market with two symmetric suppliers, and predicts a higher level of conducted R&D under a vertical cooperation scenario than under a non-cooperation scenario, independent of the level of spillovers. Japanese vertical keiretsus have been frequent objects for research on vertical cooperation and spillovers. In studies of the Japanese automobile industry, both Kawasaki and McMillan (1987), and Asanuma and Kikutani (1992) found that subcontracting through vertical Keiretsu significantly reduced the risk of suppliers as the risk was shared with the manufacturer. Suzuki (1993) finds significant spillovers in the Japanese electrical machinery industry within the vertical Keiretsu, but also between competing vertical Keiretsus, though these are smaller. Branstetter (2000) reach similar conclusions using a larger sample of Japanese keiretsus. Spillovers are found to increase the rate of return of R&D, but the effect of cooperation on the level of R&D is not a subject of the studies. Nevertheless, increased rate of return should, for a given level of R&D unit cost, increase the optimum level of R&D. The risk reduction results of these studies must be seen in the context of the Keiretsus,

[9] Cf. the implications of a unit cost reduction for one firm in a Bertrand duopoly.

which by nature are more permanent than other vertical cooperatives, and hence reduces the small-number-bargaining problem described by e.g. Williamson (1975:26-30).

In a study of German firms, Kaiser (2002) finds no significant relationship between spillovers and the propensity to form vertical R&D cooperatives. However, Cassiman and Veugelers (2002b) analyse the impact of incoming spillovers and appropriability on the propensity to enter into R&D cooperation with customers and suppliers, and research institutes respectively. They find that firms which experience high incoming spillovers and find the public available pool of knowledge of great importance, are less likely to cooperate with suppliers or competitors. Lack of appropriability affects the propensity to enter into a vertical R&D cooperative negatively. The authors suggest that this is due to the fear of leaking strategic information and knowledge to competitors via customers or suppliers. López (2008), examining Spanish firms, reaches the same conclusion, who also states that cost reduction is a motive of entering into vertical R&D collaboration.

Belderbos et al. (2004b) find, in a study of Dutch innovating firms, that both temporary and persistent R&D cooperation with competitors have a positive impact on labour productivity, and that persistent cooperation positively impact novel sales.

Linking customer cooperation to demand-push theories, von Hippel (1988:102-115) suggests cooperation with lead users to determine the user needs for new products and services in rapidly changing markets. Tether (2002) draws the same conclusions. Though, Belderbos et al. (2004b) estimate an insignificant, yet positive, marginal effect of customer cooperation on growth of novel sales. The advantages of customer cooperation in general are discussed in detail in Shaw (1994).

Institutional cooperation

Industry-university cooperatives and research thereof was intensified in the 1990's (Hagedoorn et al. 2000; Hall et al. 2003). In general, cooperation with universities are seen as a useful way of acquiring technology and knowledge which require sorts of research that many firms regard as excessively expensive to undertake alone (Tether 2002). Such cooperation is found especially beneficially when coupled with public funding (Belderbos et al. 2004a). Cassiman and Veugelers (2002b) find that firms which experience high incoming spillovers and find the public available pool of knowledge of great importance, are more likely to cooperate with universities and independent research institutions. The propensity to cooperate with research institutes is increasing with lack of appropriability. Their results are supported by Belderbos et al. (2004a) and López (2008).

From a resource-based perspective, Miotti and Sachwald (2003) analyse the propensity to cooperate in R&D. They find that firms operating on “the technological frontier” and, hence, are more dependent on new science, have higher probability to cooperate with universities. Mohnen and Hoareau (2003) draw a somewhat different conclusion in a study of French, German, Irish and Spanish firms: R&D intensive and radically innovating firms tend not to cooperate directly or formally with universities and government research institutions, but rather source knowledge from them through spillovers. Monjon and Waelbroeck (2003) may provide explanations of these results. In a study of French manufacturers, they find that for highly innovative firms, which are at the frontier of the domestic academic knowledge in their industry and have state-of-the-art research department, cooperation with universities outside France, and not with French universities, increase the probability of innovating: “They only marginally benefit from aggregate (or industry-wide) spillovers from domestic universities. They need new forms of academic knowledge that they acquire through formal cooperation with foreign universities” Monjon and Waelbroeck (2003: 1267). The authors find that less innovative firm, increases the likelihood of innovation by cooperating with domestic universities, and suggest that these firms use universities as a source of acquiring and catch up the state-of-the-art knowledge. Addressing the risk of cooperation failures in a study of almost the same sample of French manufacturers, L’Huillery and Pfister (2009) find that R&D collaboration with foreign universities are especially prone of failures. However, the probability of failure is lower for large firms and subsidiaries, and firms which have experience in R&D collaboration.

Hagedorn et al. (2000: 579) refer to Cockburn and Henderson (1997), who show the importance of ties with universities for innovative pharmaceutical firms, and propose that research ties with universities increase the absorptive capacity as defined by Cohen and Levinthal (1989). Belderbos et al (2004a) find a similar relationship, but with the reverse interpretation: R&D intensive firms are more likely to cooperate with universities and research institutions.

Within the economics of agglomeration, geographical location is of strategic importance (Porter 1990:148-159). Locating the firm near a university is also described as an advantage: “Universities located near a group of competitors will be most likely to notice the industry, perceive it important, and respond accordingly. In turn, competitors are more likely to fund and support local university activity. (…) Geographical concentration of an industry acts as a strong magnet to attract talented people and other factors to it.” (Porter 1990: 157). In certain geographical areas, spillovers from research institutions, suppliers, customers and competitors are large. An example of the first is the “Research Triangle” in Piedmont, North Carolina[10].

Consultants make up another institution for acquiring technology and knowledge. Tether (2002: 953) refers to Bruce and Morris (1998), who argue that external consultants are more likely to provide new, innovative ideas than internals, because the latter is bounded by internal traditions and habits. In the innovation process, Bessant and Hush (1995: 101-102) see consultants as more than a provider of specialised, expert knowledge; the consultants also help users to understand and prioritize problems and needs for innovation; consultants working with several users have the advantage of sharing experiences and knowledge between users, and also act as a “ ’marriage broker’, providing users with a single point of contact through which to access a wide range of specialist services”.

[10] The area has a high concentration of high-tech companies within i.a. pharmaceutcals, biotechnology, nanotechnology and informatics, as well as several universities: i.a. North Carolina University, Duke University and University of North Carolina at Chapel Hill (Research Triangle Region, 2011).

3. The effect of external R&D sources on internal R&D

3.1 Introduction

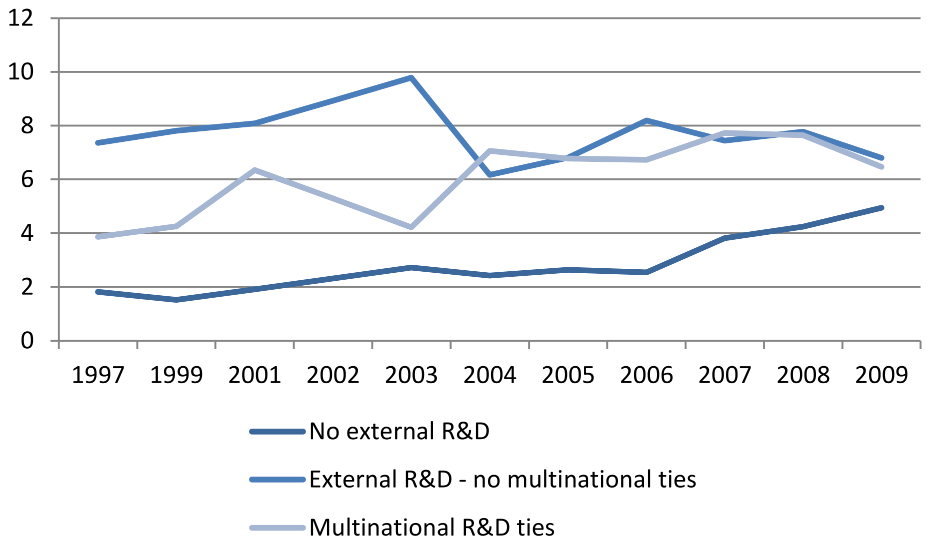
In this section we explore the impact of acquiring external R&D on internal R&D activity. External R&D sources take three forms: R&D contracting; through merging or acquisition with R&D active firms; and through R&D cooperation with other firms. Regarding M&A as an R&D source, a pure transfer of R&D between a Norwegian firm and another firm within the same enterprise must be accounted as R&D expenditures and R&D revenues[11]. As for R&D collaboration, we assume that each firm accounts collaboration costs as internal R&D expenditures. Hence, acquiring R&D through M&A appears as either external R&D expenditures (similar to R&D contracting) or R&D cooperation.

Following the transaction cost theory, external and internal R&D are substitutes, and one should expect external R&D purchases to negatively impact internal R&D expenditures. Regarding the theories of absorptive capacity, internal R&D activity is necessary for utilization of external R&D. Hence, both external R&D purchases, but also R&D cooperation, demand at least a certain level of internal R&D, and are expected to be positively associated with internal R&D expenditures. Besides the need of absorptive capacity, R&D cooperation is expected to affect internal R&D activity in several ways. R&D cooperation with competitors internalizes spillovers, and increases in general the incentives to perform R&D. Though, under certain market conditions and level of spillovers this effect is not found (cf. section 2.5 on R&D cooperation in the literature section). Vertical R&D cooperation is found to increase cost efficiency and provide first-hand customer information, both giving incentives to increase internal R&D. Institutional R&D cooperation is thought to give, at least the less productive firms, access to the newest technology and knowledge. This effect might positively affect internal R&D, in accordance with absorptive capacity and

[11] Internal transfer of R&D between two firms within the same enterprise should be entered in accordance with transfer pricing principle described in Lov 1999 nr. 14 § 13-1, if both firms are Norwegain, and in Lov 1999 nr. 14 § 13-1 (4) and "Transfer Pricing Guidelines for Multinational Enterprises and Tax Administrations" by OECD (2010) if a Norwegian firm buys R&D from a foreign firm within the same enterprise. The usual procedure is pricing in accordance with the arm's length principle.

complementarity theories, or negatively affect internal R&D, in accordance with transaction cost and substitutability theory. As described in the literature section, changes in the market structure post M&A between two competitors might affect the incentives for performing R&D. Whether the effect is positive or negative is not clear. R&D purchases from foreign firms within the same enterprise might then be affected by changes in market structure for newly merged or acquired firms which start purchasing R&D internally in the enterprise. With the data available, we are not able to control for this effect.

Figure 3.1 – Internal R&D expenditures in Bn. 2009 NOK



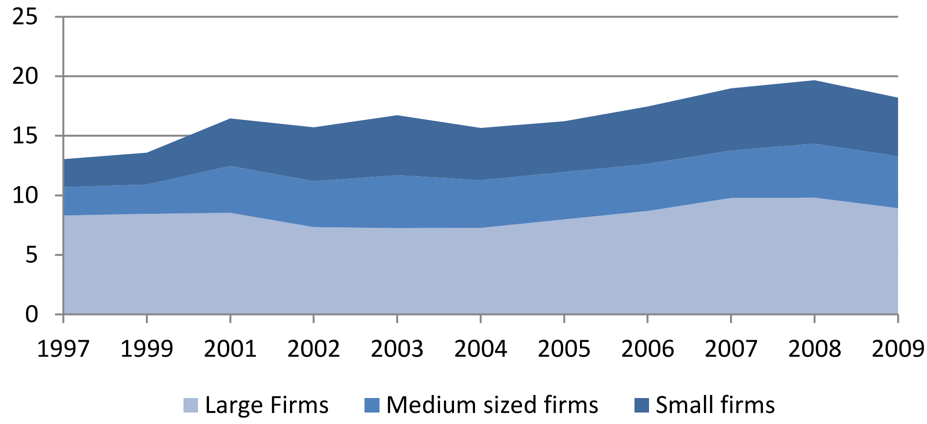
Source: R&D and innovation surveys, Statistics Norway. External multinational refers to R&D expenditures from foreign firms within the same enterprise. The survey covers all Norwegian firms with more than 50 employees and a sample of firms with 10-49 employees. Aggregation based on weights provided by Statistics Norway. Deflation in accordance with price indices for R&D from "Indikatorrapporten".

Figure 3.1 shows aggregated investments in intramural R&D following three different R&D strategies for R&D active firms. Firms that rely solely on conducting in-house R&D have lower investments in intramural R&D than those who acquire R&D outside the firm. Internal R&D expenditures have increased throughout the decade for firms with multinational R&D ties. Investments carried out by firms that buy R&D or engage in R&D cooperation outside the enterprise are approximately on the same level in 2009 as in 1997. This may indicate that investments in internal R&D are indeed stimulated by investments in external R&D, in line with the notion of absorptive capacity.

Looking at firms with respect to firm size we see from figure 3.2 that large firms invest more in intramural R&D than smaller firms, constituting roughly 50 % of aggregated internal

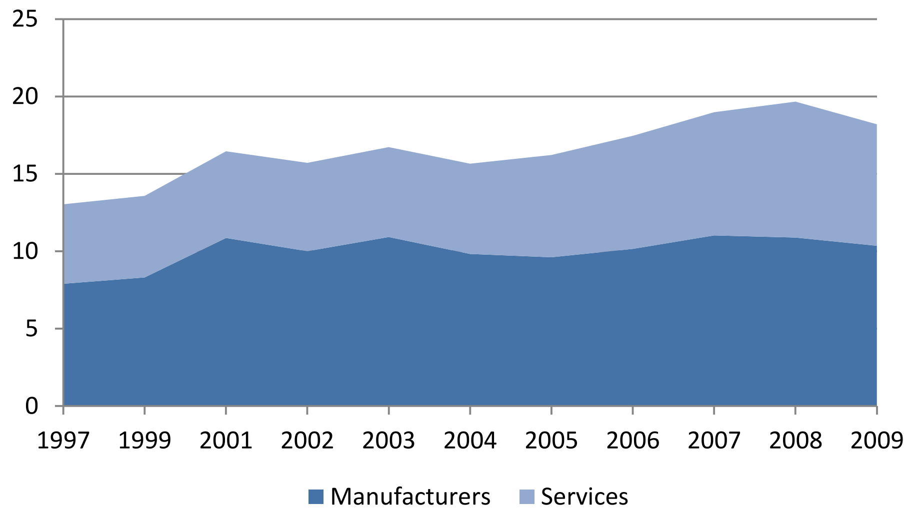
R&D investments in 2009. However, the small and medium sized firms have increased their investments throughout the decade and represent a significantly larger proportion of aggregated internal R&D in 2009. Examining firms classified as manufacturing firms and service firms we find a similar pattern, with service firms closing the gap throughout the decade.

Figure 3.2: Internal R&D expenditures. Bn. 2009 NOK.



Source: R&D and innovation surveys, Statistics Norway. External multinational refers to R&D expenditures from foreign firms within the same enterprise. The survey covers all Norwegian firms with more than 50 employees and a sample of firms with 10-49 employees. Aggregation based on weights provided by Statistics Norway. Deflation in accordance with price indices for R&D from "Indikatorrapporten". Small firms have less than 50 employees, medium up to 249, and large firms more than 250 employees.

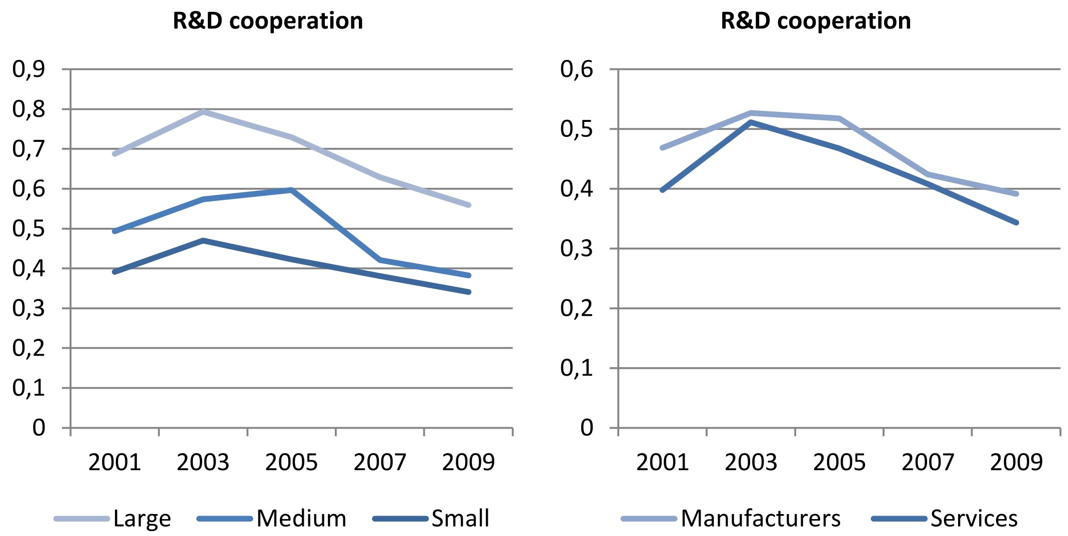
Figure 3.3: Internal R&D expenditures. Bn. 2009 NOK.



Source: R&D and innovation surveys, Statistics Norway. External multinational refers to R&D expenditures from foreign firms within the same enterprise. The survey covers all Norwegian firms with more than 50 employees and a sample of firms with 10-49 employees. Aggregation based on weights provided by Statistics Norway. Deflation in accordance with price indices for R&D from "Indikatorrapporten". [1]Manufacturing firms are defined as all firms with NACE-codes up to 50. Service firms are defined as all other firms with NACE-codes starting at 50.

Seeing that large firms and firms from the manufacturing sector performs more in-house R&D than the rest we expect them to have a higher representation when it comes to engagement in R&D cooperation as well as contracting out R&D, in line with our findings in figure 3.1. From figure 3.4 we see that large firms and manufacturing firms indeed have a higher frequency of R&D cooperation. In all subsamples we see a trend of lower frequencies of cooperation throughout the decade.

Figure 3.4: Frequency of R&D cooperation. R&D active firms.



Source: R&D and innovation surveys, Statistics Norway. External multinational refers to R&D expenditures from foreign firms within the same enterprise. The survey covers all Norwegian firms with more than 50 employees and a sample of firms with 10-49 employees. Aggregation based on weights provided by Statistics Norway. Deflation in accordance with price indices for R&D from "Indikatorrapporten". Small firms have less than 50 employees, medium up to 249, and large firms more than 250 employees. Manufacturing firms are defined as all firms with NACE-codes up to 50. Service firms are defined as all other firms with NACE-codes starting at 50.

Internal R&D expenditures were relatively stable the first half of the decade. This was accompanied by a decrease in the amount of external R&D bought outside the firm. Following the period with little or no growth in internal R&D spending, expenditures increased significantly, peaking in 2008. The growth period were accompanied by an increase in R&D bought outside the firm.

In section 3.4 we examine the effect different strategies for acquiring R&D have on internal R&D. In the introduction for this thesis we find that firms acquiring R&D through multinational ties within the enterprise have much higher average internal R&D expenditures. On that note we will pay special attention to R&D strategies involving multinational R&D ties.

3.2 Data

Variable construction

When constructing the explanatory variables concerning cooperation we have used the vast amount of cooperation dummies in our set. In all the years of our set, except 2002, a section concerning cooperation in R&D or innovation has been included. We are therefore able to identify firms engaging in some sort of co-op. The dummy for cooperation, CO_{it}, takes the value of 1 if the firm claims to have any sort of cooperation, and 0 otherwise. The dummy indicating R&D cooperation with foreign firms in same enterprise, MCO_{it}, is constructed in a similar fashion as the dummy indicating cooperation at any level, the difference being that we restrict the cooperation to foreign firms in same enterprise in regions or countries outside of Norway. For the final estimation of our model we create a set of dummy variables used to reveal whether the significance of multinational cooperation diminishes when we control for other forms of cooperation. We construct variables reflecting horizontal cooperation (HCO), vertical cooperation (VCO), domestic cooperation within enterprise (DCO) and cooperation with independent research institutions (ICO). Horizontal cooperation is defined as cooperation with competitors at home or abroad. Vertical cooperation considers all cooperation attributed to suppliers or customers. For the independent research institutions we include all institutions, both private and public. This means that universities, private research labs, consultancy firms, science institutions etc. are accounted for. For more details on the construction of the variables please turn to appendix 1.

R&D expenditures are deflated according to the price indices for R&D costs from "Indikatorrapporten" (Forskningsrådet, 2010), base year 2009.

List of variables used in our calculations are to be found in Appendix A. In the variable list we have included a column called transitions where we have identified the number of transitions from 0 to 1 or vice versa for the cooperation dummies within the firms.

3.3 Model specification

A first test to check for the need of absorptive capacity including possible complementarity between internal R&D and external R&D activities would be to estimate the effect of external R&D activities on internal R&D. The absorptive capacity theory presumes the need for internal R&D when contracting R&D externally or cooperating in R&D. One should therefore assume internal R&D to be positively related to external R&D activities. Also, complementarity should lead to an increase in internal R&D, while substitutability should lead to a reduction.

The focus of this chapter is limited to the effect of external R&D activities on internal R&D. In order to reveal complementarity or substitutability between internal R&D and external R&D activities one must consider both as inputs, and regress both on innovation output. This is subject for chapter 4.

We expect external R&D to be endogenous with respect to internal R&D. Whether or not external R&D sourcing actually affects internal R&D, there may be other sources affecting both internal and external R&D simultaneously, making external R&D sourcing endogenous in estimation. If external R&D sourcing is endogenous, the estimated relationship between external R&D sources and internal R&D will be biased. Firms optimizing R&D investment strengthens this endogeneity problem: One should not expect the data sample to consist of random observations of internal and external R&D; to a lesser or greater extent firms take into account factors within and outside the firm when deciding the level of R&D investments. Market structure, R&D spillovers, demand side and supply side factors etc. may simultaneously affect the choice of entering R&D cooperation, the level of external R&D sourcing, as well as the level of internal R&D investments. An example may clarify: A monopolist has lower incentives to conduct R&D, both internally and externally, than competing firms (Arrow, 1962), and by nature no possibility to enter a horizontal R&D cooperative. Observations of low internal R&D together with low external R&D investment and no R&D cooperation investment among monopolists should be attributed to the market structure; low internal R&D investment should not be attributed to the low level of external R&D or the absence of horizontal R&D cooperation. Such effects should be corrected for as far as possible.

Veugelers (1997) estimates the impact of external R&D activity – i.a. external R&D contracting and R&D cooperation – on internal R&D for a cross section of Flemish firms. She corrects for a simultaneous problem between internal and external R&D contracting by lagging the latter in regression, but admits that the external R&D expenditure variable has significant autocorrelation (Veugelers, 1997: 309). R&D cooperation is time constant. Its simultaneous problem with internal R&D is corrected for by fitting R&D cooperation and internal R&D into a simultaneous equation set and regressing the equation set by two stage OLS.

We define our basic model to analyze the effect of acquiring external R&D on internal R&D activity as[12]:

$$(3.1) \quad ird_{it} = \beta_0 + \eta erd_{it} + \theta CO_{it} + d_t + nace_i + \varepsilon_{it} \qquad \varepsilon_{it} = a_i + u_{it}$$

where subscript i and t refer to firm i and time t respectively (subscripts are dropped in text for convenience), ird is log of internal R&D expenditures, erd is log of external R&D expenditures, and CO is a dummy taking 1 if the firm cooperates in R&D and 0 if not. d_t is year dummy, $nace_i$ is two digit industry dummies, a_i is the firm specific error term and u_{it} is the idiosyncratic error term.

The log-log specification reduces the problem of outliers, as log transformation reduces large observed values of R&D expenditures more than small observed values.

The longitudinal nature of our dataset gives us certain advantages. It allows us, provided that certain assumptions are fulfilled, to exploit variance both between and within the firms in the dataset. The OLS estimator exploits these two dimensions. For the coefficients to be unbiased, the estimator requires both the firm specific and the idiosyncratic error term to be uncorrelated with the explanatory variables. This restriction is too strict for our data sample since we expect external R&D activities to be endogenous, as described earlier. We therefore apply the fixed effect (within group) estimator, which only exploits variation within firms in

[12] We do not have sufficient variables to control for other factors. Sales could have been used, but this variable is missing for 2009. Including sales, data on R&D for 2009 would be lost in regression, but the results would not be significantly altered. We therefore exclude sales, in order to include the R&D variables for 2009.

the sample. The estimator requires only the idiosyncratic error term to be uncorrelated with the explanatory variables for the coefficients to be unbiased. Both estimators are applied in order to reveal possible presence of firm specific effects (i.e. unobserved heterogeneity). As time or the number of firms goes to infinity both estimators are consistent. The large numbers of firms in our dataset indicate that the last requirement is approximately met.

We cannot correct for the simultaneous problem noted by Veugelers (1997). According to the absorptive capacity, firms performing internal R&D are more likely to engage in external R&D activities. Assuming that external R&D activities affect the level of internal R&D as well – either as a result of complementarity or substitutability, or also the need for absorptive capacity – a simultaneous problem arises. In order to correct for this simultaneous problem, we would need time varying exogenous instruments for both the internal R&D variable and the external R&D activity variables. The instruments identifying the first should not be correlated with the instruments identifying the latter. Due to our limited dataset, we do not have proper instruments at hand, and must leave the simultaneous problem unsolved. As all R&D variables seem highly correlated with itself over time, and one year of observations is lost in regression when lagging the explanatory variables, we do not find Granger causality appropriate to correct for the simultaneous problem either.

On the other hand, we expect much of the endogeneity of external R&D activities to be corrected for by applying the fixed effect estimator; all time constant, firm specific effects, such as industry, geographical location, and to some extent market structure, level of spillovers in the industry, firm size etc. is corrected for. In addition, the year dummies also corrects for endogeneity by capturing external shocks affecting all firms in the sample simultaneously. E.g. demand and supply shocks should be captured by these dummies. For our OLS estimation we have included a set of industry dummies as well as year dummies. This will control for some of the industry specific effects, reducing the bias in the OLS estimates. These are not included in the FE regressions, seeing that they are present in the time constant and firm specific effects which will disappear when running the FE-estimation. However, it should be noted that the idiosyncratic error term is still required to be uncorrelated with the external R&D activity variables[13].

[13] Additional ways of correcting for potentially endogeneity would be to instrument the external R&D activities but this is not possible in our case. Our dataset is limited, and we do not have any variables that identifies external R&D contracting or R&D cooperation and meets the exogenous requirement.

Multinational R&D ties

We pay special attention to possible differences in R&D activity between multinational and non-multinational firms. External R&D contracting is therefore differentiated into two parts: Contracting with a foreign firm within the same enterprise and other contracting (merd and oerd respectively). We redefine the model as:

$$(3.2)\quad ird_{it} = \beta_0 + \eta_1 merd_{it} + \eta_2 oerd_{it} + \theta CO_{it} + d_t + nace_i + \varepsilon_{it} \qquad \varepsilon_{it} = a_i + u_{it}$$

R&D cooperation

R&D cooperation is differentiated into horizontal, vertical and institutional cooperation, as well as cooperation with a foreign or domestic firm within the same enterprise (HCO, VCO, ICO, MCO and DCO respectively). These different forms of R&D cooperation are found to affect internal R&D activity differently in both theoretical and empirical studies (cf. section 2.5 on theory and empirics of R&D cooperation). Multinational firms are thought to be more frequently engaged in R&D cooperation. Bertrand (2009) finds that target firms increase external R&D purchases from domestic firms after acquisition, in a study of French firms. Taking these relationships into consideration, (3.2) should be extended[14]. The extended model is:

$$(3.3)\quad ird_{it} = \beta_0 + \eta_1 merd_{it} + \eta_2 oerd_{it} + \theta_1 MCO_{it} + \theta_2 DCO_{it} + \theta_3 HCO_{it} + \theta_4 VCO_{it} + \theta_5 ICO_{it} + d_t + nace_i + \varepsilon_{it} \qquad \varepsilon_{it} = a_i + u_{it}$$

We apply the fixed effect estimator on both (3.2) and (3.3) in order to correct as much as possible for the initially expected endogeneity of external R&D contracting and R&D cooperation as described earlier in this section.

[14] One should however note that an extensive division of the variables reduces the number of observations available for the regression; the aggregated cooperation variable has, necessarily, more observations. As noted earlier in this chapter, the estimator is consistent when the number of firms approaches infinity. By reducing the number of observation this requirement will be harder to reach.

3.4 Regression results

Estimating equation (3.1) we find positive effects on internal R&D using both OLS and FE for both cooperation in R&D and contracted R&D. The coefficients from the OLS differs to some extent from those from the FE, which is not surprising seeing that we expect some unobserved heterogeneity to be present. The regression results are presented in table 3.1[15].

Table 3.1: Regression results. All firms.

	Internal R&D	*Internal R&D*	*Internal R&D*	*Internal R&D*	*Internal R&D*	*Internal R&D*
Model	(3.1)	(3.1)	(3.2)	(3.2)	(3.3)	(3.3)
Estimator	OLS	FE	OLS	FE	OLS	FE
External R&D	0.5055***	0.3410***				
	(0.0070)	(0.0100)				
External R&D from same enterprise abroad			0.0515**	0.0611*	0.0644**	0.0335
			(0.0181)	(0.0252)	(0.0229)	(0.0323)
External R&D from others			0.4879***	0.3044***	0.4340***	0.2502***
			(0.0143)	(0.0232)	(0.0181)	(0.0297)
R&D cooperation	6.0643***	3.2268***	7.5253***	3.8015***		
	(0.0979)	(0.1112)	(0.1207)	(0.1494)		
R&D cooperation with same enterprise abroad					0.5812’	0.1529
					(0.2926)	(0.3126)
R&D cooperation with same enterprise domestic					0.3631	0.4926’
					(0.2733)	(0.2911)
R&D cooperation horizontal					-0.0269	0.5859*
					(0.2667)	(0.2479)
R&D cooperation vertical					4.7561***	1.5196***
					(0.2184)	(0.2057)
R&D cooperation institutional					3.6713***	1.7979***
					(0.2349)	(0.2173)
Constant	1.9496***	2.8737***	1.3044***	2.1309***	2.3737***	2.198***
	(0.5516)	(0.0913)	(0.6635)	(0.0923)	(0.6907)	(0.1020)
Industry dummies	Included		Included		Included	
Year dummies	Included	Included	Included	Included	Included	Included
R^2 (overall for FE)	0.5080	0.4431	0.3758	0.2929	0.3407	0.2409
N obs.	37,659	37,659	32,158	32,158	23,717	23,717

‘ significant at 10%, * significant at 5%, ** significant at 1%, and *** significant at 0.1%. Robust standard errors in parentheses. Internal and external R&D are log of R&D expenditures in 2009 NOK. R&D cooperation is dummies, taking 1 if cooperation and 0 otherwise. All regressions ran in STATA software.

Expanding the model we disaggregate contracted R&D, introducing external R&D from same enterprise abroad and external R&D from other sources as explanatory variables. The

[15] We also ran the random effect (RE) estimator. This estimator utilizes variation both between and within the firms in the sample. As with the OLS estimator, the RE estimator also requires the firm specific, the idiosyncratic error term and the explanatory variables to be uncorrelated. It can be shown that the RE estimator is more efficient than the FE estimator if its requirements is fulfilled (Verbeek 2008: 366). We ran the RE estimator, and tested if the firm specific error term and the explanatory variables were uncorrelated. Comparing estimates from the FE and RE estimations by a Hausman test revealed correlation. Hence, the RE requirements were breached, and estimates were dropped.

estimated effects of the fixed effect estimator suggest that external R&D from sources outside the enterprise has a greater impact on intramural R&D than R&D contracted out to foreign firms within the enterprise. The disaggregation of contracted R&D also leads to increased stimulation of intramural R&D following a decision to engage in R&D cooperation.

We finally estimate equation (3.3), where we disaggregate the cooperation dummy as well. Controlling for a set of different cooperation strategies, and two sources of contracting out R&D, our results suggest that contracted R&D and cooperation with foreign affiliates within the enterprise no longer has a significant impact on internal R&D spending. Cooperation

Table 3.2: Regression results, firm size subsamples

	Internal R&D	*Internal R&D*	*Internal R&D*	*Internal R&D*	*Internal R&D*	*Internal R&D*
Firm size	Small	Small	Medium	Medium	Large	Large
Model	(3.3)	(3.3)	(3.3)	(3.3)	(3.3)	(3.3)
Estimator	OLS	FE	OLS	FE	OLS	FE
External R&D from same enterprise abroad	-0.0041	0.0176	0.0491	0.0415	0.135***	0.0645
	(0.0433)	(0.0588)	(0.0365)	(0.0515)	(0.0430)	(0.0627)
External R&D from others	0.467***	0.156***	0.436***	0.254***	0.383***	0.309***
	(0.0293)	(0.0437)	(0.0285)	(0.0451)	(0.0412)	(0.0804)
R&D cooperation with same enterprise abroad	0.510	0.432	1.174**	0.484	-0.888	-1.429*
	(0.527)	(0.475)	(0.432)	(0.500)	(0.640)	(0.666)
R&D cooperation with same enterprise domestic	0.253	-0.295	0.459	1.050*	0.604	0.857
	(0.445)	(0.514)	(0.433)	(0.441)	(0.592)	(0.618)
R&D cooperation horizontal	0.018	0.732'	0.143	0.862*	-0.365	0.0475
	(0.425)	(0.402)	(0.418)	(0.416)	(0.584)	(0.490)
R&D cooperation vertical	5.150***	1.179***	4.183***	1.600***	3.180***	0.689
	(0.309)	(0.317)	(0.344)	(0.319)	(0.649)	(0.553)
R&D cooperation institutional	3.532***	1.860***	3.504***	1.688***	3.806***	2.478***
	(0.339)	(0.327)	(0.354)	(0.345)	(0.727)	(0.659)
Constant	1.211	2.343***	3.922**	3.117***	0.819	4.285***
	(0.782)	(0.094)	(1.329)	(0.109)	(0.756)	(0.288)
Industry dummies	Included		Included		Included	
Year dummies	Included	Included	Included	Included	Included	Included
R^2 (overall for FE)	0.3375	0.1834	0.3350	0.2276	0.5023	0.3912
N	13,012	13,012	8,741	8,741	1,964	1,964

' significant at 10%, * significant at 5%, ** significant at 1%, and *** significant at 0.1%. Standard errors in parentheses. Internal and external R&D are log of R&D expenditures in 2009 NOK. R&D cooperation is dummies, taking 1 if cooperation and 0 otherwise. All regressions ran in STATA software. Small firms have less than 50 employees, medium up to 249, and large firms more than 250 employees.

with domestic firms within the enterprise turns out to be significant at a 10 % level, with a coefficient of 0.4926. This suggests that a decision to pursue the strategy will increase internal R&D spending by roughly 49 %. All other cooperation dummies are significant at the 5 % level or lower. When it comes to contracting out R&D we find that external R&D acquired outside the enterprise has a highly significant positive impact on internal R&D. A

1 % increase in R&D bought outside the enterprise increases internal R&D spending with 0.25 %. The implications for these findings will be discussed in the next section.

Dividing the sample with respect to firm size we find that the effects on internal R&D vary somewhat dependent on firm-size. When it comes to contracted R&D only R&D purchased from others has a significant coefficient, as for the full sample. Compared to our previous results there are some differences; 1) domestic cooperation within the enterprise is significant only for medium sized firms and 2) horizontal and vertical cooperation is insignificant for large firms. The relative effect of the various forms of cooperation differs to some extent between the groups as well. All significant coefficients are positive, and economically significant. The magnitudes of the coefficients are hard to assess, seeing that we haven't come across any papers with comparable variable and model specifications.

For large firms with more than 250 employees two factors stimulates investments in internal R&D; a) external R&D from others, b) institutional R&D cooperation. Both coefficients are positive and economically significant, e.g. the coefficient for R&D cooperation with institutions suggesting that pursuing this strategy will increase expenditures on intramural R&D with 247.8 %. R&D cooperation with a foreign firm within the same enterprise is insignificant for small and medium sized firms, but significantly negative for large firms. The coefficient suggests an unrealistic high drop in internal R&D of 142.9 %. The magnitudes of the cooperation variables will be discussed in next chapter.

The medium sized firms in our sample face positive effects from all variables except those concerning R&D interactions with foreign firms in same enterprise. All coefficients are positive and very much economically significant. For the small firms we find that vertical and institutional cooperation, along with external R&D bought outside the enterprise has a statistical and economical significant impact on internal R&D.

Our final estimation for this chapter considers possible differences between the manufacturing and service sector. We have classified firms as manufacturing or service firms using the NACE codes in our data[16].

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[16]Manufacturing firms are defined as all firms with NACE-codes up to 50. Service firms are defined as all other firms with NACE-codes starting at 50.

Institutional cooperation seems to have an approximately identical effect on the firms, independent of industry, coefficients estimated to 1.920 and 1.777 for manufacturing and service firms respectively. Vertical cooperation are statistically significant for both industries, however the estimated effect is roughly twice as high for manufacturing firms. When it comes to horizontal cooperation the coefficients are fairly similar, the effect being a bit higher for service firms. External R&D from other sources outside the enterprise is statistically significant for both groups, with similar magnitude of the coefficients. For the firms in the service sector we find positive effects for domestic R&D cooperation within the enterprise. All statistically significant variables contribute to an increase in intramural R&D and are all economically significant. Out results suggest that cooperation in R&D outside the enterprise stimulates investments in intramural R&D independent of industry.

Table 3.3: Regression results for internal R&D and external R&D sources.

	Internal R&D	*Internal R&D*	*Internal R&D*	*Internal R&D*
Firm sector	Manufacturers	Manufacturers	Service	Service
Model	(3.3)	(3.3)	(3.3)	(3.3)
Estimator	OLS	FE	OLS	FE
External R&D from same enterprise abroad	0.0387	0.0102	0.109***	0.0665
	(0.0288)	(0.0443)	(0.0381)	(0.0496)
External R&D from others	0.430***	0.256***	0.440***	0.241***
	(0.0223)	(0.0401)	(0.0334)	(0.0444)
R&D cooperation with same enterprise abroad	0.979**	-0.292	0.0185	0.839
	(0.382)	(0.396)	(0.449)	(0.533)
R&D cooperation with same enterprise domestic	0.125	0.101	0.736’	1.104*
	(0.348)	(0.366)	(0.441)	(0.472)
R&D cooperation horizontal	-0.071	0.590’	0.066	0.724’
	(0.338)	(0.319)	(0.432)	(0.393)
R&D cooperation vertical	4.999***	1.784***	4.349***	0.811*
	(0.283)	(0.268)	(0.342)	(0.317)
R&D cooperation institutional	3.533***	1.920***	3.934***	1.777***
	(0.308)	(0.292)	(0.362)	(0.326)
Constant	2.134***	2.54***	1.686*	3.131***
	(0.705)	(0.0912)	(0.745)	(0.141)
Industry dummies	Included		Included	
Year dummies	Included	Included	Included	Included
R^2 (overall for FE)	0.3266	0.2638	0.3629	0.2044
N	14,495	14,495	9,222	9,222

‘ significant at 10%, * significant at 5%, ** significant at 1%, and *** significant at 0.1%. Standard errors in parentheses. Internal and external R&D are log of R&D expenditures in 2009 NOK. R&D cooperation are dummies, taking 1 if cooperation and 0 otherwise. All regressions ran in STATA software. Manufacturers also include fishing, mining, energy and construction sectors.

3.5 Discussion and concluding remarks

The coefficient for buying external R&D sources outside the enterprise is fairly similar in all cases, with some deviation for small and large firms. The positive effect points towards a possible complementary relationship between internal R&D spending and R&D acquired outside the enterprise. This seems reasonable due to absorptive capacity. The investments in intramural R&D are necessary for the firms to process and exploit new information.

Disaggregation of the cooperation dummy removes most of the explanatory power of the dummies concerning cooperation within the enterprise. Vertical and institutional cooperation have a significantly greater impact on internal R&D spending on average.

One possible error in our estimation would be if there was too little variation in our variables. For the estimation to tell us anything about the effects of cooperation or contracting the transition from one state to another, e.g. entering a vertical R&D cooperation, must be made by a sufficient number of firms. To check for this we have tabulated all dummies with a mean between 0 and 1 for all samples. We find that for large firms 139 firms make a transition when it comes to cooperation with foreign firms within the enterprise. This is the dummy with least variation in the samples, thus we conclude that our estimations don't suffer from neither too few observations nor too little variation.

4. Internal and external R&D – complements or substitutes?

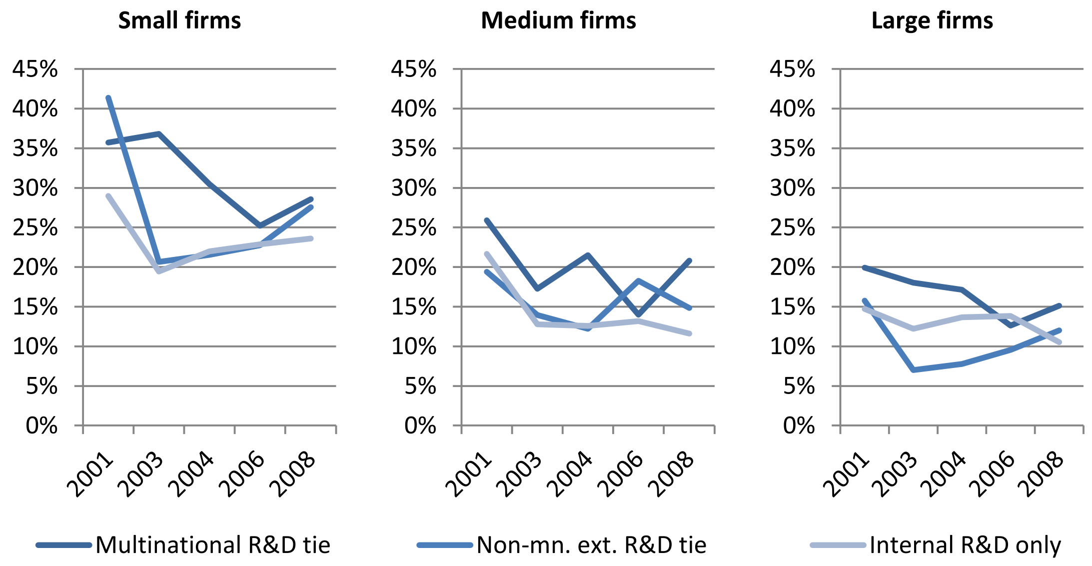
4.1 Introduction

In this chapter, we seek to find out if external R&D and internal R&D are complements or substitutes. In chapter 3 we found evidence for some external R&D sources to increase internal R&D activity among Norwegian firms. We pointed out the need for absorptive capacity as one explanation for the positive relationship. Beyond the need for absorptive capacity, external R&D may complement internal R&D, giving the firm incentives to increase internal R&D when entering an R&D cooperative or contracting out R&D. On the other side, the effect of R&D contracting on internal R&D was less than proportional, indicating a positive, but decreasing relationship; for large levels of internal R&D, external R&D sourcing may be substitutable with internal R&D. For external R&D sources not affecting the level of internal R&D, a substitutable rather than complementary relationship between the two are more likely to exist.

In order to reveal possible complementarity or substitutability between internal and external R&D, both must be treated as inputs for innovation. The factors are complementary if an increase in one of the factors leads to an increase in the marginal productivity of the other. If the effect is negative, they are substitutes. A further description of the modelling of internal and external R&D as input factors in innovation is given in section 4.2 “Model specification”.

While internal R&D is found to increase after acquiring non-multinational external R&D, there is no sign of innovative superiority for R&D active firms with non-multinational external R&D ties. On the other side, firms with multinational R&D ties hold a higher level of innovativeness. Figure 4.1 shows that firms with multinational R&D ties have a varying and sometimes higher level of sales attributable to new sales than firms with other external R&D ties as well as firms only performing internal R&D. Firms with other external R&D ties have slightly higher levels of new sales than firms relying solely on performing internal R&D. A less clear pattern appears for manufacturers and services in figure 4.2. Firms with multinational R&D ties, non-multinational external R&D ties, and firms only performing internal R&D, do not seem to differ significantly among manufacturers. Services with multinational R&D ties seem to have a slightly higher level of new sales than other services. Figure 4.1 and 4.2 show that firms combining internal R&D and external R&D have only slightly higher levels of new sales than those who only perform internal R&D. Given that an average firm only performing internal R&D faces the same price for internal R&D as an average firm with external R&D ties in addition to internal R&D, no clear differences in innovativeness between the two firms indicate diseconomies of scope, i.e. substitutability, in internal R&D and external R&D.

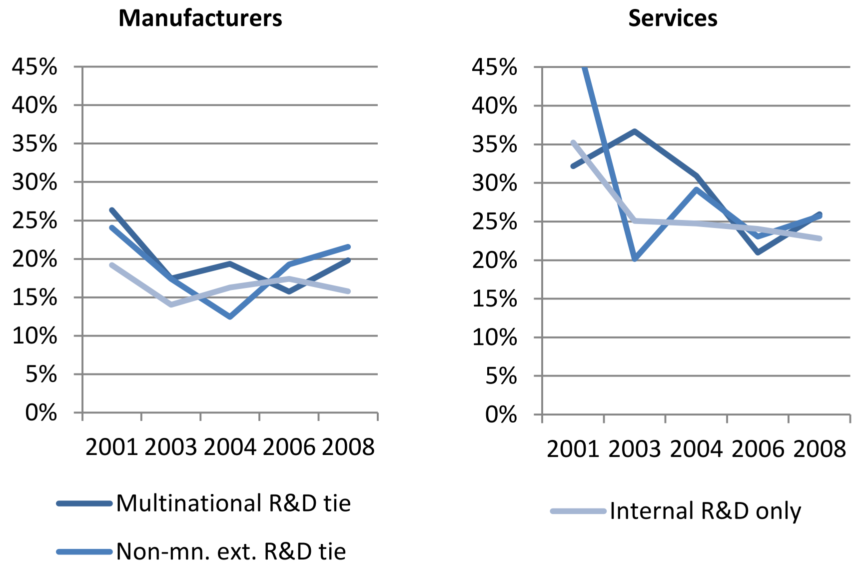
Figure 4.1: Share of sales attributed to new products among small, medium sized and large R&D active firms



Source: R&D and innovation surveys, Statistics Norway. The survey covers all Norwegian firms with more than 50 employees, and a sample of firms with 10-49 employees. Aggregation based on weights provided by Statistics Norway. Multinational R&D tie refers to firms either purchasing R&D from, or collaborates in R&D with, a foreign firm within the same enterprise, or both. Non-multinational external R&D tie refers to either R&D purchasing or R&D cooperation with all other firms.Small firms have less than 50 employees, medium up to 249, and large firms more than 250 employees.

The literature section gave an overview of theoretical approaches, as well as empirical evidence, on how internal R&D and external R&D interact as inputs of innovation. According to the absorptive capacity theory, a certain level of internal R&D is required to utilize external R&D sources (Cohen and Levinthal, 1989; 1990; Mowery and Oxley, 1995). However, one should not expect this part of internal R&D to affect the innovation activity per se; the effect of external R&D on innovation should be attributed to the external R&D only, and the absorptive capacity should be considered as nothing more than an interpreter of external R&D.

Figure 4.2: Share of sales attributed to new products among R&D active manufacturers and services



Source: R&D and innovation surveys, Statistics Norway.

In the case of substitutability between (the non-absorptive capacity part of) internal R&D and external R&D sourcing, external R&D should have the same properties as internal R&D, including the impact on the marginal returns to innovation of the latter. Hence, under the assumption of decreasing marginal returns of internal R&D, external R&D should lower the marginal return of internal R&D for any given level of the latter. For a given price of internal R&D (which may be interpreted as the alternative cost of internal R&D investments), external R&D sourcing should, ceteris paribus, lower the optimal level of internal R&D. Hence, substitutability and absorptive capacity may pull the effect of external R&D on total internal R&D in opposite directions; substitutability makes external R&D replace and reduce the non-absorptive capacity part of internal R&D, while the absorptive capacity requires an increase in the absorptive capacity part of internal R&D, making the effect on total internal R&D ambiguous.

On the other hand, if synergies between external R&D and the non-absorptive capacity part of internal R&D arises external R&D sourcing will raise the marginal return of internal R&D for any given level of the latter. Internal R&D and external R&D sourcing will then be complements and the optimal level of internal R&D should increase. Hence, both complementarity and absorptive capacity should, other things equal, increase the optimal level of internal R&D.

If the level of absorptive capacity does not affect the economies of scale of internal R&D, and neither substitutability nor complementarity exists, external R&D sources should have no impact on the marginal product of internal R&D.

In the following, we model and estimate the impact of acquiring external R&D on the marginal effect of internal R&D on innovativeness in order to reveal possible complementarity or substitutability between internal R&D and different external R&D sources.

4.2 Data

We use the same data and variables for estimation as in section 3. See section 3.2 for further description. Two variables are used to measure innovativeness. Following i.a. Crépon et al. (1998) we use the share of novel sales to total sales. We also use whether or not the firm has made any product or process innovation (i.e. an innovation dummy, taking 1 if innovation and 0 otherwise), following i.a. Schmiedeberg (2008) and Criscuolo et al. (2005).

Variable construction

The share of new sales and innovation variables were only available for 2001, 2003, 2004, 2006 and 2008. The variable new sales refers to the share of sales attributed to sale of new or considerably improved products introduced the prior or last two years. The variable innovation refers to whether or not the firm has made a product or process innovation also during the prior or last two years. Hence the variables contain information on the innovativeness for three years intervals. We therefore have constructed the explanatory variables of R&D expenditures and sales as a three year average. The cooperation variables take the form 1 if a firm has been engaged in cooperation in one of the three years and 0 if not. We are, unfortunately, not able to control for the overlapping caused by the fact that the variables appears every two years and contains information on a three year period. Appendix C contains detailed information of the variable construction. Sales are deflated using the

Consumer Price Index from Statistics Norway. A list of descriptive statistics for all variables is presented in appendix B.

4.3 Model specification

We treat internal R&D and external R&D activities as inputs in the innovation process. In order to reveal possible complementarity or substitutability between internal and external R&D activities, we would like to estimate the impact of external R&D activity on the marginal effect of internal R&D activities on innovation. We do this by specifying the cross product of internal and external R&D activities in addition to separate variables for internal R&D and external R&D activities.

$$(4.1) \quad Inno_{it} = \tau_0 + \varphi ird_{it} + \omega erd_{it} + \kappa_E erd_{it} ird_{it} + \lambda CO_{it} + \kappa_C CO_{it}\, ird_{it} + \tau_1 s_{it} + d_t + nace_i + \varepsilon_{it}$$

$$\varepsilon_{it} = a_i + u_{it}$$

where – for firm i at time t – Inno is innovativeness, ird is log of internal R&D expenditures, erd is log of external R&D expenditures, CO is a dummy, taking 1 if the firm cooperates in R&D and 0 if not, erdird and COird are the cross products, s is log of sales, d_t is year dummy, $nace_i$ is two digit industry dummiy, a_i is the firm specific error term and u_{it} is the idiosyncratic error term. Innovation is measured both as: a dummy, taking 1 if the firm has made a product or process innovation the current or last two years or 0 otherwise; percentage of sales attributed to products introduced or substantially improved the current or last two years. The variables containing R&D expenditures are specified on log-form in order to reduce the size of outliers.

Schmiedberg (2008) specify a similar model, regressing i.a. internal R&D, R&D contracting and R&D cooperation on both percentage of sales attributed to new products and number of patents on a cross section. All three variables are specified as binary, taking 1 in the case of performing an R&D activity and 0 otherwise. Instrumenting the choice of conducting internal and external R&D or not, she finds weak evidence for complementarity between internal and external R&D.

The results of chapter 3 indicate that the variables containing external R&D contracting and R&D cooperation in model (4.1) should be split up. In chapter 3, we found significant differences between R&D contracting with foreign firms within the same enterprise and R&D contracting with others with respect to their effect on internal R&D expenditures. We found significant differences in the effects of different forms of R&D cooperation partners on internal R&D expenditures as well. We expect the different forms of R&D contracting and R&D cooperation to have different properties with respect to internal R&D; some may be substitutable and others complementary, making the estimated effect of the aggregated external R&D and R&D cooperation variables in (4.1) ambiguous. We define our augmented model as:

(4.2) $Inno_{it} = \tau_0 + \lambda ird_{it} + \omega_1 merd_{it} + \kappa_1 merd_{it} ird_{it} + \omega_2 oerd_{it} + \kappa_2 oerd_{it}\, ird_{it} + \lambda_3 MCO_{it} + \kappa_3 MCO_{it}\, ird_{it} + \lambda_4 DCO_{it} + \kappa_4 DCO_{it}\, ird_{it} + \lambda_5 HCO_{it} + \kappa_5 HCO_{it}\, ird_{it} + \lambda_6 VCO_{it} + \kappa_6 VCO_{it}\, ird_{it} + \lambda_7 ICO_{it} + \kappa_7 ICO_{it}\, ird_{it} + \tau_1 s_{it} + d_t + nace_i + \varepsilon_{it}$ $\quad \varepsilon_{it} = a_i + u_{it}$

Following the endogenous growth theory, R&D activities and innovation may be connected with productivity growth. At the aggregate level, productivity is interpreted as the knowledge stock, and growth in the knowledge stock interpreted as the production of new ideas and new knowledge. The latter relationship is modelled as a knowledge production function, where the current stock of knowledge, or its time derivative, is defined as a function of past knowledge stock and current knowledge input (Griliches 1979; Romer 1990; Jones 1995; 2005). In empirical approaches, the knowledge stock is seen as the innovative capability or innovative success: "its technological knowledge obtained via R&D or its competency at transforming research results into useful products and processes (Hall, 2011: 10)". Treating Inno as growth in the knowledge stock, (4.1) can be specified as a Cobb Douglas knowledge production function in level form. We are however careful in interpreting model (4.1) as such a knowledge production function since the Cobb Douglas form presumes complementarity between the input variables. We can not a priori assume internal R&D and external R&D activities to be either complementary or substitutes; in this chapter we explore if internal and external R&D activities are complementary or substitutes a posteriori.

Crépon et al. (1998) provide an econometric framework for combining R&D and innovation with productivity (the so called CDM-model in the R&D literature, extended for panel data by Raymond et al., (2009)). The CDM-model consists of four sets of equations. The first and second equation is a censored regression model for R&D expenditures, which takes account for R&D determining variables, including demand pull and technology push variables. The third equation expresses innovation, measured either by number of patent or novel sales as share of total sales, as a function of R&D input. The last equation expresses labour productivity as a function of innovation. Cassiman and Veugelers (2006) build on this framework, when examining possible complementarity between making R&D internally and contracting R&D externally on a cross section of Belgian manufacturers. As in Schmiedberg (2008), internal and external R&D is binary variables. Instrumenting internal and external R&D, they model productivity as a supermodular function of internal and external R&D, and find evidence for complementarity.

Our panel data set, where R&D expenditures are on interval form, give us certain advantages when estimating (4.1) with respect to new sales. The relationship between innovation and R&D activities are expected to be influenced by common unobserved factors (Athey and Stern 1998: 3): “[T]he talent and past experience of managers and workers, the beliefs held within the firm about current and future market conditions, labour-management relation, the formal and informal processes for adapting changes in organizational design in a given firm, the influence exerted by various interest groups within the firm, and other adjustment costs” all are firm specific and may affect both the level of R&D expenditures, R&D cooperation, and the innovativeness. However, they may not be observable in the dataset. Both Schmiedberg (2008) and Cassiman and Veugelers (2006) instrument internal and external R&D in order to overcome possible endogeneity problems. By applying the fixed effect estimator, we can more precisely correct for unobserved heterogeneity, reducing the expected endogeneity. However, lacking proper instruments, we are unable to correct for possible remaining endogeneity.

The innovation dummy provides a broader measure for innovativeness than sales attributed to new products and to some extent productivity. This dummy captures process as well as product innovation. Bergman (2011) and Lokshin et. al. (2007) test for complementary between internal and external R&D activities. They assume R&D to affect labour productivity through the knowledge stock, and regress internal R&D, external R&D, and their cross product directly on labour productivity. As pointed out by Hall (2011), however positive in general, the relationship between innovation, i.e. the knowledge stock, and labour productivity is not unambiguous. In a summary of studies on innovations and productivity, Hall (2011) states that share of novel sales and product innovations have a stronger impact on labour productivity than process innovations. One explanation for this may be the way labour productivity is derived. Because productivity is derived from production, measured as sale revenues, product innovations and new sales should be expected to be closer related to productivity than process innovation. The latter are expected to provide cost reductions, not necessarily leading to increased sales, but still increasing profitability. By including process innovation in the dependent variable, our approach may better take into account innovations leading to cost reductions.

When using the innovation dummy as an explanatory variable, we are unable to correct for unobserved heterogeneity. We would like to apply a binary estimator which corrects for unobserved heterogeneity. However, unless one can make assumptions about the correlation between the unobserved heterogeneity and the explanatory variables[17], no such proper estimator exists (Wooldridge 2010: 610-619). Greene (2002) shows that the fixed effect probit estimator under maximum likelihood suffers from bias in coefficients due to unobserved heterogeneity when $N \rightarrow \infty$. For $T < 8$ the bias in the fixed effect probit estimator is severe relative to the bias in the probit on a pooled cross-section. If unobserved heterogeneity is present, Greene (2002: 14, 18) suggests to use a probit-estimator on a pooled-cross section and not the fixed effect estimator for panels with small time series. Following Green (2002) and Cruscuolo et. al. (2005) we apply the probit estimator on the pooled cross-section, aware of possible positive or negative bias in the estimated coefficients.

[17] such as the Chamberlain's correlated random effects probit estimator assumes.

4.4 Results

Tables 4.1 – 4.4 report expected but also surprising results. Table 4.1 shows the results from the estimation of (4.1) on the whole sample of firms. As expected internal R&D has a positive and significant impact on both measurements of innovativeness; a ten percent increase in internal R&D expenditures should increase the ratio of new sales to total sales by 5.59 percentage points and increase the likelihood of making an innovation by 31.9 percentage points. Surprisingly, external R&D contracting does not seem to affect the average firm's innovativeness. R&D cooperation affects innovativeness positively and significantly; establishing R&D cooperation should increase the ratio of new sales to total sales by 3.36 percentage points and the likelihood of making an innovation by 34.6 percentage points. R&D cooperation affects the marginal effect of internal R&D on innovativeness, indicating a substitutable relationship between R&D cooperation in general and internal R&D; establishing R&D cooperation reduces the effect of internal R&D by approximately a half. However, the results from estimations of model (4.2) presented in table 4.2, 4.3 and 4.4 show a more nuanced picture.

Table 4.1: Regression results for novel sales and innovation

	Novel sales	*Novel sales*	*Innovation*
Model	(4.1)	(4.1)	(4.1)
Estimator	OLS	FE	Probit
Internal R&D (ird)	0.00931***	0.00549***	0.0319***
	(0.000378)	(0.000583)	(0.00073)
External R&D	-0.00099'	0.000839	0.00207
	(0.000552)	(0.000802)	(0.00165)
ird x external R&D	0.0000687	-0.000026	-0.000034
	(0.0000549)	(0.000077)	(0.00012)
R&D cooperation	0.0450***	0.0336***	0.346***
	(0.00623)	(0.0078)	(0.0182)
ird x R&D cooperation	-0.000819	-0.00207*	-0.0150***
	(0.00068)	(0.000867)	(0.00133)
Sales	-0.00845***	-0.00328'	-0.00183
	(0.00085)	(0.0017)	(0.00197)
Constant	0.241***	0.194***	-1.638***
	(0.0304)	(0.0347)	(0.288)
Industry dummies	Included		Included
Year dummies	Included	Included	Included
R^2	0.2468	0.1933	0.3093
N	17,511	17,511	18,330

' significant at 10%, * significant at 5%, ** significant at 1%, and *** significant at 0.1%. Standard errors in parentheses. R^2 is overall for FE and pseudo R^2 for probit. Novel sales is the sale revenue of new products in percent of total sales. Innovation is dummy taking 1 if the firm has made a product or process innovation, and 0 otherwise. Probit estimates are marginal effects calculated from mean values of explanatory variables. For dummies, marginal effects describe changes from 0 to 1 in variable. All regressions ran in STATA software.

The results from the OLS-estimation are larger in magnitude than the results from the FE-estimation. Unobserved heterogeneity was confirmed by running a Hausman-test of FE- and RE-estimates for model (4.1). Firm specific effects affect the innovativeness as well as R&D strategies and activities as we expected and discussed in the previous section.

By splitting up the variables, differences between multinational R&D contracting and other external R&D contracting, and differences between different forms for R&D cooperation with respect to innovativeness appear. The OLS results in table 4.2 are significantly higher than the FE-results for model (4.2) as well. We confirm presence of unobserved heterogeneity and conclude that the estimates from the OLS are biased. We therefore concentrate on the results from the FE-estimator. Table 4.2 shows that internal R&D expenditures in model (4.2) has approximately the same effect on innovativeness as in model (4.1). Multinational R&D contracting – i.e. external R&D purchases from a foreign firm within the same enterprise – has a significant and positive effect on innovativeness; a ten percent increase in multinational R&D contracting leads, ceteris paribus, to an increase in the share of sales attributed to new products and the likelihood of making innovation by 3.68 and 16.7 percentage points respectively for the average firm. At the same time, the marginal effect of internal R&D on innovativeness is reduced by approximately a third. The latter effect indicates internal R&D and multinational R&D contracting to be substitutable.

Somewhat puzzling, external R&D purchases from others lower the probability of making innovations, but are complementary with internal R&D. If the average firm increases external R&D purchases from others, the likelihood of innovating should be reduced by 41.8 percentage points, but at the same time approximately double the marginal effect of internal R&D on the same likelihood. External R&D purchases are not found to have a statistically significant impact on the share of sales related to new products.

R&D cooperation with both a foreign firm and a domestic firm within the same enterprise increases the likelihood of innovating. The increase in the likelihood of innovating is slightly higher for R&D cooperation with a foreign firm within the same enterprise than a domestic firm within the same enterprise, 18.9 and 22.5 percentage points respectively. Evidence of substitutability is found between internal R&D and R&D cooperation with a firm within the same enterprise with respect to the likelihood of innovating. The coefficients of the cross products indicate that the marginal effect of internal R&D on the likelihood of innovation decreases by approximately a quarter and a third when entering an R&D cooperative with a foreign and domestic firm within the same enterprise respectively. R&D cooperation with a domestic firm within the same enterprise has similar effect on the share of sales attributed to new products as on the likelihood of innovating. Entering such an R&D cooperative increases the share by 3.41 percentage points and reduces the effect of internal R&D by more than two thirds.

Table 4.2: Regression results for novel sales and innovation

	Novel sales	*Novel sales*	*Innovation*
Model	(4.2)	(4.2)	(4.2)
Estimator	OLS	FE	Probit
Internal R&D (ird)	0.00914***	0.00494***	0.0323***
	(0.000333)	(0.000512)	(0.0007)
External R&D from same enterprise abroad	0.00393**	0.00368*	0.0167***
	(0.00123)	(0.00185)	(0.00347)
ird x external R&D from same enterprise abroad	-0.000309**	-0.000251’	-0.00117***
	(0.000113)	(0.000151)	(0.00025)
External R&D from others	-0.0134***	-0.00538	-0.0418***
	(0.00365)	(0.00421)	(0.0118)
ird x external R&D from others	0.00116***	0.000459	0.00312***
	(0.000268)	(0.000346)	(0.00077)
R&D cooperation with same enterprise abroad	0.0333’	0.0241	0.189***
	(0.0193)	(0.0226)	(0.0496)
ird x R&D cooperation with same enterprise abroad	-0.00107	0.000496	-0.00735**
	(0.00153)	(0.00180)	(0.00289)
R&D cooperation with same enterprise domestic	0.0399**	0.0341’	0.225***
	(0.0136)	(0.0178)	(0.0401)
ird x R&D cooperation with same enterprise domestic	-0.00392**	-0.00348*	-0.0119***
	(0.00117)	(0.00159)	(0.0024)
R&D cooperation horizontal	-0.0226	-0.0232	-0.0941**
	(0.0143)	(0.0206)	(0.0289)
ird x R&D cooperation horizontal	0.000481	0.000868	0.00576*
	(0.00125)	(0.00171)	(0.00282)
R&D cooperation vertical	0.0359**	0.0455**	0.267***
	(0.0115)	(0.0131)	(0.0337)
ird x R&D cooperation vertical	0.00153	-0.00124	-0.00761***
	(0.00108)	(0.00119)	(0.00217)
R&D cooperation institutional	0.0134	0.000754	0.159***
	(0.012)	(0.0153)	(0.0352)
ird x R&D cooperation institutional	-0.00118	0.0000517	-0.00976***
	(0.00107)	(0.00132)	(0.00229)
Sales	-0.00944***	-0.00287	-0.00147
	(0.000934)	(0.00193)	(0.00227)
Constant	0.131***	0.0737*	-2.266***
	(0.0269)	(0.0355)	(0.293)
Industry dummies	Included		Included
Year dummies	Included	Included	Included
R^2 (pseudo R^2 for probit)	0.2513	0.1938	0.3311
N	15,752	15,752	15,811

‘ significant at 10%, * significant at 5%, ** significant at 1%, and *** significant at 0.1%. Standard errors in parentheses. Novel sales is the sale revenue of new products in percent of total sales. Innovation is dummy taking 1 if the firm has made a product or process innovation, and 0 otherwise. Internal and external R&D are log of R&D expenditures in 2009 NOK. R&D cooperation is dummies, taking 1 if cooperation and 0 otherwise. Sales are log of sales in 2009 NOK. Probit estimates are marginal effects calculated from mean values of explanatory variables. For dummies, marginal effects describe changes from 0 to 1 in variable. All regressions ran in STATA software.

Horizontal R&D cooperation lowers the probability of innovating for the average firm by 9.41 percentage points, while vertical and institutional R&D cooperation increases the same probability by 26.7 and 15.9 percentage points respectively. R&D cooperation with competitors and internal R&D are found to be complements, although somewhat small of magnitude. Both vertical and institutional R&D cooperation are found to be substitutes with internal R&D, each reducing the marginal return on innovation of internal R&D by approximately a quarter. Regarding the effect of horizontal, vertical and institutional R&D cooperation when new sales is dependent variable, only vertical R&D cooperation gives a statistically significant effect. Vertical R&D cooperation gives an increase in the revenue from new sales to total sales ratio of 4.55 percentage points for the average firm. No substitutability or complementarity with internal R&D is found.

By splitting up the sample, some differences across firm sizes and firm sectors appear. Table 4.3 presents the results from estimating (4.2) on small, medium sized and large firms respectively. Table 4.4 shows the results for manufacturers and services. The effects of internal R&D on new sales and innovation is relatively higher for small firms, but do not seem to differ much between medium sized and large firms or between manufacturers and services. However, regarding the effect on new sales, this may be attributed to the fact that larger firms normally have a much larger stock of products, requiring a large turnover of products to give a significant change in the sale of new products to total sales ratio.

Multinational R&D contracting becomes insignificant for medium sized and large firms with respect to new sales. For all firm sizes external R&D purchases from a foreign firm within the same enterprise has a significant and positive impact on the probability of innovating. The effect on innovation is almost the same for manufacturers and services. For new sales it is significant and positive for small firms and manufacturers only. Multinational R&D contracting and internal R&D is found to be substitutable with respect to the likelihood of making innovations. The substitutable relationship is stronger for larger firms than medium sized and small firm.

External R&D purchases from others affect innovation for medium sized and large firms, and for manufacturers only. The likelihood of innovation is negatively affected. For these subsamples complementarities between external R&D from others and internal R&D are found. Hence, the effect of external R&D purchases on innovativeness is still negative and has complementary properties with internal R&D. The puzzle is now limited to manufacturers, and small and medium sized firms.

Table 4.3: Regression results for novel sales and innovation. Small, medium and large firms.

	Novel sales	*Innovation*	*Novel sales*	*Innovation*	*Novel sales*	*Innovation*
Firm size	Small	Small	Medium	Medium	Large	Large
Model	(3.2)	(3.3)	(3.2)	(3.3)	(3.2)	(3.3)
Estimator	FE	Probit	FE	Probit	FE	Probit
Internal R&D (ird)	0.00726***	0.0332***	0.00342***	0.0302***	0.00306*	0.0307***
	(0.00108)	(0.00099)	(0.000623)	(0.00114)	(0.00135)	(0.00289)
External R&D from same enterprise abroad	0.00548*	0.0135*	0.00396	0.0221***	0.00271	0.0196
	(0.00234)	(0.00534)	(0.00354)	(0.00525)	(0.00257)	(0.0122)
ird x external R&D from same enterprise abroad	-0.000305	-0.000907*	-0.000286	-0.00137**	-0.000099	-0.00173*
	(0.000224)	(0.00042)	(0.000291)	(0.0004)	(0.000198)	(0.00082)
External R&D from others	-0.00769	-0.0032	-0.00553	-0.0849***	-0.0192	-0.0437
	(0.00804)	(0.0208)	(0.00626)	(0.0228)	(0.0127)	(0.0275)
ird x external R&D from others	0.000931	0.000465	0.000463	0.00587***	0.00110	0.00435*
	(0.000755)	(0.00138)	(0.000536)	(0.00151)	(0.000803)	(0.00171)
R&D cooperation with same enterprise abroad	0.00660	0.194*	-0.0133	0.187**	0.136**	0.301*
	(0.0506)	(0.0987)	(0.0308)	(0.0687)	(0.0433)	(0.125)
ird x R&D cooperation with same enterprise abroad	0.00157	-0.00638	0.0019	-0.00703'	-0.00556'	-0.0148'
	(0.00415)	(0.00526)	(0.00238)	(0.00422)	(0.00302)	(0.009)
R&D cooperation with same enterprise domestic	0.0722	0.163*	0.0068	0.234***	0.0460	0.235*
	(0.0457)	(0.0661)	(0.0215)	(0.0586)	(0.0401)	(0.117)
ird x R&D cooperation with same enterprise domestic	-0.00859*	-0.011**	-0.00156	-0.0112**	-0.00199	-0.0112
	(0.00427)	(0.00386)	(0.00214)	(0.00373)	(0.00287)	(0.00795)
R&D cooperation horizontal	-0.0759*	-0.153***	-0.0303	-0.0616	0.00321	0.0353
	(0.0383)	(0.0251)	(0.0356)	(0.0547)	(0.0267)	(0.116)
ird x R&D cooperation horizontal	0.00323	0.0123**	0.00148	0.00416	-0.00201	-0.00707
	(0.00354)	(0.00434)	(0.00283)	(0.0047)	(0.00227)	(0.00818)
R&D cooperation vertical	0.0904**	0.342***	0.0317*	0.211***	0.00652	0.283**
	(0.0297)	(0.0521)	(0.0156)	(0.0524)	(0.0198)	(0.100)
ird x R&D cooperation vertical	-0.00226	-0.00927**	-0.000629	-0.0061'	-0.0000329	-0.00795
	(0.00265)	(0.0031)	(0.00162)	(0.00356)	(0.00165)	(0.00767)
R&D cooperation institutional	0.0285	0.233***	0.0118	0.123*	-0.0203	0.119
	(0.0395)	(0.0593)	(0.0198)	(0.0534)	(0.0198)	(0.102)
ird x R&D cooperation institutional	-0.00288	-0.0167***	-0.000067	-0.00471	0.000664	-0.00285
	(0.00315)	(0.00343)	(0.00184)	(0.00366)	(0.00188)	(0.00772)
Sales	-0.00785*	0.000583	0.000713	0.000514	-0.00565	-0.00487
	(0.00377)	(0.00374)	(0.00266)	(0.00482)	(0.00554)	(0.0104)
Constant	0.154*	-2.243***	0.00998	-2.577***	0.146	-1.131'
	(0.0651)	(0.4287)	(0.0509)	(0.494)	(0.112)	(0.613)
Industry dummies		Included		Included		Included
Year dummies	Included	Included	Included	Included	Included	Included
R^2 (pseudo R^2 for probit)	0.2528	0.3564	0.1575	0.3079	0.1170	0.3589
N	8,131	8,101	6,106	6,104	1,515	1,488

' significant at 10%, * significant at 5%, ** significant at 1%, and *** significant at 0.1%. Standard errors in parentheses. Novel sales is the sale revenue of new products in percent of total sales. Innovation is dummy taking 1 if the firm has made a product or process innovation, and 0 otherwise. Internal and external R&D are log of R&D expenditures in 2009 NOK. R&D cooperation is dummies, taking 1 if cooperation and 0 otherwise. Sales are log of sales in 2009 NOK. Probit estimates are marginal effects calculated from mean values of explanatory variables. For dummies, marginal effects describe changes from 0 to 1 in variable. All regressions ran in STATA software. Small firms have less than 50 employees, medium up to 249, and large firms more than 250 employees.

Table 4.4: Regression results for novel sales and innovation. Small, medium and large firms.

	Novel sales	*Innovation*	*Novel sales*	*Innovation*
Firm sector	Manufacturers	Manufacturers	Services	Services
Model	(3.2)	(3.3)	(3.2)	(3.3)
Estimator	FE	Probit	FE	Probit
Internal R&D (ird)	0.00446***	0.0336***	0.00571***	0.0304***
	(0.000543)	(0.0009)	(0.00106)	(0.00113)
External R&D from same enterprise abroad	0.00405’	0.0165***	0.00148	0.0183**
	(0.00208)	(0.00436)	(0.00397)	(0.0058)
ird x external R&D from same enterprise abroad	-0.000236	-0.00102**	-0.000167	-0.00151***
	(0.000161)	(0.00032)	(0.000321)	(0.00042)
External R&D from others	-0.00435	-0.0455***	-0.000523	-0.0242
	(0.00413)	(0.0143)	(0.0117)	(0.0229)
ird x external R&D from others	0.000153	0.00307**	0.000492	0.00247’
	(0.000348)	(0.00094)	(0.000805)	(0.00145)
R&D cooperation with same enterprise abroad	-0.00734	0.0711	0.0597*	0.233***
	(0.0355)	(0.0799)	(0.0302)	(0.0623)
ird x R&D cooperation with same enterprise abroad	0.00309	-0.00024	-0.00246	-0.0109**
	(0.00253)	(0.00496)	(0.00297)	(0.0038)
R&D cooperation with same enterprise domestic	0.0243	0.293***	0.0561’	0.146*
	(0.0234)	(0.0545)	(0.0288)	(0.0581)
ird x R&D cooperation with same enterprise domestic	-0.00134	-0.0153***	-0.00739**	-0.00795*
	(0.00186)	(0.00319)	(0.00285)	(0.00369)
R&D cooperation horizontal	-0.0304	-0.122***	-0.00868	-0.0645
	(0.0309)	(0.0369)	(0.0250)	(0.0459)
ird x R&D cooperation horizontal	-0.000675	0.00791*	0.00404	0.00511
	(0.00239)	(0.00394)	(0.00250)	(0.0042)
R&D cooperation vertical	0.0359**	0.267***	0.0472*	0.256***
	(0.0135)	(0.0469)	(0.0219)	(0.0492)
ird x R&D cooperation vertical	-0.000296	-0.0069*	-0.00156	-0.00832**
	(0.00121)	(0.00296)	(0.00234)	(0.0033)
R&D cooperation institutional	0.0171	0.182***	-0.0171	0.152**
	(0.0178)	(0.0498)	(0.0226)	(0.0513)
ird x R&D cooperation institutional	-0.000515	-0.0113***	0.0000227	-0.00895**
	(0.00147)	(0.00318)	(0.00226)	(0.0034)
Sales	-0.00475	-0.00347	-0.00193	-0.00119
	(0.00332)	(0.00333)	(0.00242)	(0.00313)
Constant	0.107’	-2.213***	0.0573	-1.507***
	(0.0608)	(0.326)	(0.0448)	(0.429)
Industry dummies		Included		Included
Year dummies	Included	Included	Included	Included
R^2 (pseudo R^2 for probit)	0.1913	0.3446	0.1921	0.3138
N	9,535	9,570	6,217	6,241

‘ significant at 10%, * significant at 5%, ** significant at 1%, and *** significant at 0.1%. Standard errors in parentheses. Novel sales is the sale revenue of new products in percent of total sales. Innovation is dummy taking 1 if the firm has made a product or process innovation, and 0 otherwise. Internal and external R&D are log of R&D expenditures in 2009 NOK. R&D cooperation is dummies, taking 1 if cooperation and 0 otherwise. Sales are log of sales in 2009 NOK. Probit estimates are marginal effects calculated from mean values of explanatory variables. For dummies, marginal effects describe changes from 0 to 1 in variable. All regressions ran in STATA software. Manufacturers also include fishing, mining, energy and construction sectors.

Regarding R&D cooperation, the results differ somewhat in size and between manufacturers and services. R&D cooperation with a foreign firm within the same enterprise, affects the ratio of new sales to total sales for large firms and services only. The coefficient indicates that entering R&D cooperation with a foreign firm within the same enterprise increases the ratio by 13.6 and 5.97 percentage points for large firms and services respectively. The likelihood of innovation is significantly and positively affected by multinational R&D cooperation for all firm sizes. The effect is strongest for the large firms in our sample. For large firms, multinational R&D cooperation has a significant negative effect on the marginal effect of internal R&D on innovativeness. Entering an R&D cooperative with a foreign firm within the same enterprise, should turn the marginal effect of R&D on the share of sales attributed to new products negative, and reduces the same effect by a half with respect to the likelihood of innovating. A substitutable relationship between multinational R&D cooperation and internal R&D activity with respect to the likelihood of innovating is also found for medium sized firms and services. The substitutable relationship indicates the marginal effect of internal R&D to be reduced by a fourth for medium sized firms and a third for services.

R&D cooperation with a domestic firm within the same enterprise increases the likelihood of innovation for all subsamples of firms, and substitutability with internal R&D except for large firms is found. The change in innovation likelihood and the effect of substitutability is increasing in firm size. Entering an R&D cooperative with a domestic firm within the same enterprise increases the likelihood of innovating by 16.3, 23.4 and 23.5 percentage points for small, medium sized and large firms respectively. For manufacturers and services the same effects are 29.3 and 14.6 percentage points respectively. The reduction in the marginal effect on innovation due to internal R&D is approximately a third for small and medium sized firms, a half for manufacturers, and a third for services. R&D cooperation with a domestic firm within the same enterprise is found significantly substitutable with internal R&D with respect to share of sales attributed to new products for small firms and services. Entering the cooperative should turn the marginal effect of internal R&D with respect to share of new sales negative. No direct effect on share of new sales is found for small firms when entering an R&D cooperative with a domestic firm within the same enterprise, but a positive effect is found for services.

R&D cooperation with competitors has a significant effect on the probability of innovating for small firms and manufacturers. The same effect is found for small firms with respect to new sales. The effect is negative, while there is evidence for complementarity with internal R&D with respect to the likelihood of innovating.

R&D cooperation with customers and suppliers are positively affecting the probability of innovating for all firm sizes, and for both manufacturers and services. The effect is strongest for small firms. Entering a vertical R&D cooperative increases the probability with 34.2, 21.1 and 28.3 percentage points for the average small, medium sized and large firms respectively. The effect is quite similar for manufacturers and services, 26.7 and 25.6 respectively. There is evidence for weak substitutability between vertical R&D cooperation and internal R&D in the likelihood of innovating for all but large firms. New sales are positively affected by vertical R&D cooperation for all subsamples of firms except large firms. The effect is stronger for small firms relative to medium sized firms, and approximately the same for manufacturers and services. No evidence for substitutability with internal R&D with respect to new sales is found.

Institutional R&D cooperation positively affects the likelihood of innovating for small firms and medium sized firms, and for both manufacturers and services. The likelihood increases with 23.3 and 12.3 percentage points after entering an institutional R&D cooperative for the average small and medium sized firm respectively. For the average manufacturer, the increase is 18.2 percentage points, and for the average service firm 15.2 percentage points. There is evidence for substitutability with internal R&D for small firms, and for manufacturers and services. The substitutability is reducing the marginal return on innovation of internal R&D by approximately a third for both services and manufacturers. For small firms this reduction is almost 50 percent.

Overall, the OLS and probit results are more frequently significant than the FE results. Confirming presence of unobserved heterogeneity, the FE results for the share of new sales attributed to new products proves more robust than the OLS results. The probit results for the likelihood of making innovation do not correct for unobserved heterogeneity. However, one should note that the likelihood of innovating includes process innovations as well as product innovations. Hence, the probit results take a much broader measure of innovativeness into account than the FE results, as described in section 4.3. As the frequency of innovating was very high for the R&D active firms in the sample, described in chapter 1, one might naturally expect a stronger relationship between R&D activities and innovation. There is enough observations of cooperation dummies with variation to identify the cooperation coefficients. Number of observations with variation in the dummies is given in the table with descriptive statistics in appendix B.

4.5 Conclusion

A short summary and some short conclusions can be drawn. No increase in internal R&D due to R&D contracting or R&D cooperation with a foreign firm within the same enterprise, as well as only a slightly higher level of innovativeness was observed prior to our estimation. Not surprisingly we found evidence for foreign R&D inflow within the multinational enterprises to be substitutable with internal R&D for Norwegian multinationals.

For external R&D contracting other than purchases from within multinational enterprises, we observed a positive effect on internal R&D. Estimations in this chapter indicate a complementary relationship with this non-multinational R&D contracting and internal R&D.

The theory chapter discussed how different forms of R&D cooperation to have different impact in R&D activity. After splitting up the cooperation variable, we found horizontal, vertical and institutional R&D cooperation to affect internal R&D, and also innovativeness, differently. A further discussion of the results is given in the next chapter.

5. Discussion and conclusion

5.1 Discussion

R&D purchases from foreign firms within the same enterprise

Across both firm sizes and firm sectors, internal R&D has a stronger impact than external R&D purchased from a foreign firm within the same enterprise on innovativeness. Norwegian firms benefit from acquiring R&D from abroad through their multinational linkage with respect to innovation likelihood. This holds for both manufacturers and services, as well as for small and medium sized firms.

There is strong evidence for external R&D purchased from enterprises abroad to be substitutable with internal R&D. A ten percent increase in such external R&D purchases reduces, ceteris paribus, the marginal effect of internal R&D on innovativeness by approximately a third. The results from section 3 showed that multinational firms neither increase nor decrease their internal R&D expenditures after such purchases, which is not in accordance with the findings of Bandick et. al. (2010), Bertrand (2009), and Bertrand et. al. (2008). They find internal R&D in newly acquired subsidiaries to be increased post foreign acquisition. The results may be attributed to several factors. Norwegian parent companies may invest in subsidiaries abroad in order to both augment and exploit the knowledge stock of the subsidiary (Kuemmerle, 1999). Inflow of technology and knowledge from foreign subsidiaries may reduce the need for performing R&D internally at home for parent companies with sufficient absorptive capacity.

For Norwegian subsidiaries, the results may be somewhat surprising, given the relatively strong patent protection and the high skilled workforce, favouring R&D investment in Norway. However, the high proportion of high skilled workers is able to absorb R&D spillovers and may hence reduce the attractiveness of conducting R&D in Norwegian subsidiaries (Ekholm and Hakkala, 2007). Norwegian firms, and perhaps especially multinationals conducting R&D, may for similar reasons have high levels of absorptive capacity, reducing the need of increasing internal R&D when buying R&D (Ito and

Wakasugi, 2007; Erken and Kleijn, 2010). The high skilled workforce may also ease transfer of R&D from abroad to Norwegian subsidiaries, favouring R&D specialization in parent companies abroad (Belderbos et. al., 2008).

The results for multinational firms may also be directly attributed to consequences of mergers or acquisition. High reorganization costs may reduce the capability of conducting R&D itself, favouring contracting out R&D (Lei and Hitt, 1995). M&A may also alter the market structure, reducing the incentives of conducting R&D in order to capture market shares (Dasgupta and Stiglitz, 1980; Blundell et. al., 1999).

R&D purchases from other firms

The negative effect of R&D purchases on the likelihood of innovation, at least for medium sized and large firms, and manufacturers, as well as the insignificant impact on the innovativeness of small firms and services, is somewhat puzzling. Taking the findings of complementarity into consideration, as well as the considerable increase in internal R&D due to such R&D contracting, firms may not buy R&D in order to acquire specific innovations, but rather to access knowledge and technology in general. At a later stage, after processing the acquired knowledge and technology – which involves internal R&D – innovations occur. At this stage, the innovations are attributed to internal R&D, and not the external R&D. The considerable increase in internal R&D related to external R&D sourcing is in line with the findings of Veugelers (1997), who finds support for complementarity between internal R&D and external R&D sources for firms with internal R&D departments. Taking the evidence of complementarity between internal and external R&D into consideration as well, our results are in accordance with the findings of Hagedoorn and Wang (2010) and Belderbos et. al. (2008). However, the negative effect on the innovativeness is in conflict with most other empirics.

R&D cooperation with foreign firms within the same enterprise

We have found a positive impact of R&D cooperation with a foreign firm within the same enterprise on the likelihood of making innovations as well as evidence of substitutability with internal R&D. These results suggest that international collaborations for Norwegian multinationals results in innovations but reduce the innovativeness of internal R&D, and may be due to displacement of internal R&D resources into international collaboration, to which the innovation is attributed. Hence, foreign R&D collaboration within the enterprise may be considered a substitute for (the non-absorptive capacity part of) internal R&D.

R&D cooperation with a domestic firm within the same enterprise

We find weak evidence for a positive effect on internal R&D following the decision to engage in R&D cooperation with domestic firms in the same enterprise. This linkage turns out to be positive only for medium sized firms and for service firms at an aggregated level. In all cases we find increased probabilities for innovations, but substitutability between the cooperation strategy and internal R&D except for large firms. One possible explanation for these findings may be the persistency of the cooperation strategy, with synergy effects converging towards zero as time passes. With no synergy effects and costs of sustaining the cooperation, conducting own R&D or contracting out R&D in an isolated fashion may be more profitable for the firms.

Horizontal R&D cooperation

The probability of innovating decreases by engaging in horizontal cooperation at the aggregated level, as well as for small firms and manufacturing firms. We also find this R&D strategy to stimulate investments in internal R&D, for all samples except the large firms. Despite the negative effect on innovation activity we find evidence suggesting complementarity between internal R&D and horizontal cooperation.

We cannot differentiate between intra-industry and inter-industry cooperation. Regarding intra-industry cooperation, i.e. firms competing with imperfect substitutes or complements, our results are in line with predictions from Katz (1986) suggesting increased investments in R&D following horizontal cooperation. In the case of inter-industry cooperation our results can be attributed to internalization of spillovers (D'Aspremont & Jacquemin, 1988). However this requires certain levels of R&D spillovers prior to the cooperation (De Bondt &

Veugelers, 1991) and a low level of R&D spillovers within the cooperative (Kamen et al., 1992; Kaiser, 2002). Internalization of R&D spillovers is thought to increase the efficiency of internal R&D, hence facilitating complementarity.

Horizontal cooperation may reduce competition in the output market (e.g. Dasgupta & Stiglitz, 1980) given homogenous products (Katz, 1986). However, we do not expect this effect to a large extent in Norway because horizontal cooperation between firms with significant market power are prohibited by law (EU Commission Regulation, 2010).

Our results are in line with the findings of Inkmann (2000).

Vertical R&D cooperation

Cooperation with suppliers and customers are found to significantly increase the probability of innovation in all cases, as well as increasing the contribution to total sales attributable to new or improved products for all but large firms. As for the test of complementarity our results points towards vertical R&D cooperation to be a substitute for internal R&D regarding innovation except for large firms, where the results are inconclusive.

It seems reasonable to assume that process innovations are favored by cooperation with suppliers, whereas product innovations are favored by cooperation with customers (von Hippel, 1988; Tether, 2002; Belderbos et al., 2004). Cost reduction is expected to be one of the main motives for engaging in vertical R&D cooperation (Belderbos et al., 2004; Lopéz, 2008), due to i.a. risk sharing between the participants in the co-op (Kawasaki and McMillan, 1987; Asanuma and Kikutani, 1992). In the case of lacking appropriability, vertical cooperation may lead to internalization of external R&D spillovers increasing the efficiency of internal R&D (Cassiman and Veugelers, 2002; Lopéz, 2008). However we don’t see lack of appropriability as a severe problem in Norway, thus the cost reduction motive may explain the finding of substitutability between vertical R&D cooperation and internal R&D.

Institutional R&D cooperation

For small and medium sized firms, manufacturing and service firms, and the full sample the coefficient for institutional R&D cooperation suggests a positive effect on the probability of innovating. Internal R&D cooperation and internal R&D are found to be substitutes for all subsamples except for medium sized and large firms.

The estimated increase in internal R&D following R&D cooperation with institutions can be ascribed to the need for absorptive capacity (Cockburn and Henderson, 1997), or the fact that R&D intensive firms have a higher propensity to cooperate with universities and research institutions (Belderbos et al., 2004).

Institutional R&D cooperation will provide firms with leading technology, in particular technology laggards, increasing the innovativeness of the laggards (Monjon and Waelbrock, 2003). Universities is also seen as a less costly way of acquiring technology for firms lacking financial muscles and the possibility to conduct own R&D (Tether, 2002), making institutional R&D cooperation substitutable with internal R&D. These conditions are more likely to be met for small firms as opposed to medium sized or large firms, which have easier access to capital, in accordance with our results.

5.2 Conclusion

In the introduction we noted that multinational enterprises have grown in importance the recent decades. Questions have been raised about the impact of foreign ownership on domestic R&D investment. Multinational firms were thought to access foreign R&D easier, but at the aggregate level there was no sign of increased inflow of foreign R&D through multinational enterprises into Norway during the last decade. We found no clear evidence for R&D purchases from foreign firms within the same enterprise to increase internal R&D expenditures; when controlling for other forms of external R&D purchases and R&D cooperation, the impact of foreign R&D through multinational enterprises on internal R&D expenditures among Norwegian multinationals were insignificant. The same results were found for R&D cooperation with a foreign firm within the same enterprise. As discussed in the theory section, and noted throughout chapter 3 and 4, absorptive capacity seem to be a driver for increased internal R&D activity when sourcing R&D externally. Modelling internal and different forms of external R&D as inputs in the innovation process, we found interesting evidence for substitutability between multinational R&D sourcing and internal R&D. As discussed in the introduction to chapter 4, a substitutable relationship between internal and external R&D and the need for absorptive capacity have contrary effects on internal R&D; the substitutable relationship affects internal R&D negatively, while absorptive capacity increases internal R&D when sourcing externally. The insignificant effect of multinational R&D ties on internal R&D may then be due to a counterbalancing of the substitutable relationship and absorptive capacity effects. Hence for initially high levels of internal R&D, multinational R&D sourcing should reduce internal R&D among Norwegian multinationals.

Significant positive effects on internal R&D expenditures were found for other forms of external R&D purchases and R&D cooperation. Firms with non-multinational R&D ties were seen to perform on average less internal R&D than firms with multinational R&D ties. Hence the need for absorptive capacity should be more precarious for these firms than for firms with multinational R&D ties. In chapter 4, we found evidence for a complementary relationship between non-multinational R&D contracting and internal R&D. Hence, the need for absorptive capacity as well as the complementary relationship seems to drive the positive relationship between internal R&D and non-multinational external R&D expenditures. The need for absorptive capacity is also found to be prevalent for the relationship between R&D cooperation and internal R&D expenditures, also for vertical and institutional R&D cooperation which were found substitutable with internal R&D activity.

As final remarks we will point out three important implications of our results. The need for absorptive capacity seems to be a driver for the increase in internal R&D due to external R&D activity. However, for high levels of internal R&D, absorptive capacity is present, and complementary and substitutable properties of internal and external R&D seem to be the underlying drivers for the impact of the latter on internal R&D expenditures.

Multinational R&D ties do not seem to stimulate internal R&D investment among Norwegian multinationals. Quite the opposite; disregarding the need for absorptive capacity, e.g. for high levels of internal R&D which is the case for most multinationals, multinational

R&D ties seem to have substitutable properties with internal R&D, making multinational R&D sources displace domestic internal R&D activity.

Other forms of external R&D sources do seem to stimulate domestic internal R&D investment. For other external R&D purchases, this is the case also beyond the need for absorptive capacity due to the complementary relationship with internal R&D. Regarding vertical and institutional R&D cooperation, the need for absorptive capacity seems to drive a positive relationship despite of a an underlying substitutable relationship with internal R&D.

References

Asanuma B. and T. Kikutani (1992) Risk absorption in Japanese subcontracting: A microeconomic study of the automobile industry. *Journal of the Japanese and International Economies* 6(1) 1-29.

Arora, A. and Gambardella, A. (1994) Evaluating Technological Information and Utilizing it: Scientific Knowledge, Technological Capability, and External Linkages in Biotechnology. *Journal of Economic Behavior and Organization*, 24(1) pp. 91-114

Arora, A. and Gambardella, A. (1990) Complementarity and external linkages: The Strategies of the Large Firms in Biotechnology. *The Journal of Industrial Economics*, 38(4) 361-379

Arrow, K. (1962) Economic welfare and the allocation of resources for invention. In: Nelson, r. (ed.) *The Rate and the Direction of Inventive Activity: Economic and Social Factors*. NBER. Princeton: Princeton University Press.

D'Aspremon, C. and A. Jacquemin (1988) Cooperative and non-cooperative R&D in duopoly with spillovers. *The American Economic Review* 78(5).

Atallah, G. (2002) Vertical R&D spillovers, cooperation, market structure, and innovation. *Economics of Innovation and Technology* 11(3) 179-209.

Athey, S. and Stern, S. (1998) An Empirical Framework for Testing Theories about Complementarity in Organizational Design. *Working papers WP* 4022-98., Massachusetts Institute of Technology (MIT), Sloan School of Management.

Bandick, R., H. Görg and P. Karpaty (2008) Foreign acquisitions, domestic multinationals and R&D. *IZA Discussion Paper* No. 5252.

Belderbos, R., Ito, B. and Wakasugi, R. (2008a) Intra-firm Technology Transfer and R&D in Foreign Affiliates: Substitutes of Complements? Evidence from Japanese Multinational Firms *UNU-MERIT Working Papers* No. 2008-045 United Nations University.

Belderbos, R., E. Lykogianni and R. Veugelers (2008b) Strategic R&D location by multinational firms: Spillovers, technology sourcing and competition. *Journal of Economics and Management Strategy* 17(3) 759-779.

Belderbos, R., Carree, M. and Lokshin, B. (2006) Complementarity in R&D Cooperation Strategies. *Review of Industrial Organization*, 28(4) pp. 401-426

Belderbos, R., M. A. Carree, B. Diederen, B. Lokshin, and R. Veugelers (2004a) Heterogeneity in R&D cooperation strategies. *International Journal of Industrial Organization* 22(8-9) 1237-1263.

Belderbos, R., M. A. Carree and B. Lokshin (2004b) Cooperative R&D and firm performance. *Research Policy* 33(10) 1477-1492.

Bergman, K. (2011) Internal and External R&D and Productivity – Evidence from Swedish Firm-Level Data. *Working Papers* No. 2011-27 Lund University, Department of Economics

Bertrand, O. (2008) Effects of foreign acquisitions on R&D activity: Evidence from firm-level data for France. *Research Policy* 38(6) 1021-1031.

Bertrand, O., K. N. Hakkala, P. Norbäck and L. Persson (2008) Should R&D champions be protected from foreign takeovers? *Working Paper Series* No. 459, Research Institute of Industrial Economics,

Bertand, O. and P. Zuniga (2006) R&D and M&A: Are cross-boarder M&A different? An investigation on OECD countries. *International Journal of Industrial Organization* 24(2) 401-423.

Bessant, J. and H. Hush (1995) Building bridges for innovation: The role of consultants in technology transfer. *Research Policy* 24(1) 97-114.

Blundell, R., R. Griffith and J. van Reenen (1999) Market share, market value and innovation in a panel of British Manufacturing Firms. *Review of Economic Studies* 66(3) 529-554.

De Bondt R. and R. Veugelers (1991) Strategic investment with spillovers. *European Journal of Political Economy* 7 345-366.

Branstetter, L. G. (2001) Are knowledge spillovers international or intranational in scope? Microeconomic evidence from the U.S. and Japan. *Journal of International Economics* 53(1) 53-79.

Branstetter, L. G. (2000) Vertical keiretsu and knowledge spillovers in Japanese manufacturing: An empirical assessment. *Journal of Japanese and International Economies* 14(2) 73-104.

Bruce, M. and B. Morris (1998) In house, out-sourced or a mixed approach to design. In: Bruce, M. and B. Jevnaker (eds.) *Management of Design Alliances: Sustaining Competitive Advantage.* Chichester: Wiley.

Cassiman and Veugelers (2006) In Search of Complementarity in Innovation Strategy: Internal R&D and External Knowledge Acquisition, *Management Science,* 52(1) pp. 68-82

Cassiman, B. and Veugelers, R. (2002a) Complementarity in the Innovation Strategy: Internal R&D, External Technology Acquisition, and Cooperation in R&D. *Working paper* No. 457. IESE Business School

Cassiman, B. and R. Veugelers (2002b) R&D cooperation and spillovers: Some empirical evidence from Belgium. *American Economic Review* 92(4) 1169-1184.

Van Cayseele, P. J. G. (1998) Market structure and innovation: A survey of the last twenty years. *De Economist* 146(3) 391-417.

Coase, R. H. (1937). The nature of the firm. *Economica* 4(16), 386-405.

Cockburn, I. M. and Henderson, R. M. (1998) Absorptive Capacity, Coauthoring Behavior, and the Organization of Research in Drug Discovery. *The Journal of Industrial Economics,* 46(2) pp. 157-182

Cockburn, I. and R. Henderson (1997) Public–private interaction and the productivity of pharmaceutical research. *NBER Working Paper* No. 6018.

Cohen, W. M. and Levinthal, D. A. (1990) Absorptive Capacity: A new perspective on Learning and Innovation. *Administrative Science Quarterly,* 35(1) pp. 128-152

Cohen, W. M. and Levinthal, D. A. (1989) Innovation and Learning: The two Faces of R&D. *The Economic Journal,* 99(237) pp. 569-596

Commission Regulation, EU (2010) *No 1217/2010 of 14 December 2010 on the application of Article 101(3) of the Treaty on the Functioning of the European Union to certain categories of research and development agreements.* The European Commission.

Crépon, B., E. Duguet and J. Mairesse (1998*) Research, innovation and productivity : An econometric analysis at the firm level.* Economics of Innovation and Technology 7(2) 115-158.

Cruscuolo, C., J. E. Haskel and M. J Slaughter (2005) Global engagement and the innovation activities of firms. *NBER Working Papers* No.. 11479.

Dasgupta, P. and J. Stiglitz (1980) Uncertainty, industrial structure and the speed of R&D. *The Bell Journal of Economics* 11(1) 1-28.

Desai M. A., D. S. Foley and J. R. Hines Jr. (2008) Domestic effects of the foreign activities of U.S. multinationals. *American Economic Journal: Economic Policy* 1(1) 181-203.

Ekholm, K. and K. Hakkala (2007) Location of R&D and high-tech production by vertically integrated multinationals. *The Economic Journal* 117(518) 512-543.

Erken, H. and M. Kleijn (2010) Location factors in international R&D activities: An econometric approach. *Economics of Innovation and New Technology* 19(3) 203-232.

Forskningsrådet (2010) *Det norske forsknings- og innovasjonssystemet. Indikatorrapporten 2011.* The Research Council of Norway (Noregs Forskningsråd).

Gambardella, A. (1992) Competitive Advantages from In-House Scientific Research: The US Pharmaceutical Industry in the 1980s. *Research Policy,* 21(5) pp. 391-407

Greene, W. (2002) The behaviour of the fixed effect estimator in nonlinear models. New York University, Leonard N. School of Business, Department of Economics, *Working Paper* No 02-05.

Griffith, R., R. Harrison and J. van Reenen (2006) How special is the special relationship? Using the impact of U.S. R&D spillovers on U.K. firms as a test of technology sourcing. *American Economic Review* 95(5) 1859-1875.

Griffith, R., Redding, S. J. and Reenen, J. V. (2004) Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries. *Review of Economics and Statistics,* 86(4) pp. 883-895

Griliches, Z. (1979) Issues in assessing the contribution of research and development to productivity growth. *The Bell Journal of Economics* 10(1) 92-116.

Gupta, A. K. and V. Govindarajan (2000) Knowledge flows within multinational corporations. *Strategic Management Journal* 21 473-496.

Hagedoorn, J., A. N. Link and N. S. Vonortas (2000) Research partnerships. *Research Policy* 29(4-5) 567-586.

Hall, B. H. (2011) Innovation and productivity. *NBER Working Paper* No. 17178.

Hall, B. H., A. N. Link and J. T. Scott (2003) Universities as research partners. *Review of Economics and Statistics* 85(2) 485-491.

Hamida, L. B. and L. Piscitello (2010) The impact of foreign R&D activities on the MNC's performance at home: Evidence from the case of Swiss manufacturing firms. *HEG Working Paper* No. BJIR2010.

Hagedoorn, J. and Wang, N. (2010): Is there complementarity or substitutability between internal and external R&D strategies? *UNU-MERIT Working Papers* No. 2010-005 United Nations University

Herstad, S. J. and S. O. Nås (2007) "De store selskapene. Forskningslokomotiver eller dresiner?" *Rapport 18/2007 NIFU-STEP* Oslo
Von Hippel, E. (1988) *Sources of Innovation*. Oxford: Oxford University Press.

Ito, B. and R. Wakasugi (2007) What factors determine the mode of overseas R&D by multinationals? Empirical evidence. *Research Policy* 36(8) 1275-1287.

Jones, C. I. (2005) Growth and ideas in Aghion, P. and S. Durlauf (eds.) *Handbook of Economic Growth*. Amsterdam: Elsevier, North-Holland Publishing Company.
Jones, C. I. (1995) R&D-based models of economic growth. *Journal of Political Economy* 103(4) 759-784.

Kaiser, U. (2002) An empirical test of models explaining research expenditures and research cooperation: Evidence from the German service sector. *International Journal of Industrial Organization* 20 747-774.

Kamien, M. I., E. Muller and I. Zang (1992) Joint ventures and R&D cartels. *American Economic Review* 82(5) 1293-1306.

Kamien M. I. and N. L. Schwartz (1975) Market structure and innovation: A survey. *Journal of Economic Literature* 13(1) 1-37.

Katz, M. L. (1986) An analysis of cooperative research and development. *The Rand Journal of Economics* 17(4) 527-543.

Kawasaki, S. and J. McMillan (1987) The design of contracts: Evidence from Japanese subcontracting. *Journal of the Japanese and International Economies* 1(3) 327-349.

Keller, W. (2002) Geographical localization of international technology diffusion. *American Economic Review* 92(1) 120-142.

Keller, W. (1996) Absorptive Capacity: On the Creation and Acquisition of Technology in Development. *Journal of Development Economics,* 49(1) pp. 199-227

Kogut, B. and S. J. Chang (1991) Technological capabilities and Japanese foreign investment in the United States. *The Review of Economics and Statistics* 73(3) 401-413.

Kuemmerle, W. (1999) The drivers of foreign direct investment into research and development: An empirical investigation. *Journal of International Business Studies* 30(1) 1-24.

L'Huillery, S. and E. Pfister (2009) R&D cooperation and failures in innovation projects: Empirical evidence from French CIS data. *Research Policy* 38(1) 45-57.

Lei, D. and M. A, Hitt (1995) Strategic restructuring and outsourcing: The effect of mergers and acquisitions and LBOs on building firm skills and capabilities. *Journal of Management* 21(5) 835-859.

Leiponen, A. (2005) Skills and innovation. *International Journal of Industrial Organization*. 23(5-6) 303-323.

Lokshin, B., Belderbos, R. and Carree, M. (2008) The Productivity Effects of Internal and External R&D: Evidence from a Dynamic Panel Data Model. *Oxford Bulletin of Economics and Statistics,* 70(3) pp. 399-413

Lokshin, B., Carree, M. and Belderbos, R. (2007) Testing for Complementarity and Substitutability in case of Multiple Practices. *Open access publications* from Katholieke Universiteit Leuven

López, A. (2008) Determinants of R&D cooperation: Evidence from Spanish manufacturing firms. *International Journal of Industrial Organization* 26(1) 113-136.

Lov 1999 nr. 14: Lov om skatt og formue (skatteloven)

Love, J. H. and Roper, S. (2001) Location and Network Effects on Innovation Success: Evidence for UK, German and Irish Manufacturing Plants. *Research Policy,* 30(4) pp. 643-661

Mairesse, J. and P. Mohnen (2010) Using innovations surveys for econometric analysis. *NBER working paper* No. 15857.

Miotti, L. and F. Sachwald (2003) Co-operative R&D: Why and with whom? An integrated framework of analysis. *Research Policy* 32(8) 1481-1499.

Mohnen, P. and C. Hoareau (2003) What type of enterprise forges close links with universities and government labs? Evidence from CIS 2. Managerial and Decision Economics 24(2-3) 133-145.

Monjon, S. and P. Waelbroeck (2003) Assessing spillovers from universities to firms: Evidence from French firm-level data. *International Journal of Industrial Organization* 21(9) 1255-1270.

Mowery, D. C. and Oxley, J. E. (1995) Inward Technology Transfer and Competitiveness: The Role of National Innovation Systems. *Cambridge Journal of Economics*, 19(1) pp. 67-93

OECD (2010) T*ransfer Pricing Guidelines for Multinational Enterprises and Tax Administrations*. Organization for Economic Co-operation and Development. Looked up 2011/11/03 from http://www.oecd-ilibrary.org/taxation/oecd-transfer-pricing-guidelines-for-multinational-enterprises-and-tax-administrations-2010_tpg-2010-en

OECD (2005) *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data, 3rd ed.* Organization for Economic Co-operation and Development.

OECD (2002) *Frascati Manual: Proposed Standard Practice for Survey on Research and Experimental Development, 2nd ed.* Organization for Economic Co-operation and Development.

Pisano, G. P. (1990) The R&D bounderies of the firm: An empirical analysis. *Administrative Science Quarterly* 35(1) 153-176.

Porter, M. (1990) *The Competitive Advantage of Nations*. London: MacMillan Press.

Raymond, W., J. Mairesse, P. Mohnen and F. Palm (2010) *R&D, innovation, and productivity in Dutch and French manufacturing: A panel data analysis.* World Congress of the Econometric Society, Shanghai, August 16-21, 2010.

Reinganum, J. F. (1983) Uncertain innovation and the persistence of monopoly. *The American Economic Review* 73(4) 741-748.

Research Triangle Region (2011) Official website. Looked up 2011/10/09 from http://www.researchtriangle.org/

Romer, P. M. (1990) Endogenous technological change. *Journal of Political Economy* 98(5) 71-102.

Rosenberg, N. (1990) Why do firms do basic research (with their own money)? *Research Policy*, 19(2) pp. 165-174

Sadowski, B. M. and G. Sadowski-Rasters (2006) On the innovativeness of foreign affiliates: Evidence from companies in The Netherlands. *Research Policy* 35(3) 447-462.

Sah, R. K. and J. Stiglitz (1987) The invariance of market innovation to the number of firms. *The Rand Journal of Economics* 18(1) 98-108.

Sasidharan, S. and Kathuria, V. (2011) FDI and R&D: Substitutes or Complements - A Case of Indian Manufacturing after 1991 Reforms. *World Development,* 39(7) pp. 1226-1239

Schmiedeberg, C. (2008) Complementarities of Innovation Activities: An Empirical Analysis of the German Manufacturing Sector. *Research Policy,* 37(9) pp. 1492-1503

Schumpeter, J. A. (1947) *Capitalism, Socialism and Democracy*. New York: Harper.

Shimizutani, S. and Y. Todo (2008) What determines overseas R&D activities? The case of Japanese multinational firms. *Research Policy* 37(3) 530-544.

Statstics Norway (2007) ”Utenlandske foretak står for 30 prosent av FoU-aktiviteten i Norge” *SSB Magasinet* Published 2009/08/04. Looked up 2011/09/18 from http://www.ssb.no/vis/magasinet/analyse/art-2009-08-04-01.html

Stiebale, J. and F. Reize (2008) The impact of FDI on innovation in target firms. *Ruhr Economic Papers* No. 0050.

Suzuki, K. (1993) R&D spillovers and technology transfer among and within vertical keiretsu groups: Evidence from Japanese electrical machinery industry. *International Journal of Industrial Organization* 11(4) 573-591.

Teece, D. J. (1992) Competition, cooperation and innovation. Organizational arrangements for regimes of rapid technological progress. *Journal of Economic Behaviour and Organization* 18(1) 1-25.

Teece, D. J. (1977) Technology transfer by multinational firms: The resource cost of transferring technological know-how. *The Economic Journal* 87(346), 242-261.

Tether, B. S. (2002) Who co-operates for innovation, and why. An empirical analysis. *Research Policy* 31(6) 947-967.

Todo, Y. and S. Shimizutani (2008) Overseas R&D activities and home productivity growth: Evidence from Japanese firm-level data. *The Journal of Industrial Economics* 56(4) 752-777.

Verbeek, M. (2008) *A guide to modern econometrics.* Chichester: John Wiley & Sons.

Veugelers, R. (1998) Collaboration in R&D: An assessment of theoretical and empirical findings. *De Economist* 146(3) 419-443.

Veugelers, R (1997) Internal R&D Expenditures and External Technology Sourcing. *Research Policy*, 26(3) pp. 303-315

Wagner, M. (2007) Determinants of the acquisition of smaller firms by larger incumbents in high-tech industries: Are they related to innovation and technology sourcing? *SFB 649 Discussion Paper* 2007-063.

Williamson, O. E. (1981) The economies of organization: The transaction cost approach. *Journal of Sociology* 87(3), 548-577.

Williamson, O. E. (1979) Transaction-cost economics: The governance of contractual relations. *Journal of Law and Economics* 22(2), 233-261

Williamson, O. E. (1975) *Markets and Hierarchies: Analysis and Antitrust Implications*. New York: The Free Press.

Wooldridge, J. M. (2010) *Econometric analysis of cross section and panel data*. Cambridge, Massachusetts: MIT Press.

Wooldridge, J. M. (2009) *Introductory econometrics. A modern approach.* 4th ed. Mason, Ohio: South-Western Cengage Learning.

Zahra, S. A. and George, G. (2002) Absorptive Capacity: A Review, Reconceptualization, and Extension. *Academy of Management Review,* 27(2) pp. 185-203

Appendices

Appendix A: Variable list chapter 3

Full sample

	mean	sd	N	Median	Transitions
ird	4.585	6.933	39909	0	
erd	2.530	5.386	40169	0	
merd	0.362	2.264	32418	0	
oerd	0.509	2.674	32418	0	
CO	0.170	0.376	37925	0	2327
MCO	0.040	0.195	37925	0	609
DCO	0.044	0.205	37925	0	887
HCO	0.061	0.239	27793	0	825
VCO	0.136	0.343	27793	0	1537
ICO	0.113	0.316	37925	0	1733

Small firms

	mean	sd	N	Median	Transitions
ird	3.730	6.383	20150	0	
erd	1.631	4.359	20297	0	
merd	0.152	1.433	17486	0	
oerd	0.254	1.834	17486	0	
CO	0.123	0.328	19469	0	1069
MCO	0.018	0.131	19469	0	181
DCO	0.024	0.154	19469	0	302
HCO	0.042	0.202	14549	0	325
VCO	0.104	0.305	14549	0	676
ICO	0.076	0.264	19469	0	759

Medium firms

	mean	sd	N	Median	Transitions
ird	4.924	7.040	15604	0	
erd	2.882	5.617	15687	0	
merd	0.388	2.315	12142	0	
oerd	0.536	2.709	12142	0	
CO	0.189	0.391	14655	0	957
MCO	0.045	0.208	14655	0	280
DCO	0.047	0.211	14655	0	388
HCO	0.068	0.252	10561	0	336
VCO	0.146	0.354	10561	0	627
ICO	0.123	0.328	14655	0	724

Large firms

	mean	sd	N	Median	Transitions
ird	7.464	8.106	4155	0	
erd	5.570	7.377	4185	0	
merd	1.562	4.652	2790	0	
oerd	1.998	5.238	2790	0	
CO	0.343	0.475	3801	0	302
MCO	0.130	0.337	3801	0	139
DCO	0.133	0.340	3801	0	189
HCO	0.135	0.341	2683	0	144
VCO	0.271	0.445	2683	0	203
ICO	0.264	0.441	3801	0	267

Produsenter

	mean	sd	N	Median	Transitions
ird	4.850	6.993	25201	0	
erd	2.915	5.642	25400	0	
merd	0.414	2.417	19948	0	
oerd	0.622	2.937	19948	0	
CO	0.186	0.389	24039	0	1497
MCO	0.044	0.205	24039	0	380
DCO	0.048	0.214	24039	0	580
HCO	0.069	0.254	17483	0	576
VCO	0.146	0.353	17483	0	981
ICO	0.127	0.333	24039	0	1166

Service

	mean	sd	N	Median	Transitions
ird	4.133	6.806	14708	0	
erd	1.867	4.844	14769	0	
merd	0.279	1.992	12470	0	
oerd	0.329	2.175	12470	0	
CO	0.144	0.351	13886	0	811
MCO	0.032	0.176	13886	0	225
DCO	0.037	0.188	13886	0	306
HCO	0.047	0.212	10310	0	242
VCO	0.120	0.325	10310	0	533
ICO	0.088	0.284	13886	0	561

Appendix B: Variable list chapter 4

Full sample

	mean	sd	N	Median	Transitions
innovasjon	0.331	0.471	21704	0	
turnin	0.084	0.194	19598	0	
ird3	5.350	7.105	39943	0	
erd3	3.343	5.849	40171	0	
merd3	0.525	2.667	35875	0	
oerd3	0.414	1.723	35875	0	
CO3	0.234	0.423	39383	0	2031
irdCO3	2.994	6.038	39154	0	
MCO3	0.061	0.240	39643	0	550
irdMCO3	0.894	3.676	39414	0	
DCO3	0.074	0.263	39643	0	799
irdDCO3	1.001	3.810	39414	0	
HCO3	0.094	0.292	31378	0	739
irdHCO3	1.287	4.265	31374	0	
VCO3	0.197	0.398	31378	0	1239
irdVCO3	2.615	5.762	31374	0	
ICO3	0.175	0.380	39643	0	1461
irdICO3	2.419	5.584	39414	0	
sale3	18.098	2.154	37785	18.069	
N	40172				

Small firms

	mean	sd	N	Median	Transitions
innovasjon	0.294	0.456	11329	0.000	
turnin	0.092	0.210	10273	0.000	
ird3	4.304	6.612	20171	0.000	
erd3	2.174	4.835	20297	0.000	
merd3	0.222	1.707	18526	0.000	
oerd3	0.201	1.144	18526	0.000	
CO3	0.164	0.371	19873	0.000	936
irdCO3	2.076	5.136	19746	0.000	
MCO3	0.028	0.166	19944	0.000	161
irdMCO3	0.396	2.432	19817	0.000	
DCO3	0.038	0.192	19944	0.000	260
irdDCO3	0.491	2.663	19817	0.000	
HCO3	0.064	0.244	15605	0.000	264
irdHCO3	0.837	3.429	15602	0.000	
VCO3	0.147	0.354	15605	0.000	519
irdVCO3	1.923	5.001	15602	0.000	
ICO3	0.116	0.321	19944	0.000	613
irdICO3	1.576	4.583	19817	0.000	
sale3	17.001	1.855	18415	17.068	

Medium sized firms

	mean	sd	N	Median	Transitions
innovasjon	0.350	0.477	8168	0.000	
turnin	0.074	0.173	7381	0.000	
ird3	5.869	7.179	15613	0.000	
erd3	3.912	6.085	15687	0.000	
merd3	0.563	2.718	13919	0.000	
oerd3	0.441	1.726	13919	0.000	
CO3	0.267	0.442	15407	0.000	876
irdCO3	3.340	6.236	15333	0.000	
MCO3	0.072	0.259	15545	0.000	267
irdMCO3	1.012	3.846	15471	0.000	
DCO3	0.085	0.279	15545	0.000	369
irdDCO3	1.079	3.884	15471	0.000	
HCO3	0.107	0.309	12424	0.000	332
irdHCO3	1.435	4.435	12423	0.000	
VCO3	0.218	0.413	12424	0.000	552
irdVCO3	2.791	5.857	12423	0.000	
ICO3	0.198	0.398	15545	0.000	630
irdICO3	2.668	5.752	15471	0.000	
sale3	18.778	1.671	15291	18.759	

Large firms

	mean	sd	N	Median	Transitions
innovasjon	0.456	0.498	2207	0.000	
turnin	0.082	0.176	1944	0.000	
ird3	8.470	7.954	4159	12.824	
erd3	6.883	7.469	4187	0.000	
merd3	2.014	5.095	3430	0.000	
oerd3	1.457	3.252	3430	0.000	
CO3	0.444	0.497	4103	0.000	261
irdCO3	6.139	7.859	4075	0.000	
MCO3	0.180	0.384	4154	0.000	123
irdMCO3	2.848	6.336	4126	0.000	
DCO3	0.208	0.406	4154	0.000	169
irdDCO3	3.154	6.493	4126	0.000	
HCO3	0.190	0.392	3349	0.000	140
irdHCO3	2.833	6.263	3349	0.000	
VCO3	0.357	0.479	3349	0.000	156
irdVCO3	5.180	7.642	3349	0.000	
ICO3	0.370	0.483	4154	0.000	208
irdICO3	5.529	7.725	4126	0.000	
sale3	20.506	1.998	4079	20.596	

Produsenter

	mean	sd	N	Median	Transitions
innovasjon	0.354	0.478	13595	0.000	
turnin	0.078	0.179	12129	0.000	
ird3	5.665	7.130	25224	0.000	
erd3	3.789	6.038	25402	0.000	

merd3	0.595	2.830	22290	0.000	
oerd3	0.496	1.869	22290	0.000	
CO3	0.254	0.435	24939	0.000	1297
irdCO3	3.312	6.245	24760	0.000	
MCO3	0.067	0.250	25101	0.000	346
irdMCO3	1.018	3.898	24922	0.000	
DCO3	0.081	0.274	25101	0.000	526
irdDCO3	1.116	4.005	24922	0.000	
HCO3	0.107	0.309	19770	0.000	522
irdHCO3	1.470	4.514	19768	0.000	
VCO3	0.211	0.408	19770	0.000	802
irdVCO3	2.864	5.952	19768	0.000	
ICO3	0.196	0.397	25101	0.000	986
irdICO3	2.740	5.851	24922	0.000	
sale3	18.147	1.850	23751	18.076	

Service

	mean	sd	N	Median	Transitions
innovasjon	0.293	0.455	8109	0.000	
turnin	0.093	0.215	7469	0.000	
ird3	4.809	7.028	14719	0.000	
erd3	2.576	5.422	14769	0.000	
merd3	0.411	2.369	13585	0.000	
oerd3	0.280	1.443	13585	0.000	
CO3	0.199	0.399	14444	0.000	734
irdCO3	2.446	5.624	14394	0.000	
MCO3	0.051	0.221	14542	0.000	196
irdMCO3	0.682	3.248	14492	0.000	
DCO3	0.063	0.242	14542	0.000	274
irdDCO3	0.803	3.441	14492	0.000	
HCO3	0.073	0.260	11608	0.000	210
irdHCO3	0.975	3.783	11606	0.000	
VCO3	0.174	0.379	11608	0.000	421
irdVCO3	2.191	5.397	11606	0.000	
ICO3	0.138	0.345	14542	0.000	459
irdICO3	1.865	5.045	14492	0.000	
sale3	18.016	2.586	14034	18.060	

Appendix C: Do file

```
*Section 1 - Merging the yearly data

*Destring and compress
use f1997_multi
destring _all, replace
gen aargang = 1999
compress _all
save 1999

use f1999_multi
gen aargang = 2000
destring _all, replace
compress _all
save 2000

use f2001_multi
destring _all, replace
compress _all
save 2001

use f2002_multi
destring _all, replace
compress _all
save 2002

use f2003_multi
destring _all, replace
compress _all
save 2003

use f2004_multi
destring _all, replace
compress _all
save 2004

use f2005_multi
drop rdepint
destring _all, replace
compress _all
save 2005

*marloc and mareur are dummies representing the markets where the firm sell its products
use f2006_multi
destring _all, replace
compress _all
drop marloc
```

```
drop mareur
drop oekreg
save 2006

use f2007_multi
drop rdepint
destring _all, replace
compress _all
save 2007

use f2008_multi
destring _all, replace
compress _all
save 2008

use f2009_multi
destring _all, replace
compress _all
save 2009

*Merge data sets
clear
append using 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
sort frtk_id aargang
egen id = group(frtk_id)
save fou
clear


***PART 2: CLEANING UP THE DATASET***

use fou

*2.1: CORRECTING FOR DIFFERENT NAMES OF IDENTICAL VARIABLES
*nace1
replace nace1 = nace1_sn07 if (aargang == 2008 | aargang == 2009)

*cooperation
replace samarb = co if (missing(samarb) & co != .)

*Year
replace aargang = 2007 if missing(aargang)

*sales
replace omsetning = oms_rev if (aargang == 2008 | aargang == 2007 | aargang == 2006 | aargang == 2005 | aargang == 2003 | aargang == 2002 | aargang == 2001)
replace omsetning = oms if (aargang == 1999 | aargang == 2000)

*Value generated by new products weighted by sales
replace turnin = no_turnin if (missing(turnin) & no_turnin != .)
```

```
replace turnin = turnnew if (missing(turnin) & turnnew != .)

*Other operational costs associated with R&D
replace adk = adkost if (adk == . & (aargang == 2006 | aargang == 2007 | aargang == 2008 | aargang == 2009))


*2.2: REMOVING MISSING VALUES WHERE POSSIBLE

*Utfrt: If utfrt (dummy on performing rd or not) is missing, but intfou (sum of internal rd expenditures) is positive, utfrt is replaced with 1.
replace utfrt = 1 if (missing(utfrt) & intfou > 0 & intfou != .)
replace utfrt = 1 if utfrt == 2
replace utfrt = 0 if intfou == 0

*Bought r&d: If finan (dummy on buying or not buying external rd) is missing, but if sum of external rd expenditures (xdkskn, xdksku etc) is positive, finan is replaced with 1.
*The sum of extrenal rd expenditures are set to 0 if the firm has reported no external rd bought (finan=0) and the external rd expenditures are missing.
replace finan = 1 if ((xdkskn != . & xdkskn != 0) | (xdksku != . & xdksku != 0) | (xdkakn != . & xdkakn != 0) | (xdkauf != . & xdkauf != 0) | (xdkain != . & xdkain != 0) | (xdkuin != . & xdkuin != 0) | (xdkuhn != . & xdkuhn != 0) | (xdkfok != . & xdkfok != 0) | (xdkuhu != . & xdkuhu != 0) | (gave != . & gave != 0) | (xdkfor != . & xdkfor != 0) | (xdkfuhn != . & xdkfuhn != 0) | (xdkfuhu != . & xdkfuhu != 0) | (xdkfuh != . & xdkfuh != 0) | (xdkoff != . & xdkoff != 0) | (xdkeu != . & xdkeu != 0) | (xdkfon != . & xdkfon != 0) | (xdkutl != . & xdkutl != 0) | (xdk != . & xdk != 0))
replace finan = 0 if missing(finan)
replace xdksku = 0 if (missing(xdksku) & finan == 0 & aargang != 2002)
replace xdk = 0 if (missing(xdk) & finan == 0)

*Sum of internal r&d expenditures
replace intfou = 0 if (missing(intfou) & utfrt == 0)


*Cooperation variables: same variables with different names in some years are combined.
replace saminnn = 1 if (saminnn >= 1 & saminnn != . & (aargang == 1999 | aargang == 2000))
replace saminnno = 1 if (saminnno >= 1 & saminnno != . & (aargang == 1999 | aargang == 2000))
replace saminneu = 1 if (saminneu >= 1 & saminneu != . & (aargang == 1999 | aargang == 2000))
replace saminnan = 1 if (saminnan >= 1 & saminnan != . & (aargang == 1999 | aargang == 2000))
replace samforn = 1 if (samforn >= 1 & samforn != . & (aargang == 1999 | aargang == 2000))
replace samforno = 1 if (samforno >= 1 & samforno != . & (aargang == 1999 | aargang == 2000))
replace samforeu = 1 if (samforeu >= 1 & samforeu != . & (aargang == 1999 | aargang == 2000))
```

```
replace samforan = 1 if (samforan >= 1 & samforan != . & (aargang == 1999 | aargang == 2000))
replace samuohn = 1 if (samuohn >= 1 & samuohn != . & (aargang == 1999 | aargang == 2000))
replace samuohno = 1 if (samuohno >= 1 & samuohno != . & (aargang == 1999 | aargang == 2000))
replace samuoheu = 1 if (samuoheu >= 1 & samuoheu != . & (aargang == 1999 | aargang == 2000))
replace samuohan = 1 if (samuohan >= 1 & samuohan != . & (aargang == 1999 | aargang == 2000))
replace samannn = 1 if (samannn >= 1 & samannn != . & (aargang == 1999 | aargang == 2000))
replace samannno = 1 if (samannno >= 1 & samannno != . & (aargang == 1999 | aargang == 2000))
replace samanneu = 1 if (samanneu >= 1 & samanneu != . & (aargang == 1999 | aargang == 2000))
replace samannan = 1 if (samannan >= 1 & samannan != . & (aargang == 1999 | aargang == 2000))

replace samarb = 1 if (samuohn == 1 | samuohno == 1 | samuoheu == 1 | samuohan == 1 | samforn == 1 | samforno == 1 | samforeu == 1 | samforan == 1 | saminnn == 1 | saminnno == 1 | saminneu == 1 | saminnan == 1 | samannn == 1 | samannno == 1 | samanneu == 1 | samannan == 1 | saminnreg == 1 | samannreg == 1 | samforreg == 1 | samuohreg == 1 | saminn == 1 | saminnusa == 1 | samlevn == 1 | samlevno == 1 | samleveu == 1 | samlevusa == 1 | samlevan == 1 | samkunn == 1 | samkunno == 1 | samkuneu == 1 | samkunusa == 1 | samkunan == 1 | samkonkn == 1 | samkonkno == 1 | samkonkeu == 1 | samkonkusa == 1 | samkonkan == 1 | samkonsn == 1 | samkonsno == 1 | samkonseu == 1 | samkonsusa == 1 | samkonsan == 1 | samkomn == 1 | samkomno == 1 | samkomeu == 1 | samkomusa == 1 | samkoman == 1 | samunin == 1 | samunino == 1 | samunieu == 1 | samuniusa == 1 | samunian == 1 | samoffn == 1 | samoffno == 1 | samoffeu == 1 | samoffusa == 1 | samoffan == 1 | co11 == 1 | co12 == 1 | co13 == 1 | co14 == 1 | co15 == 1 | co16 == 1 | co17 == 1 | co18 == 1 | co19 == 1 | co21 == 1 | co22 == 1 | co23 == 1 | co24 == 1 | co25 == 1 | co26 == 1 | co27 == 1 | co28 == 1 | co29 == 1 | co31 == 1 | co32 == 1 | co33 == 1 | co34 == 1 | co35 == 1 | co36 == 1 | co37 == 1 | co38 == 1 | co39 == 1 | co41 == 1 | co42 == 1 | co43 == 1 | co44 == 1 | co45 == 1 | co46 == 1 | co47 == 1 | co48 == 1 | co49 == 1 | co51 == 1 | co52 == 1 | co53 == 1 | co54 == 1 | co55 == 1 | co56 == 1 | co57 == 1 | co58 == 1 | co59 == 1 | co61 == 1 | co62 == 1 | co63 == 1 | co64 == 1 | co65 == 1 | co66 == 1 | co67 == 1 | co68 == 1 | co69 == 1 | co71 == 1 | co72 == 1 | co73 == 1 | co74 == 1 | co75 == 1 | co76 == 1 | co77 == 1 | co78 == 1 | co79 == 1 | co81 == 1 | co82 == 1 | co83 == 1 | co84 == 1 | co85 == 1 | co86 == 1 | co87 == 1 | co88 == 1 | co89 == 1 | no_co12 == 1 | no_co22 == 1 | no_co32 == 1 | no_co42 == 1 | no_co51 == 1 | no_co52 == 1 | no_co53 == 1 | no_co54 == 1 | no_co61 == 1 | no_co62 == 1 | no_co63 == 1 | no_co64 == 1 | no_co71 == 1 | no_co72 == 1 | no_co73 == 1 | no_co74 == 1)
replace samarb = 0 if (missing(samarb) & aargang != 2002)

 replace co11 = 0 if (samarb == 0 & co11 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
 replace co12 = 0 if (samarb == 0 & co12 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
```

```
replace co13 = 0 if (samarb == 0 & co13 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co14 = 0 if (samarb == 0 & co14 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co15 = 0 if (samarb == 0 & co15 == . & (aargang == 2001 | aargang == 2008))
replace co16 = 0 if (samarb == 0 & co16 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
replace co17 = 0 if (samarb == 0 & co17 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co18 = 0 if (samarb == 0 & co18 == . & (aargang == 2006 | aargang == 2008))
replace co19 = 0 if (samarb == 0 & co19 == . & (aargang == 2006 | aargang == 2008))

replace co21 = 0 if (samarb == 0 & co21 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co22 = 0 if (samarb == 0 & co22 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co23 = 0 if (samarb == 0 & co23 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co24 = 0 if (samarb == 0 & co24 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co25 = 0 if (samarb == 0 & co25 == . & (aargang == 2001 | aargang == 2008))
replace co26 = 0 if (samarb == 0 & co26 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
replace co27 = 0 if (samarb == 0 & co27 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co28 = 0 if (samarb == 0 & co28 == . & (aargang == 2006 | aargang == 2008))
replace co29 = 0 if (samarb == 0 & co29 == . & (aargang == 2006 | aargang == 2008))

replace co31 = 0 if (samarb == 0 & co31 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co32 = 0 if (samarb == 0 & co32 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co33 = 0 if (samarb == 0 & co33 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co34 = 0 if (samarb == 0 & co34 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co35 = 0 if (samarb == 0 & co35 == . & (aargang == 2001 | aargang == 2008))
replace co36 = 0 if (samarb == 0 & co36 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
replace co37 = 0 if (samarb == 0 & co37 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co38 = 0 if (samarb == 0 & co38 == . & (aargang == 2006 | aargang == 2008))
replace co39 = 0 if (samarb == 0 & co39 == . & (aargang == 2006 | aargang == 2008))

replace co41 = 0 if (samarb == 0 & co41 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co42 = 0 if (samarb == 0 & co42 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co43 = 0 if (samarb == 0 & co43 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
```

```
replace co44 = 0 if (samarb == 0 & co44 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co45 = 0 if (samarb == 0 & co45 == . & (aargang == 2001 | aargang == 2008))
replace co46 = 0 if (samarb == 0 & co46 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
replace co47 = 0 if (samarb == 0 & co47 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co48 = 0 if (samarb == 0 & co48 == . & (aargang == 2006 | aargang == 2008))
replace co49 = 0 if (samarb == 0 & co49 == . & (aargang == 2006 | aargang == 2008))

replace co51 = 0 if (samarb == 0 & co51 == . & (aargang == 2001 | aargang == 2005))
replace co52 = 0 if (samarb == 0 & co52 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co53 = 0 if (samarb == 0 & co53 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co54 = 0 if (samarb == 0 & co54 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co55 = 0 if (samarb == 0 & co55 == . & (aargang == 2001 | aargang == 2008))
replace co56 = 0 if (samarb == 0 & co56 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
replace co57 = 0 if (samarb == 0 & co57 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co58 = 0 if (samarb == 0 & co58 == . & (aargang == 2006 | aargang == 2008))
replace co59 = 0 if (samarb == 0 & co59 == . & (aargang == 2006 | aargang == 2008))

replace co61 = 0 if (samarb == 0 & co61 == . & (aargang == 2001 | aargang == 2005))
replace co62 = 0 if (samarb == 0 & co62 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co63 = 0 if (samarb == 0 & co63 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co64 = 0 if (samarb == 0 & co64 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co65 = 0 if (samarb == 0 & co65 == . & (aargang == 2001 | aargang == 2008))
replace co66 = 0 if (samarb == 0 & co66 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
replace co67 = 0 if (samarb == 0 & co67 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co68 = 0 if (samarb == 0 & co68 == . & (aargang == 2006 | aargang == 2008))
replace co69 = 0 if (samarb == 0 & co69 == . & (aargang == 2006 | aargang == 2008))

replace co71 = 0 if (samarb == 0 & co71 == . & (aargang == 2001 | aargang == 2005))
replace co72 = 0 if (samarb == 0 & co72 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co73 = 0 if (samarb == 0 & co73 == . & (aargang == 2001 | aargang == 2005))
replace co74 = 0 if (samarb == 0 & co74 == . & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co75 = 0 if (samarb == 0 & co75 == . & (aargang == 2001 | aargang == 2008))
replace co76 = 0 if (samarb == 0 & co76 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
```

```
replace co77 = 0 if (samarb == 0 & co77 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co78 = 0 if (samarb == 0 & co78 == . & (aargang == 2006 | aargang == 2008))
replace co79 = 0 if (samarb == 0 & co79 == . & (aargang == 2006 | aargang == 2008))

replace co81 = 0 if (samarb == 0 & co81 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co82 = 0 if (samarb == 0 & co82 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co83 = 0 if (samarb == 0 & co83 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005))
replace co84 = 0 if (samarb == 0 & co84 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co85 = 0 if (samarb == 0 & co85 == . & (aargang == 2001 | aargang == 2008))
replace co86 = 0 if (samarb == 0 & co86 == . & (aargang == 2001 | aargang == 2006 | aargang == 2008))
replace co87 = 0 if (samarb == 0 & co87 == . & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008))
replace co88 = 0 if (samarb == 0 & co88 == . & (aargang == 2006 | aargang == 2008))
replace co89 = 0 if (samarb == 0 & co89 == . & (aargang == 2006 | aargang == 2008))

replace no_co12 = 0 if (samarb == 0 & no_co12 == . & aargang == 2004)
replace no_co22 = 0 if (samarb == 0 & no_co22 == . & aargang == 2004)
replace no_co32 = 0 if (samarb == 0 & no_co32 == . & aargang == 2004)
replace no_co42 = 0 if (samarb == 0 & no_co42 == . & aargang == 2004)
replace no_co52 = 0 if (samarb == 0 & no_co52 == . & aargang == 2004)
replace no_co62 = 0 if (samarb == 0 & no_co62 == . & aargang == 2004)
replace no_co72 = 0 if (samarb == 0 & no_co72 == . & aargang == 2004)
replace no_co71 = 0 if (samarb == 0 & no_co71 == . & aargang == 2004)
replace no_co61 = 0 if (samarb == 0 & no_co61 == . & aargang == 2004)
replace no_co51 = 0 if (samarb == 0 & no_co51 == . & aargang == 2004)
replace no_co53 = 0 if (samarb == 0 & no_co53 == . & aargang == 2004)
replace no_co63 = 0 if (samarb == 0 & no_co63 == . & aargang == 2004)
replace no_co73 = 0 if (samarb == 0 & no_co73 == . & aargang == 2004)
replace no_co54 = 0 if (samarb == 0 & no_co54 == . & aargang == 2004)
replace no_co64 = 0 if (samarb == 0 & no_co64 == . & aargang == 2004)
replace no_co74 = 0 if (samarb == 0 & no_co74 == . & aargang == 2004)

replace samuohn = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang == 2003))
replace samuohno = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang == 2003))
replace samuoheu = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang == 2003))
replace samuohan = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang == 2003))

replace samforn = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang == 2003))
```

```
 replace samforno = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))
 replace samforeu = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))
 replace samforan = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))

 replace saminnn = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))
 replace saminnno = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003 | aargang == 2007 | aargang == 2009))
 replace saminneu = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003 | aargang == 2007 | aargang == 2009))
 replace saminnan = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003 | aargang == 2007 | aargang == 2009))

 replace samannn = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))
 replace samannno = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))
 replace samanneu = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))
 replace samannan = 0 if (samarb == 0 & (aargang == 1999 | aargang == 2000 | aargang ==
2003))

 replace saminnreg = 0 if (samarb == 0 & aargang == 2003)
 replace samannreg = 0 if (samarb == 0 & aargang == 2003)
 replace samforreg = 0 if (samarb == 0 & aargang == 2003)
 replace samuohreg = 0 if (samarb == 0 & aargang == 2003)

 replace saminn = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace saminnusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samlevn = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samlevno = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samleveu = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samlevusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samlevan = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkunn = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkunno = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkuneu = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkunusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkunan = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))

 replace samkonkn = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkonkno = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkonkeu = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkonkusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
 replace samkonkan = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))

 replace samkonsn = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
```

```
replace samkonsno = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samkonseu = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samkonsusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samkonsan = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))

replace samkomn = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samkomno = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samkomeu = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samkomusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samkoman = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))

replace samunin = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samunino = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samunieu = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samuniusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samunian = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))

replace samoffn = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samoffno = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samoffeu = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samoffusa = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))
replace samoffan = 0 if (samarb == 0 & (aargang == 2007 | aargang == 2009))


*New products and processes
replace inpdgd = 0 if (inpdgd != 1 & aargang == 2008)
replace inpdsv = 0 if (inpdsv != 1 & aargang == 2008)
replace newmkt = 0 if (missing(newmkt) & (inpdgd == 0 & inpdsv == 0) & (aargang == 2004 | aargang == 2006 | aargang == 2008))
replace newmkt = inmar if (missing(newmkt) & inmar != .)
replace turnmar = 0 if (missing(turnmar) & newmkt == 0 & (aargang == 2001 | aargang == 2003 | aargang == 2004 | aargang == 2006 | aargang == 2008))
replace turnmar = turnmar/100 if (aargang == 2003 | aargang == 2006 | aargang == 2008)
replace inpdgd = inpdt if (aargang == 1999 | aargang == 2001 | aargang == 2003)
replace inpdsv = inpcs if (aargang == 1999 | aargang == 2001 | aargang == 2003)
replace turnin = 0 if (missing(turnin) & (inpdgd == 0 & inpdsv == 0) & (aargang == 2000 | aargang == 2001 | aargang == 2003 | aargang == 2004 | aargang == 2006 | aargang == 2008))
replace turnin = turnin/100 if (aargang == 2000 | aargang == 2003 | aargang == 2006 | aargang == 2008)

*Employees
replace ansatte = syss_rev if (aargang == 2002 | aargang == 2003 | aargang == 2005 | aargang == 2006 | aargang == 2007)
replace ansatte = syss if (aargang == 1999 | aargang == 2000)
replace ansatte = emp if aargang == 2001
replace ansatte = emp04 if aargang == 2004

keep if ansatte>9
```

DUMMIES USED FOR DEFLATING

*Dummies used for deflating nominal expenditures and revenues not related to R&D - 2009 base year

```
gen cpi = .
replace cpi = 1.258691 if aargang == 1999
replace cpi = 1.203324 if aargang == 2000
replace cpi = 1.166825 if aargang == 2001
replace cpi = 1.132457 if aargang == 2002
replace cpi = 1.118074 if aargang == 2003
replace cpi = 1.091312 if aargang == 2004
replace cpi = 1.086496 if aargang == 2005
replace cpi = 1.069505 if aargang == 2006
replace cpi = 1.045879 if aargang == 2007
replace cpi = 1.037943 if aargang == 2008
replace cpi = 1 if aargang == 2009
```

*Dummies used for deflating expenditures related to R&D. The dummies are weighted with average factor intensity, found from the firms reporting expenditures for wages, other operational costs, buildings and property, and machinery. Base year 2008 = 1.

```
gen rdcpi = .
replace rdcpi = 1.525036 if aargang == 1999
replace rdcpi = 1.423347 if aargang == 2000
replace rdcpi = 1.304614 if aargang == 2001
replace rdcpi = 1.268977 if aargang == 2002
replace rdcpi = 1.241073 if aargang == 2003
replace rdcpi = 1.209838 if aargang == 2004
replace rdcpi = 1.188914 if aargang == 2005
replace rdcpi = 1.145626 if aargang == 2006
replace rdcpi = 1.09198 if aargang == 2007
replace rdcpi = 1.036639 if aargang == 2008
replace rdcpi = 1 if aargang == 2009
```

```
*DEFLATING ALL EXPENSES AND REVENUES
*Sales
gen sales = omsetning*cpi if omsetning != .

*Expenditures internal R&D
replace intfou = intfou*rdcpi if intfou != .

*Expenditures bought R&D
replace xdksku = xdksku*rdcpi if xdksku != .
replace xdk = xdk*rdcpi if xdk != .
```

COOPERATION DUMMIES USED AS EXPLANATORY VARIABLES

```
*Cooperation of some nature
gen CO = samarb
```

*Cooperation with foreign firm in same enterprise
gen MCO = .
replace MCO = 1 if (co12 == 1 | co13 == 1 | co14 == 1 | co15 == 1 | co16 == 1 | co17 == 1 | no_co12 == 1 | samkonsno == 1 | samkonseu == 1 | samkonsusa == 1 | samkonsan == 1 | saminnno == 1 | saminneu == 1 | saminnan == 1)
replace MCO = 0 if (missing(MCO) & (aargang == 1999 | aargang == 2000 | aargang == 2001 | aargang == 2003 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2007 | aargang == 2008 | aargang == 2009))

*Cooperation with domestic firm in same enterprise
gen DCO = .
replace DCO = 1 if ((co11 == 1 & (aargang == 2001 | aargang == 2004 | aargang == 2005)) | (co18 == 1 & (aargang == 2006 | aargang == 2008)) | (co19 == 1 & (aargang == 2006 | aargang == 2008)) | (saminnreg == 1 & aargang == 2003) | (saminnn == 1 & (aargang == 2003 | aargang == 1999 | aargang == 2000)) | (saminn == 1 & (aargang == 2009 | aargang == 2007)))
replace DCO = 0 if (missing(DCO) & (aargang == 1999 | aargang == 2000 | aargang == 2001 | aargang == 2003 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2007 | aargang == 2008 | aargang == 2009))

*Horizontal cooperation (competitors)
gen HCO = .
replace HCO = 1 if ((co41 == 1 & aargang == 2001) | (co21 == 1 & (aargang == 2004 | aargang == 2005)) | (co48 == 1 & (aargang == 2006 | aargang == 2008)) | (co49 == 1 & (aargang == 2006 | aargang == 2008)) | (samkonkn == 1 & (aargang == 2009 | aargang == 2007)) | (co42 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co43 == 1 & aargang == 2001) | (co44 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co45 == 1 & aargang == 2001) | (co46 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co47 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co22 == 1 & aargang == 2005) | (no_co22 == 1 & aargang == 2004) | (co23 == 1 & (aargang == 2004 | aargang == 2005)) | (co24 == 1 & (aargang == 2004 | aargang == 2005)) | (co27 == 1 & (aargang == 2004 | aargang == 2005)) | (samkonkno == 1 & (aargang == 2009 | aargang == 2007)) | (samkonkeu == 1 & (aargang == 2009 | aargang == 2007)) | (samkonkusa == 1 & (aargang == 2009 | aargang == 2007)) | (samkonkan == 1 & (aargang == 2009 | aargang == 2007)))
replace HCO = 0 if (missing(HCO) & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2007 | aargang == 2008 | aargang == 2009))

*Vertical cooperation (customers and suppliers)
gen VCO = .
replace VCO = 1 if ((co21 == 1 & aargang == 2001) | (no_co51 == 1 & aargang == 2004) | (co51 == 1 & aargang == 2005) | (co28 == 1 & (aargang == 2006 | aargang == 2008)) | (co29 == 1 & (aargang == 2006 | aargang == 2008)) | (samlevn == 1 & (aargang == 2009 | aargang == 2007)) | (co31 == 1 & (aargang == 2001 | aargang == 2004 | aargang == 2005)) | (co38 == 1 & (aargang == 2006 | aargang == 2008)) | (co39 == 1 & (aargang == 2006 | aargang == 2008)) | (samkunn == 1 & (aargang == 2009 | aargang == 2007)) | (co22 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co23 == 1 & aargang == 2001) | (co24 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co25 == 1 & aargang == 2001) | (co26 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co27 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co32 == 1 &

aargang == 2005) | (no_co32 == 1 & aargang == 2004) | (co33 == 1 & (aargang == 2004 | aargang == 2005)) | (co34 == 1 & (aargang == 2004 | aargang == 2005)) | (co37 == 1 & (aargang == 2004 | aargang == 2005)) | (co52 == 1 & aargang == 2005) | (no_co52 == 1 & aargang == 2004) | (no_co53 == 1 & aargang == 2004) | (no_co54 == 1 & aargang == 2004) | (co53 == 1 & aargang == 2004) | (co54 == 1 & aargang == 2004) | (co57 == 1 & (aargang == 2004 | aargang == 2005)) | (co32 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co33 == 1 & aargang == 2001) | (co34 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co35 == 1 & aargang == 2001) | (co36 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co37 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (samkunno == 1 & (aargang == 2009 | aargang == 2007)) | (samkuneu == 1 & (aargang == 2009 | aargang == 2007)) | (samkunusa == 1 & (aargang == 2009 | aargang == 2007)) | (samkunan == 1 & (aargang == 2009 | aargang == 2007)) | (samlevno == 1 & (aargang == 2009 | aargang == 2007)) | (samleveu == 1 & (aargang == 2009 | aargang == 2007)) | (samlevusa == 1 & (aargang == 2009 | aargang == 2007)) | (samlevan == 1 & (aargang == 2009 | aargang == 2007)))
replace VCO = 0 if (missing(VCO) & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2007 | aargang == 2008 | aargang == 2009))

*Cooperation with independent research institutions
gen ICO = .
replace ICO = 1 if ((co51 == 1 & aargang == 2001) | (co61 == 1 & aargang == 2001) | (co71 == 1 & aargang == 2001) | (co81 == 1 & (aargang == 2001 | aargang == 2004)) | (co41 == 1 & aargang == 2004) | (no_co61 == 1 & aargang == 2004) | (no_co71 == 1 & aargang == 2004) | (co58 == 1 & (aargang == 2006 | aargang == 2008)) | (co68 == 1 & (aargang == 2006 | aargang == 2008)) | (co78 == 1 & (aargang == 2006 | aargang == 2008)) | (co88 == 1 & (aargang == 2006 | aargang == 2008)) | (co59 == 1 & (aargang == 2006 | aargang == 2008)) | (co69 == 1 & (aargang == 2006 | aargang == 2008)) | (co79 == 1 & (aargang == 2006 | aargang == 2008)) | (co89 == 1 & (aargang == 2006 | aargang == 2008)) | (samkonsn == 1 & (aargang == 2009 | aargang == 2007)) | (samkomn == 1 & (aargang == 2009 | aargang == 2007)) | (samunin == 1 & (aargang == 2009 | aargang == 2007)) | (samoffn == 1 & (aargang == 2009 | aargang == 2007)) | (samforreg == 1 & aargang == 2003) | (samuohreg == 1 & aargang == 2003) | (samforn == 1 & (aargang == 2003 | aargang == 1999 | aargang == 2000)) | (samuohn == 1 & (aargang == 1999 | aargang == 2000 | aargang == 2003)) | (co52 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co53 == 1 & aargang == 2001) | (co54 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co55 == 1 & (aargang == 2008 | aargang == 2001)) | (co56 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co57 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co62 == 1 & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co63 == 1 & (aargang == 2001 | aargang == 2005)) | (co64 == 1 & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co65 == 1 & (aargang == 2001 | aargang == 2008)) | (co66 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co67 == 1 & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co72 == 1 & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co73 == 1 & (aargang == 2001 | aargang == 2005)) | (co74 == 1 & (aargang == 2001 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co75 == 1 & (aargang == 2001 | aargang == 2008)) | (co76 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co77 == 1 & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co82 == 1 & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co83 == 1 & (aargang == 2001 | aargang == 2004 | aargang == 2005)) | (co84 == 1

& (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (co85 == 1 & (aargang == 2001 | aargang == 2008)) | (co86 == 1 & (aargang == 2001 | aargang == 2006 | aargang == 2008)) | (co87 == 1 & (aargang == 2001 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2008)) | (no_co42 == 1 & aargang == 2004) | (co42 == 1 & aargang == 2005) | (co43 == 1 & (aargang == 2004 | aargang == 2005)) | (co44 == 1 & (aargang == 2004 | aargang == 2005)) | (co47 == 1 & (aargang == 2004 | aargang == 2005)) | (no_co62 == 1 & aargang == 2004) | (no_co63 == 1 & aargang == 2004) | (no_co64 == 1 & aargang == 2004) | (no_co72 == 1 & aargang == 2004) | (no_co73 == 1 & aargang == 2004) | (no_co74 == 1 & aargang == 2004) | (samkonsno == 1 & (aargang == 2009 | aargang == 2007)) | (samkonseu == 1 & (aargang == 2009 | aargang == 2007)) | (samkonsusa == 1 & (aargang == 2009 | aargang == 2007)) | (samkonsan == 1 & (aargang == 2009 | aargang == 2007)) | (samkomno == 1 & (aargang == 2009 | aargang == 2007)) | (samkomeu == 1 & (aargang == 2009 | aargang == 2007)) | (samkomusa == 1 & (aargang == 2009 | aargang == 2007)) | (samkoman == 1 & (aargang == 2009 | aargang == 2007)) | (samunino == 1 & (aargang == 2009 | aargang == 2007)) | (samunieu == 1 & (aargang == 2009 | aargang == 2007)) | (samuniusa == 1 & (aargang == 2009 | aargang == 2007)) | (samunian == 1 & (aargang == 2009 | aargang == 2007)) | (samoffno == 1 & (aargang == 2009 | aargang == 2007)) | (samoffeu == 1 & (aargang == 2009 | aargang == 2007)) | (samoffusa == 1 & (aargang == 2009 | aargang == 2007)) | (samoffan == 1 & (aargang == 2009 | aargang == 2007)) | (samuohno == 1 & (aargang == 1999 | aargang == 2000 | aargang == 2003)) | (samuoheu == 1 & (aargang == 1999 | aargang == 2000 | aargang == 2003)) | (samuohan == 1 & (aargang == 1999 | aargang == 2000 | aargang == 2003)) | (samforno == 1 & (aargang == 1999 | aargang == 2000 | aargang == 2003)) | (samforeu == 1 & (aargang == 1999 | aargang == 2000 | aargang == 2003)) | (samforan == 1 & (aargang == 1999 | aargang == 2000 | aargang == 2003)))
replace ICO = 0 if (missing(ICO) & (aargang == 1999 | aargang == 2000 | aargang == 2001 | aargang == 2003 | aargang == 2004 | aargang == 2005 | aargang == 2006 | aargang == 2007 | aargang == 2008 | aargang == 2009))

*Logarithm of internal R&D expenditures
gen ird = ln(1+(1000*intfou)) if intfou != .

*Logarithm of external R&D expenditures
gen erd = ln(1+(1000*xdk)) if xdk != .

*Logarithm of external R&D expenditures (R&D bought from foreign firm in same enterprise)
gen merd = ln(1+(1000*xdksku)) if xdksku != .

*External R&D expenditures (R&D bought outside the enterprise)
gen xdkothers = xdk-xdksku if (xdk != . & xdksku != .)
gen oerd = ln(1+(1000*xdkothers)) if xdkothers != .

*Sales
gen sale = ln(1+(1000*sales)) if sales != .

***VARIABLES FOR COMPLEMENTARITY

***YEAR DUMMIES TO CONTROL FOR EXOGENOUS SHOCKS

```
gen D01 = 1 if aargang == 1999
replace D01 = 0 if missing(D01)
gen D02 = 1 if aargang == 2000
replace D02 = 0 if missing(D02)
gen D03 = 1 if aargang == 2001
replace D03 = 0 if missing(D03)
gen D04 = 1 if aargang == 2002
replace D04 = 0 if missing(D04)
gen D05 = 1 if aargang == 2003
replace D05 = 0 if missing(D05)
gen D06 = 1 if aargang == 2004
replace D06 = 0 if missing(D06)
gen D07 = 1 if aargang == 2005
replace D07 = 0 if missing(D07)
gen D08 = 1 if aargang == 2006
replace D08 = 0 if missing(D08)
gen D09 = 1 if aargang == 2007
replace D09 = 0 if missing(D09)
gen D10 = 1 if aargang == 2008
replace D10 = 0 if missing(D10)
gen D2009 = 1 if aargang == 2009
replace D2009 = 0 if missing(D2009)
```

***CALCULATING THE WEIGHTED AVERAGE USED FOR DEFLATING THE EXPENDITURES AND REVENUES ASSOCIATED WITH R&D

```
*gen intfou2 = intfou if (intfou != . & bygn != . & mask != . & adk != . & lonn != .)
*replace intfou2 = intfou if (intfou != . & lonn != . & adk != . & inv != . & aargang == 2002)
*bysort aargang: sum intfou2 lonn adk bygn mask inv if intfou2 != .
*From the means provided by the sum function we can calculate the weight each post has in the internal R&D expenses
*For the year 2002 the firms are not asked to specify the amount used on buildings and property, and machinery. These to are merged into a post called investments.
*So we have calculated the average weights that these to posts have in the other words, and weighted the investment post accordingly.
```

```
gen year = 1 if aargang == 2001
replace year = 2 if aargang == 2003
replace year = 3 if aargang == 2004
replace year = 4 if aargang == 2006
replace year = 5 if aargang == 2008
```

```
generate D11 = 1 if year == 1
replace D11 = 0 if missing(D11)
generate D12 = 1 if year == 2
replace D12 = 0 if missing(D12)
```

```
generate D13 = 1 if year == 3
replace D13 = 0 if missing(D13)
generate D14 = 1 if year == 4
replace D14 = 0 if missing(D14)
gen D15 = 1 if year == 5
replace D15 = 0 if missing(D15)

 *Generate innovasjon_egen: dummy on whether or not the firm has made product or process innovation
 gen innovasjon = .
 replace innovasjon = 1 if ((inpdgd == 1 & inpdsv == 0) | (inpdgd == 0 & inpdsv == 1) | (inpdgd == 1 & inpdsv == 1))
 replace innovasjon = 0 if (inpdgd == 0 & inpdsv == 0)
 gen innovasjon_egen = 1 if (innovasjon == 1 & inpdtw == 1 | innovasjon == 1 & inpcsw == 1)
 replace innovasjon_egen = 0 if ((innovasjon == 1 & (inpdtw == 2 | inpdtw == 3)) | innovasjon == 0)

 *Finding average measurements for explanatory variables

xtset id aargang, yearly

gen sales3 = (l2.sales + sales + l.sales)/3 if (l2.sales != . & sales != . & l.sales != .)
replace sales3 = (l2.sales + sales)/2 if (l2.sales != . & sales != . & l.sales == .)
replace sales3 = (l2.sales + l.sales)/2 if (l2.sales != . & sales == . & l.sales != .)
replace sales3 = (sales + l.sales)/2 if (l2.sales == . & sales != . & l.sales != .)
replace sales3 = l2.sales if (l2.sales != . & sales == . & l.sales == .)
replace sales3 = sales if (l2.sales == . & sales != . & l.sales == .)
replace sales3 = l.sales if (l2.sales == . & sales == . & l.sales != .)

gen sale3 = ln(1000*sales3 + 1)

gen intfou3 = (l2.intfou + intfou + l.intfou)/3 if (l2.intfou != . & intfou != . & l.intfou != .)
replace intfou3 = (l2.intfou + intfou)/2 if (l2.intfou != . & intfou != . & l.intfou == .)
replace intfou3 = (l2.intfou + l.intfou)/2 if (l2.intfou != . & intfou == . & l.intfou != .)
replace intfou3 = (intfou + l.intfou)/2 if (l2.intfou == . & intfou != . & l.intfou != .)
replace intfou3 = l2.intfou if (l2.intfou != . & intfou == . & l.intfou == .)
replace intfou3 = intfou if (l2.intfou == . & intfou != . & l.intfou == .)
replace intfou3 = l.intfou if (l2.intfou == . & intfou == . & l.intfou != .)

gen ird3 = ln(1000*intfou3 + 1)

gen xdksku3 = (l2.xdksku + xdksku + l.xdksku)/3 if (l2.xdksku != . & xdksku != . & l.xdksku != .)
replace xdksku3 = (l2.xdksku + xdksku)/2 if (l2.xdksku != . & xdksku != . & l.xdksku == .)
replace xdksku3 = (l2.xdksku + l.xdksku)/2 if (l2.xdksku != . & xdksku == . & l.xdksku != .)
replace xdksku3 = (xdksku + l.xdksku)/2 if (l2.xdksku == . & xdksku != . & l.xdksku != .)
replace xdksku3 = l2.xdksku if (l2.xdksku != . & xdksku == . & l.xdksku == .)
replace xdksku3 = xdksku if (l2.xdksku == . & xdksku != . & l.xdksku == .)
replace xdksku3 = l.xdksku if (l2.xdksku == . & xdksku == . & l.xdksku != .)
```

```
gen merd3 = ln(1000*xdksku3 + 1)

gen xdkothers3 = (l2.xdkothers + xdkothers + l.xdkothers)/3 if (l2.xdkothers != . & xdkothers != . & l.xdkothers != .)
replace xdkothers3 = (l2.xdkothers + xdkothers)/2 if (l2.xdkothers != . & xdkothers != . & l.xdkothers == .)
replace xdkothers3 = (l2.xdkothers + l.xdkothers)/2 if (l2.xdkothers != . & xdkothers == . & l.xdkothers != .)
replace xdkothers3 = (xdkothers + l.xdkothers)/2 if (l2.xdkothers == . & xdkothers != . & l.xdkothers != .)
replace xdkothers3 = l2.xdkothers if (l2.xdkothers != . & xdkothers == . & l.xdkothers == .)
replace xdkothers3 = xdkothers if (l2.xdkothers == . & xdkothers != . & l.xdkothers == .)
replace xdkothers3 = l.xdkothers if (l2.xdkothers == . & xdkothers == . & l.xdkothers != .)

gen oerd3 = ln(xdkothers3 + 1)

gen MCO3 = 1 if (MCO == 1 | l.MCO == 1 | l2.MCO == 1)
replace MCO3 = 0 if (MCO == 0 & l.MCO == 0 & l2.MCO == 0)
replace MCO3 = 0 if (MCO == 0 & l.MCO == . & l2.MCO == 0)
replace MCO3 = 0 if (MCO == 0 & l.MCO == 0 & l2.MCO == .)
replace MCO3 = 0 if (MCO == . & l.MCO == 0 & l2.MCO == 0)
replace MCO3 = 0 if (MCO == . & l.MCO == . & l2.MCO == 0)
replace MCO3 = 0 if (MCO == . & l.MCO == 0 & l2.MCO == .)
replace MCO3 = 0 if (MCO == 0 & l.MCO == . & l2.MCO == .)

gen DCO3 = 1 if (DCO == 1 | l.DCO == 1 | l2.DCO == 1)
replace DCO3 = 0 if (DCO == 0 & l.DCO == 0 & l2.DCO == 0)
replace DCO3 = 0 if (DCO == 0 & l.DCO == . & l2.DCO == 0)
replace DCO3 = 0 if (DCO == 0 & l.DCO == 0 & l2.DCO == .)
replace DCO3 = 0 if (DCO == . & l.DCO == 0 & l2.DCO == 0)
replace DCO3 = 0 if (DCO == . & l.DCO == . & l2.DCO == 0)
replace DCO3 = 0 if (DCO == . & l.DCO == 0 & l2.DCO == .)
replace DCO3 = 0 if (DCO == 0 & l.DCO == . & l2.DCO == .)

gen HCO3 = 1 if (HCO == 1 | l.HCO == 1 | l2.HCO == 1)
replace HCO3 = 0 if (HCO == 0 & l.HCO == 0 & l2.HCO == 0)
replace HCO3 = 0 if (HCO == 0 & l.HCO == . & l2.HCO == 0)
replace HCO3 = 0 if (HCO == 0 & l.HCO == 0 & l2.HCO == .)
replace HCO3 = 0 if (HCO == . & l.HCO == 0 & l2.HCO == 0)
replace HCO3 = 0 if (HCO == . & l.HCO == . & l2.HCO == 0)
replace HCO3 = 0 if (HCO == . & l.HCO == 0 & l2.HCO == .)
replace HCO3 = 0 if (HCO == 0 & l.HCO == . & l2.HCO == .)

gen VCO3 = 1 if (VCO == 1 | l.VCO == 1 | l2.VCO == 1)
replace VCO3 = 0 if (VCO == 0 & l.VCO == 0 & l2.VCO == 0)
replace VCO3 = 0 if (VCO == 0 & l.VCO == . & l2.VCO == 0)
replace VCO3 = 0 if (VCO == 0 & l.VCO == 0 & l2.VCO == .)
replace VCO3 = 0 if (VCO == . & l.VCO == 0 & l2.VCO == 0)
replace VCO3 = 0 if (VCO == . & l.VCO == . & l2.VCO == 0)
```

```
replace VCO3 = 0 if (VCO == . & l.VCO == 0 & l2.VCO == .)
replace VCO3 = 0 if (VCO == 0 & l.VCO == . & l2.VCO == .)

gen ICO3 = 1 if (ICO == 1 | l.ICO == 1 | l2.ICO == 1)
replace ICO3 = 0 if (ICO == 0 & l.ICO == 0 & l2.ICO == 0)
replace ICO3 = 0 if (ICO == 0 & l.ICO == . & l2.ICO == 0)
replace ICO3 = 0 if (ICO == 0 & l.ICO == 0 & l2.ICO == .)
replace ICO3 = 0 if (ICO == . & l.ICO == 0 & l2.ICO == 0)
replace ICO3 = 0 if (ICO == . & l.ICO == . & l2.ICO == 0)
replace ICO3 = 0 if (ICO == . & l.ICO == 0 & l2.ICO == .)
replace ICO3 = 0 if (ICO == 0 & l.ICO == . & l2.ICO == .)

gen irdmerd3 = ird3*merd3 if (ird3 != . & merd3 != .)
gen irdoerd3 = ird3*oerd3 if (ird3 != . & merd3 != .)
gen irdMCO3 = ird3*MCO3 if (ird3 != . & MCO3 != .)
gen irdDCO3 = ird3*DCO3 if (ird3 != . & DCO3 != .)
gen irdHCO3 = ird3*HCO3 if (ird3 != . & HCO3 != .)
gen irdICO3 = ird3*ICO3 if (ird3 != . & ICO3 != .)
gen irdVCO3 = ird3*VCO3 if (ird3 != . & VCO3 != .)

gen industri = 0
replace industri = 1 if (nace1 < 50 & aargang != 2008)
replace industri = 1 if (nace1 < 45 & aargang == 2008)

xtset id aargang, yearly
bysort id: gen nyear=[_N]
keep if nyear != 1

gen nace2 = int(nace1)
xi i.nace2

save fou2


**** Regressions
clear

*CHAPTER 3

*Table 3.Ø
use fou2
xtset id aargang, yearly
reg ird erd CO _Inace2* D01-D2009, robust
xtreg ird erd CO  D01-D2009, fe robust
reg ird merd oerd CO _Inace2* D01-D2009, robust
xtreg ird merd oerd CO  D01-D2009, fe robust
reg ird merd oerd MCO DCO HCO VCO ICO _Inace2* D01-D2009, robust
xtreg ird merd oerd MCO DCO HCO VCO ICO D01-D2009, fe robust
clear
```

```
*Table 3.Ø Small firms
use fou2
xtset id aargang, yearly
keep if ansatte < 50
reg ird merd oerd MCO DCO HCO VCO ICO _Inace2* D01-D2009, robust
xtreg ird merd oerd MCO DCO HCO VCO ICO D01-D2009, fe robust
clear

*Table 3.Ø Medium firms
use fou2
xtset id aargang, yearly
keep if (ansatte > 49 & ansatte < 250)
reg ird merd oerd MCO DCO HCO VCO ICO _Inace2* D01-D2009, robust
xtreg ird merd oerd MCO DCO HCO VCO ICO D01-D2009, fe robust
clear

*Table 3.Ø Large firms
use fou2
xtset id aargang, yearly
keep if ansatte > 249
reg ird merd oerd MCO DCO HCO VCO ICO _Inace2* D01-D2009, robust
xtreg ird merd oerd MCO DCO HCO VCO ICO D01-D2009, fe robust
clear

*Table 3.Ø Manufacturers
use fou2
xtset id aargang, yearly
keep if industri == 1
reg ird merd oerd MCO DCO HCO VCO ICO _Inace2* D01-D2009, robust
xtreg ird merd oerd MCO DCO HCO VCO ICO D01-D2009, fe robust
clear

*Table 3.Ø Service
use fou2
xtset id aargang, yearly
keep if industri == 0
reg ird merd oerd MCO DCO HCO VCO ICO _Inace2* D01-D2009, robust
xtreg ird merd oerd MCO DCO HCO VCO ICO D01-D2009, fe robust
clear

*CHAPTER 4

*Table 4.Ø
use fou2
xtset id year, yearly
reg turnin ird3 erd3 irderd3 CO3 irdCO3 sale3 _Inace2* D11-D15, robust
xtreg turnin ird3 erd3 irderd3 CO3 irdCO3 sale3 D11-D15, fe robust
probit innovasjon ird3 erd3 irderd3 CO3 irdCO3 sale3 _Inace2* D11-D15
mfx compute
clear
```

```
*Table 4.Ø
use fou2
reg turnin ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 _Inace2*  D11-D15, robust
xtreg turnin ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 D11-D15, fe robust
probit innovasjon ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 _Inace2* D11-D15
mfx compute
clear

*Table 4.Ø Small firms
use fou2
keep if ansatte < 50
xtreg turnin ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 D11-D15, fe robust
probit innovasjon ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 _Inace2* D11-D15
mfx compute
clear

*Table 4.Ø Medium firms
use fou2
keep if (ansatte > 49 & ansatte < 250)
xtreg turnin ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 D11-D15, fe robust
probit innovasjon ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 _Inace2* D11-D15
mfx compute
clear

*Table 4.Ø Large firms
use fou2
keep if ansatte > 249
xtreg turnin ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 D11-D15, fe robust
probit innovasjon ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 _Inace2* D11-D15
mfx compute
clear

*Table 4.Ø Manufacturers
use fou2
keep if industri == 1
xtreg turnin ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 D11-D15, fe robust
probit innovasjon ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 _Inace2* D11-D15
mfx compute
```

```
clear

*Table 4.Ø Services
use fou2
keep if industri == 0
xtreg turnin ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 D11-D15, fe robust
probit innovasjon ird3 merd3 irdmerd3 oerd3 irdoerd3 MCO3 irdMCO3 DCO3 irdDCO3 HCO3 irdHCO3 VCO3 irdVCO3 ICO3 irdICO3 sale3 _Inace2* D11-D15
mfx compute
clear
```