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Economic impact of research collaborations with NTNU

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1 Executive summary

Norwegian University of Science and Technology (NTNU) has the main responsibility for higher education in technology in Norway, and it is the country's premier institution for the education of engineers. The University was founded in 1996 with the merging of several research and educational institutions in Trondheim. As of January 1, 2016, NTNU merged again with the University College in Sør-Trøndelag, the University College in Gjøvik and the University College in Ålesund. Together they are Norway's largest university. NTNU has 9 units at faculty level and 56 departments and divisions with approximately 39 000 students and 6 700 fulltime employees, over 4 000 of whom are in teaching, research, and outreach positions.

NTNU's vision is to achieve knowledge for a better world. To use the university's technical and scientific main profile, its academic breadth and interdisciplinary expertise to address the challenges facing Norway and the world. Their mission is to develop the technological foundation for tomorrow's society. To achieve the vision and mission NTNU is working in close collaboration with the surrounding society and business environment.

This analysis is the first to estimate the economic impact of research collaborations between the private sector and NTNU. Collaboration with companies is crucial in the transmission of knowledge between universities and industry and in commercialization of new ideas and innovation. The analysis therefor aims at investigating the causal relationship between the companies R&D collaborations with NTNU and their economic performance, i.e. whether the companies experience a positive economic development due to their collaboration with NTNU.

1.1 Key findings

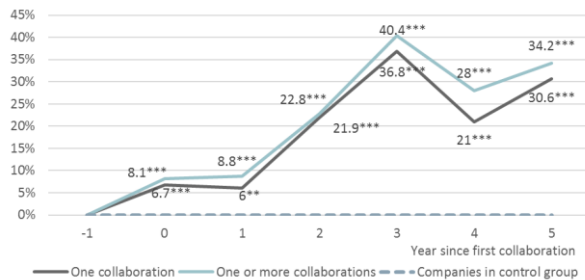
NTNU has entered into more than 10,000 R&D collaborations with Norwegian and foreign private sector companies during the period 2005 to 2015. In total, roughly 1,200 different Norwegian companies and 760 foreign companies have collaborated with NTNU. The number of R&D collaborations has doubled for most collaboration types over the period, while public R&D collaborations in 2015 are five times higher than they were in 2005. Recent developments point to a larger focus on R&D purchase collaborations in the future.

Companies that engage in R&D collaborations with NTNU are highly productive, export oriented and very knowledge intensive. As an example, NTNU's collaboration partners generate a value added per full time employee of 834,000 NOK compared to approximately 389,000 NOK per employee in the private sector in general.

R&D collaborations with NTNU have contributed positively to the companies' economic performance. The analysis demonstrates that companies that have collaborated with NTNU have achieved better results. They have had higher revenue growth, invested more and created more jobs than they otherwise would have:

1. **Additional revenue growth.** Companies that have collaborated with NTNU have, 5 years after the first collaboration, experienced an **additional growth in revenue of 34.2 pct. points** compared to the control group. For those companies that have only collaborated with NTNU once, the effect is only slightly lower, 30.6 pct.

FIGUR 1.1
Impact on revenue for companies collaborating with NTNU



Source: DAMVAD Analytics 2017

Note: *** $p < 0,01$ ** $p < 0,05$ * $p < 0,1$

2. **Created more jobs.** Companies that have collaborated with NTNU have, 5 years after the first collaboration, had an **additional growth in employment of 9.0 pct. points** compared to the control group. For those companies, that have only collaborated with NTNU once, the effect is 6.5 pct. after 4 years, after which the effect is diminishing. This indicates that it is necessary to have a lasting collaboration relation with NTNU to maintain employment growth.
3. **Invested more.** Companies that have collaborated with NTNU have, 3 years after the first collaboration, experienced an **additional growth in business investments of 28.8 pct. points** compared to the control group. For those companies that have only collaborated with NTNU once, the effect is 18 pct. after 3 years.

2 NTNU's private sector research collaborations

The purpose of this chapter is to shed light on research collaborations and patterns between NTNU and private businesses. The analysis will thus explore the characteristics, extent and development in business collaborations over time. Moreover, it will touch on which types of businesses tend to collaborate with NTNU.

2.1 Collaboration types

In this study, we analyse the extent and impact of four types of research collaborations between NTNU and private businesses:

1. **R&D purchases**, referring to businesses' purchase of science and innovation at the university.
2. **Co-financed R&D projects**, where university and business partners collaboratively finance research projects.
3. Collaborations via **public R&D programmes**, where collaborations with private sector partners are facilitated by public funds.

4. **Joint publications** of academic work in international peer reviewed journals by NTNU and private sector businesses.

These types of research collaborations have been identified using three primary data sources:

- Economic transactions between companies and NTNU, dating back to 2005, are provided by NTNU. Where missing, business IDs have been added from the Brønnøysund Register Centre where possible. These include only the primary company in the collaboration, excluding other potential collaborators.
- Further collaborations are provided by The Research Council of Norway (RCN), to identify secondary collaborators that may not be identified in NTNU's database. These are all defined as *public R&D* programmes, for which budgetary data are not available.
- DAMVAD Analytics' Research Database, which is based on the international Elsevier's Scopus database, makes it possible to identify all co-publishing made by NTNU together with Norwegian and foreign companies.

TABLE 2.1
Number of collaborations with Norwegian and foreign companies across collaboration types 2005-2015

Collaboration type	Norwegian companies	Foreign companies	Total
R&D Purchase	1,661	239	1,900
Co-financed R&D projects	2,357	50	2,407
Public R&D programmes	2,836	717	3,553
Joint publications	1,851	667	2,518
Total	8,705	1,673	10,378

Source: DAMVAD Analytics 2017

Note: R&D purchase, public R&D programmes and co-financed R&D project data given by NTNU as well as RCN, where NTNU is a registered project partner or leader. Publications are derived from Scopus. Includes all Norwegian and foreign collaborations. Discrepancy between these data and those used in the impact evaluation, as private firms here are defined on a case by case basis.

- Statistics Norway's registers provide background information and economic performance indicators using business ID's, in order to follow company development over time.

The data collected from NTNU classifies each collaboration by type, defined as either "Oppdrag" or "Bidrag", with the first group defining collaboration type 1, *R&D purchase*, and the second group defining other public/private co-financed R&D projects (type 2 and 3). The second group is further classified by its source of finance. This serves to distinguish between collaboration type 2 and 3, with collaborations funded by public institutions, funds or EU grants classified as *Public R&D programmes* while those funded by private actors are classified as *Co-financed R&D projects*. As mentioned above, collaborations collected from RCN are also grouped with *public R&D programmes* while *joint publications* are identified using Scopus.

Table 2.1 shows the extent of NTNU's collaborations with Norwegian and foreign companies, totaling 10,327 collaborations in the period 2005-2015. These span across 1,177 unique Norwegian firms and 759 unique foreign firms.¹

The table reveals that a high share of collaborations are classified as *public R&D programmes*, making up 33 pct. of domestic collaborations and 43 pct. of foreign collaborations. These are collaborations financed by RCN, EU grants, or other state and regional funding schemes. *Co-financed R&D* make up roughly the same share as publicly funded R&D projects for Norwegian firms, but is the least common mode of collaboration for international firms at only 3 pct.

¹ In contrast to Norwegian firms, unique business IDs are not available for foreign firms, for which reason they are identified by their firm name only. This number is thus likely to be overestimated, as the same company can

Joint publications make up a large share of international collaborations in total, at 40 pct., compared to 21 pct. for Norwegian collaborations. Conversely, R&D purchase makes up a larger share for Norwegian firms than for international firms, though still relatively low, at only 19 pct. of total Norwegian collaborations.

2.2 Extent of collaborations

NTNU has collaborated with 1,177 Norwegian companies in the period 2005-2015, with 56 pct. collaborating only once. The mean number of collaborations however is 7.1, indicating a few firms collaborating many times over multiple years. Among the most frequent collaborators (top 10 pct.), the companies have collaborated at least 9 times, with the top 1 pct. of the sample collaborating over 100 times.

TABLE 2.2
Typical number of collaborations per Norwegian company

Measure of typical company	Number of collaborations
Average	7.1
Top 10 pct.	9
Top 25 pct.	3
Median	1
Share with 1 collaboration	55.9%

Source: DAMVAD Analytics 2017
Note: Data covers 1,177 unique Norwegian companies with business IDs, 2005-2015.

In terms of collaboration size, the typical project budget is roughly 500.000 NOK, as measured by the median. The mean is significantly higher at roughly 1.5 million NOK, with a number of financially heavy collaborations at the higher end of the distribution. Notably the top 10 pct. of the distribution has

be counted twice for slight variations in business name. This is not the case for Norwegian firms, which we can uniquely identify on the basis of a unique firm ID.

budgets of nearly 3 million NOK- in stark contrast to only roughly 50.000 NOK at the bottom 10 pct. of the distribution.

Table 2.3 shows the distribution of budgets across modes of collaboration. It is clear that public R&D projects make up the majority of larger projects over 500.000 NOK. Co-financed R&D projects are likewise large, with 50 pct. of these types of collaborations in the highest budget category. The size of R&D purchase collaborations is in the lower end, however, with only 30 pct. of collaborations with budget data in the highest category.

TABLE 2.3
Number of collaborations across type and financial size pr. partner (EUR) 2005-2015

Collaboration type	Less than 50.000	Less than 100.000	Less than 250.000	Less than 500.000	over 500.000	Missing cost	Total
R&D Purchase	245	209	376	248	453	369	1,900
Co-financed R&D projects	214	153	336	222	943	539	2,407
Public R&D programmes	112	175	322	243	1,412	1,289	3,553
Joint publications						2518	2,518
Sum	571	537	1,034	713	2,808	4,715	10,378

Source: DAMVAD Analytics 2017

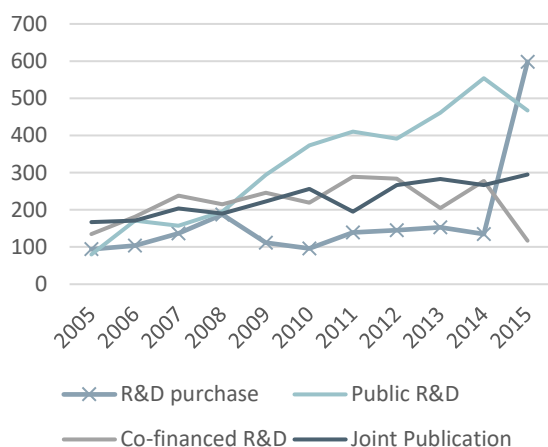
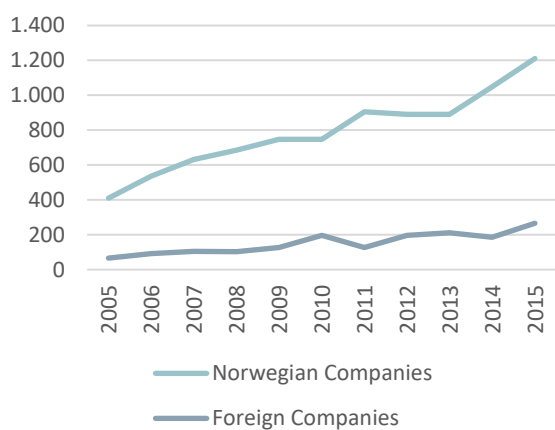
Note: Financial records included for all projects over 10.000, as well as those over 0 to avoid smaller sub-projects and misreporting given the discrepancies in the financial report. Foreign collaborations and joint publications have no budgetary data, and are therefore set to missing. Budgets should be interpreted with some caution as figures reflect budgeted costs, not necessarily realized cost. Furthermore, some budgets cover multiple subprojects, while others simply group budgets in one total projected cost.

2.3 Development over time

There has been a rising trend in collaborations over time, both in terms of foreign and Norwegian collaborations, though more so for Norwegian firms.

FIGURE 2.4

Development in number of collaborations with private businesses



Source: DAMVAD Analytics 2017

Note: Collaborations are classified according to their start date.

In terms of collaboration types, the largest growth in collaborations is seen among public R&D programmes. From 2005, this group grew nearly 500 pct, while co-financed R&D and publications grew closer to 100 pct. R&D purchase is the most infrequent and slowest growing mode of collaboration,

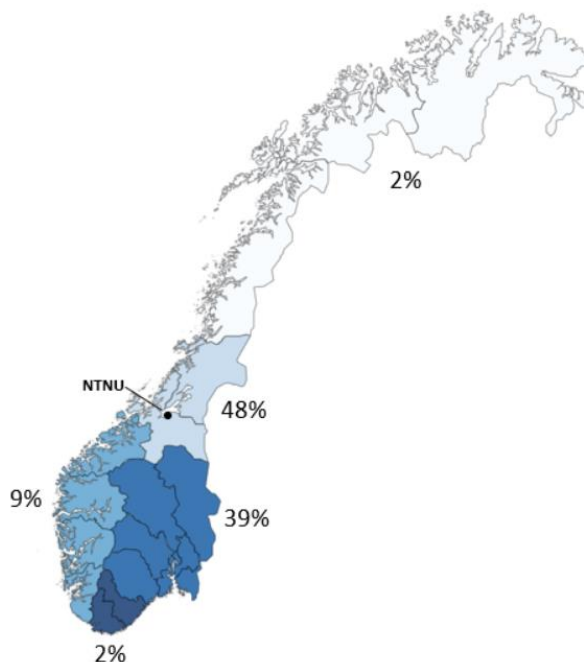
with the exception of 2015, which is not included in the impact analysis.

2.4 Geographical distribution of collaboration partners in Norway

NTNU collaborates with firms located in all five regions of Norway, though particularly concentrated in *Trøndelag* and *Østlandet*. Measured by the number of collaborations with the private sector, companies in Trøndelag account for 48 pct. of all collaborations, cf. figure 2.5. Meanwhile, the figure also reveals that NTNU also collaborates with companies in other parts of the country, Nord Norge, Vestlandet and Sørlandet, with respectively 2 pct., 9 pct. and 2 pct. of the total number of collaborations.

FIGUR 2.5

Share of collaborations per region



Source: DAMVAD Analytics 2017

Note: N = 2,759 collaborations between Norwegian firms and NTNU in the period 2005-2014.

NTNU's collaboration relations with companies in different regions tend to have different characters. As per table 2.6, the largest share of all collaborations are located in either Trøndelag or Østlandet. A large share of the large research-intensive companies are located in this region, and it is this expected that NTNU has the highest share of R&D collaborations with companies in this region. Joint publications are slightly more dispersed, with a relatively high percentage in the Nord Norge, Sørlandet and Vestlandet, compared to other collaboration modes, despite 50% still being located in Østlandet.

TABLE 2.6
Collaboration types across region (pct.)

	R&D Purchase	Public R&D	Joint publication	Co-financed R&D	Total collaborations	All collaborations
Nord Norge	3.6%	0.9%	6.0%	0.6%	2.1%	57
Trøndelag	45.7%	60.8%	23.9%	38.6%	47.8%	1,318
Vestlandet	10.9%	9.2%	11.9%	7.1%	9.4%	260
Østlandet	38.8%	27.4%	51.9%	53.3%	39.0%	1,076
Sørlandet	1.0%	1.6%	6.3%	0.3%	1.7%	48

Source: DAMVAD Analytics 2017.

Note: Based on register data from Statistics Norway. N= 2,759 collaborations with NTNU in the period 2005-2014. Regional data only available for industries within construction, mining and quarrying, and manufacturing. Not available for nace rev. 2 branches H, I, J, as the region of registry does not always reflect the center of the activity of the firm. For this reason, the above trend is skewed towards regions active in the aforementioned industries.

2.5 Key characteristics of business partners

Companies that collaborate with NTNU are generally highly productive, have a high export-intensity, and are relatively knowledge-intensive, cf. table 2.7.

The revenue per employee among collaborating firms is more than twice as high as that of the rest of the private sector. The same is true of productivity, as value added per employee among NTNUs collaborating partners is 834,000 compared to just 389,000 among private businesses in general.

A much larger share of NTNU's collaborating partners are exporters than the private sector in general, with 39% engaged in export activity over the

period, compared to just 5.4% among other businesses. Furthermore, the export intensity for those who export, defined as the share of exports in revenue, is nearly four times higher among NTNU partners than other businesses². The same is true of exports per employee among exporting firms, at roughly 70,000 for NTNU partners, and 20,000 for other businesses.

The distribution of education levels among employees of NTNU's business partners is also considerably more knowledge-intensive than the private sector in general, cf. table 2.7. Most notably, the share of employees with higher tertiary education or higher is roughly 30 pct., roughly five times higher than businesses in general. Likewise, the combined

TABLE 2.7

Key economic indicators for companies collaborating with NTNU compared to private businesses in general

	Business partners of NTNU	Private businesses in general
Economic indicators for typical company		
Revenue per employee 2015 prices (1000s, NOK)	1,737	880
Value added per employee 2015 prices (1000s, NOK)	834	389
Export per employee 2015 prices (1000s, NOK)	70	20
Export intensity	4.7%	1.0%
Share that are exporters	39%	5.4%
Employee education level		
Share with primary/secondary education or less	9.4%	26.7%
Share with upper secondary	32.6%	46.9%
Share with lowest level or lower-degree tertiary	24.2%	16.6%
Share with higher-degree level tertiary	24.9%	5.5%
Share with doctorate or equiv. level tertiary	6.9%	0.3%
Not available	1.9%	3.9%

Source: DAMVAD Analytics 2017

Note: Calculated for the private sector, here defined as companies with economic sectors A-N in NACE rev.2. Revenue, value added and export per employee has been calculated for the median company. Data based on employment and firm statistics from Statistics Norway, figures based on firms for which there is data. Not available pertains to those found in the education data, with undisclosed education levels. N=5948 collaborations over 722 unique firms who have education data. A further 2362 collaborations in total are not present in the education register, and are not included in the second half of the table. Businesses in general includes business partners of NTNU.

² The export intensity is strongly underestimated due to inadequate data access. Primarily, because the data does not include the oil and gas

sector, which is normally export intensive. This concerns both the business partners of NTNU and private businesses in general.

share with no tertiary is just 42 pct., compared to 74 pct. among firms in general.

2.5.1 Collaborations with companies from many different economic sectors

Figure 2.8 shows the distribution of firms across all economic sectors, while figure 2.9 shows the distribution across 15 more detailed sectors. As per table 2.8, business partners of NTNU are concentrated in *Professional, scientific, and technical activities* and *Manufacturing*, each making up a fourth of collaborations. Given that they together make up just 15 pct. of the rest of the private sector, these sectors are largely overrepresented among NTNU collaborators. Within manufacturing, partners are most frequently occupied with manufacture of electronic products, food products, as well as chemicals and

machinery and equipment. Collaborators in the professional and scientific sector are highly concentrated in architectural and engineering activities and technical testing, analysis and scientific R&D, cf. Table 2.9.

Administrative and support services activities makes up the third largest sector among partners, and is similar in percentage to the private sector in general at nearly 10 pct. On the other hand, the fourth largest sector among NTNU collaborators, *Trade, transportation and storage* makes up only 7.9 pct. compared to the 27 pct. the sector makes up of the overall economy. The fifth and sixth largest sectors are made up of *Information and communication* and *Mining and quarrying*, a 7.9 and 6.3 pct. respectively. Both are larger than their shares in the

TABLE 2.8
Distribution of companies across economic sectors

	Business partners of NTNU	Private businesses in general
Professional, scientific and technical activities	24.9%	9.3%
Manufacturing	24.3%	6.2%
Administrative and support service activities	9.7%	12.0%
Trade, transportation and storage	7.9%	27.3%
Information and communication	7.9%	4.0%
Mining and Quarrying	6.3%	0.3%
Electricity, gas, steam and air conditioning supply	6.0%	0.2%
Real estate	3.9%	16.0%
Construction	3.7%	17.4%
Agriculture, forestry and fishing	2.0%	2.6%
Financial and insurance activities	1.4%	0.4%
Accommodation and food services	0.8%	4.0%
Other	1.2%	0.3%
Total	100%	100%

Source: DAMVAD Analytics 2017

Note: Economic sector based on high-level nace 2/istic rev.4 aggregation. Based on register data from Statistics Norway and own data. Averages for the period 2005-2014. For business partners of NTNU, N= 6467 (firms with branch data), based on 766 unique firms.

general economy, and are made up largely of computer programming and consultancy and mining support services, respectively.

TABLE 2.9
Top 15 detailed collaboration sectors

Economic sector	Pct.
Architectural and engineering activities; technical testing and analysis	15.1%
Scientific research and development	9.7%
Computer programming; consultancy and related activities	6.8%
Electricity, gas, steam and air conditioning supply	5.9%
Wholesale trade, except of motor vehicles and motor-cycles	4.6%
Real estate activities	3.9%
Mining support service activities	2.6%
Other professional, scientific and technical activities	2.5%
Manufacture of computer, electronic and optical products	2.5%
Publishing activities	2.5%
Construction of buildings	2.2%
Manufacture of food products	2.2%
Activities of head offices; management consultancy activities	2.2%
Manufacture of chemicals and chemical products	2.1%
Manufacture of machinery and equipment n.e.c.	2.1%
Share of all collaborations	66.6%

Source: DAMVAD Analytics 2017

Note: Economic sector based on NACE divisions (two-digit level). Based on figures 2008-2014, N= 4658 observations, 751 unique firms. Based on register data from Statistics Norway and own data. Differs from table 2.8 due to difference in time period.

In terms of collaboration type and frequency, the *Professional, scientific and technical activities* sector accounts for the largest shares of public R&D as well as R&D purchase collaborations, making up 44 pct. and 30 pct. of total collaborations, respectively. Other dominant sectors in public R&D are *Information and communication* (21 pct.) and *Manufacturing* (11.6 pct.). Furthermore, the *Professional, scientific and technical activities* sector is responsible for the second largest shares of both of joint publications and co-financed R&D at 25 pct. and 19 pct. respectively, following *Manufacturing* as the largest

sector in publications (32 pct.) and *Mining and Quarrying* as the largest sector in co-financed R&D (23 pct.).

Looking at NTNU's collaboration partners across more detailed sectors, it is clear that *Architectural and engineering activities* and *Scientific R&D* are very dominant sectors, making up roughly 15 pct. and 10 pct. respectively. Together, they make up nearly all collaborating firms within the *Professional, scientific and technical activities* sector.

2.5.2 Collaborations with small and large companies

NTNU's private sector R&D collaborations are relatively evenly distributed across size categories compared to the private sector in general, which is dominated by smaller firms. Large companies with more than 250 employees make up 19 pct. cf. table 2.10, while small and micro companies with less than 30 employees jointly make up 50 pct.

TABLE 2.10
Company size (pct.)

	Business partners of NTNU	Private sector in general
Micro	34.2%	91.6%
Small	16.0%	6.1%
Medium	30.6%	2.1%
Large	19.2%	0.2%
Total	100.0%	100.0%

Source: DAMVAD Analytics 2017

Note: Based on register data from Statistics Norway and own data. Averages for the period 2005-2014. N=945 unique firms. Number of employed is compiled from two sources: individual level registry data, and firm level data. The individually aggregated employment does not include owners, while the firm level employment figures do include owners. There is therefore a slight discrepancy between the two sources, though for most branches the discrepancy is unbiased. For nace rev 2 branched B, A there is a slight downward bias, while for branched L and C there is a slight upwards bias. Missings are absent data from both sources. Micro= less than 10, Small= less than 30, Medium= less than 250, large= greater than 250.

When tabled across economic sectors, large companies are most frequently *Manufacturing*, accounting for 30 pct. of the sector cf. table 2.12. The *Professional scientific and technical activities* sector, on the other hand, is dominated by companies with less than 30 employees, with 60 pct. belonging to these categories. This is true to an even larger extent for *Administrative and support services activities*, with small and micro firms making up roughly 75 pct. Within the sectors *Information and communication* and *Trade, transportation and storage*, NTNU's collaboration partners are more evenly distributed across different company sizes.

In terms of collaborations, however, there is a tendency for larger firms to account for a larger share of the collaborations, as would be expected. While table 2.11 shows that there are a smaller share of unique firms in the sample of collaborating partners, the few large firms account for the largest share of all collaborations modes. Grouping small and micro firms, together, the collaborations are more evenly distributed among the remaining size categories. Co-financed R&D collaborations and joint publications, however, are relatively more size-intensive than the other collaboration modes.

TABLE 2.12
Collaboration modes across company size

	Purchase	Co-financed	Publicly financed	Joint publication
Micro	19.8%	5.6%	22.2%	9.9%
Small	6.7%	8.0%	15.8%	6.6%
Medium	22.5%	30.6%	26.1%	21.4%
Large	51.1%	55.8%	35.9%	62.1%
Total	100.0%	100.0%	100.0%	100.0%

Source: DAMVAD Analytics 2017

Note: N= 5710 collaborations over the period 2005-2014. Based on register data from Norway and own calculations.

TABLE 2.11
NTNU's collaboration partners across the top 5 economic sectors and company size (pct.)

	Micro	Small	Medium	Large	Number
Professional, scientific and technical activities	40%	19%	30%	11%	1,566
Manufacturing	20%	13%	37%	30%	1,624
Information and communication	33%	13%	35%	15%	530
Trade, transportation and storage	25%	23%	38%	14%	511
Administrative and support service activities	54%	22%	13%	8%	650

Source: DAMVAD Analytics 2017

Note: Economic sector based on high-level Nace 2/ ISIC rev 4. aggregation. Based on register data from SSB Norway. Averages for the period 2005-2014. N= 4881 observations. Observations do not always add to 100% due to presence of missing values.

3 Economic impact of NTNU's private sector R&D collaborations

In this chapter, we analyse the economic effects on private businesses from engaging in R&D collaborations with NTNU. The analysis sheds light on whether there is evidence for a causal relationship between the companies' R&D collaborations and their economic performance, i.e. whether the company experiences a positive economic development *because* of the collaboration with NTNU – a development that would not have taken place otherwise. Specifically, we investigate how R&D collaborations with NTNU affect their revenue and employment growth³. In addition, we investigate the importance of different collaboration modes.

3.1 Study design

3.1.1 Method

For natural reasons, it is impossible to observe how the same company fares both with and without an R&D collaboration. Either a company has collaborated on R&D with NTNU, or it has not. For this reason, it is not possible to directly measure the economic gain that companies obtain from collaborating with NTNU.

At the same time, as revealed by the previous chapter, the companies that tend to collaborate with NTNU represent a particular type of company. A simple statistical analysis would therefore not be able to determine, whether companies that engage in R&D collaborations with NTNU perform better because of the R&D collaboration, or whether companies that already perform well tend to engage in R&D collaborations with NTNU.

In order to shed light on the economic effects of collaborating on research and development with

NTNU, we therefore employ advanced econometric techniques that make it possible to compare the economic development that NTNU's business partners experience in the years after a collaboration with the economic development in a control group of companies. The aim is to construct a group of companies that is so similar to NTNU's business partners that the only apparent difference between the two groups is, that the companies in the control group did not chose to collaborate with NTNU on R&D projects.

Based on the composite control group it is possible to estimate the causal effect of one or more R&D collaborations with NTNU on company performance in a regression model. In this way other factors of potential importance for company performance and their choice to collaborate with NTNU are accounted for to the highest possible extent.

In this analysis we use the method *Coarsened Exact Matching*, which represents best practice within the field and has a number of advantages compared to the frequently used Propensity Score Matching that until recently represented best practice⁴. The employed matching method and the models are described more thoroughly in chapter 4.

3.1.2 Identification of effects

In order to investigate the economic effects for companies from engaging in research and development projects with NTNU, the companies' R&D collaborations are analysed as a binary choice on an annual basis: in each year, a company chooses to collaborate with NTNU or it chooses not to.

³ We did also test how R&D collaborations were affecting the company's investments growth (change in fixed assets) but results were insignificant.

⁴ Iacus, Stefano M., Gary King, and Giuseppe Porro. 2011. Multivariate matching methods that are Monotonic Imbalance Bounding. Journal of the American Statistical Association.

The mapping of collaboration relations in chapter 2, however, illustrated that the companies are often engaged in a complex collaboration pattern with NTNU. A single company can thus be engaged in multiple collaborations simultaneously, be participating in different types of research collaborations of different financial sizes, and more importantly, they might engage in repeated collaborations over time.

This gives rise to a challenge in distinguishing effects from entering into collaboration relations of differing character, such as collaboration encompassing various collaboration modes or varying intensity measured by financial contribution per partner in a given year. Even more importantly, however, short- and long-term effects can be blurred for companies that engage in repeated collaboration relations over time. The reason is that economic effects from research- and development projects are expected to develop over time. Positive effects that only materialize several years after the project has been initiated can thus be ascribed to new research collaborations. Conversely, potential short-term negative effects of later research collaborations, e.g. during implementation of new working procedures, might blur potential long-term positive effects of earlier collaborations.

In previous analyses, this has been solved by exclusively including companies with a single collaboration over the data window in the impact analysis. A great disadvantage of this, however, is that almost half of all companies would be excluded from the analysis, cf. table 2.2.

Instead, we estimate two base models:

- Model 1 measures the effect of initiating any collaboration relationship with NTNU. In other words, we follow all companies that have engaged in R&D collaborations with

NTNU from their first collaboration year – disregarded whether the collaboration relationship in question is limited in time or whether the relationship extends over multiple years.

- Model 2 measures the isolated effect from initiating an R&D relation with NTNU that is limited in time. In this model, deferred effects from later potential collaborations are thus accounted for.

Model 1 thus gauges the general effect of establishing a collaboration relationship with NTNU, while model 2 captures the effect of initiating R&D collaborations that are limited in time.

In section 3.3 we investigate further, whether collaboration relations that involve certain collaboration modes or a certain financial amount per partner are more likely to generate positive effects on company performance than others. Here model 2 is used as base model to underline the development over time, and take account of the fact that potentially repeated relations over time might change character.

3.2 Effects of R&D collaborations with NTNU

The econometric analysis indicates that there is a statistically and economically significant causal positive relation between engaging in an R&D collaboration with NTNU and a company's economic performance. At the same time, the analysis indicates that repeated collaboration relations often lead to larger economic effects than one-time R&D collaborations. In the following sections, the results are presented in detail.

Collaborations with NTNU increase company revenue growth

The econometric analysis reveals, that there is a significant positive effect on company revenues from entering into an R&D collaboration with NTNU.

Figure 3.1 shows the accumulated revenue effect (model 1 and 2) on NTNU's business partners compared to the control group (the dotted line) over time. There is a significant positive effect on company sales and production from initiating a collaboration relation with NTNU on research and development. The impact can be measured already in the first year of collaboration (year 0) and is rising over time.

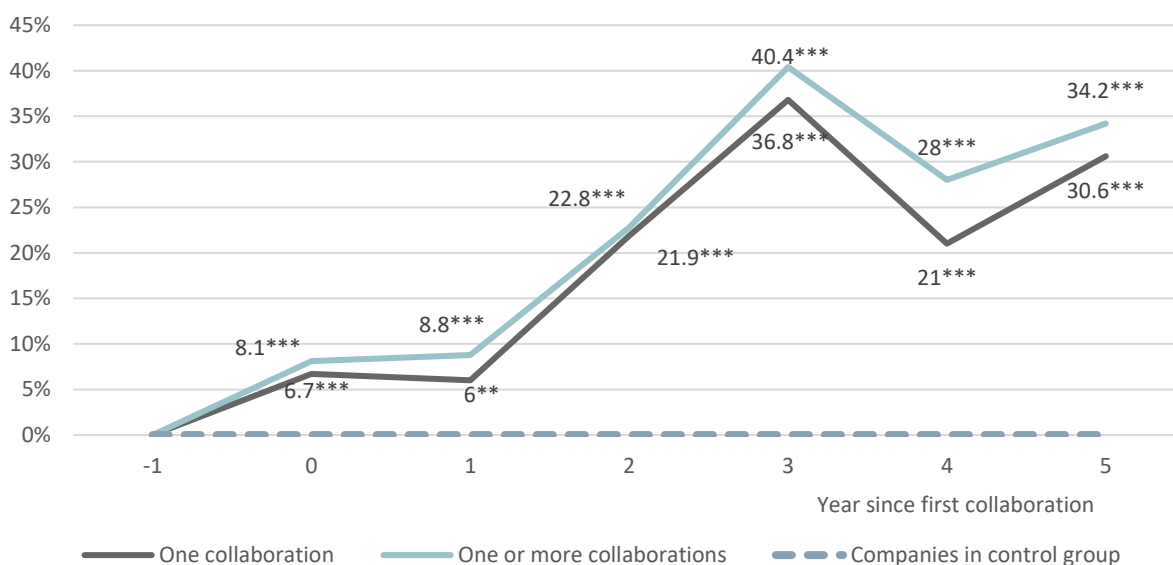
Looking first at the isolated effect from establishing a collaboration relation with NTNU that is limited in time (Model 2) we observe an additional revenue growth for NTNU's business partners, which is 6.7

pct. points higher than the control group already in the collaboration year. There is a rising – although somewhat unstable -trend until year 5 after the collaboration was initiated. The later the collaboration was initiated, the fewer years we can observe after the collaboration. This is due to the fact that we cannot measure the effect 4 or 5 years after the collaboration, if the collaboration occurred later than 2011. The instability may be due to the lower number of observations the further away we are from the first collaboration.

NTNU's collaboration partners have thus experienced an additional growth in revenue since the year before the collaboration was initiated that is 30.6 pct. points above the revenue growth of the control group. Altogether, the effect is not only significant from an economic perspective – there is

FIGURE 3.1

Estimated impact on revenue for companies collaborating with NTNU compared to control group (pct.)



Source: DAMVAD Analytics 2017

Note: *** p<0,01 ** p<0,05 * p<0,1

also a high level of statistical certainty about the observed difference between NTNU's business partners and the control group.

The development in revenue growth compared to the control group is largest in first and the third year after the first collaboration. The revenue growth is positive but somewhat unstable over the period. This is demonstrated most clearly in table 3.1., which shows the average additional annual growth of NTNU's business partners compared to the control group since the year before the collaboration was initiated.

TABLE 3.1
Average additional annual growth in revenue

Years since first year of collaboration	0	1	2	3	4	5
One collaboration	6.7 (***)	3.0 (**)	7.3 (***)	9.2 (***)	4.2 (***)	5.1 (***)
One or more collaborations	8.1 (***)	4.4 (***)	7.6 (***)	10.1 (***)	5.6 (***)	5.7 (***)

Source: DAMVAD Analytics 2017

Note: *** p<0,01 ** p<0,05 * p<0,1

When looking at the general effect of establishing a collaboration relation with NTNU – i.e. irrespective of whether the relationship is limited in time or there are repeated collaborations over time – (model 1), the estimated revenue effect compared to the control group is even more substantial. 5 years after the first collaboration relationship was established, NTNU's business partners have experienced a total revenue growth that is 34.2 pct. points above the control group.

While the timing of the establishment of the first collaboration is similar across all companies in the

model (year 0), this model does not account for the timing of any potential later collaborations or their frequency. For this reason, it is not possible to establish, whether repeated collaborations over time have a similar or even larger effect on company revenue – e.g. if companies that have gained experience from earlier collaborations are better at translating knowledge obtained into revenue effects – or if the effect decreases when engaging in repeated collaborations over time. The results demonstrate, however, that repeated collaborations over time on average contribute to additional positive revenue growth compared to the control group. This is also seen in table 3.1., in which the average annual revenue effect is around 1 pct. point higher when looking at the general effect of establishing a relationship (one or more collaborations) than for the isolated effect of a time-limited collaboration (one collaboration).

It may seem surprising, that a quite significant revenue effect can be observed already in the very first year of the collaboration – both when looking at a single collaboration and one or more collaborations. In this connection, it is important to note however, that there is some uncertainty as to the exact initiation of the collaboration relationship:

- Firstly, companies are observed only on an annual basis. This implies that a company might have had up to a full year to translate the R&D collaboration into effects.
- Secondly, DAMVAD Analytics have in previous studies documented, that formal R&D collaborations are often based on a far broader and often informal set of relations between the participating partners⁵. An R&D project might thus have been under preparation for a longer period, before it

⁵ DAMVAD 2012: "Measuring the Economic Effects of Companies Collaborating with the University of Copenhagen"

leads to a formal R&D collaboration financed either by the partners themselves or by public funds.

- Thirdly, there might be some uncertainty as to the projects' actual starting date as these to a wide extent are based on accounting data rather than e.g. project evaluation systems in which the project duration and progress are main focus areas. This also concerns co-publications for which the R&D projects actual starting date is actually unknown, but assumed initiated 2 years before the date of publication.

Collaborations with NTNU create new jobs

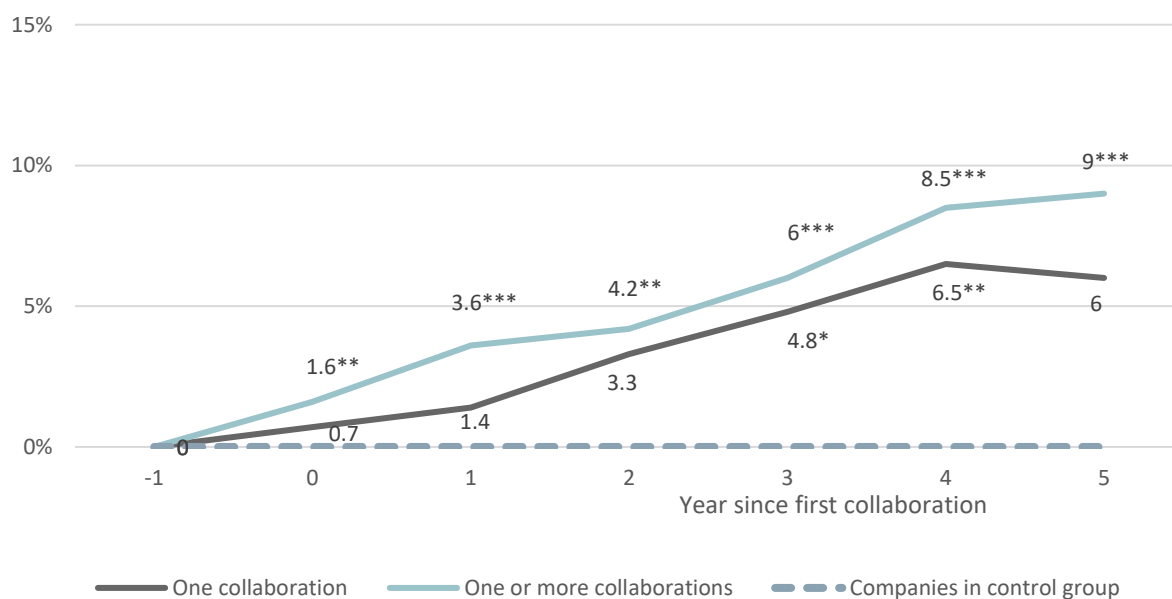
The companies do not only achieve higher revenue growth as a result of their R&D collaborations with

NTNU. We also find that there is a significant positive employment effect from engaging in a collaborative relationship on research and development with NTNU. In other words, companies that initiate R&D collaborations with NTNU are hiring more employees than comparable companies without collaborations.

Two years after the collaboration is initiated the isolated effect of a time-limited collaboration relationship (model 2) is 3.3 pct., rising to 6.5 pct. in year 4 cf. figure 3.2. This implies that 4 years after the R&D collaboration with NTNU, NTNU's business partners have employed 6.5 pct. more employees, than they would have, if they have decided not to engage in the relationship. Opposite the revenues, the devel-

FIGURE 3.2

Estimated impact on employment for companies collaborating with NTNU compared to control group (pct.)



Source: DAMVAD Analytics 2017

Note: *** p<0,01 ** p<0,05 * p<0,1

opment in employment growth compared to the control group is positive and stable around over the whole period.

The general effect from establishing a collaboration relationship with NTNU – irrespective of whether the relationship is limited in time or covers multiple collaborations over time (model 1) – increases continuously and roughly at the same pace over the whole period. More specifically, the average annual impact on employment lies relatively constant around 1.5 pct. points over the whole period, cf. table 3.2.

TABLE 3.2
Average additional annual growth in employment

Years since first year of collaboration	0	1	2	3	4	5
One collaboration	0.7	0.7	1.1	1.2 (*)	1.3 (**)	1.0
One or more collaborations	1.6 (**)	1.8 (***)	1.4 (**)	1.5 (***)	1.7 (***)	1.5 (***)

Source: DAMVAD Analytics 2017
Note: *** p<0,01 ** p<0,05 * p<0,1

5 years after the collaborative relationship was initiated, it is still possible to measure a statistically and economically significant employment effect of 9 pct. – which is almost twice as much as the isolated effect of a time-limited collaboration. The fact that many R&D collaborations between NTNU and private businesses is characterized by repeated collaborations over time thus contributes to a lasting positive job effect that is increasing over time. Around one third of the companies collaborating with NTNU are only collaborating with NTNU once, this contributes to explain the lower and less significant effect for companies with only one collaboration.

Collaborations with NTNU increase business investments

The positive effect on the company's economic performance engaging in an R&D collaboration with NTNU is also seen when looking at the company's investments.

Figure 3.3 shows the accumulated investment effect (model 1 and 2) on NTNU's business partners compared to the control group (dotted line) over time. A company's investments are measured as growth in fixed assets e.g. buildings, machinery but also patents, licenses etc.

There is a significant positive effect on business investments from initiating a collaboration relation with NTNU on research and development. The impact can be measured already in the first year of collaboration (year 0) and has a rising – although somewhat unstable – trend until year 5 after the collaboration was initiated. NTNU's collaboration partners have thus experienced an additional growth in investment since the year before the collaboration was initiated to 3 years after that is 28.8 pct. points above the investment growth of the control group.

The average annual impact on business investments is rising over the whole period from 5.5 pct. (year 0) to 11.1 pct. (year 5), cf. table 3.3.

TABLE 3.3
Average additional annual growth in business investment

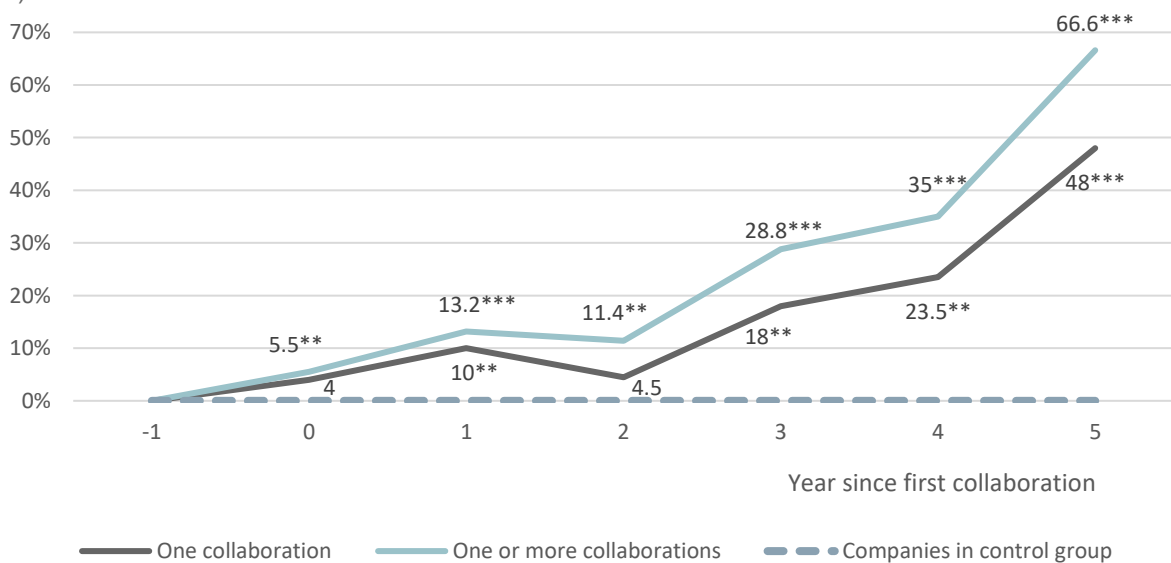
Years since first year of collaboration	0	1	2	3	4	5
One collaboration	4.0	5.0 (**)	1.5	4.5 (**)	4.7 (**)	8.0 (***)
One or more collaborations	5.5 (**)	6.6 (***)	3.8 (**)	7.2 (***)	7.0 (***)	11.1 (***)

Source: DAMVAD Analytics 2017
Note: *** p<0,01 ** p<0,05 * p<0,1

Again, the overall effect of initiating a collaboration relation with NTNU – irrespective of whether the relationship is limited in time or covers multiple collaborations over time (one or more collaborations) – is slightly higher and more significant than the isolated effect of a time-limited collaboration (one collaboration). The average annual investment effect is around 3 pct. points higher three years after the first collaboration relationship. 3 years after the first collaboration relationship was established, NTNU's business partners have invested 18-28.8 pct. more in fixed assets such as machinery and buildings than comparable companies that have not chosen to collaborate with NTNU on R&D projects.

FIGURE 3.3

Estimated impact on business investment for companies collaborating with NTNU compared to control group (pct.)



Source: DAMVAD Analytics 2017

Note: *** p<0,01 ** p<0,05 * p<0,1

3.3 Collaboration modes

In this section, we investigate whether collaborative relationships on R&D projects that involve certain collaboration modes or certain project amounts per partner contribute more to the companies' economic performance than others.

3.3.1 Collaboration modes

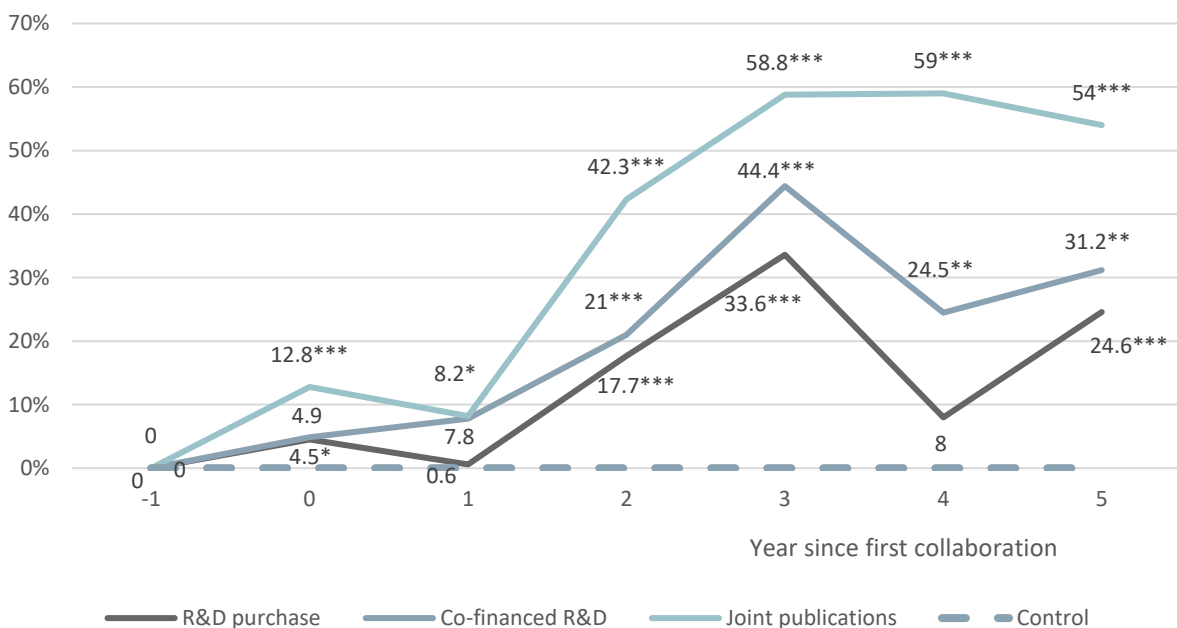
In order to analyse the effect of various collaboration modes, we estimate a model that measures the isolated effect of the first year involving at least one collaboration of the type:

- R&D purchase
- Co-financed R&D
- Publicly financed R&D programmes
- Joint publications

In other words, we control for potential repeated collaborations over time, although there might be more than one collaboration in the first collaboration year.

The analysis points to positive and statistically significant revenue effects over the period for all collaboration modes except the publicly financed R&D programmes cf. figure 3.4 that shows the accumulated revenue effect for various collaboration modes over time, and table 3.4 that shows the average annual effects.

FIGURE 3.4
Estimated impact on revenue for different collaboration modes compared to control group (pct.)



Source: DAMVAD Analytics 2017

Note: For significance levels, see table 3.3. "Public R&D programmes" is not shown since it is unstable over time and insignificant.

TABLE 3.4

Average additional annual growth in revenue for various collaboration modes

Years since first year of collaboration	0	1	2	3	4	5
R&D purchase	4.5 (*)	0.3	5.9 (***)	8.4 (***)	1.6	4.1 (***)
Co-financed R&D	4.9	3.9	7.0 (***)	11.1 (***)	4.9 (**)	5.2 (**)
Public R&D programmes	0.2	3.1	3.2	2.2	-0.8	3.1
Joint publications	12.8 (***)	4.1 (*)	14.1 (***)	14.7 (***)	11.8 (***)	9.0 (***)

Source: DAMVAD Analytics 2017

Note: *** p<0,01 ** p<0,05 * p<0,1

They also reveal however, that the results are somewhat unstable both across collaboration mode, time and in terms of statistical significance (see table 3.4.). This relates to the lower number of collaborations when collaboration types are analysed separately rather than jointly cf. table 2.1 in chapter 2. These latter estimated effects should thus be viewed with great caution.

Apart from public R&D programmes, all collaboration types appear to have a similar effect on revenue over time.

The joint-publications differ slightly from the others, in that they have a rather high estimated revenue effect of 12.8 pct. already in the year that the collaboration was initiated. This could relate to the fact, that there is somewhat higher uncertainty about the actual starting date for joint publications as previously mentioned. In addition, however the estimated revenue effect of R&D collaborations on joint publications tends to remain at a level slightly higher than the other collaboration modes throughout the period. In this connection, it is important to mention, that co-publications also differ from the other collaboration modes in that they might be a result of other

types of collaborations. A co-financed or publicly financed R&D project might, for example, generate new theoretical or empirical knowledge within a certain research area. As such, the co-publication could thus be seen as a quality indicator for other collaboration types: projects that have resulted in cutting edge knowledge in an international context, generally lead to larger positive revenue effects for the participating companies than other projects.

It has also been analysed whether there are different employment effects across various collaboration modes. Due to the lower estimated employment effects most estimates are however statistically insignificant, given the lower number of collaborations in each group. Again, the joint-publications differ from the others, in that they have a significant positive employment effect.

4 Data and methods

4.1 Data

The analysis is based on a unique integrated dataset on NTNU's R&D collaborations with private Norwegian and foreign companies.

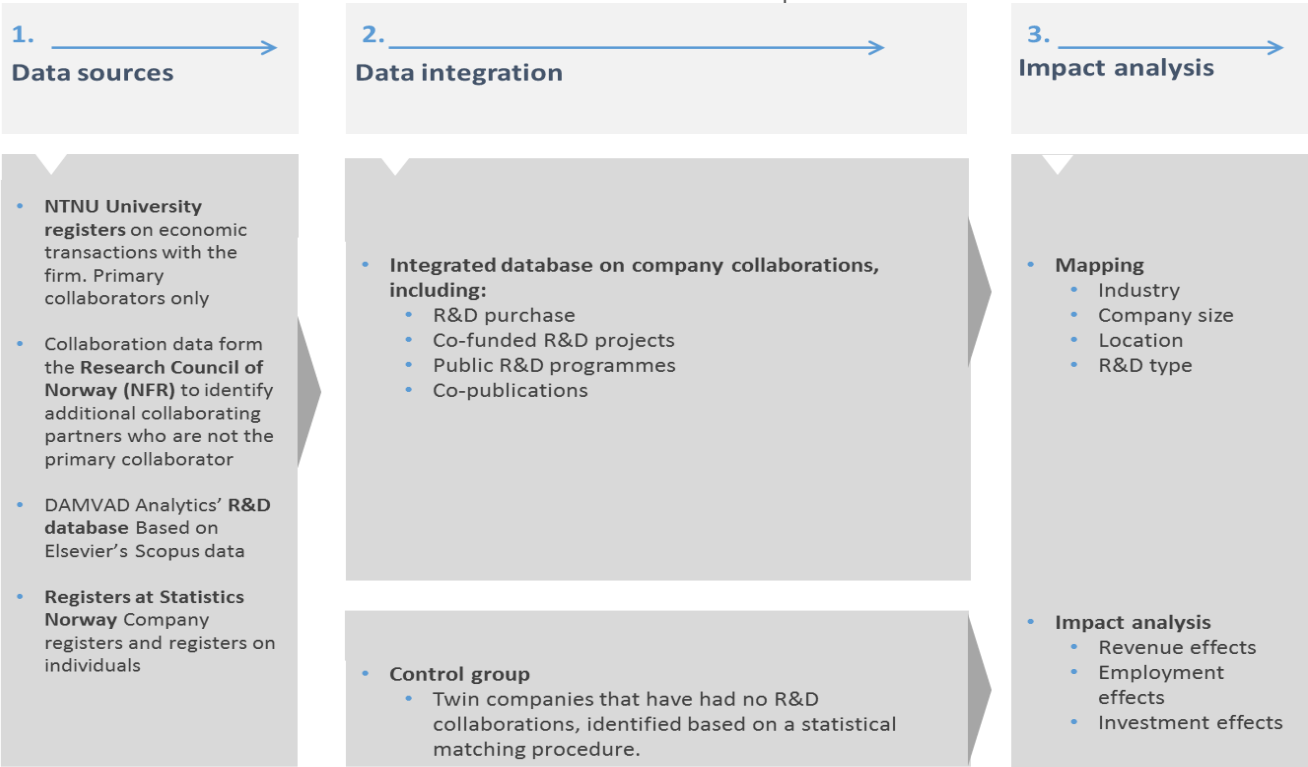
The data is constructed from four primary data sources, from which information about research collaborations with Norwegian and foreign companies over time can be extracted including the R&D collaborations' characteristic and detailed information about each individual Norwegian collaboration partner, cf. figure 4.1.

The data preparation and integration process is described further in the following sections.

4.1.1 NTNU's financial accounts

Based on the financial accounts of NTNU, it is possible to extract information about R&D purchases, co-financed R&D projects and publicly financed R&D projects with private companies. Based on current and historical data, we identify actual R&D collaborations with Norwegian and foreign companies. Information about the collaboration partner, collaboration type and financial contribution is generated based on NTNU's accounting codes.

FIGURE 4.1
Establishment of database on NTNU's research collaborations with private businesses



Source: DAMVAD Analytics 2017.

It should be noted that budgetary data is excluded from the analysis due to the discrepancies in the methodology employed in registering budgets. Some budgets reflect an expected cost, while other reflect an actual cost. This gives rise to negative or zero budgets for several projects, making the exact budget amount uncertain. These figures are reported for positive amounts above 10.000 NOK in the descriptive chapter, however, the budgetary size is excluded from the impact analysis.

Furthermore, some projects are classified as subprojects of other projects, leading to accounting inconsistencies in terms of whether the total cost of the project is filed among subprojects, or totalled in the main project. This is also a source of zero budgets in many projects. Due to uncertainties surrounding precise identification of subprojects and their parent project, further assumptions on project type and group are likely to introduce errors into the data. It is thus assumed that number of projects is an accurate portrayal of the extent of collaboration, regardless of whether the project is classified as a subproject or a main project.

NTNU's financial accounts cover collaborations initiated from 2005 until present, including some future projects. The end date spans from 2005-2025, with some projects missing expected termination date. The analysis, however, only considers collaborations initiated in the period 2005-2014, with the resulting dataset covering all information on R&D purchases, co-financed R&D projects and public R&D projects.

4.1.2 DAMVAD Analytics' Research Database

Information about joint publications between NTNU and private businesses has been established based on DAMVAD Analytics' research database.

The database is based on the international Elsevier's Scopus database, which, as the largest abstract and citation database of peer reviewed scientific publications contains more than 20,800 peer reviewed journals, 54 million publications and 6,4 million conference articles. All publications authored by one or more researchers at NTNU or one of its predecessors has been extracted. Subsequently relevant Norwegian and foreign business partners and their VAT-numbers are identified using intelligent text analysis tools cf. the information box above, supplemented with manual quality assurance.

The identified publications are subsequently used as an indicator of whether there has been a joint publication collaboration between NTNU and a private company. To indicate the starting year of the co-publication collaboration between the company and NTNU, the publication year of the corresponding journal is used as a starting point. The R&D collaboration that forms the basis of the joint publication will however have been initiated at some unknown point prior to this publication year. The time lag between the initiation of a joint publication collaboration and the resulting publication will cover both the research process and the subsequent peer review period. In the impact study we therefore assume, that on average R&D collaborations on joint publications have been initiated two years prior to the publication year.

No information exists on the use of resources (the company's own financial contribution, NTNU's financial contribution or potential public financial contributions) in the process leading up to a co-publication. The financial size is thus unknown for all joint publication collaborations.

In this regard, it is important to note, that co-publications might also be the result of other types of col-

laboration forms, e.g. if a publicly financed or co-financed R&D collaboration leads to new empirical or theoretical knowledge within a research area that is subsequently published. This might in certain cases lead to double counting of research collaborations. Moreover, co-publication collaborations can have an alternative interpretation as a quality indicator for the remaining collaboration types.

4.1.3 Statistics Norway (SSB)'s registers

DAMVAD Analytics has specifically been granted access to micro data from Statistics Norway containing detailed information about all companies in Norway⁶.

Based on various Norwegian registers covering 2002-2014, DAMVAD Analytics has access to information about the economic sectors that NTNU's business partners are operating within, their geographic location, and their economic development over time. Moreover, DAMVAD Analytics has access to the education levels of employees, which are used to map knowledge-intensity of collaborating firms. While this data is obtained from individual-level data, aggregated at the firm-level, the economic variables on the firm-level are obtained separately from selected industries. There is thus a discrepancy in sources among industries, as well as education-level data, leading a number of firms with partial or incomplete data. For many firms this will disqualify them from analysis, for which reason the number of firms in the descriptive statistics differs from the amount included in the impact analysis. However, for firms with missing data only for some years, linear extrapolation can keep firms in the analysis, without introducing bias. This is only done for the share of employees within each education

level, as this is a relatively constant indicator, merely used to identify similar firms. Lastly, unique business ID's are used to connect this register data to the collaboration data obtained by the university.

While the descriptive statistics on the *number of collaborations and their characteristics* are based on collaborations with both Norwegian and foreign companies during the period 2005-2015, the descriptive statistics concerning *NTNU's collaboration partners as well as the impact study* are restricted to R&D collaborations with Norwegian companies in the period 2005-2014. This is due to unavailability of foreign company data in Norwegian registers and not yet published data for 2015.

4.2 Method

The impact study aims at investigating whether there is evidence for a *causal relationship* between the companies' R&D collaborations with NTNU and their economic performance, i.e. whether the company experiences a positive economic development *due to* their collaboration with NTNU.

4.2.1 Matching

To obtain the most accurate estimate of this effect, it is necessary to establish a control group as a credible basis for comparison.

For this purpose, we use a statistical matching method called *Coarsened Exact Matching*. Exact matching is preferred over the often used *Propensity Score Matching*, which was generally considered best practice few years ago, as it has a number of statistical advantages, that inter alia ensures that

⁶ We would like to acknowledge the Department of Industrial Economics and Technology Management at NTNU who has applied for access to data and facilitated the implementation of the data analysis.

companies are not compared on the basis of an average of their characteristics⁷.

Specifically, companies are matched on the following characteristics in the year prior to the collaboration year (t-1) that are expected to have an impact on the company and its future economic performance⁸:

- *Company size*, measured on number of employees⁹
- *Exports*, i.e. whether the company is an exporting company or not.
- *Capital intensity*. The amount of capital available to employees, measured as total fixed assets per employee.
- *Education level*, measured as the share of employees with at least the lowest level of tertiary education.
- *2-year real revenue growth* in the preceding years.
- *Statistical classification of economic activity*, at division level based on NACE rev. 2.
- *Timing*, i.e. the year prior to the first collaboration year.

The match on sector classification, export and year is exact, which implies that a company within the sector trade never will occur in the composite control group for a company in the sector research and development. Similarly, the development in a company that has e.g. initiated a collaboration with NTNU in 2007 will never be compared with the development in a company from 2003 – even if these two companies are similar on all other parameters

in the years concerned. This ensures that companies operating under fundamentally different conditions cannot be compared.

Lastly, it is ensured that companies, which at any point in time over the period 2002-2014 have collaborated with NTNU are never included in the control group. Thus, a company that has collaborated with an NTNU predecessor in 2003 will never appear as a control for another company with a research collaboration in 2004.

The method also implies that observations in the treatment and control group, for which no reasonable match can be found, are excluded from the analysis. Approximately 362 treated companies and 128.000 control companies are included in the data set after matching.

4.2.2 Handling of extreme observations

The presence of extreme observations can distort the effects and reduce the precision of the impact analysis. Data can contain extreme values because of typos or other factors like mergers or break ups of companies. Such changes can have a disproportionate effect on the results.

To remedy such problems, extreme observations are identified and handled as follows:

- First, the study follows a method applied by Hall and Mairesse (1995), DAMVAD 2012a and DAMVAD 2012b¹⁰ removing all observation for companies, that in any two subsequent years

⁷ Lacus, Stefano M., Gary King, and Giuseppe Porro. 2011. Multivariate matching methods that are Monotonic Imbalance Bounding. Journal of the American Statistical Association.

⁸ All values are calculated in 2014 prices.

⁹ Full time employees is a commonly used alternative, to account for part-time employees. The variable received from Statistics Norway (SSB) is inconsistent and incomplete across data sources, for which reason number of employees is used. Given that matching also accounts for economic

sector, any bias generated by certain sectors employing more part-time employees is accounted for.

¹⁰ Mairesse, Jacques og Hall, Bronwyn Hughes, (1995), " Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms.," DAMVAD 2012: "Measuring the Economic Effects of Companies Collaborating with the University of Copenhagen", DAMVAD 2012: "DTU's værdiskabelse for Samfundet".

have experience extreme growth rates on the dependent variable in question. Specifically, companies that have experienced more than a 300 pct. growth or a 100 pct. fall in annual revenues or experience a doubling or a cut in the number of employees by half.

- Companies that in at least one period have negative revenues or employment are excluded.
- Companies belonging to the economic sector mining and quarrying are excluded from the analysis. This sector differs quite fundamentally from other economic sectors due to very large capital stocks and corresponding effects on company performance. Excluding this economic sector thus reduces the risk of extreme observations distorting the analysis.
- To further minimize potential effects of extreme observations the analysis follows Mairesse (1995), DAMVAD 2012a and DAMVAD 2012b¹¹ in removing the top and bottom 5 percent of the observations in the treatment and control group respectively (on annual basis).

There exists no unanimously accepted method for handling extreme observations or the employed economic thresholds, even if these might substantially influence the quality of the analysis and its results. Among others, it is an open question what should be characterized as extreme annual or multiannual growth rates from an economic point of view. For this reason, extensive robustness checks of the selected outlier procedure have been carried out in order to ensure that the obtained results do not change significantly with different performance criteria.

4.2.3 Models and estimation

Based on the composite control group it is possible to estimate the economic effects on company performance using difference-in-differences estimation. Difference-in-differences is basically based on a comparison of changes in economic performance over time. In this analysis, it is employment and revenues for companies that engage in R&D collaborations with NTNU (treatment companies) compared to companies that do not engage in R&D collaborations with NTNU (the control group). The basic principle can be written as follows:

$$\delta = Y_{t+n}^T - Y_{t-1}^T - (Y_{t+n}^C - Y_{t-1}^C)$$

Where δ is the effect, calculated as the difference between the development in the dependent variable for the treatment group (T) and the control group (C). The development in the dependent variable (Y) is measured as the growth rates from the year prior to the collaboration year (t-1) and up to 5 years after the collaboration (t+n). Since R&D collaborations might be initiated at any point during an accounting year, i.e. no account is taken of whether the collaboration was initiated in the beginning or end of the year in question, the year before the collaboration was initiated is used as base year.

Whether there is a significant difference between the two groups is tested using an OLS regression. Specifically, three different models are estimated:

- *Model 1:* Effect of the first collaboration year without controlling for possible subsequent collaboration years. Measures the effect of initiating a collaboration relation with NTNU, irrespective of whether the company engages in further collaborations at a later point in time.

¹¹ Mairesse, Jacques og Hall, Bronwyn Hughes, (1995), "Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms,," DAMVAD 2012: "Measuring the Economic Effects of Companies

Collaborating with the University of Copenhagen", DAMVAD 2012: "DTU's værdiskabelse for Samfundet".

- *Model 2*: Effect of the first collaboration year controlling for potential subsequent collaboration years. Measures the isolated effect of the first collaboration year so that potential lagged effects of later R&D collaborations are accounted for.
- *Model 2a*: Effect of the first collaboration year involving at least one collaboration of the type R&D purchase, co-financed R&D, public R&D programmes or co-publications. The model controls for subsequent collaboration years, i.e. it measures the isolated effect of the first collaboration year with the collaboration type in question.

analysis, however, it is possible to obtain a solid approximation. Therefore, it is possible to interpret the estimated effects as causal effects of engaging in R&D collaborations with NTNU on the companies' economic performance.

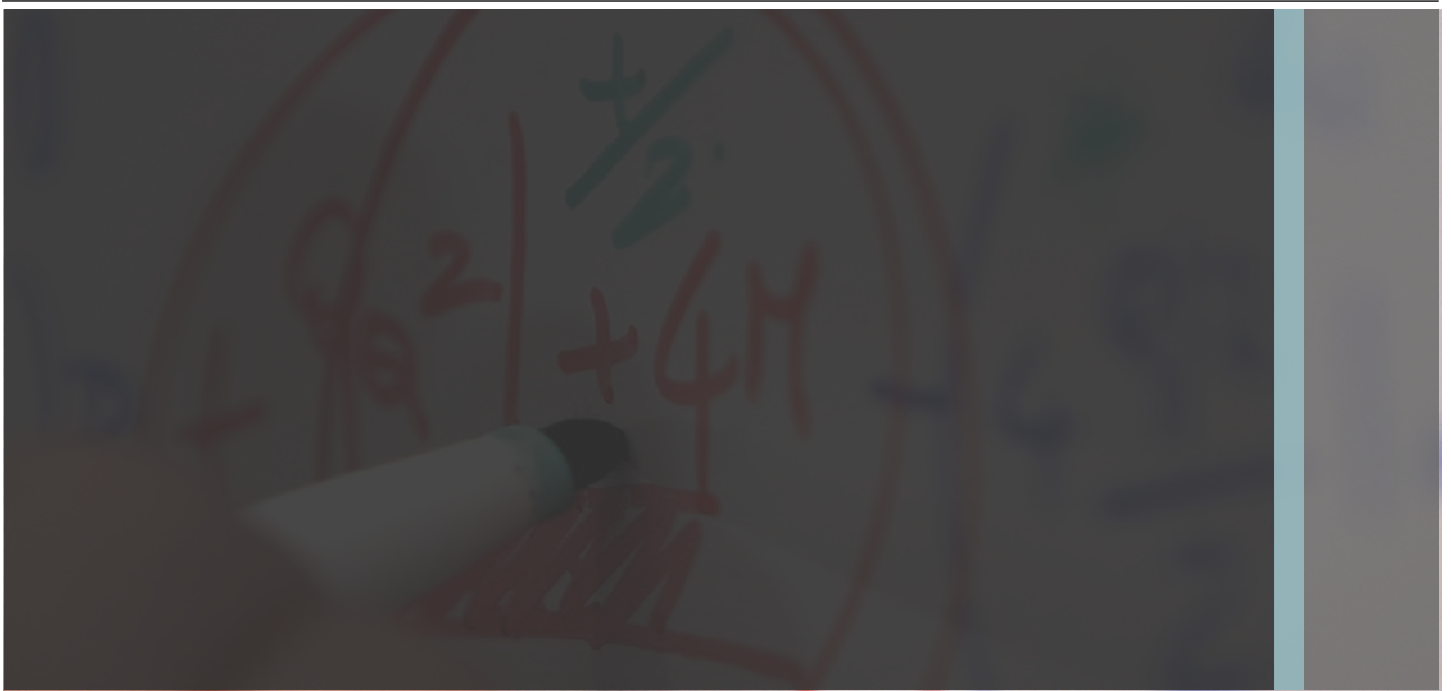
In addition, all models include the same covariates as the matching procedure, where relevant with increased level of detail¹².

Overall, the employed method aims to isolate the development in company performance that can be directly ascribed to the company's R&D collaboration with NTNU. For this reason, as many potentially relevant explanatory variables as possible have been employed in the establishment of the control group and regression models. Certain factors that influence company performance over time are however not directly observable. This would cover factors that do not affect company size, employee composition, capital intensity, degree of internationalization etc. leading up to the collaboration with NTNU, but has systematic consequences for company performance across the treatment- and control groups.

It will never be possible to identify a completely identical control group or account for all potentially relevant parameters. Based on the employed statistical models and a rich data set serving as basis for the

¹² Compared to the matching model, the following adjustments are made: the natural logarithm of the number of employees and capital intensity in

fixed 2015-prices, export intensity – a more nuanced measure of company participation on export markets



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