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THE CONCEPT OF INNOVATIVE CAPACITY AND ITS IMPACT ON INNOVATION OUTCOMES

ILLUSTRATED BY THE EXAMPLE OF THE GERMAN AEROSPACE INDUSTRY

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ABSTRACT

This paper investigates the impact of innovative capacity on innovation related outcomes, such as publications, patents, process and product innovations as well as technology readiness levels (TRL). Innovative capacity is derived from three indicators, namely human capital, relational capital and structural capital. For our estimation model, we use a unique dataset on innovative capacity and innovation activities by companies of the German aerospace sector. We find that the concept of innovative capacity has a strong impact on the analysed innovation dimensions. It can explain innovation outcomes in early stages by using patents and publications as innovations related outcomes. We find the strongest explanatory power of the model when we look at the impact of innovation capacity on product innovations. We also find some evidence by investigating the impact of innovative capacity on process innovations. This is different for the changes in TRL. Here we do not find any significance that innovative capacity influences the speed of technology development. However, the overall findings are promising: Innovative capacity is a relevant concept explaining innovation outcomes of firms within high-tech sectors, like the aerospace industry in Germany. A second basic result of our analysis is that self-reports by experts, who are in charge with innovation processes, deliver – at least to some extend – reliable data. For this reason, we are able to confirm statistically our theoretical assumptions, that innovative capacity is relevant for innovation outcome.

1. INTRODUCTION

Even though innovation is hard to measure, there is a general agreement that the capability to innovate and to bring innovation to market successfully is a crucial determinant of competitiveness at the firm level, at industry level and at the national level. Therefore, innovation is essential for growth in employment, production and welfare. Besides the general economic importance, innovation helps to address global challenges, such as climate change and sustainable development.[1]

Given all these positive effects, innovation became a central target of policymakers. Many countries implemented national strategies to promote innovation and enhance its economic impact. Moreover, in 2000 the EU created the Lisbon Agenda to make Europe the most competitive and the most dynamic knowledge-based economy in the world. However, after nearly twenty years of innovation policy it has become obvious, that there is no simple switch that policy can turn to push innovations. Actually, the success of innovation policy has been quite different across countries, regions and time and it is difficult to identify individual factors for success or failure. What is clear is that there is no single policy method to promote innovation, but rather a mix of policies. Among them, the accumulation of human capital in schools and universities, basic research, public infrastructure and private research activity play a very important role. To support innovation, policy must improve the regulatory and institutional framework for innovative activities. In addition, public investment in science and basic research is needed to develop general-purpose knowledge and technologies that build the foundation for further applied research and innovations. Finally, in particular to create employment and growth effects, it is necessary that basic research is transferred into industrial applications (OECD 2007). To some extent the transfer is in the interest of individual firms and therefore takes place without public support. However, as research and innovation activities often have positive externalities, there are good reasons for giving public support to private innovation activity. Here, a mix of direct and indirect instruments such as tax credits, direct support and designed public private partnerships might be appropriate (cf. Aghion et al. 2009: 681).

The speed of transfer from new ideas to innovative products, services and production processes differs between industries and firms of different size. In general, high-tech industries and larger firms manage the transfer more quickly than smaller firms and low-tech industries (Baesu et al. 2015). One reason is that they are more used to innovation, i.e. they have internal research capacities and they are better integrated in research networks. The concept of innovative capability was therefore recognised as the explanation of innovations success (Cohen and Levinthal, 1990). The concept is especially important when it comes to an evaluation of publicly funded R&D programmes. Absorptive capacity is one of the most important aspects of the innovative capability of a company or organisation in general. Cohen and Levinthal describe absorp-

1 For a general discussion see OECD (2011) and Álvarez-Herránz et al (2017) for recent empirical investigation.

tion capacity as the "ability to recognize the value of new information, assimilate it, and apply it to commercial ends (op. cit., p. 128)". From this perspective, absorption capacity refers to the general ability of an organisation to recognise external information and opportunities (e.g. new technologies, new organisational forms) and to use them for their own (innovation) purposes.

The significance of innovation as a source of growth and welfare contrasts with the lucidity and measurability of innovation. In particular, there is neither one single generally accepted definition of innovation (cf. Baregheh et al. 2009: 1324; Gault 2018: 617ff.) nor an accepted way to measure innovation activity. Paul Krugman (1991a, p. 53) has surrendered the possibility of directly measuring innovative activity because, "knowledge flows are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes."

In summary, neither the input of innovation activity nor the innovation output is precisely measurable. Consequently, a wide number of diverse indicators is used to approximate the input or the output in the process and to show how innovative an organisation is or how many innovations are established by an organisation. On the output side, the most commonly used indicators are the number of patents and publications. While counting these numbers gives a quantitative impression of innovation activity, the numbers clearly fail to measure the qualitative importance of innovations.

The input side of innovation is even more difficult to measure (cf. Carayannis & Provance 2008: 94f.). Hence, different approaches have been used for measuring innovative capacity. Ter Haar (2018) composed a meta-analysis by scrutinising the wide range of various concepts for measuring innovation. While there are also qualitative approaches of measuring the ability to create innovations, most of them aim at a quantification (cf. Ter Haar 2018: 413f.). Furthermore, approaches and indices differ in the addressed level. Some concepts focus on the country-level, while most of them concentrate on the company-level, for example Goffin and Mitchell (2010) or Tidd and Bessant (2014). Other approaches use the team- or employee-level as their basis. Based on the various theoretical frameworks, the methods use a variety of different indicators (cf. Ter Haar 2018: 414ff.).

This paper contributes to the understanding of effectiveness of public technology programmes by analysing the German Aeronautic Programme (LuFo), that supports research and innovation in the German civil aviation industry. Our unique dataset gives a detailed description of all LuFo-funded projects in industrial firms, research institutes and universities. For the innovation output we can use different indicators such as patents, publications, dissertations, product and process innovations or technology readiness levels (TRL)[2]. As indicators for innovation input, we can use the R&D spending and public funds. In addition, we have information of the type of institution and its size.

For the use of Technology Readiness Levels for impact assessments see Kerlen and Hartmann (2014).

Most importantly, we also have a variety of indicators for the innovative capacity at the beginning of the project. Therefore, we can test the importance of innovative capacity for the success of the innovation process.

The paper is structured in the following way. First, we introduce the German LuFo programme, which is the source of our data set. Then, we explain the concept of innovative capacity in more detail. Sections 4 introduces the dataset and first statistical results. Section 5 presents the results of our estimations and testing. In section 6 we shortly summarise our main findings.

2. THE AERONAUTIC R&D PROGRAMME OF THE GERMAN GOVERNMENT

The Federal Government's aviation research programme aims to support Germany as a high-tech location and to contribute to the competitiveness of the domestic aviation industry. It further contributes to achieve the "Strategic Research and Innovation Agenda" (SRIA) of the "Advisory Council for Aviation Research and Innovation in Europe" (ACARE 2018) of the EU Commission. The following five central "Challenges" are relevant in this context: (1) Addressing social and economic needs, (2) Maintaining and expanding industrial technology leadership, (3) Protecting the environment and energy supply, (4) Ensuring safety, and (5) Prioritising research, test environments and education systems. The SRIA environmental targets (ACARE 2018) have a cross-sectional impact on technology development and aim at reducing fuel consumption and emissions.

Building on these overarching objectives, the LuFo funding programme focuses specifically on the innovation system and current developments in Germany. Aircrafts are highly complex and elaborated technology systems. Major characteristics are remarkably long research, development and product cycles: the transfer of technologies to market maturity is time intensive and needs careful preparation in form of certification. This makes it common that results from current publicly funded research projects enter with a time lag of 10 to 20 years into newly developed aircrafts. The concept of innovative capacity is therefore highly relevant as it can be assessed earlier than other intended effects of the funding as e.g. new aircraft or components being introduced into the market.

Another goal of aviation research is to maintain and expand the technological core capabilities required to develop products and services for aircraft. The broadening and deepening of the competences of employees working in the industry and a further strengthening of the research infrastructure are further goals pursued by LuFo.

The overall economic objective of LuFo is to preserve and sustainably expand jobs in Germany along the entire value chain of the aviation industry, from research, development and production to maintenance and overall (MRO) services. In order to strengthen the competitiveness of companies, value-added activities as well as technological approaches to increasing productivity are supported. A current focus is the digitisation of aviation-specific manufacturing processes and products (under the keyword Industry 4.0). Artificial intelligence (AI) has been added as a new focus in LuFo VI. The objectives of the German LuFo programme are

2 For the use of Technology Readiness Levels for impact assessments see Kerlen and Hartmann (2014).

coherent with the European "Flightpath 2050" (European Commission 2011) strategy.

Aviation is more and more oriented towards social needs and requirements (including a reduction in noise and harmful gas emissions and an increase in flight safety). This is in line with international targets by the International Civil Aviation, which defined the so called (ICAO 2018) standards. New technologies are one key element to address the relevant environmental and sustainability targets. This has brought the German Ministry of Economic Affairs and Energy to implement the new funding line "Electric and Hybrid Flying".

In order to strengthen Germany's international position as a relevant aviation industry actor, an additional aim of LuFo is to support diversification of the supply industry. For this reason, there is a separate funding line directly focusing on small and medium-sized companies (SMEs). A further objective is to reduce the shortage of skilled workers and to support the development of skills, by supporting cooperative projects of industry and research institutions. Research institutions are approached individually in a funding line "eco-efficient flying", which has recently been expanded in LuFo VI to include the topic of "disruptive innovation".

3. THE CONCEPT OF INNOVATIVE CAPACITY AND HYPOTHESES

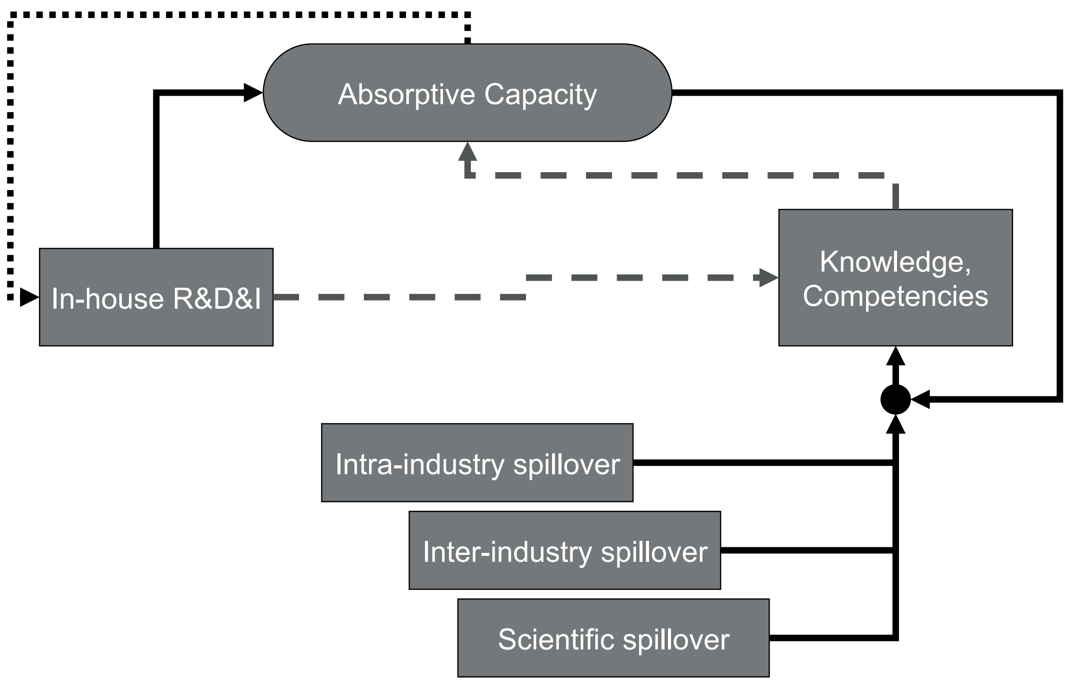
As pointed out earlier, the most important aspect of the innovative capacity of an organisation is its absorptive capacity, referring to its general ability to recognise external information and opportunities (e.g. new technologies, new organisational forms) and to use them for its own innovation purposes.

Figure 1 shows the interdependencies between absorptive capacity, external knowledge, own research, development and innovation (R&D&I) with regard to the organisation and the knowledge and competences within the organisation. Absorptive capacity is essential, as it determines the extent to which external information enhances firm specific R&D activities. Different dimensions of knowledge flows can be distinguished: the dimension of the own industry (intra-industry spill-over), other industries (inter-industry spill-over) and the science system (science spill-over).

Absorptive capacity itself is in turn determined by relevant knowledge and competences in the organisation. This not only refers to specialized gatekeepers who observe external developments, but ultimately to all employees who are affected by innovation: "Even when a gatekeeper is important, his or her individual absorptive capacity does not constitute the absorptive capacity of his or her unit within the firm. The ease or difficulty of the internal communication process and, in turn, the level of organizational absorptive capacity are not only a function of the gatekeeper's capabilities, but also of the expertise of those individuals to whom the gatekeeper is transmitting the information. Therefore, relying on a small set of technological gatekeepers may not be sufficient; the group as a whole must have some level of relevant background knowledge, and when knowledge structures are highly differentiated, the requisite level of background may be rather high" (Cohen und Levinthal 1990).

Public funding therefore aims at improving individual as well as organisational learning to enhance the innovative capacity as a core prerequisite for actual innovation of an organisation. Within research programmes individual learning is targeted by giving opportunities for academic research (e.g. in forms of dissertations) or by changing informal learning conditions, e.g. by introducing new, more intellectually

Figure 1: Absorption capacity and its relationship to knowledge and competences (modified from Cohen und Levinthal 1990, p. 141, taking into account enlargement proposals by Zahra und George 2002 and Schmidt 2005).



demanding tasks and operating procedures, or new organisational structures and processes. Public funding also aims at influencing organisational learning directly: Organisational learning can be conceptualised as building up on the organisation's intellectual capital which encompasses the three dimensions of human capital, structural capital, and relational capital (e.g. Kerlen and Hartmann (2014); Globisch et al. (2011); Alwert (2006)).

1. **Human capital:** this refers to the knowledge, skills, competences, motivation and attitudes of the employees of a company and determines the extent to which important external developments in science and industry are perceived and how these developments then flow into business processes. The company's own R&D also requires corresponding competencies, not only in the R&D departments, but ultimately (almost) throughout the entire company.
2. **Structural capital:** this refers to structures (e.g. organisational structure, but also technical infrastructures) and processes (e.g. work and communication processes) that influence the innovation capability of the company. Questions such as these arise here: How is research and development organised within the company? How does R&D interact with other departments, how is it communicated across departments? How learning and innovation-oriented is the corporate culture? How learning intensive are the working conditions for individual employees resulting from the company organisation?
3. **Relational capital:** This includes relationships with external partners in business, science, education, politics and administration. Especially important are relationships along the value chain, in one's own industry, with research institutions and training providers. These relationships serve to obtain information that is relevant in the innovation context (e.g. new technologies, new business models), to carry out R&D projects jointly with external partners and not least to develop other aspects of innovative capacity (e.g. development of human capital through cooperation with education providers).

In the context of publicly funded innovation processes, the concept of innovation capacity is very helpful to address outcomes of R&D programmes in early stages. During the funding period (in general three years) the exploitation of R&D results as innovation can hardly be observed especially in high-tech-sectors like the aerospace industry, due to long research and development cycles. Different to this, innovative capacity in the dimensions of human, structural and relational capital can be perceived before the R&D results are commercially exploited and, therefore, can be part of an impact assessment.

If this is true, we should be able to measure the impact of innovative capacity on innovation related outcomes. This would demonstrate that the concept is indeed suitable to assess the achievement of the programme's objectives at an earlier stage. Based on the theory presented above, we define the following hypotheses for our econometric approach, in order to test the impact of innovation capacity on innovation. As proxys for innovation we use different indicators like scientific publications, patents, training of PhD students, product innovation, process innovation and technology readiness levels. Following this reasoning, to test our overall hypotheses that innovative capacity has an important impact on innovation, we proceed by defining the following five specific hypotheses.

- H1: High innovative capacity at the beginning of the project leads to a high number of publications.
- H2: High innovative capacity at the beginning of the project leads to a high number of patents.
- H3: High innovative capacity at the beginning of the project has a positive effect on the training of PhD students.
- H4a: High innovative capacity at the beginning of the project favours product innovation.
- H4b: High innovative capacity at the beginning of the project favours process innovations.
- H5: High innovative capacity positively influences the speed of technology development (TRL jumps).

We test these hypotheses using data collected for an impact assessment of the German Aeronautic R&D programme (Wangler et al. 2019).

4. DESCRIPTIVE STATISTICS

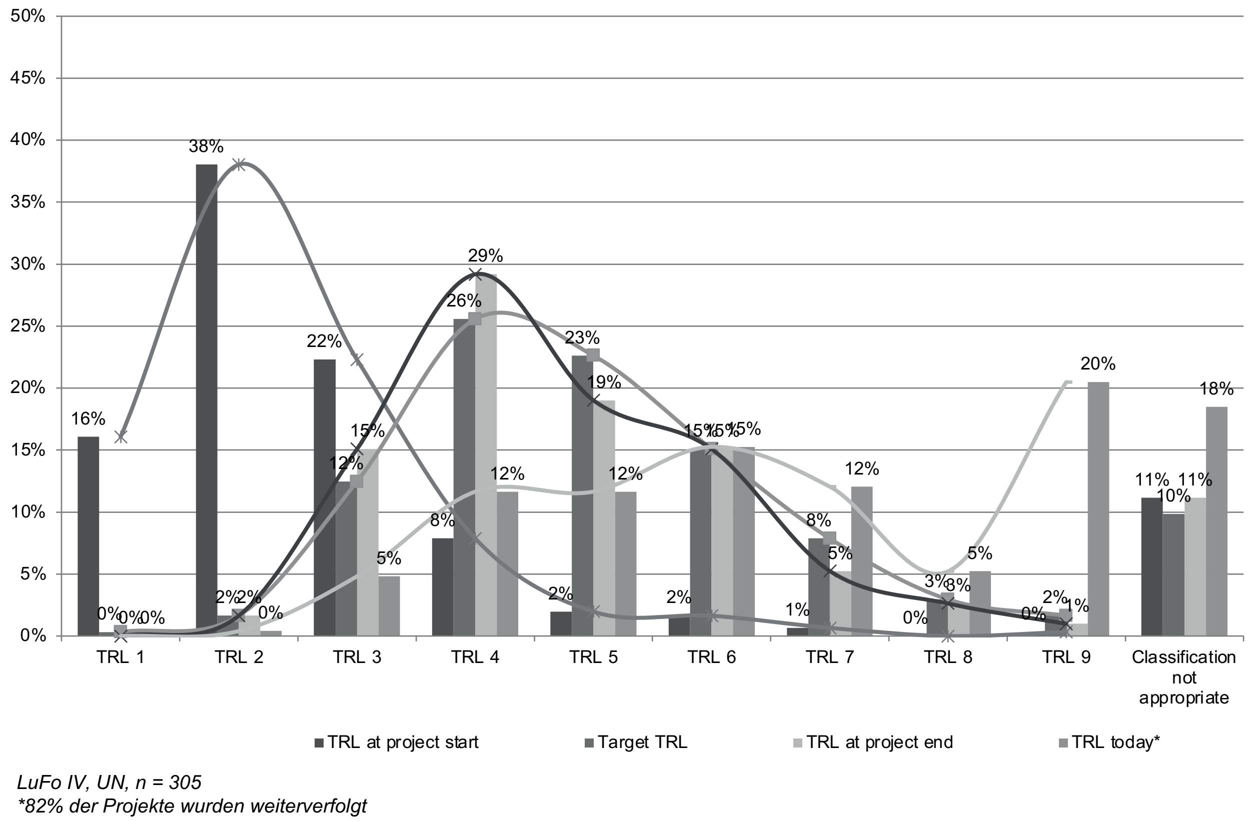
For our empirical investigation we use a unique dataset on the German civil aviation industry. It contains data from two different sources: the input-data (funding dataset) and the survey data based on an online-questionnaire gathering information on firms participating in the LuFo programme. The dataset is representative in that it encompasses information on all main industry actors, including original equipment manufacturers (OEMs) and main suppliers (Tier I to Tier n) along the whole value chain. In addition, university and research institutes are covered. Overall, the dataset consists of 2097 projects that received publicly funded supported for R&D. However, the dataset has missing variables and shrinks, depending on the variables integrated into the econometric model. This leads to much lower N's when estimating our econometric models.

The following results summarise some major statistical outcomes from Wangler et al. (2019). With regard to the overall spending on R&D projects, between 2007 and 2018 a budget of 3246 Mio. Euro has been realised. With 1781 Mio. Euro the share of public funding was about 52 percent. The remainder of 1464 Mio. Euro was contributed by the participating companies. Most of the projects have been cooperative projects, with three or four partners. Almost half of the projects are carried out by large companies, about a third by research organisations and about 16 percent by small and medium-sized enterprises.

Within the publicly funded projects, technologies are being advanced along several TRL. Figure 2 shows that most projects start at TRL 2 – technology concept and/or application formulated – (TRL at the start) and advance two technology stages (TRL at the end of the project) on average. The flattening of the curves illustrates that within some projects higher TRL are targeted and achieved. Curves for target TRL and TRL at the project's end are very close to each other: 75 percent of the projects are able to realise the targeted technology readiness level, 21 percent reach only a lower level (without own illustration). 20 percent of the technologies developed are marketable at the time of the survey: they reached TRL 9 – actual system proven through successful mission operations – at the time of the survey.

50 percent of the projects are expected to deliver marketable results in the near future. The projects proved to be of high relevance for the partners involved. 84 percent of the companies and 85 percent of the research organisations continue research and development on the topic area beyond projects' end dates. LuFo also fosters long-term research partnerships. About half of them can be considered as enduring cooperations.

Figure 2: TRL-Levels (Wangler et al. 2019)



Knowledge transfer is another programme outcome. Nearly all research organisations present their research results on conferences and 87 percent publish articles in research journals. Companies are playing an important part in knowledge transfer as well. 71 percent of them present their results in conferences and 62 percent publish articles. 30 percent of companies and research organisations file patents with an average of 4,5 patents per project in companies and 1,3 patents per project in research institutions. Research organisations are especially important for technology spill-over. 63 percent of the results of their projects can be used within the aviation industry and 20 percent in other industries. But companies play their part in technology transfer as well. Results of their projects can be used by other organisations within the aviation industry by 40 percent and by 4 percent in other industries. LuFo is also important for research cooperations between universities and private companies. In nearly 50 percent of the projects in enterprises and over 80 percent of the projects in research organisations, dissertations are written. Almost three quarters of these students pursue a career in the aviation industry or related research institutions.

For companies by far the most important benefit resulting from funded projects is the development of new products and processes, underlining the importance of LuFo to foster innovation. Over 59 percent of the enterprises state that they introduced a new or significantly improved product or process within the last three years prior to the survey. The participating companies also self-report relatively high scores on all dimensions of innovative capacity with higher scores at the end of the programme than in the beginning. They attribute a significant share of this improvement to their participation in LuFo. For research organisations LuFo plays an even more vital role. Maintaining and improving their position in the scientific community is attributed to LuFo in comparison to other research programmes even more strongly than by LuFo funded companies.

Regarding LuFo's objectives almost two thirds of the projects declare that they are contributing strongly to creating a competitive and efficient aviation industry, followed by contributing to an environmentally friendly aviation industry. Overall LuFo's impact is very strongly related to maintaining research competencies. Keeping competitiveness and innovative capacity up in the long run are the most important aspects. As a result of participating in LuFo, companies engage in continuous improvements of products and processes and were able to improve their innovative capacity.

5. ESTIMATION RESULTS

For our estimation model we build on this data and use patent applications, dissertations, product and process innovation as well as TR-levels as major output variables. We use determinants such as R&D spending and R&D personnel or company size (SMEs vs. OEMs) as control.

Based on the theory introduced at the beginning of our paper, the indicators on innovative capacity of private companies, with their dimensions (i) human capital, (ii) structural capital, and (iii) relational capital, are of major interest. The measurement for these variables refers to the beginning of the publicly funded projects. Table 3 gives an overview of the relevant questions and the weighting of the indicators to measure innovative capacity. The data in innovative capacity is based on the assessment of R&D managers, who are in charge with innovation processes.

Finally, we are able to use other indicators as control variables such as the size of the firm measured by revenue, the change in TRL, and R&D personnel. Table 6 (appendix, p. 19) gives an overview on the indicators and some relevant basic statistics. Table 7 (appendix, p. 19) shows the correlation matrix.

Table 1: Innovative Capacity

Human capital	Indicators	Weight
Indicator 1 (scale 0-5)	The personnel working in R&D have technological knowledge that allows research and development at an internationally outstanding level.	1/3
Indicator 2 (scale 0-5)	The personnel involved in the production have the knowledge and skills that allow production at a very high level technologically.	1/3
Indicator 3 (scale 0-5)	The company is able to keep its employees' knowledge and skills up to date by taking appropriate measures (e.g. various forms of further training, learning at work, temporary staff exchanges with research institutions, knowledge management systems, etc.).	1/3

Structural capital	Indicators	Weight
Indicator 1 (scale 0-5)	There are one or more organisational units responsible for R&D whose structures (e.g. subdivisions) enable them to carry out research and technology at an internationally outstanding level.	1/5
Indicator 2 (scale 0-5)	There is an R&D department equipped with resources (e.g. enough personnel) that enables conducting research and technology at an internationally outstanding level.	1/5
Indicator 3 (scale 0-5)	The R&D department has a technical infrastructure and tools (e.g. IT, measuring instruments, production technology for the manufacture of models and prototypes) that enable it to carry out research and technology at a high level.	1/5
Indicator 4 (scale 0-5)	Cooperation between R&D and production departments is organised in such a way that knowledge and experience can be exchanged in both directions.	1/5
Indicator 5 (scale 0-5)	The employees in our company very often have to learn new things in their work or solve problems creatively.	1/5

Relational capital	Indicators	Weight
Indicator 1 (scale 0-5)	Our company is very well networked with suppliers and customers, so that it is possible to carry out R&D projects and other innovation projects together - outside of public funding.	1/5
Indicator 2 (scale 0-5)	Our company is very well connected to research institutions, so that it is possible to jointly carry out R&D projects and other innovation projects on an internationally outstanding level.	1/5
Indicator 3 (scale 0-5)	Our company is very well connected to educational institutions - vocational and university education - so that we can meet our qualification needs through training and further education at a high level.	1/5
Indicator 4 (scale 0-5)	Our company has a good public image (for example, we are perceived as an economically efficient and innovative company or as an attractive employer).	1/5
Indicator 5 (scale 0-5)	We provide transfer services in terms of technological knowledge between the aviation industry and other industries.	1/5

Innovative capacity	Indicators	Weight
Indicator 1 (scale 0-5)	Human capital	1/3
Indicator 2 (scale 0-5)	Structural capital	1/3
Indicator 3 (scale 0-5)	Relational capital	1/3

In order to test our main hypotheses we define innovation in three different ways:

1. We analyse the impact of innovative capacity on innovations as measured by the number of patents, publications and dissertations.
2. Innovation is defined as a binary variable [0,1], i.e. innovations (product and process innovation) occurred or not.
3. We define innovations by the change in the technological readiness level (TRL) during the project. For comparability of the models we establish a baseline model with our controls and integrate step by step our main variables of interest about innovative capacity.

5.1 IMPACT OF INNOVATIVE CAPACITY ON PATENTS AND PUBLICATIONS

As estimation model we choose a poisson regression with fixed effects, which seems appropriate as the outcome variable consists of count-data and a small sample size. For our control variables (revenue= REV, technology readiness level = TRL and R&D personnel = R&D_PERS) we do not get any significant outcome for our model with patents as the dependent variable. This is different when we use publications as the dependent variable. Some of the control variables are significant. We find strong evidence that innovative capacity has a positive effect on patenting as well as publication performance of companies in the dimensions of human capital and structural capital. Integrating the three indicators on innovative capacity together into the estimation model (Model 4), shows highly significant results also.

The regression results with patents as the outcome variable (Table 1) show strong positive results for the factors human capital and structural capital and innovative capacity as aggregated indicator across all three capital dimensions. However, for relational capital we do not find any significant result. We interpret the negative and non-significant result for relational capital in case of patenting activities thus that in case of cooperation, innovation is more like an open science project. The more firms cooperate, the less likely it is that they patent their ideas.

When we look at publications, we get similar results. Strong positive correlation is found for human capital, structural capital and aggregated innovative capacity. Relational capital is still insignificant but has a positive effect, which supports the hypothesis. We also test the impact of innovative capacities by using dissertations as the dependent variable (Table 8, appendix, p. 19), but do not find any significant result. A possible explanation could be, that firms are less focused on dissertations, compared to research institutes and universities.

Based on these findings we are able to confirm H1 and H2, namely “high innovative capacity at the beginning of the project leads to a high number of publications as well as a high number of patents”.

Table 2: Patents as Independent Variable

	(1)	(2)	(3)	(4)
	Patents			
REV	-4.85e-10	-5.64e-10	-4.06e-10	-3.86e-10
	(-1.32)	(-1.61)	(-1.32)	(-1.31)
TRL	0.0334	0.0519	0.00657	-0.00347
	(0.37)	(0.58)	(0.07)	(-0.04)
R&D_PERS	0.00152	0.00161	0.00154	-0.000108
	(0.80)	(0.82)	(0.72)	(-0.06)
HC_t1_U	**0.525*** **			
	(2.59)			
SC_t1_U		**0.782*** **		
		(3.64)		
RC_t1_U			-0.237	
			(-0.90)	
IC_t1_U				**0.657** **
				(2.45)
N	59	59	50	50
bic	148.2	140.0	136.7	130.8

t statistics in parentheses
p < 0.10, ** p < 0.05, *** p < 0.01

Table 3: Publications as Independent Variable

	(1)	(2)	(3)	(4)
	Publications			
REV	-1.83e-12	5.12e-12	1.35e-10**	1.27e-10**
	(-0.16)	(0.51)	(2.45)	(2.32)
TRL	**-0.152****	0.00225	0.0524	0.0641
	(-2.19)	(0.03)	(0.54)	(0.66)
R&D_PERS	**0.00471****	**0.00734*****	-0.0157	-0.0155
	(2.54)	**(3.71)**	(-0.75)	(-0.74)
HC_t1_U	**0.476*****			
	(3.34)			
SC_t1_U		**0.677*****		
		(5.28)		
RC_t1_U			0.220	
			(1.04)	
IC_t1_U				**0.326***
				(1.67)
N	52	52	40	40
bic	238.2	212.1	93.81	91.83

t statistics in parentheses * p < 0.10, ** p < 0.05, *** p < 0.01

5.2 IMPACT OF INNOVATIVE CAPACITY ON PRODUCT AND PROCESS INNOVATIONS

We proceed with the estimations using product innovation and process innovation as dependent variables and we use the indicators on innovative capacity as explanatory indicators. Therefore, the estimation is based on a logit-model. As control variable we implement revenue to capture the effect of the size of the companies. As a robustness check, we also include productivity calculated as revenues by number of employees (REV/EMPL). As a result, the findings are robust. For product innovation we find a rather strong relationship on all three dimension: human, structural and relational capital. The aggregated indicator on innovative capacity is also significant.

Table 4: Product-Innovations as Independent Variable

	(1)	(2)	(3)	(4)
	PROD_INNO			
REV	4.55e-12	4.83e-12	2.25e-11	1.70e-11
	(0.17)	(0.18)	(0.78)	(0.60)
HC_t1_U	**0.356*****			
	(2.58)			
SC_t1_U		**0.357*****		
		(2.68)		
RC_t1_U			**0.503*****	
			(2.87)	
IC_t1_U				**0.564*****
				(2.99)
N	192	192	153	153
chi2	7.299	7.834	10.35	11.18
bic	220.3	219.8	167.6	166.8

t statistics in parentheses
* p < 0.10, ** p < 0.05, *** p < 0.01

Table 5: Process-Innovations as Independent Variable

	(1)	(2)	(3)	(4)
	PROC_INNO			
REV	-3.38e-11	-2.85e-11	-2.06e-11	-2.30e-11
	(-1.13)	(-0.97)	(-0.68)	(-0.74)
HC_t1_U	**0.333****			
	(2.45)			
SC_t1_U		0.194		
		(1.52)		
RC_t1_U			**0.296***	
			(1.82)	
IC_t1_U				0.274
				(1.59)
N	192	192	153	153
chi2	7.057	3.151	3.801	2.971
bic	225.0	228.9	179.1	179.9

t statistics in parentheses
* p < 0.10, ** p < 0.05, *** p < 0.01

Based on the same model we look on the impact of innovative capacity indicators on process innovations. Here we only find significant outcomes for human capital and relational capital. We do not find any significant result for structural capital and the overall innovative capacity. When we further control for SMEs, the estimation remains constant, however the positive significant result for relational capital and process innovation outcome is not persistent. This seems to be plausible, as innovation in SMEs is first of all a factor depending on human capital, structural capital and innovative capacity are factors that are significantly more distinct within bigger companies.

Based on these findings we come to the conclusion that our concept of innovative capacity has high impact on product innovations. The evidence on process innovation is not that obvious. We therefore find H4a confirmed while we reject H4b. That the findings are insignificant for process innovations is somehow counterintuitive at first glance. However, as process innovations are very company specific we find that human capital is one major factor explaining process innovation. Some weak evidence is found for relational capital, meaning that firms need a good network to be able to source technologies which are necessary to adapt innovative processes within the firm. Structural capital is also important within this context, but according to our regression it is less important compared to human capital and relational capital as it turns out to be insignificant. For our overall indicator on innovative capacity we also do not find any significant result for its impact on process innovation.

Table 6: Process- and Product Innovations as Independent Variable controlling for SMEs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	PROD_INNO					PROC_INNO		
REV	1.42e-13	1.63e-13	1.64e-11	1.24e-11	-3.89e-11	-3.47e-11	-2.81e-11	-2.99e-11
	(0.01)	(0.01)	(0.59)	(0.45)	(-1.21)	(-1.10)	(-0.84)	(-0.88)
SME_Dummy	**-0.837****	**-0.845****	**-0.737***	-0.710	**-0.681***	**-0.779****	-0.646	-0.677
	(-2.24)	**(-2.27)**	**(-1.65)**	(-1.58)	**(-1.84)**	**(-2.13)**	(-1.50)	(-1.56)
HC_t1_U	**0.279***				**0.265***			
	(1.95)				**(1.88)**			
SC_t1_U		**0.291****				0.125		
		(2.11)				(0.94)		
RC_t1_U			**0.412****				0.211	
			(2.26)				(1.23)	
IC_t1_U				**0.468****				0.174
				(2.37)				(0.95)
N	192	192	153	153	192	192	153	153
chi2	12.40	13.07	13.12	13.70	10.48	7.755	6.074	5.435
bic	220.5	219.8	169.9	169.3	226.8	229.5	181.8	182.5

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.3 IMPACT OF INNOVATIVE CAPACITY ON THE SPEED OF TECHNOLOGY DEVELOPMENT

As a final research question we look at the impact the concept of innovative capacity has on the speed of technology development using (TRL2-TRL1) as the dependent variable. We use OLS to regress the impact of innovative capacity on TR-Levels. We use REV as our control variable and have further integrated an SME dummy. The estimation results do not show any significant results. We therefore have to reject H5. There is no significant correlation between innovative capacity and the speed of technology development. This might have to do with the specific characteristics of the aerospace sector with its long processes and complex procedures in developing a technology. Speed is not a major characteristic of innovativeness in the aerospace industry, developing new products can take more than one decade. The negative sign of our coefficients might be a hint in this direction. The results, however, are insignificant (see Table 9, appendix, p. 19).

6. SUMMARY OF THE MAIN FINDINGS

Our findings are promising. There is strong evidence that innovative capacity influences innovation outcomes positively. The results are robust with respect to the indicators used for innovation, i.e. patents, publications and product innovations. However, we find relatively weak evidence for the relationship between innovative capacity and process innovations, and no evidence is found for the relationship between innovative capacity and the speed of technology development or on doctoral theses.

This brings us to the conclusion, that innovative capacity is a useful model in order to – at least partly – explain innovation processes within high-tech-industries. We established the model of innovative capacity for assessing outcome related R&D effects of publicly funded research. The econometric results underline that it is legitimate to use innovative capacity as an early indication for innovation success. This is even more relevant, when publicly funded R&D projects are designed in order to support developments in human, structural and relational capital. Then, the strengthening of innovative capacity will increase innovation outcomes in later stages. A second basic result of our analysis is that self-reports by experts, who are in charge with innovation processes, deliver (at least to some extend) reliable data. For this reason, we are able to confirm statistically our theoretical assumptions, that innovative capacity is relevant for innovation outcome.

Though promising, our results have some limitations. Firstly, our findings are limited to the aerospace sector with its sector-specific characteristics. It would be interesting to see if our findings also hold true for other sectors. Secondly, more research is needed to come to a better understanding how the importance of innovative capacity changes along the innovation related time-cycle. Thirdly, as this is a first paper addressing the impact of innovative capacity on innovation, more evidence is needed to further demonstrate the robustness of our results.

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APPENDIX

Table 7: Data

Variable		Obs	Mean		Std. Dev.	Min	Max
PAT	Patents	1,291	.6111541		3.011966	0	67
DISS	Dissertations	1,291	.3826491		.9863296	0	10
PUB	Publications	857	1.37923	2.633747	0	40	
TRL	Technology Readyness Level	658	4.989362		2.359903	0	10
REV	Revenue	798	3.42e+08		3.48e+09	0	7.81e+10
R&D_PERS	R&D Personnel	1,261	12.77872		93.17354	0	1900
PROD_INNO	Dummy for product innovation.	1,338	.1748879		.3800132	0	1
PROC_INNO	Dummy for process innovation.	1,338	.171151	.3767817	0	1	
HC _t1_U	Human Capital at the beginning of the R&D project	194	3.199313	1.148361	0	5	
SC _t1_U	Structural Capital at the beginning of the R&D project	194	3.083505		1.199411	0	5
RC _t1_U	Relational Capital at the beginning of the R&D project	154	3.227273		1.067908	0	5
IC _t1_U	Innovative capacity at the beginning of the R&D project	154	3.171284		.9819707	0	5

The correlation of these main variables is summarised by the following correlation matrix.

Table 8: Correlation Matrix

bbs=42	PAT	DISS	PUB	TRL	REV	R&D_ PERS	PROD_ INNO	PROC_ INNO	HC _t1_U	SC _t1_U	RC _t1_U	IC _t1_U
PAT	1.0000											
DISS	-0.0620	1.0000										
PUB	-0.0457	0.8303	1.0000									
TRL	-0.1092	-0.0907	-0.0384	1.0000								
REV	-0.0463	0.3697	0.6323	-0.0026	1.0000							
R&D_PERS	-0.0541	0.0876	0.0941	-0.3668	0.1801	1.0000						
PROD_INNO	-0.1442	0.1125	0.0742	0.1097	0.0444	0.2020	1.0000					
PROC_INNO	-0.1954	0.1261	0.0822	0.0140	0.1126	0.2208	0.6581	1.0000				
HC _t1_U	0.0955	-0.0080	0.1617	-0.0692	0.2045	0.0153	0.1889	-0.0482	1.0000			
SC _t1_U	0.1802	0.0139	0.1341	-0.1971	0.0518	-0.0762	0.0627	-0.1745	0.7089	1.0000		
RC _t1_U	-0.0709	0.1362	0.0783	-0.3361	-0.0757	0.3298	0.1356	-0.1026	0.5295	0.5239	1.0000	
IC _t1_U	0.0935	0.0493	0.1483	-0.2288	0.0754	0.0830	0.1459	-0.1316	0.8783	0.8971	0.7753	1.0000

Table 9: Dissertations as Independent Variable

	(1)	(2)	(3)	(4)
	Dissertations			
REV	4.73e-11	4.37e-11*	2.33e-10	1.93e-10
	(1.59)	(1.71)	(1.15)	(1.06)
TRL	-0.164	-0.0878	0.150	0.0593
	(-0.81)	(-0.45)	(0.49)	(0.20)
R&D_PERS	-0.00120	-0.00247	-0.0639	-0.0480
	(-0.26)	(-0.51)	(-0.84)	(-0.70)
HC_t1_U	0.0753			
	(0.21)			
SC_t1_U		0.503		
		(1.43)		
RC_t1_U			1.048	
			(1.17)	
IC_t1_U				0.318
				(0.45)
N	49	49	38	38
bic	51.49	48.95	28.66	30.32

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Speed of technology development (Delta TRL)

	(1)	(2)	(3)	(4)
	Delta TRL			
REV	7.48e-12	6.78e-12	6.51e-12	6.29e-12
	(0.69)	(0.63)	(0.57)	(0.54)
SME_ Dummy	-0.0139	-0.00407	0.0108	0.0159
	(-0.14)	(0.09)	(-0.14)	(0.14)
HC_t1_U	-0.0182			
	(-0.45)			
SC_t1_U		-0.00155		
		(-0.04)		
RC_t1_U			-0.000390	
			(-0.01)	
IC_t1_U				0.00827
				(0.13)
Intercept	0.452**	0.378**	0.348	0.310
	(2.37)	(2.12)	(1.22)	(1.08)
N	88	88	69	69
r2	0.00788	0.00530	0.00550	0.00580
F	0.204	0.137	0.107	0.113
bic	92.49	92.72	77.34	77.32

t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$