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Outcomes of science-industry collaboration: factors and interdependencies

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Abstract

We analyse the outcomes for scientists from science-industry collaboration projects and study the conditions under which these outcomes emerge. While previous research analyses the motivations for scientists to collaborate and the characteristics of such collaborations, we focus on the generated outcomes. We provide a new conceptualisation of collaboration outcomes and distinguish three different types: scientific outcomes, commercialisable outcomes, and follow-up cooperation. We argue that scientific factors influence the generation of scientific outcomes, and economic factors the generation of commercialisable outcomes, accordingly; interaction factors are proposed to influence the emergence of follow-up cooperation. We further propose that these outcomes depend on each other and hence are co-generated. We test our propositions with survey data from scientists in the German state of Thuringia. We develop novel survey items about characteristics of scientists' last collaboration with an industry partner and its outcomes. Multivariate probit estimations show that scientific factors positively relate to scientific outcomes, and interaction factors are relevant for follow-up cooperation. However, when it comes to economic factors, we find mixed evidence of their relation to commercialisable outcomes. The outcome interdependence exists between scientific outcomes and the other two types of outcomes but not between commercialisable outcomes and follow-up cooperation. Our results can be used by policymakers and science managers to design and strengthen the support for collaboration projects.

Keywords Science-Industry collaboration · Scientific outcome · Commercialisable outcome · Follow-up cooperation · Multivariate probit · Germany

JEL classification I23 · O31 · O32

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1 Introduction

There is an increasing tendency of actors from science and from industry to conduct research and innovative activity in collaboration with each other (e.g. Perkmann et al., 2013, 2021). Such science-industry collaborations (SIC) are a way not only to exchange and share knowledge but also to foster joint knowledge generation to solve technical problems and generate innovations which subsequently increase economic growth and welfare (de Wit-de Vries et al., 2019; Roncancio-Marin et al., 2022). The reasons for participating in SIC are relatively well understood, and the determinants and motives affecting the likelihood of participation in SIC have been identified (e.g. Baldini et al., 2007; Lee, 2000; Lam, 2011). For industry, especially the access to basic knowledge via SIC and the co-creation of new knowledge for their economic activities are key reasons (e.g. Perkmann et al., 2011). For science, in turn, SIC is a core component of their third-mission activities to facilitate knowledge and technology transfer from research into economic application (Etzkowitz, 2004; Schulte, 2004; Compagnucci & Spigarelli, 2020). Furthermore, the scientists' innate curiosity, i.e. finding solutions to practical problems or application of their research results, as well as access to resources, especially financial ones, are key reasons (Lam, 2011; Audretsch et al., 2010; Silva et al., 2023). However, this motivation-driven research is input-oriented and provides only limited insights on the success and outcomes of SIC.

Research in general on the success and outcomes from SIC, such as research productivity or economic impact, is scarce, as pointed out by Perkmann et al. (2021). Albats et al. (2018), furthermore, emphasise that the micro level on the individual project is of particular relevance and suggests a detailed analysis of the different outcomes from SIC projects. Especially on this micro level, there is a substantial gap in the literature, due to the complexity of SIC and their outcomes. The complexity stems from the individual characteristics of the scientists and industry actors involved, the organisational and peer context of the SIC, as well as institutional context and policy regulations that need to be considered (Albats et al., 2018; Perkmann et al., 2021; Ismail et al., 2021). However, understanding the outcomes from SIC projects is not only relevant for scholarly advancements but has substantial practical and policy-related relevance. It can provide guidance to the actors involved in a SIC to structure and manage their SIC projects. Furthermore, it allows for an evaluation of the efficiency of SIC and to assess resource allocation. Additionally, understanding the different outcomes allows for evaluation of projects and on an aggregated level the institutions involved in it, as suggested by Flores et al. (2009). The results can also be used to inform policymakers on how to provide an environment for SIC which facilitates the generation of outcomes. We pick up on the relevance to understand the SIC outcomes and try to address the gaps in the literature. In doing so, we are, to our knowledge, the first who empirically measure the direct outcomes from SIC projects from a scientist's perspective and complement existing qualitative insights on SIC outcomes (e.g. Ankrah et al., 2013; Albats et al., 2018; Barnes et al., 2002).

With the aim of providing a detailed assessment of SIC outcomes and the factors that generate them, first, we want to understand the different kinds of outcomes that can emerge from a SIC. Second, we seek to shed light on factors that influence the emergence of different kinds of outcomes. Lastly, we want to analyse the relationship between the different kinds of outcomes and if there exists a co-generation process. For this purpose, we conceptually distinguish between different kinds of outcomes, since there is no commonly accepted classification of SIC project outcomes. Several approaches exist to classify them, differentiating between the nature of the outcome, the beneficiary of the outcome, and from a temporal perspective (Arza, 2010; Nikulainen, 2010; de Fuentes & Dutrénit, 2012; Perkmann et al., 2011; Ankrah et al., 2013; Albats et al., 2018). We link findings of previous studies and the reasons for scientists to participate in SIC and distinguish between three broad groups of outcomes from the scientist's perspective: scientific outcomes motivated by research curiosity, commercialisable outcomes motivated by financial rewards, and follow-up cooperation that allow the continuation of the interaction. While the first two types of outcomes were previously suggested by Arza (2010) and de Fuentes and Dutrénit (2012), we additionally account for potential follow-up cooperation as outcomes, as suggested by Grimaldi and von Tunzelmann (2002), but usually neglected by research up to now. For these three kinds of outcomes, we provide the first empirical evidence on their frequency and their co-occurrence. Additionally, we analyse the factors that influence the generation of different outcomes. We theoretically derive propositions on potential relationships by combining different streams of literature, since an encompassing theoretical frame does not exist. Based on conceptual differences between academic and commercial settings by Dasgupta and David (1994), we propose that scientific factors drive scientific outcomes, while economic factors drive commercialisable outcomes. Furthermore, we build on research on innovation networks (Cantner & Graf, 2011; D'Este et al., 2013) and propose that interaction factors influence the generation of follow-up cooperation. To understand the interdependencies between the outcomes, we relate to the literature on the co-generation of science and technology (Rosenberg & Nelson, 1994; Dasgupta & David, 1994; Murray, 2002) and propose that the different outcomes are interdependent and are co-generated in a SIC project.

In order to answer our research questions, we use survey data from scientists in the German state of Thuringia, which was collected from the end of 2019 to beginning of 2020. Scientists were asked detailed questions about the last SIC project they have been involved in, especially about the project characteristics and about the outcomes from that particular SIC project. We complement the survey data with secondary data. We use multivariate probit regression to estimate the influence of the three sets of factors on the likelihood to receive a certain outcome from the project. This estimation method allows us to take into account interdependencies of dependent variables which is the co-generation process of outcomes we are interested in.

Our results show that most SIC generate at least one outcome and that scientific outcomes and follow-up cooperation are the most frequent ones (up to 70%), while commercialisable outcomes are generated in one-third of the projects. We find support for our proposition that scientific outcomes are influenced by scientific factors, such as the scientist's research orientation. For commercialisable outcomes, we find mixed support, such as transfer experience and projects with an economic aim of increasing the likelihood to generate such outcomes, but the organisational environment can harm the probability. For follow-up cooperation, we find support for the influence of the interaction factors. Furthermore, we find that scientific outcomes are frequently co-generated with the other two types of outcomes, supporting our proposition that outcomes are co-generated.

Our findings shed light on the SIC outcomes as well as the factors that lead to them. The results for follow-up cooperation, in particular, provide new insights about the interactive nature of SIC and university-industry networks. We address several gaps in the literature and develop a novel set of questions in order to answer them. First, we approach academic engagement from a very micro perspective that allows us to research the complexity of the issue in detail. Second, we contribute to the conceptualisation of the outcomes and classify them based on the reasons of academics to engage in SIC and moreover, we treat follow-up cooperation as an equally important outcome. Third, we address the factors influencing the outcomes from different perspectives, including organisational and institutional contexts which were not well approached in recent studies. Finally, we take into account the possibility that outcomes might be co-generated and thus we account for interdependence when evaluating the effect of the factors. In addition, this study also provides guidance for policymakers on how to support SIC and for science managers on how to organise SIC.

In the following Sect. 2, we examine the literature on SIC outcomes and the factors that influence them. We investigate the relation between these outcomes and derive propositions. Section 3 discusses the survey data and methodological approach. Section 4 presents the results and robustness tests. Section 5 discusses our findings and concludes.

2 Science-industry collaboration outcomes

2.1 Conceptualising outcomes of science-industry collaboration

Research activities and innovation are increasingly done in collaboration since knowledge co-creation, transfer and spillover can reinforce such activities. In the context of inter-firm collaboration, a substantial line of research analyses how such spillovers and other benefits emerge and the strategies related to engaging in R&D collaborations (e.g. d'Aspremont & Jacquemin, 1988; Veugelers, 1998). Additionally, in knowledge-based societies, the collaboration between science and industry becomes more important to exchange, share and co-create knowledge (Rosenberg & Nelson, 1994; Etzkowitz & Leydesdorff, 2000). Actors from science and industry join forces to generate knowledge and to solve problems that have implications for both science and industry, as well as society as a whole (de Fuentes & Dutrénit, 2012). Some solutions achieved contribute to substantial advances in science. Other results of such collaboration translate into economic application, in particular, and into broader use in the society in general (Ahmadpoor & Jones, 2017; Nelson, 1995; Dasgupta & David, 1994; Roncancio-Marin et al., 2022). Actors from science and industry, originating from different backgrounds with different norms and logics, engage in SIC for different reasons.[1] Firms engage in SIC for economic reasons, especially to access and utilise knowledge to improve existing products or processes, the development of prototypes or the solutions to technical problems (e.g. Lee, 2000; Perkmann et al., 2011; Cohen et al., 2002; Baba et al., 2009; Robin & Schubert, 2013). Scientific actors engage in such collaborations for reasons found in their individual characteristics, but they are also influenced by their research organisation (Perkmann et al., 2013, 2021; Sauermann & Cohen, 2010). In the following, we conceptualise different types of outcomes from such interactions building on the underlying reasons for scientists to participate in SIC and the factors that influence these outcomes.

On the individual level, scientists have three broader reasons to collaborate with industry: securing research funds and resources, generating research results, and reaping personal financial rewards (e.g. Lee, 2000; Lam, 2011; D'Este & Perkmann, 2011; Siegel et al., 2003). The primary reason to engage in SIC is to secure funds for research, e.g. to

[1] Scholars discuss different forms of science-industry interaction, such as among others academic spin-offs, industrial doctorates, consultancy, patenting, training programs, industrial associations and others (Ankrah & AL-Tabbaa, 2015; Lee, 2000). We, in the following, focus on formal cooperative research projects between science and industry partners and more one-sided contract research.

finance assistants and lab equipment (Meyer-Krahmer & Schmoch, 1998; D'Este & Perkmann, 2011; Lee, 2000; Tartari & Breschi, 2012). Second, more research-oriented reasons are guided by Mertonian norms, such as gaining novel research insights, testing theory, applying research findings to practical cases, gaining further intellectual insights by discovering new phenomena or solving puzzles (Lee, 2000; D'Este & Perkmann, 2011; Lam, 2011). Third, scientists may pursue SIC to economise on the results of the research or to get personal income from license revenues or entrepreneurial activity (Perkmann & Walsh, 2008). However, personal monetary interests are the least important reasons to engage in SIC (Owen-Smith & Powell, 2001; Lam, 2011; D'Este & Perkmann, 2011).

Furthermore, scientists are also influenced by their organisations. On this organisational level, two main reasons for an engagement in SIC can be distinguished. First, scientists in the last decades have experienced a changed role of research organisations for and in societies, the so-called third mission, resulting in new demands on their research activities: they are asked and incentivised to contribute to socioeconomic development and should have a direct and active role to support economic activity and hence should increasingly engage in transfer activities. For that purpose, they should engage with economic actors (Etzkowitz & Leydesdorff, 2000; D'Este & Perkmann, 2011) and SIC are considered a proper way to doing so. Second, research organisations use SIC to increase their resources or to fulfil performance targets imposed by the government, for example. Beath et al. (2003) show analytically that universities can ease their budget constraints via increasing funding from SIC. Therefore, policies and incentives to encourage academic staff to engage in SIC are implemented frequently, often directly addressing transfer and third mission objectives (Perkmann & Walsh, 2008).

Next to the reasons for engaging in SIC are their effects on the performance of scientists. The general effects of SIC are summarised in large scale reviews by Perkmann et al. (2013, 2021). Based on the existing literature, they conclude that scientists who engage in SIC increase their publication productivity and quality, indicating synergy effects from SIC. Additionally, SIC participation can positively influence the acquisition of grants. Furthermore, scientists who engage in SIC seem to file more often for patents and to consider engaging in entrepreneurial activity. However, there might be some detrimental effects on teaching quality and the academic career for young scientists. In addition, Muscio et al. (2017) show that the requirement for scientists to participate in knowledge and technology transfer according to the internal rules of the institution has a negative impact on the aggregate publication rate of Italian scientists, especially in the natural and medical sciences.

While the reasons for scientists to engage in SIC are compelling and the effects of such engagements are beneficial, the direct outcome of such interactions are not well understood. SIC can lead to heterogeneous outcomes for scientists and their organisations, and several attempts exist to classify them. Thereby, distinctions between the nature of the outcome, the beneficiary of the outcome as well as a temporal dimension are considered. From a content perspective, Arza (2010) and de Fuentes and Dutrénit (2012) distinguish outcomes into intellectual and economic benefits, based on the knowledge generated or the application of the knowledge. In a similar way, Nikulainen (2010) divide outcomes on tangible and intangible ones. Perkmann et al. (2011) distinguish outcomes from a performance perspective into short-term outputs and long-term impacts on the actors. In an evaluation of collaborative projects, Grimaldi and von Tunzelmann (2002) consider tangible outcomes, indirect-future outcomes where they evaluate the commercial exploitation and follow-up activities. In a similar evaluation attempt, Ankrah et al. (2013) use a qualitative approach and distinguish between economic, institutional (relevant for scientists and universities) and social outcomes.

These different approaches to classify outcomes of SIC are based on different perspectives on what the collaboration should deliver and for whom. Central to the classification of outcomes is the knowledge generated and how it is used, either for scientific purposes or for economic purposes. Furthermore, the beneficiary can be substantially different. Albats et al. (2018) suggest distinguishing between the outcome of SIC with respect to short-term results for the actors who are directly involved in the collaboration and the impact of the outcome which is more long-term oriented and can also involve the state and society as beneficiary (Grimaldi and von Tunzelmann (2002) refer here to positive externalities). However, long-term impacts are difficult to assess, since the application of newly created knowledge in further scientific research but also in new or improved products or processes and the respective impact on firm performance, comes with a time lag (Bozeman, 2000; Landry et al., 2006).

Based on the classification of general SIC results from the literature discussed above (e.g. Grimaldi & von Tunzelmann, 2002; Arza, 2010; de Fuentes & Dutrénit, 2012) and taking into account the reasons of the scientists to engage in collaborations (e.g. Lee, 2000), we conceptualise three groups of SIC outcomes from the scientist's perspective: *scientific outcomes*, *commercialisable outcomes* and *follow-up cooperation*.

The *scientific outcome* from a SIC is new knowledge generated from the collaboration activity and (usually) codified in publicly available publications (e.g. Abramo et al., 2009; Grimaldi & von Tunzelmann, 2002). Scientific outcomes in general correspond to the Mertonian norms of science and are the result of the scientist's urge to create new knowledge and to disseminate it (Lee, 2000). Also in the context of SIC, a scientist's reason to gain new insights for research, to apply and test theoretical concepts and to exchange knowledge with industry lead to scientific outcomes (Lee, 2000; Meyer-Krahmer & Schmoch, 1998; Arza, 2010) that are usually scientific publications. Additionally, Garcia et al. (2019) propose a more fine-grained perspective and disaggregate the scientific outcomes from SIC into knowledge results, represented by new scientific discoveries and new research projects, and academic results, represented by publications, training, theses and dissertations (see also Galan-Muros & Davey, 2019).

Commercialisable outcomes encompass the potential economic application of the generated knowledge from the SIC. This knowledge can be tacit, codified in patents or embedded in prototypes. Scientists are motivated by economic interests, such as selling the research results or seeking business opportunities to generate such commercialisable outcomes. These outcomes comprise patent applications, licence revenues, prototypes and ideas for or creation of spin-offs (Ambos et al., 2008). Besides economic reasons, science related interest are also involved here, as scientists do use invention disclosures or patents as a means to signal their scientific achievement or to gain reputation (Göktepe-Hulten & Mahagaonkar, 2010). Moreover, scientists might search for business opportunities to increase their reputation or to acquire additional funding for their research (Lee, 2000).

Follow-up cooperation is the least analysed SIC outcome in the literature. Follow-up cooperation is considered as an outcome by Grimaldi and von Tunzelmann (2002), but they do not state explicitly what such follow-up cooperation is all about. Similarly, without any discussion, de Fuentes and Dutrénit (2012) mention the ideas for new or further common scientific projects as outcomes. Conceptually, follow-up cooperation signal the potential to generate scientific or economic outcomes in follow-up interactions by further exploiting already achieved collaboration results or by exploring new directions of research. Collaboration partners want to continue working together because the initial reason for collaboration is not completely fulfilled, or the jointly generated knowledge provides a starting ground for further research, or actors experienced the current SIC so beneficial and the relation so trustful that they want to engage further on other topics. Such repeated interaction increases trust between partners and can thereby increase collaboration performance and reduce uncertainty (Powell, 1996). Besides that, scientists want to continue research activities with the same partner to maintain access to resources or inputs. In his survey, Lee (2000) asked scientists and managers of SIC how likely they are to expand their SIC. The vast majority of scientists and industry managers indicate that based on their positive experience, they would maintain or even extend their level of interaction, indicating that to continue the cooperation is in their interests.

2.2 Factors influencing collaboration outcomes

While there is a large literature on why scientists engage in SIC and what determines such an engagement (e.g. Baldini et al., 2007; Lee, 2000; Lam, 2011; Tartari & Breschi, 2012; Goel et al., 2017), however, the factors that influence the types of outcomes from a SIC are not well addressed. To theorise about relevant factors, we follow the argumentation by Dasgupta and David (1994) that scientists are embedded in a scientific setting and need to reach the commercial setting in which economic logics prevail. For a successful SIC, scientists have to bridge these two settings to generate outcomes. We extend this duality with an interaction setting motivated from research on innovation networks to shed light on the interactive nature of SIC (Cantner & Graf, 2011; D'Este et al., 2013). We use these three settings and discuss respective characteristics of scientists, their organisations and the collaboration project. We propose that factors which characterise the scientists in their scientific setting influence scientific outcomes, factors related to the economic setting influence commercialisable outcomes and factors which relate to an interactive setting affect follow-up cooperation. Since previous research has neither formulated theoretical relationships nor does there exist empirical evidence on such relationships, we derive general propositions on these relationships to guide the exploration of potentially relevant factors.

Scientific factors characterise scientists and their research activity and behaviour. The differentiation between types of scientists in terms of their research orientation, their previous research activity and their academic standing is found to be highly relevant to engage in SIC (e.g. Bikard et al., 2019; Ambos et al., 2008) and can be seen as similarly relevant in generating outcomes. The scientists' research orientation can favour scientific outcomes if the scientist has a higher tendency towards basic research (e.g. Stokes, 1997; Bikard et al., 2019). To account for this aspect, we refer to Stokes (1997) who differentiates three kinds of scientist types.[2] Bohr-type scientists lean towards basic research only, whereas the Edison-type engages in pure applied research. Pasteur-type scientists combine both aspects and have a high tendency towards fundamental understanding and a high consideration of use. Consequently, Bohr- and Pasteur-type scientists are considered to be those who engage in SIC in order to solve puzzles and gain new knowledge which should subsequently result in scientific outcomes. Furthermore, a scientist's position or role in a SIC can influence the generated outcomes. PhD candidates or Postdocs involved in SIC are motivated to generate scientific publications for their dissertations and should aim for such outcomes for their

[2] Donald E. Stokes, in his book "Pasteur's Quadrant", classifies scientific research into three distinct classes: pure basic research exemplified by the work of Niels Bohr, pure applied research exemplified by the work of Thomas Edison and use-inspired basic research exemplified by the work of Louis Pasteur.

career perspectives. Scientists' scientific performance in terms of quantity and quality of publications are indicators of experience and academic standing. Scientists of higher rank, and especially 'star-scientists' with a high publication record, generate scientific outcomes from SIC (Bikard et al., 2019; Balconi & Laboranti, 2006). Furthermore, design and nature of the collaboration, i.e. type of collaboration or the aim of the collaboration, can influence the outcome that is generated. If the initial project goal is to understand a phenomenon or to create new knowledge, scientific outcomes should be the result. Similarly, Levy et al. (2009) and de Fuentes and Dutrénit (2012) show that SIC with a focus on joint research and co-creation of knowledge lead to more effective collaborations and subsequently to scientific outcomes. Lastly, the institutional environment in which scientists conduct SIC seems to be decisive for scientific outcomes (e.g. Rossi & Rosli, 2015; Bodas Freitas & Verspagen, 2017; Lee, 2000). Research organisations with a focus on basic research should encourage the generation of scientific outcomes, because it is their core mission. Based on these considerations of different scientific factors and their potential influence on the generation of scientific outcomes in SIC, we propose that:

Proposition 1: *Scientific factors are relevant for the creation of scientific outcomes.*

Economic factors relate to scientists' experience with economic activity and respective motivations to generate economic returns from SIC. The economic perspective of scientists can relate to their research activity, which can have a high consideration of use. Stokes (1997) argues that Edison-type scientists have such a high consideration of use and conduct research with a focus on application, which frequently results in patents and spin-off activity. Similarly, Pasteur-type scientists also show such an orientation towards application. These two types of scientists should subsequently aim for commercialisable outcomes from SIC. In addition to the research orientation, experience gained outside the academic sector, such as work experience in the private sector, enables scientists to identify commercial opportunities from the generated knowledge (Dietz & Bozeman, 2005; Gulbrandsen & Thune, 2017). Moreover, if scientists already participated in transfer activities in the past – for example, by filing a patent or founding a firm – they are better able to identify the commercial potential and follow this path (e.g. de Fuentes & Dutrénit, 2012; Bekkers & Freitas, 2010; Kauppila et al., 2015). Both types of individual experience suggest an influence on commercialisable outcomes from a SIC. As to the design and nature of collaboration, if a SIC has the aim to solve a technical problem for an industry partner, this should result in commercialisable outcomes, such as patents or licensing fees (Bodas Freitas & Verspagen, 2017; Alvarado-Vargas et al., 2017). With respect to the organisation in which the scientists are embedded, the type of organisation in terms of the nature of research that is conducted and the general environment for scientists to conduct transfer activities are decisive. Research organisations with an applied research focus are more frequently exposed to the private sector than those with a basic research focus (Boardman & Ponomariov, 2009). The exposure to economic activity can positively affect the collaboration process and aims to generate outcomes that can be commercialised (e.g. D'Este & Patel, 2007; de Fuentes & Dutrénit, 2012). In line with that, research organisations with experience in transfer activities usually have well-developed infrastructure, such as technology transfer offices that help to reduce tensions between the participants in the transfer process and overcome cultural differences, which in turn leads to successful results of interaction with industry (Ambos et al., 2008).

Based on these arguments on the relevance of embeddedness in or exposure to economic activity, we propose:

Proposition 2: *Economic factors are relevant for the creation of commercialisable outcomes.*

Interaction factors address the relationships between the two types of partners in a SIC. These factors relate to the process of maintaining the collaboration as our third outcome category. Research on innovation networks provides some rationales as to why a collaboration should be extended (e.g. Cantner & Graf, 2011). Thune (2007) and D'Este et al. (2013) show that embeddedness in a previously established network is highly relevant to establish a cooperation and to be successful. Analogously, trust among actors built up in a previous cooperation increases the likelihood to generate new knowledge (Powell, 1996). Those factors can serve as basis to establish long-term interactions to generate scientific and economic knowledge in subsequent interactions (Abramo et al., 2009; Garcia et al., 2020). Hence, good experience and common success of the actors involved in a SIC can lead to follow-up cooperation. Cooperation experience and success are especially relevant for the principal investigators in SIC. They consider a SIC as a career development step, and they attempt to go for follow-up cooperation indicating continued research and a track-record of attracting third-party funding (Ambos et al., 2008; Cunningham et al., 2014). Since the principal investigators know the partners (trust) and the project well (success), they recognise and enforce follow-up cooperation. Additionally, the scientists' research orientation can influence the generation of follow-up cooperation. Pasteur- and Edison-type scientists who have higher interest in research application should have a higher inclination to prolong SIC. Lastly, the environment in which scientists are embedded can help to facilitate follow-up cooperation. If the organisation has a habit to conduct SIC frequently and experience in establishing and maintaining such interactions, the likelihood to generate a follow-up cooperation should be higher (Ambos et al., 2008). Based on these considerations on the interactive nature of SIC, we propose that:

Proposition 3: *Interaction factors are relevant for the creation of follow-up cooperation.*

2.3 Outcomes interdependence

The three previous propositions suggest a relationship between a set of factors and a respective outcome. However, the SIC outcomes are not mutually exclusive but might dependent on each other or are co-generated. Previous conceptualisations show that science and technologies co-evolve and new knowledge generated from research can be utilised in multiple ways (Rosenberg & Nelson, 1994; Dasgupta & David, 1994; Murray, 2002). Therefore, research results from the SIC can be published as a scientific outcome at the same time become commercialised via patents or used in a new venture. In the similar way, follow-up engagements can develop at the same time. In particular, the reasons why a SIC is conducted allow for an assumption that multiple outcomes are in the scientist's interest and therefore enforced (Lee, 2000; Lam, 2011; D'Este & Perkmann, 2011; Tartari & Breschi, 2012). Based on the three types of outcomes, we discuss, in the following, potential interrelationships between them and derive a proposition for our empirical analysis.

We first look at the interdependence between research activities and commercial activities. Blumenthal et al. (1996) show that in life sciences, scientists who received industry support were more commercially active, filed more patents and published more. However, they find that a high amount of industry funding reduces the quantity and quality of publications. van Looy et al. (2006) show that scientists who patent also publish more and that both activities reinforce each other. In a similar way, Fabrizio and Minin (2008) identify for a sample of scientists across organisations a complementary effect between patenting and publishing. More specifically, Murray (2002) uses publication-patent pairs to understand how the same knowledge is used in a scientific and commercial setting. Correspondingly, Breschi and Catalini (2010) show that scientists who publish and patent act as gatekeepers and brokers between these two settings. This indicates that scientists frequently produce scientific and commercialisable outcomes which are interrelated and co-generated. However, several authors argue that scientific publishing and patenting do not necessarily go hand-in-hand. They refer to the problem of novelty when one applies for a patent. An idea is only considered novel in this context when it does not form part of state of art, defined by information publicly available before the filing date. A publication of the idea before the filing date would make this idea part of the state of the art. For that reason, the publication of scientific findings is often delayed or restricted in order to first apply for a patent or to allow commercialisation of the research (e.g. Florida & Cohen, 1999; van Looy et al., 2004). In the context of a SIC, a scientist would have to choose between publishing the results or filing for a patent if there is a novelty problem. This might especially be an issue outside the US, where the patent laws do not have a grace period for scientific publications. However, contractual agreements can solve such problems ex-ante via non-disclosure agreements scientists have to sign as Lee (2000) reports or other arrangements.

Second, we look at the relationship between scientific outcomes and follow-up cooperation. A co-occurrence is substantiated by the argument that the experience and knowledge gained from the SIC was beneficial for both sides (Lee, 2000). On the one hand, scientists who generate new knowledge want to continue research in this direction and seek to extend the SIC to conduct further research or secure their position and resources. On the other hand, firms are interested in sustaining an established collaboration in order to have further access to knowledge from the science partner. To have a basis for follow-up cooperation, the former SIC should have been successful for both the scientist and the firm. A core underlying condition to continue a SIC is trust that has been established in the collaboration (Gulati, 1995). Trust is more likely to emerge and be developed if the collaboration was successful. Furthermore, the generation of a scientific outcome leads to a situation where the actors want to explore the scientific outcome further and therefore continue their interaction (March, 1991). Especially for firms, there is a clear indication that the persistence of collaboration is important (Mora-Valentin et al., 2004) because that has a positive effect on firms' innovative performance (Belderbos et al., 2015). As a drawback of that, Zollo et al. (2002) show that repeated interactions can become routine, especially if the previous partner experience is positive. This may lead to a decline in innovativeness because with repeated collaboration knowledge becomes homogenised and with that its creative potential. As a result of this decline, the inclination of the SIC actors to go for follow-up cooperation declines (e.g. Porac et al., 2004; Guimerá et al., 2005; Skilton & Dooley, 2010).

For the third type of interdependence, between commercialisable outcomes and follow-up cooperation, similar arguments as in the case of scientific outcomes and follow-up cooperation can be put forward. Securing resources and position on the side of the scientists, access to knowledge from the side of the firms and mutual trust built up (Bstieler et al., 2015; Bellini et al., 2019), as well as previous success in generating commercialisable outcomes, are also driving factors. Moreover, the stage of development of the generated commercialisable knowledge may require further collaboration, allowing reciprocal access to the specific competencies and knowledge, including tacit elements (Lee, 2020). A case in point is when commonly generated knowledge is not ready for a full commercial application yet, and prototyping, as well as small-scale production, need to be pursued (Kline & Rosenberg, 1986). Similarly, to exploit the full potential of the commercialisable knowledge, partners have interests in further exploiting such knowledge commonly (March, 1991). However, there can also be cases where follow-up cooperation is not desired because one party wants to exploit the commercialisable idea on their own. Such cases could involve contract research where the underlying basis for collaboration was purely to generate knowledge for one party.

Based on the discussion of the three possible relationships between the three types of outcomes, we find, in general, support in the literature that there is a strong interdependence between the different types of outcomes and that the different outcomes are co-generated in a SIC. We, therefore, propose that:

Proposition 4: *Scientific outcomes, commercialisable outcomes and follow-up cooperation are co-generated.*

3 Data and methods

3.1 Data collection

To understand the outcomes from SIC and the factors that influence their emergence, we conduct a novel online survey of scientists at universities and research institutes in the Free State of Thuringia, Germany.[3] Thuringia's research landscape is very heterogeneous and consists of four universities, including one technical university and one university with a university hospital, as well as seven universities of applied sciences, including one music college. Furthermore, around 30 research institutes are present, covering the whole range from basic science-oriented institutes of the Max Planck Society, the Helmholtz Association and the Leibniz Association to the applied science institutes from the Fraunhofer Society, as well as other public and private research organisations. This variety

[3] The survey data was collected in a larger project and is also used in, e.g. Cantner et al. (2021). The full questionnaire consisted of different aspects of academic engagement: core knowledge and technology transfer channels, namely research collaboration, academic entrepreneurship and patenting where respondents were randomly assigned to one of these core channels to avoid selection bias, as well as academic mobility and engagement of scientists with broader society via public lectures and talks, books and others. Those respondents that could not find themselves in core transfer activities were also asked about their motivations to not engage in transfer activities.

of organisations assures a broad coverage of different disciplines and different modes of research and resembles the overall German research landscape. We collect publicly available information about scientists from the web pages of all these organisations. We identified 7,785 scientists and invited them to participate in our web-based survey between December 2019 and January 2020. We received 1,409 responses (18.1% response rate) in total.[4] Of these 1,409 respondents, 664 scientists indicated that they participated or are currently engaged in a SIC. Out of these scientists, we randomly assigned 234 scientists to a specific part of the survey where we asked them about the details of their SIC.

These 234 scientists received a novel set of questions on the nature of one specific collaboration project and its outcomes. We developed survey questions based on reviewed literature to capture the range of potential outcomes and characteristics of the collaboration. Furthermore, we discussed the survey with other scientists and practitioners from technology transfer offices who are involved in managing such collaborations. Following Sue and Ritter (2007), we conducted a pre-test with a random sample of scientists from a comparable German State to validate our developed survey questions. Besides the collaboration-specific questions, we elicited information on scientists' socio-demographic characteristics as well as their engagement in knowledge and technology transfer in general.

Moreover, we collected data on the respondents' publication records from Web of Science (WoS) and Scopus.[5] In addition, we collect information on the scientists' organisations.

3.2 Variables

Based on these data sources, we constructed the variables for our analysis. Descriptive statistics are presented in Table 1 and a correlation table in Appendix A.2.

3.2.1 Dependent variables: SIC outcomes

We use a new set of survey items in order to measure the outcomes of a particular SIC in which the scientist is engaged. In line with Arza (2010) and de Fuentes and Dutrénit (2012), we ask about five different outcomes. Following Garcia et al. (2019), we constructed the indicator variable *scientific outcomes* that captures if a scientific surplus from the collaboration, i.e. publications but also other scientific results, is generated. Second, we asked if the collaboration resulted in intellectual property rights (IPR), sales or license revenues and ideas for firm foundation. Since they capture different economic dimensions of the SIC outcomes, we aggregate these three outcomes as *commercialisable outcomes* via an indicator variable equal 1 if any of the outcomes was named. Third, we ask for ideas

[4] The difference between the sample of respondents and the initial population is marginal and non-response bias unlikely. We compared the key characteristics of position, gender, organisational focus and academic discipline of the full Thuringian population and respondents (Armstrong & Overton, 1977). There are some statistically significant differences between the academic disciplines, especially an under-representation of scientists from medicine. We believe that our initial data collection included many medical doctors with an affiliation with the university clinic but who are not involved in research anymore. Additionally, a comparison with the overall population of scientists at universities in Germany shows that our sample is representative in terms of academic rank and gender (Statistisches Bundesamt, 2020).

[5] Our primary source for publication data is WoS. If there is no publication record in WoS for a surveyed scientist, we queried Scopus which has a larger coverage esp. for social sciences and humanities. If again, there are no publications listed, we treat such cases as zero, which is plausible, especially for PhD scientists. By doing so, we potentially underestimate the influence of publication variables.

for *follow-up cooperation*, as suggested by Grimaldi and von Tunzelmann (2002) and de Fuentes and Dutrénit (2012), and create an indicator variable equal 1 if such ideas have been generated. The three groups of outcomes resemble the results of the three main reasons to engage in SIC (e.g. Lee, 2000; Lam, 2011). Namely, to obtain new research insights which result in *scientific outcomes*, economic rewards which can be derived from *commercialisable outcomes* and securing research funds and resources via *follow-up cooperation*. All three kinds of outcomes are measured as binary variables.[6]

The distribution of outcomes for the scientists is presented in Fig. 1. Most of the projects generate *scientific outcomes* (70%) as well as *follow-up cooperation* (67%). *Commercialisable outcomes* are generated in one-third of all projects.[7] Only 16% of respondents indicated that they had no outcomes from their collaboration. Table 2 shows the co-occurrence of the outcomes and that especially *scientific outcomes* and *follow-up cooperation* are generated jointly in a SIC. Also, a substantial share of SIC resulted in all three types of outcomes.

3.2.2 Independent variables: factors influencing SIC outcomes

In order to understand which factors influence the specific outcomes from a SIC, we construct several explanatory variables. We consider a number of characteristics that describe the scientists, their research environment and their involvement in the project and group them into scientific, economic and interaction factors.

We start with the individual scientists' research characteristics. First, the individual's research orientation is derived from the position in the Pasteur quadrant (Stokes, 1997). We constructed the position based on a self-assessment on a four-point Likert scale along two dimensions, the quest for fundamental understanding and the consideration of use, similar to Amara et al. (2019). Based on these two characteristics, we assign the respondents into the respective quadrant as *Pasteur*-, *Bohr*- and *Edison*-type scientists and *Undefined* scientists. The research orientation of the individual can have an influence on what kinds of outcomes they are looking for in a SIC. We assume that *Pasteur* scientists are capable of generating all three kinds of outcomes, *Edison* scientists are producing commercialisable outcomes as well as follow-up cooperation and *Bohr* scientists are mainly seeking scientific outcomes. We measure these orientations as binary variables with the *Undefined* scientist as reference. Second, we asked survey participants if they are the *principal investigator* of the SIC, since project leaders can have specific interests in follow-up cooperation (Cunningham et al., 2014). Third, we use the *number of publications* to account for the research activity and experience (Bikard et al., 2019), which is relevant for scientific outcomes. We log-transform the data for our estimation to reduce the skewness of the distribution. Fourth, based on the publication data, we construct the *share of collaborative papers* (D'Este et al., 2019; D'Este & Patel, 2007). The variable captures the share of papers in co-authorship with non-academic actors (not university or research institute), which reflects the scientist's experience with commercial actors and is relevant for commercialisable outcomes. Fifth, we asked for work *experience outside*

[6] The individual items for the outcomes can be found in Appendix A.1. If the respondents indicated that they do not know if there was a specific outcome, we treated them as having no outcome for this item because if they are not aware of any, they most likely did not receive such an outcome for themselves.

[7] In detail, 18% of respondents have generated intellectual property rights, 18% reported that the project created ideas for potential firm foundations, and 5% indicated that the project made a licensing revenue for his/her institution.

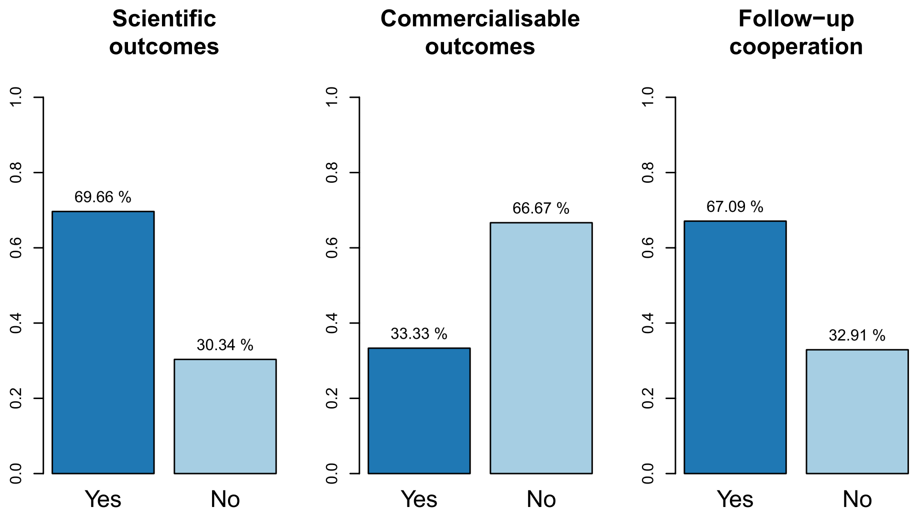

Fig. 1 Distribution of outcomes from science-industry collaboration

public science sector, since such experience can make scientists aware of commercialisable outcomes (Gulbrandsen & Thune, 2017). The variable is discrete and ranges from 0 - no experience to 4 - more than 10 years of experience. Sixth, we asked the participants to provide information about their realised transfer activities in terms of academic entrepreneurship, patenting and research collaborations. We combine this into *breadth of transfer experience*, and it consists of the sum of indicator variables capturing whether the respondent has conducted one of the transfer activities in the past five years and ranges from 0, no transfer experience except this one current collaboration, to 3, experience in all three listed activities (Bruneel et al., 2010). We argue that the more diverse their experience with previous transfer activity and economic actors, the more likely they are to generate commercialisable outcomes from SIC.

To characterise the research environment, we look at the type of research organisation and at the transfer environment. As to the former, the respondent's affiliation is categorised in three types of organisation: *basic research organisations*, such as the Max Planck institutes, the four *universities*, which are between basic and applied research organisations and *applied research organisations*, such as universities of applied sciences, Fraunhofer type institutes and others. We assign the organisations to these categories based on a classification by the German government (BMBF, 2014) (see Appendix A.3).[8] We assume that *basic research organisations* are decisive for scientific outcomes while *applied research organisations* are decisive for commercialisable outcomes. Furthermore, we construct three variables that proxy the transfer environment in which the scientists are embedded. For each scientist, we calculate the transfer activities his or her colleagues conducted in academic entrepreneurship, patenting and industry collaboration based on the overall respondents of our survey. In particular, we construct the *entrepreneurial environment*, *IPR environment* and the *collaborative environment* as the average of the other respondents' activities of the focal scientist being in the same faculty or research institute. With these variables, we can

[8] We approached scientists from 27 research institutes, and 18 are present in our sample.

Table 1 Descriptive statistics

Variable name	Factor group*	Description	Min	Mean	Max	STD	N
Dependent variables							
Scientific outcomes		Dummy: 1 - yes, 0 - no	0.00	0.70	1.00	0.46	234
Commercialisable outcomes		Dummy: 1 - yes, 0 - no	0.00	0.33	1.00	0.47	234
Follow-up cooperation		Dummy: 1 - yes, 0 - no	0.00	0.67	1.00	0.47	234
Independent variables							
Bohr	S	Dummy: 1 - Bohr-type scientist, 0 - otherwise	0.00	0.10	1.00	0.30	234
Edison	E, I	Dummy: 1 - Edison-type scientist, 0 - otherwise	0.00	0.41	1.00	0.49	234
Pasteur	S, E, I	Dummy: 1 - Pasteur-type scientist, 0 - otherwise	0.00	0.39	1.00	0.49	234
Undefined		Dummy: 1 - Undefined scientist, 0 - otherwise	0.00	0.10	1.00	0.30	234
Principal Investigator	I	Dummy: 1 - respondent is principal investigator, 0 - otherwise	0.00	0.50	1.00	0.50	234
Number of publications (log)	S	Logged number of publications	0.00	2.16	5.96	1.61	234
Share of collaborative papers	E	Share of collaborative papers with non-academic actors	0.00	0.20	1.00	0.26	234
Experience outside public science sector	E	Discrete: from 0 - no experience to 4 - more than 10 years	0.00	1.46	4.00	1.50	234
Breadth of transfer experience	E	Sum of dummies of experience in different transfer activities	0.00	0.66	3.00	0.71	234
Basic research organisation	S	Dummy: 1 - organisation with basic research focus, 0 - otherwise	0.00	0.12	1.00	0.32	234
University		Dummy: 1 - full university, 0 - otherwise	0.00	0.58	1.00	0.49	234
Applied research organisation	E	Dummy: 1 - organisation with applied research focus, 0 - otherwise	0.00	0.30	1.00	0.46	234
Entrepreneurial environment	E	Average of founded firms per scientist in faculty	0.00	0.15	2.00	0.19	234
IPR environment	E	Average of sold or licensed patents per scientist in faculty	0.00	0.18	2.44	0.30	234
Collaborative environment	I	Average of collaboration projects per scientist in faculty	0.00	1.65	8.89	1.62	234
Research collaboration	S	Dummy: 1 - research collaboration, 0 - contract research	0.00	0.76	1.00	0.43	234
Knowledge aim	S	Dummy: 1 - project aims to create basic knowledge, 0 - otherwise	0.00	0.43	1.00	0.50	234
Economic aim	E	Dummy: 1 - project aims to develop a product, service or process, 0 - otherwise	0.00	0.88	1.00	0.32	234
Known company partners	I	Dummy: 1 - at least one industry partner was known before the SIC, 0 - none	0.00	0.58	1.00	0.50	234
Controls							
Discipline		Dummy: 1 - Social Science, Humanities, Arts and Music, 0 - Science, Technology, Engineering, Mathematics and Medicine	0.00	0.15	1.00	0.36	234

Table 1 (continued)

Variable name	Factor group*	Description	Min	Mean	Max	STD	N
Female		Dummy: 1 - female respondent, 0 - otherwise	0.00	0.36	1.00	0.48	234
Academic position		Dummy: 1 - professor, 0 - otherwise	0.00	0.30	1.00	0.46	234
Finished project		Dummy: 1 - finished project, 0 - still active, unknown or abandoned	0.00	0.38	1.00	0.49	234

* ’S’- Scientific factor, ’E’ - Economic factor, ’I’ - Interaction factor

Table 2 Co-occurrence of SIC outcomes

	Scientific outcomes	Commercialisable outcomes	Follow-up cooperation
Scientific outcomes	23		
Commercialisable outcomes	13	4	
Follow-up cooperation	75	9	21
All three outcomes together: 52			
Projects without outcome: 37			

Note: Diagonal elements depict the number of projects that have only one type of outcome

account for the overall support, namely, the service from technology transfer offices and other circumstances that influence the scientist, such as heterogeneity across disciplines (D'Este & Patel, 2007). Accordingly, the *entrepreneurial environment* and the *IPR environment* should be relevant for commercialisable outcomes and the *collaborative environment* for follow-up cooperation.

On the project level, we asked the participants of the survey if they are engaged in a research collaboration or contract research (Cassiman et al., 2010). Research collaborations, especially, have the potential to generate scientific outcomes, since they are two-sided interactions and allow for research exploration (Levy et al., 2009; de Fuentes & Dutrénit, 2012). We construct an indicator variable *research collaboration* which indicates if the project is a research collaboration or if it is contract research.[9] Furthermore, we asked if the SIC aims at improving or developing a product, service or process or if it should contribute to the general knowledge base in terms of basic science. We create an indicator variable if any of the first three items were named to an *economic aim*, which indicates the target of commercialisable outcomes and the remaining one to a *knowledge aim*, indicating the target of scientific outcomes. These two indicator variables are not mutually exclusive for a respondent. Lastly, we take into account whether *known company partners* are involved in the collaboration. Since experience and trust play a larger role in collaboration, having previous experience working with the partners influences performance (Powell, 1996; Abramo et al., 2009; Garcia et al., 2020). The variable is coded 1 if the respondent worked with at least one company partner from the current SIC in the past and should increase the likelihood to generate follow-up cooperation.

3.2.3 Control variables

We control for several factors that can influence the outcomes of a collaboration. First, we control for the scientists' *discipline* (Tartari & Breschi, 2012). We separate social sciences, humanities, arts and music from science, technology, engineering, mathematics and medicine since the latter group is more attractive for transfer activities. Second, we control for whether the scientist is *female* or not, since a strong gender gap has been identified in the literature for formal (Tartari & Salter, 2015) as well as informal collaboration (Link et al., 2007). Third, we control for the *academic position* which influences the engagement

[9] In our survey, 15 respondents indicated that they do not know if the collaboration is a research collaboration or contract research. We imputed the variable based on the control variables following van Buuren and Groothuis-Oudshoorn (2011).

in collaboration (Link et al., 2007). We create a dummy variable if the respondent is a full professor, junior professor or private lecturer at a university or if the respondent is a director, head of department or head of a working group at a research institute. Lastly, we control if the collaboration project is a *finished project* or not. Unfinished projects are in most cases still ongoing, but some are abandoned.

3.3 Empirical approach

We use microeconometric approaches to understand the influence of the three groups of factors on SIC outcomes. Since we have more than one outcome variable, we consider a system of regression equations to test the relationship between the related variables jointly. As the outcome variables can be correlated, we need to account for this and rely on seemingly unrelated regression (SUR) models. A special case of SUR for binary dependent variables with more than two outcomes is the multivariate probit regression. Thus, we apply multivariate probit regression to estimate the relationships between dependent and independent variables, and we take into account the potential correlation of dependent variables (Cappellari & Jenkins, 2003; Greene, 2018). In this setup, the regressions for the three outcomes are estimated jointly. Given Y_S for scientific outcomes, Y_C for commercialisable outcomes and Y_F for follow-up cooperation, we estimate the following stylised regression system:

$$\begin{cases} Y_{S,i} = \beta_S X_{S,i} + \varepsilon_{S,i}, \\ Y_{C,i} = \beta_C X_{C,i} + \varepsilon_{C,i}, \\ Y_{F,i} = \beta_F X_{F,i} + \varepsilon_{F,i} \end{cases} \tag{1}$$

with $i = 1 \dots n$ scientists and X_i as vectors of outcome specific independent and control variables. ε_i are vectors of outcome-specific error terms. Due to the correlation in the dependent variables, the error terms are potentially correlated as well (see Eq. 2). The error terms account for the tetrachoric correlation between the outcomes across the equations and are multivariate normal with a mean of 0 and variance-covariance matrix with off-diagonal elements $\rho_{ij} = \rho_{ji}$. The error terms account for unknown variables that connect the outcomes.

$$\left(\begin{array}{c|c} \varepsilon_S & \\ \varepsilon_C & \mathbf{X} \\ \varepsilon_F & \end{array} \right) \sim N\left[\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho_{S,C} & \rho_{S,F} \\ \rho_{C,S} & 1 & \rho_{C,F} \\ \rho_{F,S} & \rho_{F,C} & 1 \end{pmatrix} \right] \tag{2}$$

4 Results

4.1 Main findings

On a descriptive level, Table 2 shows that 84% of the scientists report that their SIC generated at least one type of outcome. *Scientific outcomes* and *follow-up collaboration* are generated in about two third of all collaborations. Commercialisable outcomes are generated in every third project. Furthermore, in 64% of the SIC, at least two outcomes are generated and in 22% all three kinds of outcomes are generated, indicating strong co-generation among the outcomes. In particular, *scientific outcomes* and *follow-up collaboration* are frequently co-generated in about 54% of the projects. Given that at that point of the survey, only 38% of the SIC were finished, the responses indicate that SIC can have substantial benefits for the scientists.

For a more detailed understanding of the influence of factors on the respective outcomes in a SIC, we present in Table 3 multivariate probit estimations. We estimate two specifications, where Models 1a-1c include only the factors we deem relevant for the specific outcomes, so in Model 1a, we include only the scientific factors to explain the scientific outcomes and so forth. In Models 2a-2c, we include the full set of variables for the three outcomes, as there is little evidence in the literature on the clear relationships between factors and outcomes. We discuss the results in terms of the three propositions and the respective outcomes. Furthermore, the simultaneous estimation for the three outcomes also provides the remaining correlation between the outcomes, which we discussed in proposition four.

With respect to the *scientific factors* and their effect on the scientific outcomes, the estimation results in Table 3 show that many of them are relevant. In Model 1a, *Pasteur*-type scientists have a significantly higher likelihood of generating scientific outcomes while this is not the case for *Bohr*-type scientists compared to the other scientist-types.[10] In Model 2a, however, both types of scientists have significant coefficients. Furthermore, *Edison*-type scientists also have a significant coefficient in Model 2a. The *number of publications* is insignificant in Model 1a but significant in the full Model 2a. If the scientist is affiliated with a *basic research organisation*, it does not influence the generation of scientific outcomes. The *knowledge aim* of the project does not influence the generation of scientific outcomes. With respect to the collaboration type, if the SIC is a *research collaboration*, the likelihood of generating a scientific outcome is significantly higher compared to contract research projects in both specifications. Among the other factors in Model 2a, we additionally observe a significant negative effect of the *share of collaborative papers* on the likelihood of generating a scientific outcome. In light of our first proposition on the relevance of scientific factors, we find supporting evidence for several of the relevant variables.

The *economic factors* should be especially relevant for the generation of commercialisable outcomes. In Model 1b and 2b, the relevant scientist types *Pasteur* and *Edison* have no significant coefficients. The *share of collaborative papers* has significant coefficients in both models, as does the *breadth of transfer experience*. The *experience outside public science sector* is insignificant, as is an affiliation with an *applied research organisation* in both models. The research environment variables show opposite results. While the *entrepreneurial environment* has a positive significant effect on commercialisable outcomes, the *IPR environment* has a significant but negative coefficient in both models. The *economic aim* of the project has a significant, positive coefficient in Model 1b but is not statistically significant at the 10% level (p-value=0.127) in Model 2b. With respect to our second proposition that economic factors are relevant to generate commercialisable outcomes, our results show mixed evidence. Some factors are indeed relevant while several others are not relevant or are even detrimental to generate commercialisable outcomes.

The *interaction factors* are relevant for follow-up cooperation from SIC. In Model 1c and 2c, the coefficients for *Pasteur*- and *Edison*-type scientist are significant. The

[10] While interpreting the coefficients of the research orientation in Models 1a-c, one needs to keep in mind that the reference groups change. In Models 2a-c, it is always the undefined scientist.

Table 3 Multivariate probit estimation for the SIC outcomes

	Dependent variables					
	Scientific outcomes	Commercialisable outcomes	Follow-up cooperation	Scientific outcomes	Commercialisable outcomes	Follow-up cooperation
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Pasteur	0.491**	0.296	0.676***	1.085***	0.368	0.601**
	(0.192)	(0.270)	(0.250)	(0.333)	(0.376)	(0.312)
Bohr	0.133			0.636**	0.082	−0.328
	(0.274)			(0.382)	(0.469)	(0.410)
Number of publications (log)	0.062			0.195**	0.049	0.039
	(0.058)			(0.083)	(0.074)	(0.083)
Basic research organisation	−0.091			−0.064	0.084	−0.160
	(0.251)			(0.315)	(0.303)	(0.315)
Knowledge aim	0.059			0.034	0.015	0.035
	(0.170)			(0.187)	(0.188)	(0.190)
Research collaboration	0.418**			0.519**	−0.191	0.292
	(0.197)			(0.210)	(0.210)	(0.229)
Edison		−0.062	0.587**	0.826**	0.089	0.558**
		(0.267)	(0.248)	(0.343)	(0.376)	(0.321)
Share of collaborative papers		1.207***		−1.078***	1.021***	0.073
		(0.310)		(0.405)	(0.367)	(0.373)
Experience outside public sector		0.039		0.092	0.057	0.026
		(0.059)		(0.071)	(0.063)	(0.070)
Breadth of transfer experience		0.338***		0.220	0.304**	0.065
		(0.128)		(0.167)	(0.144)	(0.177)
Applied research organisation		−0.052		0.003	−0.176	−0.131
		(0.221)		(0.260)	(0.272)	(0.271)

Table 3 (continued)

	Dependent variables					
	Scientific outcomes	Commercialisable outcomes	Follow-up cooperation	Scientific outcomes	Commercialisable outcomes	Follow-up cooperation
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
Entrepreneurial environment		0.958**		−0.117	0.969**	−0.985**
		(0.459)		(0.464)	(0.468)	(0.526)
IPR environment		−0.522**		0.049	−0.582**	0.416
		(0.310)		(0.342)	(0.343)	(0.508)
Economic aim		0.631**		−0.432	0.564	−0.327
		(0.349)		(0.336)	(0.370)	(0.314)
Principal Investigator			0.415**	0.035	0.264	0.371**
			(0.201)	(0.202)	(0.212)	(0.212)
Collaborative environment			0.123**	−0.046	0.038	0.114
			(0.063)	(0.086)	(0.082)	(0.093)
Known company partners			0.172	0.163	0.262	0.239
			(0.182)	(0.198)	(0.192)	(0.200)
Discipline	−0.153	0.111	0.119	−0.141	0.171	0.123
	(0.244)	(0.258)	(0.260)	(0.281)	(0.286)	(0.290)
Female	−0.163	−0.480**	−0.624***	−0.036	−0.447**	−0.668***
	(0.186)	(0.193)	(0.190)	(0.192)	(0.198)	(0.192)
Academic position	−0.480**	−0.052	−0.525**	−0.695***	−0.155	−0.619**
	(0.207)	(0.199)	(0.217)	(0.247)	(0.232)	(0.247)
Finished project	0.455**	−0.046	0.330**	0.399**	−0.107	0.304
	(0.187)	(0.184)	(0.187)	(0.202)	(0.189)	(0.194)
Constant	−0.058	−1.498***	−0.251	−0.658	−1.757***	−0.102

Table 3 (continued)

	Dependent variables					
	Scientific outcomes	Commercialisable outcomes	Follow-up cooperation	Scientific outcomes	Commercialisable outcomes	Follow-up cooperation
	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)
	(0.246)	(0.467)	(0.250)	(0.550)	(0.679)	(0.559)
ρ_{2x}	0.415***			0.403***		
	(0.112)			(0.109)		
ρ_{3x}	0.459***	0.208		0.499***	0.204*	
	(0.103)	(0.126)		(0.104)	(0.122)	
Wald χ^2 (32) / (63)		103.28			163.56	
LL_0		−386.762			−369.917	
LL		−372.831			−355.777	
Observations		234			234	

Robust standard errors in parentheses. Significance levels at *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

coefficients for *principal investigator* have a positive significant coefficient in both models as well. The *collaborative environment* has a positive and significant coefficient in Model 1c but not in Model 2c. The connection with *known company partners* is insignificant in both models. Among the other factors, we find that the *entrepreneurial environment* has a significant negative effect on the likelihood of generating follow-up cooperation. Overall, for our third proposition, in which we state that interaction factors are relevant for follow-up cooperation, we find supportive evidence.

The control variables show differences between the outcomes. *Discipline* differences are insignificant for all three outcomes. Being a *female* scientist results in a significantly lower likelihood to generate commercialisable outcomes and follow-up cooperation, but there is no gender difference for scientific outcomes. The *academic position* has a negative and significant coefficient for scientific outcomes and follow-up cooperation but is insignificant for commercialisable outcomes. Lastly, the project's status in terms of a *finished project* is significant and positive for scientific outcomes and follow-up cooperation.

With respect to our fourth proposition on the *interdependence between outcomes*, the lower part of Table 3 depicts the ρ-s for the different correlations among the outcomes. These correlations of the residuals of the multivariate probit estimation, after accounting for our explanatory factors and control variables, can be used to interpret the relationships between the outcomes. We see from the positive, significant correlation $\rho_{2,1}$ in Model 1 and 2 that scientific outcomes are co-generated with commercialisable outcomes. Similarly, $\rho_{3,1}$ indicates a positive and significant correlation between scientific outcomes and follow-up cooperation. Such a strong co-generation was already indicated in the co-occurrence Table 2. For the third interdependence between commercialisable outcomes and follow-up cooperation, depicted by $\rho_{3,2}$, we see no significant correlation in Model 1 (p-value=0.100), but in Model 2, the positive correlation becomes significant at the 10% level (p-value=0.093) after controlling for all factors. For our proposition that the outcomes are co-generated, we find strong support for the co-generation of scientific outcomes with the other two outcomes, while commercialisable outcomes and follow-up cooperation seem to be less dependent on each other. Since all correlations are positive, we find no evidence that any outcomes are mutually exclusive.

4.2 Robustness test

The multivariate probit estimation allows us to capture and test the relationship between the outcomes in a system of equations. In addition to this main model, we conduct a robustness test to better understand the influence of the different factors as well as the interdependence between the outcomes. For this purpose, we estimate Eq. 1 not simultaneously but separately for each outcome as standard probit estimations. We estimate two models for each outcome (Table 4). First, we estimate the above-used Model 2a-c independently (Model 3a, 3b, 3c). Second, we include in each model the other two outcomes to account for the potential interdependence between the outcomes (Model 4a, 4b, 4c). We present for all models average marginal effects to better interpret the coefficients. Furthermore, to shed more light on the interdependence between the outcomes, we analyse the residuals of the regressions and calculate the correlation between the residuals without and with the outcomes included (Table 5).

The results for the scientific outcomes in Model 3a in Table 4 are comparable to the results in Model 2a in Table 3, except for the research orientation attributed to *Bohr*, which is not significant. If the other two outcomes are included in Model 4a, the results

Table 4 Robustness test: regression results of separate probit estimations for each SIC outcome

	Dependent variable					
	Scientific outcomes		Commercialisable outcomes		Follow-up cooperation	
	(3a)	(4a)	(3b)	(4b)	(3c)	(4c)
Scientific outcomes				0.203^{***}		0.228^{***}
				(0.244)		(0.228)
Commercialisable outcomes		0.188^{***}				0.051
		(0.242)				(0.236)
Follow-up cooperation		0.231^{***}		0.066		
		(0.224)		(0.241)		
Pasteur	0.306^{***}	0.253^{***}	0.116	0.041	0.169^{*}	0.080
	(0.326)	(0.344)	(0.344)	(0.358)	(0.322)	(0.338)
Bohr	0.183	0.210^{*}	0.037	−0.001	−0.086	−0.144
	(0.400)	(0.420)	(0.434)	(0.451)	(0.404)	(0.424)
Number of publications (log)	0.058^{**}	0.053^{**}	0.018	0.003	0.013	−0.005
	(0.082)	(0.086)	(0.079)	(0.081)	(0.082)	(0.086)
Basic research organisation	−0.017	−0.007	0.023	0.032	−0.055	−0.041
	(0.322)	(0.335)	(0.306)	(0.311)	(0.313)	(0.325)
Knowledge aim	0.010	0.004	0.008	−0.0005	0.008	0.005
	(0.194)	(0.204)	(0.190)	(0.196)	(0.197)	(0.205)
Research collaboration	0.138^{**}	0.142^{**}	−0.053	−0.095	0.081	0.049
	(0.220)	(0.234)	(0.220)	(0.228)	(0.227)	(0.240)
Edison	0.246^{**}	0.190^{**}	0.033	−0.038	0.173^{*}	0.089
	(0.329)	(0.344)	(0.351)	(0.366)	(0.328)	(0.342)
Share of collaborative papers	-0.303^{***}	-0.386^{***}	0.324^{***}	0.383^{***}	0.010	0.088
	(0.389)	(0.439)	(0.379)	(0.404)	(0.399)	(0.441)
Experience outside public sector	0.024	0.024	0.017	0.013	0.007	0.001
	(0.069)	(0.073)	(0.066)	(0.068)	(0.071)	(0.073)
Breadth of transfer experience	0.062	0.036	0.091^{*}	0.078^{*}	0.020	−0.004
	(0.167)	(0.178)	(0.153)	(0.157)	(0.163)	(0.169)
Applied research organisation	0.005	0.019	−0.047	−0.051	−0.034	−0.033
	(0.276)	(0.294)	(0.282)	(0.290)	(0.284)	(0.296)
Entrepreneurial environment	−0.037	−0.027	0.307^{*}	0.317^{*}	-0.292^{*}	-0.289^{*}
	(0.539)	(0.568)	(0.556)	(0.551)	(0.598)	(0.632)
IPR environment	0.019	0.040	−0.195	−0.190	0.108	0.122
	(0.415)	(0.433)	(0.419)	(0.409)	(0.566)	(0.647)
Economic aim	−0.151	−0.134	0.189^{*}	0.210^{*}	−0.103	−0.062
	(0.341)	(0.362)	(0.363)	(0.367)	(0.330)	(0.344)
Principal Investigator	0.009	−0.034	0.084	0.070	0.110^{*}	0.101^{*}
	(0.208)	(0.222)	(0.207)	(0.211)	(0.214)	(0.226)
Collaborative environment	−0.012	−0.024	0.012	0.012	0.029	0.036
	(0.088)	(0.093)	(0.088)	(0.091)	(0.095)	(0.103)
Known company partners	0.039	0.014	0.084	0.070	0.064	0.053
	(0.203)	(0.215)	(0.199)	(0.204)	(0.206)	(0.214)
Discipline	−0.039	−0.059	0.044	0.060	0.031	0.043
	(0.289)	(0.309)	(0.301)	(0.306)	(0.292)	(0.307)
Female	−0.021	0.064	-0.132^{**}	-0.116^{*}	-0.181^{***}	-0.176^{***}
	(0.199)	(0.222)	(0.202)	(0.210)	(0.200)	(0.210)

Table 4 (continued)

	Dependent variable					
	Scientific outcomes		Commercialisable outcomes		Follow-up cooperation	
	(3a)	(4a)	(3b)	(4b)	(3c)	(4c)
Academic position	-0.200^{***}	-0.150^{**}	−0.055	0.005	-0.182^{**}	-0.123^{*}
	(0.245)	(0.259)	(0.239)	(0.250)	(0.251)	(0.264)
Finished project	0.120^{*}	0.100^{*}	−0.035	−0.058	0.096	0.057
	(0.206)	(0.220)	(0.194)	(0.200)	(0.206)	(0.216)
Constant	−0.152	-0.291^{*}	-0.575^{***}	-0.651^{***}	−0.023	−0.099
	(0.580)	(0.631)	(0.618)	(0.637)	(0.580)	(0.614)
Log Likelihood	−123.413	−109.860	−127.349	−121.598	−119.155	−110.141
Akaike Inf. Crit.	290.826	267.719	298.699	291.195	282.309	268.282
Observations	234	234	234	234	234	234

Robust standard errors in parentheses. Coefficients are average marginal effects. Significance levels at $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

are qualitatively the same as in Model 2a. The two outcomes show both positive and significant coefficients, which supports the results from Model 2a that the correlations $\rho_{2,1}$ and $\rho_{3,1}$ account for the co-generation of the outcomes. For the commercialisable outcomes, there are slight changes in Model 3b and 4b. In both models, the *IPR environment* is not significant compared to Model 2b. Furthermore, in both models the variable *economic aim* is positive and significant, supporting the relevance of this economic factor. The inclusion of the two other outcomes shows a positive, significant coefficient for scientific outcomes and an insignificant coefficient for follow-up cooperation. These results are in line with the results from the multivariate estimation that $\rho_{2,1}$ captures the relationship between scientific and commercialisable outcomes. The weak significant correlation for $\rho_{3,2}$ in Model 2b is not confirmed, indicating that a significant relationship between the two outcomes does not exist. For the outcome of follow-up cooperation in Model 3c, we see no difference with respect to sign and significance compared to Model 2c, but for Model 4c, the coefficients for the *Edison*- and *Pasteur*-type scientist are insignificant. The inclusion of the other two outcomes mirrors the results from Model 4a and 4b, and a significant, positive coefficient for scientific outcomes exists and an insignificant one for commercialisable outcomes.

Turning to the correlation of the residuals from Models 3a-c without and Models 4a-c with the outcomes, the results are consistent with the correlations from the multivariate estimation in Model 2. There is a significant correlation in the residuals of the scientific outcomes and commercialisable outcomes as well as for scientific outcomes and follow-up cooperation and a weakly significant correlation between commercialisable outcomes and follow-up cooperation. After the inclusion of the respective outcomes, the significantly positive correlations of the residuals disappear and weakly significant negative correlations between scientific outcomes and the other two outcomes remain. The results indicate that the interdependency of the outcomes, and not a third variable that is not included in our estimation, accounts for most of the correlations in the residuals, providing support for our fourth proposition.

Table 5 Correlation of residuals from Models 3 and 4 (Table 4)

(a) Model 3 without outcomes			
	(3a)	(3b)	(3c)
(3a) Scientific outcomes	1		
(3b) Commercialisable outcomes	0.21***	1	
(3c) Follow-up cooperation	0.29***	0.12*	1
(b) Model 4 with outcomes included			
	(4a)	(4b)	(4c)
(4a) Scientific outcomes	1		
(4b) Commercialisable outcomes	−0.12*	1	
(4c) Follow-up cooperation	−0.15**	−0.03	1

Significance levels at *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5 Discussion and conclusion

We use novel survey data from scientists to empirically assess outcomes for scientists from science-industry collaboration (SIC) projects and test which factors influence the generation of these outcomes and if their emergence is interdependent. In detail, we provide a novel conceptualisation of the different kinds of outcomes from SIC projects and distinguish outcomes into scientific outcomes, commercialisable outcomes and follow-up cooperation (Grimaldi & von Tunzelmann, 2002; Arza, 2010; de Fuentes & Dutrénit, 2012; Albats et al., 2018). We conceptualise these outcomes based on key motives of scientists to engage in SIC in the first place (e.g. Lam, 2011; Lee, 2000). To understand how certain outcomes are generated, we build upon the general theory by Dasgupta and David (1994) who distinguishes between two logics for academia and industry, and we propose that scientific factors are particularly relevant for scientific outcomes and that economic factors are relevant for commercialisable outcomes. Furthermore, based on innovation network theory, we propose that interaction factors influence the generation of follow-up cooperation. Additionally, we follow the literature on the co-generation of science and technology and argue that outcomes are interdependent and co-generated (Rosenberg & Nelson, 1994; Dasgupta & David, 1994; Murray, 2002). To test our propositions, we conducted a novel survey among scientists in the German state of Thuringia who are part of a SIC project. We apply multivariate probit regressions to estimate the influence of the different groups of factors, as well as the interrelationships between the outcomes.

The majority of the scientists in our survey report at least one outcome from the SIC. Scientific outcomes are the most frequently stated ones. Scientists are highly interested in generating new knowledge or applying their knowledge in the SIC. Especially scientific publications are an important incentive in terms of career perspective and community reputation (e.g. Lam, 2011; Lee, 2000). Nearly as frequently, follow-up cooperation is reported as outcome. The high frequency is surprising but shows that follow-up cooperation is highly relevant for scientists but has been frequently overlooked when analysing SIC. Despite scientists relying on follow-up cooperation to finance their research activity, to gain access to external resources or to use them for signalling, in previous research, only Grimaldi and von Tunzelmann (2002) and de Fuentes and Dutrénit (2012) mentioned follow-up cooperation as a potential outcome. Commercialisable outcomes are reported by only one-third of the survey participants. This magnitude is comparable to the frequency reported by Ambos et al. (2008). However, given that only a bit more than one-third of the projects are finished, the number of outcomes is most likely understated. Furthermore, we observe that outcomes are frequently co-generated in the SIC and every fifth SIC generates all three kinds of outcomes. Such co-generation of scientific and technological knowledge is frequently observed in the literature (Rosenberg & Nelson, 1994; Dasgupta & David, 1994; Murray, 2002).

In our first proposition, we argue that *scientific factors*, which describe the academic environment and the scientists' activities and performance, influences the generation of scientific outcomes. Our results support such a relationship for most of the variables we consider. In particular, we use the Stokes (1997) concept of Pasteur's quadrant which shows that all scientist types increase the likelihood of generating a scientific outcome compared to the undefined scientist. In line with the finding that the number of publications also increases the likelihood of scientific outcomes, our results indicate that experienced and established scientists are more capable of producing scientific outcomes. However, being a tenured professor relates negatively to scientific outcomes, which provides some contradiction. We assume that well-skilled postdoctoral scientists who are not tenured yet could drive these results, since they require scientific outcomes for their career perspective and should be strongly motivated to generate scientific outcomes. Consistent with the results by Levy et al. (2009) and de Fuentes and Dutrénit (2012), we also find that collaborative research projects have a higher likelihood of resulting in scientific outcomes compared to contract research. However, we do not find that the project's aim to generate knowledge results in scientific outcomes. In SIC with such an aim, the industry partners may have expanded their knowledge base, but since we focus on the scientists' perspective, it would not be a direct output for the scientists. Furthermore, the type of organisation with which the scientists are affiliated does not influence the likelihood of scientific outcomes, although scientists in organisations who conduct basic research are particularly driven towards scientific outcomes. A similar pattern is mentioned by Perkmann et al. (2021) referring to academic engagement as driven by individual characteristics, rather than organisational factors. In general, our results show that even though SIC are seen as part of third mission activities to transfer knowledge into the application, the strong scientific orientation of the scientists allows them to generate scientific results from such interactions.

We find mixed results for the *economic factors* that we propose affect commercialisable outcomes. Contrary to the scientific outcomes, the scientists' types, academic rank and publication record do not influence the generation of commercialisable outcomes. Also, the type of organisation does not play a role, even though it is frequently argued that applied research organisations should be able to commercialise results better than others (Boardman & Ponomariov, 2009; D'Este & Patel, 2007). Also, work experience outside the public science sector is not relevant, contrary to the argument put forward that such experience increases the likelihood to identify commercial opportunities (Dietz & Bozeman, 2005; Gulbrandsen & Thune, 2017). However, we find strong evidence that the scientists' transfer experience and previous scientific interaction with industry increase the likelihood of generating commercialisable outcomes from SIC, supporting existing arguments in the literature that transfer experience matters (e.g. de Fuentes & Dutrénit, 2012; Bekkers & Freitas, 2010; Kauppila et al., 2015). The environment in which the scientists are embedded provides ambiguous results. While the environment in terms of the spin-off activity of faculty members increases the likelihood to generate commercialisable outcomes, the patenting activity of faculty members seems to reduce the likelihood. However, the latter result is not robust across all estimations. Generally, an environment conducive to transfer activities should increase the likelihood to generate commercialisable outcomes, since infrastructure and support facilities, such as technology transfer offices, are in place, reducing frictions in the process (Ambos et al., 2008), which we can partly support with our results. Additionally, an economic aim of the project increases the likelihood to generate a commercialisable result, which was already suggested by, e.g. Bodas Freitas and Verspagen (2017) and Alvarado-Vargas et al. (2017). Overall, our results provide a more nuanced picture of the relevant factors and indicate that factors related to a previous engagement with industry seem relevant, while factors related to the research activity do not matter.

With respect to the *interaction factors* that we propose are relevant to generate follow-up cooperation, we find partial support. We derive these factors from the innovation network literature, where trust for the individual relationship and embeddedness in a network are central for success and for maintaining a connection (Powell, 1996; Cantner & Graf, 2011; D'Este et al., 2013). However, we do not find that a collaboration with an already-known industry partner increases the likelihood to establish a follow-up cooperation. This can be explained as follows: in case the observed SIC is already a follow-up cooperation, decreasing returns from cooperation can be the reason that no further collaboration is beneficial (e.g. Zollo et al., 2002). At the same time, if scientists are embedded in an environment conducive for SIC, the likelihood to generate follow-up cooperation is increased. Similar to the argument put forward for the environment in the economic factors, routines and support infrastructure can be relevant to generate follow-up cooperation. Furthermore, the role of a principal investigator is relevant to generate follow-up cooperation. Principal investigators already established the collaboration and can be motivated to continue the SIC to maintain access to resources, to finance staff or to maintain their own position (Cunningham et al., 2014). Additionally, they bridge the economic and the scientific world and better understand the specific needs of the partner (Ambos et al., 2008). In a similar way, Pasteur scientists that are able to conduct fundamental research, which at the same time has a high consideration of use, and these scientists thus are more likely to generate follow-up cooperation. Our results also show that Edison-type scientists have a higher likelihood of generating follow-up cooperation. Both can be motivated to further exploit the SIC or to want to continue to apply their knowledge in industry. Overall, the interaction factors seem to be highly relevant to establish follow-up cooperation. However, we see some hints that repeating a cooperation for many iterations is not desirable.

While the previous results show how different factors influence the generation of outcomes, the descriptive results already indicate that *outcomes are co-created*. Our empirical results provide a fine-grained picture on the different relationships. First, our results provide strong support for a complementary relationship between scientific outcomes and commercialisable outcomes. In line with the argument that science and technology are co-created (Rosenberg & Nelson, 1994; Dasgupta & David, 1994; Murray, 2002), our results provide empirical evidence for the case of SIC. The results also relate to findings in related literature that scientists are motivated to engage in SIC for different reasons and aim for multiple outcomes (Lee, 2000; Lam, 2011; D'Este & Perkmann, 2011; Tartari & Breschi, 2012). Conflicts of interest between publishing results and patenting or other commercial application seem not to exclude the two kinds of outcomes, as discussed in previous research (e.g. Florida & Cohen, 1999; van Looy et al., 2004). Most likely, the contractual nature of the SIC regulates the usage of outcomes ex-ante. Second, we also find strong support for the co-generation of scientific outcomes and follow-up cooperation. Lee (2000) already found in his survey that interactions that were beneficial for the participants were likely to be repeated. Trust that is established in the interaction can be an underlying mechanism for the co-generation of these outcomes (Gulati, 1995). Also, the derived scientific outcomes can motivate the partners to further explore them and therefore continue the SIC (March, 1991). For the industry actors, the inflow of knowledge can increase their performance, and repeated collaboration can become a routine (Belderbos et al., 2015; Zollo et al., 2002). Third, we find only weak evidence that commercialisable outcomes and follow-up cooperation are co-generated. Even though there is the argument that commercialisable results could be further exploited by the partners (March, 1991) and that there is empirical evidence for such an interactive process of sequential technological development (Kline & Rosenberg, 1986; Lee, 2020), collaboration partners might decide to part because the initial aim of the research is fulfilled. Furthermore, different opinions on how to exploit the commercialisable outcomes might reduce the likelihood for co-generation. Also, the specific nature of the commercialisable outcome can be relevant. While further interaction could be necessary for the idea to found a firm, for generated patents and license revenues, such interaction is not necessary. However, there is no indication that the two outcomes exclude each other. In summary, while there is a strong co-generation between scientific outcomes and the other two types of outcomes, the dependency between commercialisable outcomes and follow-up cooperation is inconclusive.

With our paper, we contribute to economic theory, firstly, by proposing a holistic perspective on SIC outcomes. Our results show that SIC can generate multiple outcomes that resemble the motivations to engage in such interactions. Moreover, we put forward follow-up cooperation as a highly relevant outcome, which has been previously neglected in studying the benefits from SIC. Second, we make a methodological contribution by accounting for interdependence between the SIC outcomes and applying a multivariate probit model. We find that in many cases outcomes are co-generated and there are no signs that a trade-off has to be made between the outcome – quite the opposite. Especially, scientific outcomes show a high tendency to be co-generated with the other outcomes. Such interdependence is highly relevant to understand why scientists engage in such activity and also to assess the success of SIC. Some studies already show positive effects of commercialisation on scientific outcomes (e.g. Hottenrott & Lawson, 2017). However, we were able to depict this within the framework of one SIC project of scientist. Third, we explore the impact of the scientific, economic and interaction factors on the SIC outcomes guided by general propositions. The generation of outcomes is influenced by several factors which relate to the outcomes' underlying nature. Both the scientists' characteristics and their environment are decisive to generate outcomes, whereas the duality proposed by Dasgupta and David (1994) explains well the different factors. Furthermore, accounting for factors that resemble the interactive dimension of SIC is highly relevant to generate follow-up cooperation. This latter point links to the research on university-industry networks and the dynamics in such networks. Only if there is a benefit for the actors will the connection be sustained, increasing the stability in the network. Considering such relationships, as well as the embeddedness in the general, the collaborative environment is highly important for our understanding of SIC.

Our results have implications for policymakers and science management. Policymakers need to design support instruments in a way that desired outcomes can be generated. Our analysis on the factors provides starting points for which criteria may be relevant and which might have a higher impact than others. Furthermore, the strong co-generation of scientific outcomes with other outcomes needs to be taken into account. Supporting a strong scientific base in a collaboration can be named here. Additionally, raising actors' awareness of multiple outcomes and supporting the co-generation of outcomes should be in the interests of policymakers and science management. For example, specific funding could be provided to exploit generated knowledge for commercial application, or technology transfer offices could be harnessed to make the actors aware and help to identify commercialisable outcomes or to establish follow-up cooperation. Lastly, the different outcomes should be considered jointly in evaluations and cost-benefit assessments of SIC. Without taking into account the different outcomes and their co-generation, externalities from SIC would be not considered.

There are several limitations to our analysis and starting points for follow-up research. First, we do not capture the realised outcomes in terms of quality or quantity. A more nuanced view on the outcomes, preferably over time, would allow a better assessment of their relevance and impact on scientists, firms and society. This holds also true for the interrelationship between the outcomes. Thus, a second limitation is that we can only look at their correlation but not at their causal structure. Even though one can assume that scientific outcomes provide the starting point for commercialisable outcomes and follow-up cooperation, a detailed analysis is necessary. Third, we are only able to capture a limited number of potential factors, and a more detailed analysis – which also directly considers the motives behind the implementation of SIC – can provide more insights into why certain outcomes are generated. Lastly, we only consider the perspective of the scientists. Conducting a similar survey among the industry partner involved in the SIC can provide a different perspective on SIC and its full management (de Wit-de Vries et al., 2019; Goel et al., 2017).

Appendix

A.1 Survey items

See in Table 6.

Table 6 Survey questions for SIC outcomes

Please answer the following questions related to the general outcomes of this cooperation. This cooperation has generated	Yes	No	No answer
... ideas for potential follow-up cooperation projects with my organisation	○	○	○
... intellectual properties (e.g. patents)	○	○	○
... sales or license revenue for my organisation	○	○	○
... a scientific surplus (incl. publications)	○	○	○
... ideas for potential firm foundations	○	○	○

A.2 Correlations

See in Table 7.

Table 7 Pearson pairwise correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13
(1) Scientific outcomes													
(2) Commercialisable outcomes	0.21*												
(3) Follow-up cooperation	0.35*	0.17*											
(4) Bohr	−0.03	−0.05	−0.23*										
(5) Edison	0.00	−0.03	0.13*	−0.27*									
(6) Pasteur	0.13*	0.12	0.08	−0.27*	−0.67*								
(7) Undefined	−0.18*	−0.09	−0.12	−0.11	−0.28*	−0.27*							
(8) Principal Investigator	0.05	0.10	0.18*	−0.07	−0.02	0.06	0.00						
(9) Number of publications (log)	0.07	0.13	−0.05	0.17*	−0.23*	0.07	0.10	0.07					
(10) Share of collaborative papers	−0.10	0.20*	−0.01	−0.03	0.04	0.00	−0.04	−0.04	0.36*				
(11) Experience outside public science sector	0.07	0.05	0.07	−0.11	0.04	0.06	−0.05	0.14*	−0.24*	−0.12			
(12) Breadth of transfer experience	0.15*	0.21*	0.21*	−0.17*	0.02	0.14*	−0.10	0.22*	0.10	0.05	0.10		
(13) Basic research organisation	0.01	0.06	−0.09	0.15*	−0.08	−0.02	0.01	−0.20*	0.19*	0.15*	−0.12	−0.05	
(14) University	0.00	0.03	−0.04	0.05	−0.07	0.01	0.06	0.01	0.20*	0.02	−0.09	−0.03	−0.43*
(15) Applied research organisation	−0.01	−0.07	0.11	−0.16*	0.14*	0.00	−0.07	0.13*	−0.34*	−0.12	0.18*	0.07	−0.24*
(16) Entrepreneurial environment	0.01	0.09	−0.12	0.09	−0.11	0.03	0.04	−0.14*	0.13*	0.07	−0.01	−0.04	0.26*
(17) IPR environment	0.07	−0.01	0.11	−0.08	−0.05	0.10	0.00	0.10	0.09	0.02	−0.02	0.31*	−0.01
(18) Collaborative environment	0.06	0.03	0.21*	−0.14*	0.15*	0.01	−0.12	0.19*	−0.08	−0.06	0.01	0.40*	−0.10
(19) Research collaboration	0.13	−0.03	0.05	0.05	−0.01	0.00	−0.04	−0.02	0.17*	0.09	−0.13	0.00	0.01
(20) Knowledge aim	0.04	−0.01	0.02	0.06	−0.03	0.03	−0.06	0.03	−0.04	0.00	0.03	−0.10	−0.01
(21) Economic aim	−0.06	0.14*	0.00	−0.11	0.14*	−0.04	−0.05	−0.01	0.01	0.00	−0.10	0.17*	−0.08

Table 7 (continued)

	1	2	3	4	5	6	7	8	9	10	11	12	13
(22) Known company partners	0.11	0.15*	0.19*	−0.15*	0.02	0.12	−0.08	0.19*	0.04	0.03	0.02	0.20*	0.07
(23) Discipline	−0.11	−0.05	−0.08	−0.02	0.01	−0.05	0.09	−0.10	−0.17*	−0.03	0.07	−0.20*	−0.08
(24) Female	−0.08	−0.16*	−0.23*	−0.04	−0.06	0.07	0.04	−0.05	−0.08	0.06	−0.12	−0.11	−0.02
(25) Academic position	−0.09	−0.01	−0.11	0.06	−0.11	0.08	−0.01	0.28*	0.36*	0.05	0.08	0.02	−0.09
(26) Finished project	0.14*	0.00	0.16*	−0.08	0.06	−0.02	0.02	0.13*	0.00	−0.02	0.03	0.17*	−0.04
	14	15	16	17	18	19	20	21	22	23	24	25	26
(1) Scientific outcomes													
(2) Commercialisable outcomes													
(3) Follow-up cooperation													
(4) Bohr													
(5) Edison													
(6) Pasteur													
(7) Undefined													
(8) Principal Investigator													
(9) Number of publications (log)													
(10) Share of collaborative papers													
(11) Experience outside public science sector													
(12) Breadth of transfer experience													
(13) Basic research organisation													
(14) University													
(15) Applied research organisation	−0.78*												
(16) Entrepreneurial environment	0.04	−0.22*											
(17) IPR environment	−0.17*	0.19*	0.30*										
(18) Collaborative environment	−0.43*	0.54*	0.00	0.54*									

Table 7 (continued)

	14	15	16	17	18	19	20	21	22	23	24	25	26
(19) Research collaboration	0.05	−0.07	0.06	0.00	−0.01								
(20) Knowledge aim	−0.02	0.03	0.07	0.00	−0.04	0.08							
(21) Economic aim	0.07	−0.02	−0.08	−0.06	0.08	−0.01	−0.20*						
(22) Known company partners	−0.24*	0.21*	−0.06	0.09	0.19*	−0.05	0.04	−0.04					
(23) Discipline	0.17*	−0.13	0.02	−0.15*	−0.32*	−0.15*	−0.01	−0.25*	−0.11				
(24) Female	0.03	−0.02	−0.03	−0.04	−0.09	−0.01	−0.02	−0.12	−0.07	0.07			
(25) Academic position	0.00	0.07	0.00	0.09	0.02	0.09	0.01	−0.11	0.00	0.05	−0.03		
(26) Finished project	−0.04	0.07	0.05	0.18*	0.13*	−0.03	0.01	−0.02	0.13	−0.07	−0.10	0.07	

Significance level at * $p < 0.05$

A.3 Organisation information

See in Table 8.

Table 8 List of organisations and their research focus

Organisation	Type of organisation
Leibniz-Institut für Alternsforschung - Fritz-Lipmann-Institut e.V.	Basic research organisation
Leibniz-Institut für Naturstoff-Forschung und Infektionsbiologie Hans-Knöll-Institut	Basic research organisation
Leibniz-Institut für Photonische Technologien	Basic research organisation
Max-Planck-Institut für Chemische Ökologie	Basic research organisation
Max-Planck-Institut für Menschheitsgeschichte	Basic research organisation
Bauhaus-Universität Weimar	University
Friedrich-Schiller-Universität Jena	University
Technische Universität Ilmenau	University
Universität Erfurt	University
Duale Hochschule Gera-Eisenach	Applied research organisation
Ernst-Abbe-Hochschule Jena	Applied research organisation
Fachhochschule Erfurt	Applied research organisation
Forschungsinstitut für Mikrosensorik	Applied research organisation
Forschungszentrum für Medizintechnik und Biotechnologie	Applied research organisation
Fraunhofer-Institut für Angewandte Optik und Feinmechanik	Applied research organisation
Fraunhofer-Institut für Keramische Technologien und Systeme	Applied research organisation
Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung Institutsteil Angewandte Systemtechnik	Applied research organisation
Friedrich-Loeffler-Institut für bakterielle Infektionen und Zoonosen	Applied research organisation
Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung	Applied research organisation
Hochschule für Musik Franz Liszt Weimar	Applied research organisation
Hochschule Nordhausen	Applied research organisation
Hochschule Schmalkalden	Applied research organisation
Innovent	Applied research organisation
Institut für Angewandte Bauforschung	Applied research organisation
Institut für Bioprozess- und Analysenmesstechnik Heiligenstadt	Applied research organisation
Institut für Mikroelektronik- und Mechatronik-Systeme	Applied research organisation
Materialforschungs- und -prüfanstalt	Applied research organisation
SRH Hochschule für Gesundheit	Applied research organisation
Thüringisches Institut für Textil- u. Kunststoff-Forschung	Applied research organisation

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