Facilitating Effective Science-Industry Collaborative Research: A Literature Review

RESEARCH ARTICLE

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Abstract

Existing research indicates that science-industry collaborative research might be a powerful source of innovation and an important factor of high innovation performance and economic growth. Although a number of public policy initiatives promote collaborative research, its potential is still not being adequately reached. This paper presents a review of existing literature on science-industry collaborative research. It elaborates and discusses motives and determinants of collaborative research, and identifies obstacles to joint science-industry research, from both the companies' and public research organizations' perspective. Based on the literature review, the paper provides recommendations for innovation policies.

Keywords: innovation, science-industry link, collaborative research, knowledge and technology transfer

JEL classification: O31

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1 Introduction[1]

Cooperation between science and industry (hereafter *S-I collaboration*)[2] is one of the most important elements of the innovation system and a factor that could lead to high innovation performance, company success and economic growth (OECD, 2002; Fontana, Geuna and Matt, 2006; Azagra-Caro, Carat and Pontikakis, 2009; Muscio, 2010; Arvanitis, Kubli and Woerter, 2011; Arza and López, 2011; Ankrah et al., 2013). S-I collaboration is increasingly seen as a driver of innovation through knowledge exchange (Ankrah and Al-Tabbaa, 2015), and as such it is in the focus of innovation policies in EU countries (Perkmann and Walsh, 2007; Švarc, 2011; Švarc and Dabić, 2017). Although a number of public policy initiatives promote S-I collaboration (Radosevic, 2011), its potential is still not being adequately reached, especially in less developed economies (Kalar and Antončič, 2015). There is a consensus that S-I cooperation needs to be improved, and knowledge and technology transfer has to be intensified (Arvanitis, Kubli and Woerter, 2011).

S-I collaboration has attracted considerable attention in academic literature (Bučar and Rojec, 2015). Although S-I interactions have been explored from different perspectives (D'Este and Patel, 2007; Perkmann and Walsh, 2007; Raesfeld et al., 2012), accumulated knowledge on this topic is still fragmented (Ankrah and Al-Tabbaa, 2015). Among S-I interactions, collaborative research between science and industry is one of the most important and effective channels for conveying scientific knowledge to industry (Roessner, 1993; Schartinger, Schibany and Gassler, 2001; Perkmann and Walsch, 2007). Collaborative research is the research where several parties are engaged in achieving shared objectives and collectively build on their individual backgrounds in the creation of new knowledge. That research includes collaboration between universities and public research organizations on the one hand, and industries, small and medium

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[2] *University-industry collaboration refers to any type of cooperation between universities, their researchers and companies in order to jointly develop new goods/services or improve existing goods/services.*

enterprises, and other research and technology organizations on the other hand (Borrell-Damian, Morais and Smith, 2014). Collaborative research can range from small-scale, temporary projects to large-scale projects, often subsidized by public policy programs (Perkmann and Walsh, 2007).

A considerable body of research has examined various aspects of S-I collaborative research from the point of view of both firms and public research organizations, including motives and benefits, characteristics decisive for cooperation and obstacles to cooperation (D'Este and Patel, 2007). In light of facilitating effective knowledge and technology transfer, recent studies examine technology transfer offices (TTOs) within universities and public research organizations, which are strongly encouraged and supported by regional and national policy initiatives (Borrell-Damian, Morais and Smith, 2014). The main issue in this stream of literature is to identify the drivers of joint research and explore how this collaboration might be improved (Borrell-Damian, Morais and Smith, 2014). Despite the vast spectrum of literature dealing with strengthening and boosting S-I cooperation, the subject of collaborative research with public research organizations deserves more attention.

This paper presents a review of existing studies on S-I collaborative research and explores the motives behind cooperation, benefits and other collaborative factors. It also identifies problems and obstacles to cooperation, and proposes recommendations for innovation policies.

This study adds to the existing research in several ways. It identifies drivers, benefits and obstacles of collaborative research from the perspective of both firms and public research organizations, bringing together these two strands of literature. Namely, there is no definite conclusion about the factors that drive S-I collaboration, as most of the existing literature has examined S-I collaboration from a broader perspective. Furthermore, there are just a few papers that deal with S-I collaborative research (e.g., Borrell-Damian, Morais and Smith, 2014; Empirica, 2014)[3], which differs from other modes

[3] *S-I modes of collaboration might include, e.g., joint research, contract research, mobility and training, consultancy, contract research and "spin-off" companies (Perkmann and Walsh, 2007).*

of collaboration in several ways. These differences include higher risk and uncertainty related to research agreements due to more ambitious research targets, and a higher rate of unpredictability of outcomes and activities. The management and planning of joint research activities is more challenging as well (Siegel, Waldman and Link, 2003; Morandi, 2013).

This paper could be interesting to researchers and policy-makers in Croatia since there are few studies by Croatian authors that have examined S-I linkages (e.g., Švarc, Grubišić and Sokol, 1996; Švarc and Lažnjak, 2003; Švarc, 2014; Radas and Vehovec, 2006; Radosevic, 2011; Jeleč Raguž, Budimir and Letinić, 2015). At the same time, the efforts of the Croatian government to establish a proper framework for S-I cooperation have not yielded expected and visible economic effects. S-I collaboration is weak[4], and public R&D infrastructure is not adjusted to firms' technology upgrading needs (Račić, Radas and Rajh, 2004; Radas, 2005; Švarc, 2014; Radosevic, 2016).[5] As Croatia is currently in a transition stage towards innovation-driven growth (Radosevic, 2011), more understanding is needed on how to strengthen S-I collaborative research.

The paper is organized as follows. Section 2 presents the methodology. Section 3 examines the factors that drive S-I collaborative research from the companies' viewpoint, while section 4 deals with S-I collaborative research issues from the public research organizations' point of view. Section 5 concludes the paper with main implications and recommendations for innovation policies.

[4] The study by Jeleč Raguž, Budimir and Letinić (2015) suggests that the share of joint research in total S-I cooperation in Croatia is about 10-25 percent.

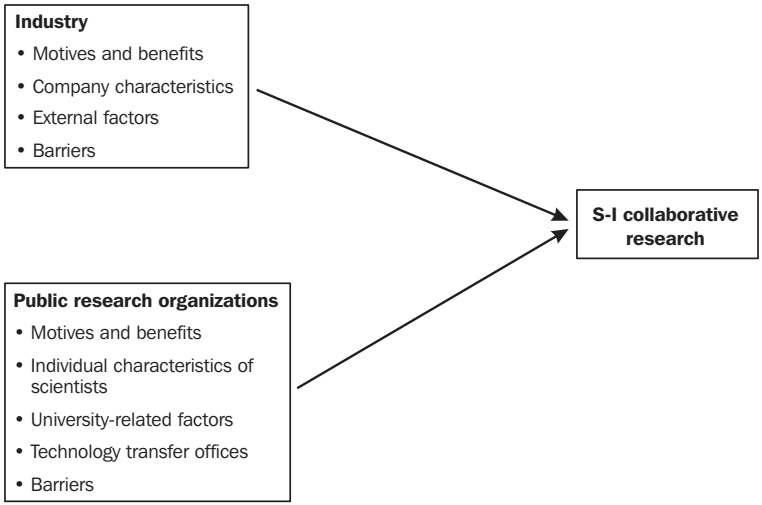
[5] In general, in less developed countries, S-I collaboration typically involves low-level industrial innovation and consultancy, while industry aims to adapt and upgrade imported technology rather than undertake R&D (Pinho and Fernandes, 2015).

2 Methodology

The literature review was conducted using a procedure commonly used in earlier research (Perkmann and Walsh, 2007; Perkmann et al., 2013). First, relevant keywords for literature search were identified. Search for the titles of published, peer-reviewed academic journals (full papers only) on the topic was conducted in several bibliographical databases, including EBSCO (Business Source Complete, EconLit with Full Text, CAB abstracts), Web of Knowledge and ScienceDirect. A manual search of top-ranked journals in the field over the past 20 years was conducted as well, including *Research Policy*, *Technovation* and *Journal of Technology Transfer*. Only articles published in English and Croatian were taken into account. Complementary information was taken from reports by the European Union, OECD, government agencies and research organizations. Papers by Croatian authors were additionally searched by using databases Hrčak (Portal of Scientific Journals of Croatia) and CROSBI (Croatian Scientific Bibliography). Searching criteria included the titles of papers and keywords. Keywords used were: "science/university collaboration/cooperation", "collaborative research", "knowledge and technology transfer", "technology transfer offices". The search using these terms initially generated a large number of studies, more than 3,000 results. For final analysis, only those papers were selected that focus on S-I collaborative research, as well as those that examine S-I collaboration from a broader perspective and include S-I collaborative research as one of the modes of collaboration. The analyzed papers explored motives, collaborative factors and obstacles to S-I collaborative research. The final list of studies that were relevant for this research and had the sufficient quality included 72 papers.

Figure 1 presents the framework used in this study. The paper examines collaborative factors, i.e., motives, benefits and other factors that were recognized in previous literature as having an effect on S-I collaborative research from the industry and public research organization point of view.

Figure 1 **Conceptual Framework**



Source: Author's compilation.

3 Companies' View on S-I Collaborative Research

3.1 Motives and Benefits

Previous research has examined and identified various motives of companies to engage in collaborative research with public research organizations. The list is quite long. Although motives differ from study to study, a few of them persistently appear to be important. According to Borrell-Damian, Morais and Smith (2014), key motives for companies to engage in collaborative research projects include strengthening their R&D capacity and increasing their competitive advantage. Further motives include applying research developed in academia to solve industrial challenges, develop new innovative products or improve existing ones. Having access to academic expertise and working with high-profile institutions with strong research capacity in areas relevant for the company are also shown to be relevant motives for companies (Borrell-Damian, Morais and Smith, 2014). According to Ankrah and Al-Tabbaa (2015), motivations for industry include necessity factors (i.e., responsiveness to government initiatives), reciprocity (i.e.,

hiring faculty members and students), efficiency (i.e., commercialization of findings, cost savings, human capital development), stability (i.e., access to new knowledge, technology, expertise, research networks, risk reduction), legitimacy (i.e., enhancement of the corporate image) and asymmetry (i.e., maintaining control over proprietary technology).

Caloghirou, Tsakanikas and Vonortas (2001) examine joint research projects in the context of European framework programs. They find several main reasons for companies to collaborate with universities, such as achieving synergies in research, keeping track of technological developments more easily and splitting research costs. The studies of Minarelli, Raggi and Viaggi (2015) and Maietta (2015) show that firms collaborate in order to access government funding and new ideas, and develop their own internal expertise. As most collaborative research is subsidized by public funds, participation in joint research projects lowers the costs for companies. Similar motives are also found in other studies (e.g., Fontana, Geuna and Matt, 2006; Decter, Bennett and Leseure, 2007; Ankrah et al., 2013).

Motives for collaboration are very often regarded as being similar to benefits obtained from collaboration. Companies benefit from collaborative activities in a way that they enhance their knowledge base, which might help them improve production processes and develop new products (Caloghirou, Tsakanikas and Vonortas, 2001; Radas, 2005). According to Ankrah et al. (2013), the most frequently mentioned benefits for industry actors include conducting more cost-effective research than in similar in-house research, improved innovative capacity, keeping up-to-date with technological developments, acquiring solutions to specific technological problems, and access to a wider network of research expertise. Similar benefits are found also in Fontana, Geuna and Matt (2006) and Decter, Bennett and Leseure (2007). According to Ankrah and Al-Tabbaa (2015), the outcomes of S-I collaboration are economic-related (i.e., new or improved products/processes, patents), institutional-related (i.e., improved innovative ability, training) and/or social-related (enhanced reputation by becoming a more socially responsible business).

3.2 Collaborative Factors

Collaborative factors examined in this study are company characteristics and external factors that might drive S-I collaborative research. Although the list of these factors is long, there is no definitive conclusion on their impact on S-I collaborative research. The most frequently mentioned collaborative factors in previous research are given in Table 1.

Table 1 **Collaborative Factors**

Factor	Impact
Industrial sector/company's activity	• Positive impact for companies operating in biotechnology, information technology and pharmaceutical industry (e.g., Veugelers and Cassiman, 2005; Fontana, Geuna and Matt, 2006; Perkmann and Walsh, 2007; Arvanitis, Kubli and Woerter, 2011)
Company's size	• Positive impact: Caloghirou, Vonortas and Tsakanikas (2000); Schartinger, Schibany and Gassler (2001); Fritsch (2003); Mohnen and Hoareau (2003); Capron and Cincera (2003); Laursen and Salter (2004); Veugelers and Cassiman (2005); Schmidt (2005); Fontana, Geuna and Matt (2006); Božić (2007); Arvanitis, Kubli and Woerter (2011)
Company's age	• Positive impact: Arvanitis, Kubli and Woerter (2011) • No relationship: Schartinger, Schibany and Gassler (2001); Laursen and Salter (2004) • Start-ups have a higher probability of benefiting from academic research (Fontana, Geuna and Matt, 2006)
Legal status	• Positive impact for independent companies: Fontana, Geuna and Matt (2006)
Foreign ownership	• Negative impact: Fontana, Geuna and Matt (2006)
Company's long-term orientation	• Positive impact: Laursen and Salter (2004); Capron and Cincera (2003)
R&D intensity	• Positive impact: Fritsch (2003); Capron and Cincera (2003); Laursen and Salter (2004); Schmidt (2005); Fontana, Geuna and Matt (2006); Božić (2007); Arvanitis, Kubli and Woerter (2011) • No relationship: Mohnen and Hoareau (2003)
Human capital intensity	• Positive impact: Arvanitis, Kubli and Woerter (2011)
Patenting	• Positive impact: Mohnen and Hoareau (2003); Capron and Cincera (2003); Schmidt (2005)
High risk	• Negative impact: Fontana, Geuna and Matt (2006)
High innovation costs	• Positive impact: Veugelers and Cassiman (2005); Fontana, Geuna and Matt (2006)
Strategic protection methods	• Negative impact: Schmidt (2005)
Organizational and institutional obstacles	• No relationship: Arvanitis, Kubli and Woerter (2011)
Geographical distance	• Negative impact: Rosa and Mohnen (2008)
Degree of openness of the company	• Positive impact: Schmidt (2005); Fontana, Geuna and Matt (2006); Božić (2007)
Government support	• Positive impact: Mohnen and Hoareau (2003); Capron and Cincera (2003)
International competition	• Positive impact: Arvanitis, Kubli and Woerter (2011)

Source: Author's compilation.

Previous studies indicate that the companies' propensity to cooperate with the academic community varies across industrial sectors. Companies tend to rely on collaborative research in the above-average innovative industries, for example in the pharmaceutical, biotechnology or chemical industries (Veugelers and Cassiman, 2005; Fontana, Geuna and Matt, 2006; Perkmann and Walsh, 2007; Arvanitis, Kubli and Woerter, 2011). Companies that are engaged in basic exploratory research, have a higher knowledge base and introduce more advanced innovations tend to cooperate more with universities (e.g., Giuliani and Arza, 2009).

Several studies have showed that the company's size (the number of employees or R&D employment) is positively related to S-I cooperation (Schmidt, 2005; Capron and Cincera, 2003; Mohnen and Hoareau, 2003; Fritsch, 2003; Veugelers and Cassiman, 2005; Fontana, Geuna and Matt, 2006; Božić, 2007; Arvanitis, Kubli and Woerter, 2011). Larger companies, as compared to small companies, have more financial and human resources, as well as technological capabilities necessary to develop cooperation with public research organizations (Radas, 2005; Ljungberg and McKelvey, 2012; McKelvey, Zaring and Ljungberg, 2015), and thus have a higher probability of benefiting from academic research (Fontana, Geuna and Matt, 2006). On the other hand, small companies see the university as a "problem-solver" for their technologies, whereas they prefer short-term cooperation that is market-oriented and focused on specific projects (McKelvey, Zaring and Ljungberg, 2015).

The age of a company (years of operation) is another characteristic that drives S-I collaboration. Although some studies show no relationship (e.g., Schartinger, Schibany and Gassler, 2001), there is empirical evidence that age is positively related to cooperation (Arvanitis, Kubli and Woerter, 2011). Older companies are experienced and more inclined to get involved in knowledge and technology transfer than younger ones (Arvanitis, Kubli and Woerter, 2011). The study by Fontana, Geuna and Matt (2006) indicates that start-ups have a higher probability of benefiting from academic research.

Other company characteristics that might affect S-I collaboration are legal status and ownership of the company. Mohnen and Hoareau (2003) find that independent companies rely more on collaborations with academic institutions than companies that are a part of large organizations. Previous research shows that foreign ownership (foreign headquarters of a company) has a negative effect on cooperation with universities. For example, foreign subsidiaries located in Belgium tend to be less involved in S-I collaboration (Veugelers and Cassiman, 2005). Therefore, a high share of foreign-owned enterprises in an economy may be a restricting factor to S-I collaboration, as the local affiliates of multinational enterprises may not carry out the type of basic research that strongly relies on new scientific knowledge. Basic R&D is typically conducted centrally at a headquarter level (Veugelers and Cassiman, 2005).

The study by Arvanitis, Kubli and Woerter (2011) shows that long-term orientation of a company has a positive impact on knowledge and technology transfer (Arvanitis, Kubli and Woerter, 2011). Newer studies examine the impact of STI (science and technology-based innovation) mode of learning, which relies on scientific human capital, public and private R&D organizations and universities, and DUI mode of learning (i.e., learning by doing, using and interacting), which relies on non-scientific drivers. Empirical evidence shows that a combination of STI and DUI modes of learning is more effective for product innovation, while process innovation is more closely linked to DUI-related partnerships undertaken by companies (González-Pernía, Parrilli and Peña-Legazkue, 2015; Parrilli and Heras, 2016).

Previous research suggests that R&D intensity (the share of R&D expenditures in sales, the share of R&D employees, gross investment per employee) is positively related to S-I collaboration (Fritsch, 2003; Schmidt, 2005; Veugelers and Cassiman, 2005; Fontana, Geuna and Matt, 2006; Arvanitis, Kubli and Woerter, 2011), although there are papers that did not find a correlation (Mohnen and Hoareau, 2003). Companies that invest heavily in R&D are likely to possess a high technological capability that allows them to absorb the knowledge developed outside the firm (Fontana,

Geuna and Matt, 2006). They also invest more in in-house innovative activities and technology (Arza and López, 2011), and have greater ability to produce innovative output as compared to non-collaborating companies. As shown in previous research, companies with high absorptive capacity are in general more likely to collaborate (Arvanitis and Bolli, 2009; Giuliani and Arza, 2009; Dalziel, Tahmina and Zhao, 2013).

Human capital intensity (share of employees with tertiary education) is another factor that is positively correlated with S-I collaboration and knowledge and technology transfer (Arvanitis, Kubli and Woerter, 2011). Companies that employ highly educated employees are more likely to be engaged in S-I collaborative research, as those workers understand scientists better and might act as a bridge between the company and the academic community. Patenting (i.e., firms having patents applied for) also contributes positively to S-I collaboration (Mohnen and Hoareau, 2003; Veugelers and Cassiman, 2005; Arza and López, 2011).

Many studies show that among external factors, the extent of public funding has a decisive role in whether companies engage in collaboration with public research organizations (Mohnen and Hoareau, 2003; Capron and Cincera, 2003; Abramovsky et al., 2009; Arvanitis and Bolli, 2009; Jensen, Thursby and Thursby, 2010). This is particularly the case when costs are considered an important obstacle to conducting innovation activities within the company, while collaboration offers the opportunity to apply for government subsidies and decrease costs of innovation activities (Veugelers and Cassiman, 2005).

The company's openness to its environment (measured by the use of external sources of information or by market-orientation index) is also a factor that positively affects S-I collaboration (Fontana, Geuna and Matt, 2006). Companies demonstrating a high level of market orientation are more open to their customers and are more inclined to collaborate with other partners on innovation development (Božić, 2007). A few studies show that international competition positively affects S-I collaboration (Arvanitis, Kubli and Woerter, 2011).

Geographical proximity of the company also affects S-I collaboration (D'Este, Guy and Iammarino, 2013; Maietta, 2015), although there are studies indicating that companies give more preference to the research quality of a university partner than to its geographical closeness (Laursen, Reichstein and Salter, 2011). The studies in favor of geographical proximity show that companies located near universities frequently collaborate with them and benefit from knowledge spillovers. The theory of localized knowledge spillovers suggests that profits will be greater in agglomerations and spatial clusters, since the access to tacit knowledge is easier. The study by Rosa and Mohnen (2008) indicates that distance matters. It is found that a 10 percent increase in distance decreases the proportion of total R&D paid to a university by 1.4 percent for enterprises that do not report any codified transfer of knowledge flow, and by half as much for enterprises that report codified knowledge flows.

Existing studies conducted by Croatian authors show that companies with more intensive collaboration are those with a stronger technology and innovation orientation (Radas, 2005). Croatian enterprises with experienced and highly-educated employees tend to develop more intense collaboration with other enterprises and scientific institutions. Božić (2007) further suggests that the number of radical innovations and the amount of investment in R&D are the variables that contribute the most to collaboration on product innovation in Croatia. The study by Aralica, Račić and Redžepagić (2008) shows that innovation activities tend to be enhanced when a company is a part of a multinational enterprise.

3.3 Barriers

Various barriers significantly negatively affect S-I collaborative research. Although the list of barriers is quite long, there are some obstacles that often appear in the literature. One of the most frequently cited factors is a discrepancy in objectives and expectations between industry and the scientific community (Fontana, Geuna and Matt, 2006; Bruneel, D'Este and Salter, 2010). While companies search for the commercial value of research,

public research organizations pay more attention to the academic value of research that is publishable in order to ensure academic advancement (Bruneel, D'Este and Salter, 2010; Arza and López, 2011). Such research is not necessarily research that could be commercialized on the market (Liu and Jiang, 2001). Research results with significant economic benefits are often considered to be of lower scientific value, while high academic value does not necessarily lead to high economic performance.

Lack of or reduced government support for R&D collaborative projects as well as unbalanced division of benefits between companies and public research organizations are additional factors that hinder S-I collaboration (Liu and Jiang, 2001). Furthermore, previous research indicates that partners involved in EU research programs pay attention, to a great extent, to rules and procedures imposed by universities or government funding agencies, which prolongs the research process and makes it more difficult (Bruneel, D'Este and Salter, 2010; Bach, Matt and Wolff, 2014). As companies operate under significant time constraints and must produce value for the market in a short time period, prolonged time needed for the university to produce results might hinder S-I collaboration (Fontana, Geuna and Matt, 2006).

Other barriers might include potential conflicts with the university regarding royalty payments, intellectual property rights and concerns about confidentiality (Bruneel, D'Este and Salter, 2010). Companies for which risk is an important barrier to innovate are less likely to cooperate with universities (Veugelers and Cassiman, 2005). When companies perceive that they have diminished control over proprietary information, the likelihood of their involvement in S-I collaboration is lower (Ankrah et al., 2013). Other risks are market risks arising from uncertainty in the success of new products or technologies and the risk of incompetent and incomplete transfer of knowledge and technologies (Lee and Win, 2004; Ankrah et al., 2013). Earlier research suggests that trust is the most important factor for S-I collaboration. High trust in university partners is associated with lower barriers, while low trust is related to high barriers (Bruneel, D'Este and Salter, 2010).

Croatian authors have identified a few factors that hinder S-I collaboration. Božić (2007) suggests that enterprises that do not collaborate with other partners on product innovation lack qualified and educated employees. Moreover, they develop radical innovations significantly less and invest less in R&D (Božić, 2007). The study by Bučar and Rojec (2015) suggests that a lack of companies with in-house R&D activities is the main structural deficit for S-I cooperation. Short-term development vision, lack of funds for R&D, and non-availability of advanced technologies are all factors that negatively impact cooperation with scientists (Radas, 2005).

4 S-I Collaborative Research from the Point of View of Public Research Organizations

4.1 Motives and Benefits

For scientists, cooperation with companies represents an opportunity to obtain government support and additional funding for their research, purchase new equipment and hire new researchers (Lee, 2000; Morandi, 2013; Ankrah et al., 2013; Borrell-Damian, Morais and Smith, 2014). S-I collaboration provides an opportunity for researchers to test practical applications of their theories and to translate them into specific outcomes. Academic institutions also highlight the opportunity to develop high-quality research that could lead to an increase in the number of publications (Borrell-Damian, Morais and Smith, 2014). According to Ankrah and Al-Tabbaa (2015), motivations for universities include necessity factors (i.e., responsiveness to government policy), reciprocity (i.e., access to complementary expertise, equipment, facilities and employment opportunities), efficiency (i.e., access to funding for research, business opportunities, financial gain for academics), stability (i.e., discovering new knowledge, testing application of theory, publication of papers) and legitimacy (i.e., societal pressure, services provided to the industrial community, innovation promotion and contribution to national economy).

The benefits of long-term collaborative research for public research organizations might include increased budgets, enhanced visibility, increased range of external partners, improved specialization of human resources, and organizational changes implemented in order to better adapt to collaborative research (Borrell-Damian, Morais and Smith, 2014). Other benefits include stimulated technological advancement, professionalization of the staff, training opportunities for students, feedback from practice, access to a wider network and better links with industry (Ankrah et al., 2013; Borrell-Damian, Morais and Smith, 2014). According to Ankrah and Al-Tabbaa (2015), the outcomes of S-I collaboration are economic-related (i.e., source of revenue, patents, business opportunities), institutional-related (i.e., access to new equipment, training, joint publication with industry) and/or social-related (i.e., provision of services to the community).

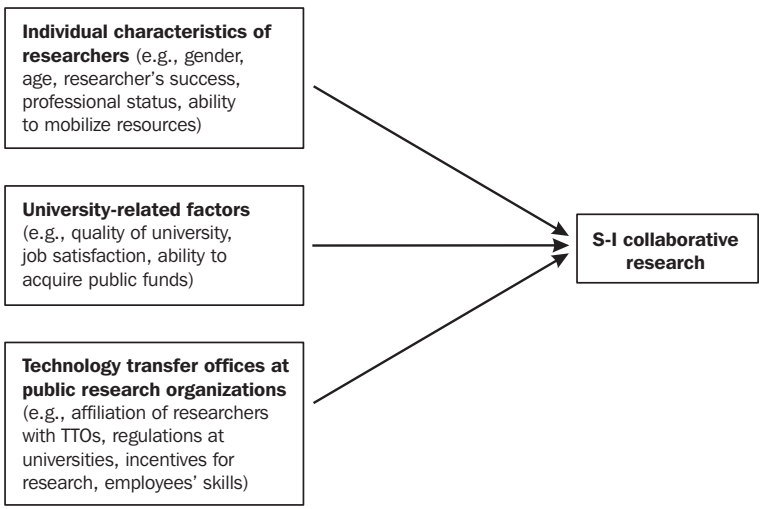
Considerable attention in the literature is given to the publication of results from S-I collaborative research, which is one of the most important goals for scientists as they advance in their careers based on the number of publications. Previous studies thus indicate that the publication rate of a scientist with an average level of collaboration tends to be higher than that of a scientist with no collaborative activity. However, there is also evidence that researchers with a higher industrial exposure may publish less over their career as a whole, and that publishing may have an inverse U-shaped relationship with engagement in collaborative research. According to Banal-Estanol, Macho-Stadler and Pérez-Castrillo (2013), collaboration with companies increases the quantity and quality of the research output only when the firms' characteristics make them valuable partners for universities. Empirical evidence suggests that there is a positive relationship between academics' research quality and commercialization of research activities (Perkmann et al., 2013; Van Looy et al., 2011). However, fewer scientists are involved in commercialization (Perkmann et al., 2013). In sum, collaborative projects often yield new, academically valuable insights and ideas even if they have limited application and do not directly result in publishable results or lead to commercialization of research results, and as such are valuable for scientists (Lee, 2000; Perkmann and Walsh, 2009).

Studies conducted by Croatian authors show a few indicative motives of scientists to engage in S-I collaborative research. Radas and Vehovec (2006) find that intellectual challenge and additional income are two major motives for S-I collaboration. Bučar and Rojec (2015) additionally confirm that public funding, access to specific empirical data that can result in publications, and additional employment opportunity for graduate students are important motives for scientists to engage in S-I collaboration in Slovenia, which might be indicative for Croatia as well.

4.2 Collaborative Factors

Collaborative factors examined from the point of view of public research organizations are characteristics of the scientists, university factors and involvement of technology transfer offices at the research organizations. The most frequently mentioned factors in previous research are presented in Figure 2.

Figure 2 **Collaborative Factors**



Source: Author's compilation.

Characteristics of the researchers play an important role in predicting S-I collaboration. With respect to gender, male researchers are significantly more likely to engage with industry than females. Age was shown to be positively related to propensity to interact with industry (Perkmann and Walsh, 2007). Older scientists tend to accept multiple offers of firm involvement, whereas younger scientists are more likely to be involved with a local firm than with a non-local firm or to not be involved at all (Maietta, 2015). Furthermore, productivity of a researcher is generally positively related to S-I engagement. In other words, the best and most successful scientists are those who engage the most with industry (Perkmann et al., 2013).

Professional status of a researcher and patenting activity are also positively correlated with a higher propensity to interact with industry (Perkmann and Walsh, 2007). Full professors tend to accept multiple offers of firm involvement, whereas research assistants are more likely to be involved with a local firm than with a non-local firm or to not be involved at all (Maietta, 2015). Researchers' ability to mobilize resources for their research was also shown to be positively linked to collaboration with industry.

There are studies suggesting that higher-quality universities make stronger academic contributions to industrial innovation. Job satisfaction is one of the most influential prerequisites for research collaboration. The more satisfied a scientist is with his or her position, the more he or she collaborates with industry (Bozeman, Fay and Slade, 2013). The ability of the scientific institution to acquire public resources is the next university-related factor that increases the likelihood of S-I collaboration (Perkmann et al., 2013).

The literature indicates that there are different groups of researchers. According to the study by Dabic, Gonzalez-Loureiro and Svarc (2012), there are three groups of researchers: the "unsatisfied-disaffected professors", the "team-working professors" and the "engager-professors". The "unsatisfied-disaffected professors" perceive a lack of institutional support for their ideas and present a risk of possible resignation in their entrepreneurial attitude. "Team-working professors" act in terms of the best for the group,

being rather satisfied with their university and department policies for entrepreneurialism, although they think some policies need improvement. The "engager-professors" think "outside the box" to overcome institutional limitations and are the key drivers of university-industry collaboration (Dabic, Gonzalez-Loureiro and Svarc, 2012).

To support S-I collaboration and commercialization of research results, many universities have established technology transfer offices (Perkmann et al., 2013; Borrell-Damian, Morais and Smith, 2014; Empirica, 2014).[6] The existence of TTOs and the affiliation of researchers with them increase the likelihood of researchers to participate in S-I research projects and commercialization (Perkmann et al., 2013). Success factors of TTOs include: fruitful cooperation among TTOs, the existence of trustful links between TTOs and researchers, as well as between TTOs and industry, the existence of scientific excellence and adequate scientist incentives, adequate technology transfer skills of employees at TTOs, developed technology transfer networks, and conducive university regulations and procedures for technology transfer (Borrell-Damian, Morais and Smith, 2014). Muscio (2010) suggests that universities make greater use of TTOs if they have a clear mission and objectives, and are run by non-academic managers.

[6] *The TTOs' responsibility includes identifying the needs of companies and matching those needs with the know-how of public research organizations, bringing together research institutions and companies interested in collaborative research, informing companies about inventions and expertise of research institutions, negotiation with industry and commercialization of research results, helping researchers secure financial resources, providing legal and administrative assistance and guarding the university's intellectual property (Siegel, Waldman and Link, 2003; O'Shea et al., 2005; Borrell-Damian, Morais and Smith, 2014; Weckowska, 2015). The role of TTOs consists primarily of support in contract negotiation (regarding intellectual property rights), disseminating information on open calls and potential funding sources for projects, and providing support for the development of the management structure of collaborative research projects. According to Empirica (2014), which was based on an online survey of European knowledge transfer offices (N=101) and interviews with 18 experts in EU countries, most of the TTOs in the EU are fairly young and two-thirds were founded after the year 2000. Three-quarters of the TTOs are affiliated with a university, and the rest with governmental or non-profit research organizations, hospitals or research parks. The average number of personnel in the sampled TTOs was seven, and the average number of staff with formal TT training was four.*

4.3 Barriers

Borrell-Damian, Morais and Smith (2014) suggest that challenges to collaborative research include low awareness of the added value of S-I partnerships, different expectations, needs and timeframes between public research organizations and industry, lengthy and complex administrative procedures, and integration of collaborative research in different departments and universities. Researchers and the business sector often have different objectives, research orientations and expectations (Wolson, 2007). Companies are usually short-term and market-oriented, while researchers are focused on having their research published and are less interested in the commercialization of their research results. While university researchers and laboratories prefer projects of a basic nature, firms expect higher benefits from projects that can be more easily applied (Banal-Estanol, Macho-Stadler and Pérez-Castrillo, 2013). While basic projects are more likely to generate academic output, they often address topics that are less directly relevant to industry (Perkmann and Walsh, 2007).

According to Ankrah et al. (2013), the most frequently cited drawbacks for university actors are digression from the organization's core objectives, quality issues and risks. Some observers fear that collaborating with industry shifts researchers' agendas towards more applied topics at the expense of the long-term benefits of basic science (Perkmann et al., 2013), which might degrade an organization's quality. Becoming more business-linked poses challenges to the main university mission of teaching and research, and can detract it from "open science" and academic freedom, the unbiased pursuit of truth and the widest possible dissemination of knowledge (Ankrah et al., 2013). Conflicts may arise from collaboration when researchers have priorities that conflict with strict industry schedules. The cooperation might pressure researchers to follow the directions or wishes of corporations, exposing academics to conflicts of interest, while the researchers sponsored by companies may be biased in favor of reporting positive experimental results for company products. Another source of

conflict between universities and businesses may arise from intellectual property disputes and patenting disagreements (Ankrah et al., 2013).

Another stream of literature examines technology transfer offices at public research organizations and barriers for effective knowledge and technology transfer (Wolson, 2007). These offices play an important role in S-I collaboration. The most important barriers for TTOs are the following factors: gap in expectations between industry and public research organizations, expected delays in research, lack of TTO competencies, complex administrative procedures at universities, complex management of intellectual property rights, limited capacity of TTOs and lack of continuous government funding. Further obstacles involve lack of human resources at TTOs and lack of support from the universities in technology transfer (Decter, Bennett and Leseure, 2007; Muscio, 2010; Empirica, 2014).

Croatian authors have also examined obstacles to S-I collaboration from the point of view of public research organizations. Radas and Vehovec (2006) suggest that scientists think major obstacles exist more in the internal organization of academic institutions than in external relationships with industry. Researchers are convinced that industry is not as interested in collaboration as they are (Radas and Vehovec, 2006). Scientists often perceive that most companies lack long-term vision and educated employees, and that they are not informed well enough about what scientists can do (Radas and Vehovec, 2006). Croatian researchers also point out that academic promotion rules do not include enough incentives for collaboration with industry and that it is not possible to earn enough from collaboration because of heavy taxation. They also find that firms implement the results of collaboration to a lesser degree. Other obstacles are more or less similar as those in other studies, and relate to discrepancies in objectives between industry and the academic community, and difficulty in publishing the results of the research collaboration with industry.

Additional insight into obstacles to S-I collaborative research might be derived from observing the obstacles related to TTOs in Croatia. The study by Anić (2016), which presents the results of interviews conducted with

Croatian TTOs, reveals that TTOs in Croatia are relatively young and the system is still at a developing stage.[7] All TTOs in the sample were established after the year 2000 and have on average five employees. The TTOs are active in their work, but they cannot be considered successful enough. The TTOs' contribution to S-I collaboration is marginal. The most important barriers for Croatian TTOs refer to the following: lack of clearly defined sphere of responsibility, reliance on project-based funding, limited capacity of TTOs, limited financial resources and a high fluctuation of personnel. The reliance on project-based funding has resulted in variation in funding levels and the scope and quality of services that the TTOs can offer. This is also closely linked to the staffing and number of employees, and the types of backgrounds and qualifications that TTOs possess. Lack of experienced managers is another problem for TTOs. Other barriers involve delays in research, and different objectives and expectations between researchers and the business sector (Anić, 2016).

5 Conclusions

There is a consensus in the literature that S-I cooperation needs to be improved, and knowledge and technology transfer has to be intensified (Arvanitis, Kubli and Woerter, 2011). However, there is no consensus on the factors that affect S-I collaborative research. This paper presents a review of previous research and identifies motives, benefits, collaborative factors and obstacles to S-I collaborative research from the companies' and public research organizations' point of view. As such, it contributes to the better assessment of factors that might impact S-I collaborative research, which play an important role in designing innovation policies.

From the literature review, it could be concluded that companies and public research organizations have different views on S-I collaborative research. As many factors affect S-I collaboration, the issue becomes very complex

[7] *The study by Anić (2016) presents the results of five semi-structured interviews with the heads of TTOs at five public universities and research institutes in Croatia, which were conducted in November 2016. The interviews contained questions about the TTOs' profile, the type and scope of cooperation, the impact of cooperation, the barriers TTOs face and the measures that might facilitate more effective collaborative research and knowledge transfer.*

to solve. Key motives for companies to engage in collaborative research projects range from strengthening the company's R&D capacity to applying for projects undertaken by academic institutions in order to solve industrial challenges and develop new innovative products or improve existing ones. Companies that are more likely to be engaged in S-I collaborative research are those that operate in the above-average innovative industries, are bigger in size, older, have a higher knowledge base and introduce advanced innovations more often. These companies also have higher R&D intensity, more educated employees and are more open to their external environment. Collaboration offers them the opportunity to apply for government subsidies, and to split and decrease the costs of innovation activities. S-I collaborative research is more effective for product innovation. The most important barriers to S-I collaborative research include a discrepancy in objectives and expectations between industry and the scientific community, lack of or reduced government support for R&D collaborative projects, potential conflicts regarding royalty payments, intellectual property rights and concerns about confidentiality, market risks, and uncertainty in the success of research results.

For scientists, cooperation with companies presents an opportunity to obtain government support and funds for their research, acquire new equipment and technologies, and hire new researchers. Scientists are motivated to test practical applications of their theories and translate research results into specific products. Scientists that are more likely to engage in collaborative research with industry are senior researchers, more productive researchers, researchers that are more satisfied with their job and work at higher-quality universities that are able to acquire public resources for S-I collaboration. The affiliation of researchers with TTOs at universities also positively contributes to S-I collaborative research. S-I collaboration provides an opportunity for scientists to engage in high-quality research that could lead to an increase in the number of publications.

Previous research also indicates that fewer scientists are involved in the commercialization of research results and that TTOs actually have a marginal role in knowledge and technology transfer. Barriers that affect

S-I collaborative research from scientists' point of view are different expectations, needs and timeframes between public research organizations and industry, lengthy and complex administrative procedures, and lack of public programs related to S-I collaborative research on a continuous basis. TTOs have limited capacities, lack human and financial resources and often do not have adequate support from universities to facilitate an effective knowledge and technology transfer.

The review of studies on S-I collaboration written by Croatian authors shows that there are very few studies on this topic in Croatia. These studies deal mostly with S-I collaboration from a broader perspective, where S-I collaborative research is just one of the modes of S-I interactions. Although some of the existing studies are fairly old, it might be assumed that some results are still valid today. In line with these research results, Croatian companies that collaborate with the academic sector are companies with a stronger technology and innovation orientation, and higher R&D intensity. Barriers to S-I collaboration from the point of view of companies include lack of qualified and educated employees, lack of funds for R&D activities, short-term development vision of companies, and lack of funds for R&D. On the other hand, Croatian researchers collaborate with industry if they perceive the cooperation as an intellectual challenge and can gain additional income. For them it is important to get continuous access to public funding, access to specific empirical data that can result in publications and employment opportunities for new and junior researchers.

Croatian scientists perceive that major obstacles to collaboration exist more in the internal organization of academic institutions than in external relationships with industry. They are convinced that industry is not as interested in collaboration as they are, and that companies usually do not know what scientists can do. Additionally, they think that academic promotion rules in Croatia do not include enough incentives for collaboration with industry and that it is not possible to earn enough from collaboration because of heavy taxation. TTOs in Croatia have a marginal role, and major barriers for TTOs are the reliance on project-based funding,

limited capacity of TTOs, limited financial resources and a high fluctuation of personnel.

From above-mentioned evidence (Radas and Vehovec, 2006; Radosevic, 2011; Jeleč Raguž, Budimir and Letinić, 2015), several recommendations for Croatian innovation policy can be provided. There is a necessity to improve Croatian innovation policy to create favorable conditions for S-I collaborative research. This includes the improvement of legal framework that would support and motivate the researchers and innovators better, allocation of more financial funds to the transfer of new knowledge and technologies, and the provision of better support for the commercialization of research results. Strengthening S-I collaborative research would also include raising awareness and better promotion of the added value of joint collaborative research. Both public research organizations and companies need to work together to overcome obstacles to their joint collaborative research. Some obstacles may be removed by introducing changes to academic rules and requirements that might include practical experiences resulting from collaboration with companies.

The role of TTOs at public research organizations should be strengthened. Some of the possible improvements for making TTOs more effective might include the improvement of overall innovation framework at the state level, which would define the status of TTOs better, enable the provision of more financial resources to TTOs by the government and university alike, provide better support to human resources, minimize bureaucracy and introduce more autonomy in the work of TTOs. Furthermore, improvements could be made in the national innovation system so that it could facilitate better networking and cooperation among national and international TTOs.

Finally, some recommendations for future research might be useful. In general, more studies on S-I collaboration and collaborative research need to be carried out in Croatia to update the research results found in previous studies. More empirical research targeting collaborative research and TTOs

might be carried out in the context of smart specialization strategies,[8] linking collaborative research with concepts such as global value chains, industrial clusters, cluster initiatives, smart skills and various other strategy-related instruments. Future research might further explore the efficiency and performance impact of collaborative research in developing countries, as well as the relationship between academic engagement, commercialization and institutional aspects (Perkmann et al., 2013). Researchers might also improve the methodology, quality, reliability and validity of measures related to academic engagement, activities, motives, barriers and outcomes, which might improve the quality and comparability of conducted studies (Perkmann et al., 2013).

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