Chapter 2
Inputs, Resources and Research Collaboration

Here we examine resources and inputs into collaboration as they interact with the institutional settings for collaboration, including teams, research centers, and firms, among others. We examine (1) people (researchers and research support) with their respective “caches” of human capital, (2) materiel both physical and intangible, and (3) social structures and norms.

2.1 Individuals and Groups: STHC as Inputs and Resources

This component of the framework addresses the attributes of individual and interactive groups of researchers, specifically their STHC, including (1) formal training, (2) past productivity, (3) social capital, (4) career status and career experiences, (5) personal characteristics, and (6) organizational characteristics and motivations. Though STHC theory proposes that these are interrelated, for convenience in description we treat them separately in our review of the literature. Moreover, most published articles focus on just one of these aspects of human capital. Most of the articles discussed in this section are at the individual level of analysis, though a few consider team and organizational level characteristics (as teams and organizations are comprised of people and too can exhibit behaviors like productivity and other characteristics like motivations).

2.1.1 Formal Training at the Individual and Project, Organizational Levels

Formal training is perhaps the most traditional way to operationalize human capital. For the most part the economics literature uses the concept to distinguish the college-educated from non-college educated. But this sort of variation seldom exists in boundary-spanning research collaborations wherein almost all researchers have doctorates.

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The literature on boundary-spanning research collaborations distinguishes different backgrounds and formal training at the doctoral level, albeit more typically as control variables rather than as antecedents of primary (or even secondary) interest. Most of this "controlling" has occurred with the work of Bozeman and colleagues and their series of survey- and curriculum vitae-based research on the scientific values of and participation in research collaborations by academic researchers in the US. This series of articles (e.g. Bozeman and Corley 2004; Bozeman and Gaughan 2007, 2011; Boardman and Ponomariov 2007; Boardman and Corley 2008; Bozeman and Boardman 2013) has elicited no consistent results connecting formal training (which Bozeman and colleagues mostly operationalize as respondents' PhD field) to particular research collaboration strategies or behaviors. Perhaps the most consistent result across this series of articles is that there are considerable differences across fields with regard to the propensity to collaborate with industry and most find that engineering disciplines are the most likely to collaborate with industry.

A more useful operationalization of formal training for designing and implementing team science and research centers is at the project and/or organizational level, specifically addressing the heterogeneity of disciplines for a particular project or organization. The reason this is more useful is because both public and private sector research is becoming increasingly multidisciplinary due to the increasing complexity of the scientific and technical innovation required to address social, economic, health, energy, defense, and other national problems (Zerhouni 2003). Also, methodological and epistemic norms across disciplines can be quite different, sometimes diverging sharply (Snow 1964; Clark 1983; Becher 1989; Kekale 2002; Turner et al. 2002; Van Gigch 2002a, b) and therefore an impediment to boundary-spanning research collaboration (Goldman 1986, Corley et al. 2006).

There are a few studies that look at what we prefer to call "disciplinary heterogeneity" (to avoid unnecessary discussion, *here*, of the differences between interdisciplinary, multidisciplinary, and transdisciplinary research). Chompalov et al. (2002) find as disciplinary heterogeneity increases, so does productivity, but also so does heterogeneity of incentives and motives to collaborate and thusly collaborations become more hierarchical as well as more formalized organizationally.

Many other studies focus on the relationship between collaboration and disciplinary differences or collaboration and multi- and interdisciplinary issues. Some studies (e.g. Qin et al. 1997; Bordons et al. 1999; Schummer 2004; van Rijnsoever and Hessels 2011), measuring the degree of interdisciplinary collaboration and drawing conclusion based on those differences). Other studies are more normative, evaluating or prescribing means to overcome or exploit disciplinary differences (e.g. Hall et al. 2008; Porter et al. 2006). The lesson from all these studies is that multi- and inter-disciplinary collaboration often prove difficult to organize and manage but also that they are especially likely to prove beneficial in terms of both the creation and diffusion of knowledge and technology.

2.1.2 Past Productivity

Human capital constitutes a vital transfer mechanism for knowledge and technologies across boundaries, e.g., from universities to industry, from one academic discipline to another, from one individual to another (Schartinger et al. 2001). Due to easy availability of productivity data for some industries, a popular way to measure "observable" human capital is to assess productivity, which according to economists may be considered proxies for human capital to the extent they represent productivity an individual and/or organization would not be able to produce without a particular human capital component (Aboud et al. 2005). However, for the research collaboration literature there are not many studies addressing bibliometric and/or patenting productivity as an input *per se* (i.e., as a key predictor rather than as an antecedent control variable) into team science or research center processes, outputs, and/or outcomes. One example of this sort of study (i.e., conceptualizing scientific and technical productivity as an antecedent to research collaboration) are those studies focused on "star scientists," i.e., scientists who are very productive bibliometrically because of their own innovative techniques and ideas (e.g., Zucker and Darby 1996). However, this particular "brand" of scientist is demonstrated to collaborate less to protect her or his techniques and ideas from imitation and emulation (Zucker and Darby 1996). Another example are articles focused on predicting and explaining the bibliometric productivity of team science or research centers that include lagged measures of bibliometric productivity as antecedent control variables for contemporaneous bibliometric productivity (e.g., Ponomariov and Boardman 2010).

One reason the research collaboration literature has not followed many economists in operationalizing past productivity as contemporaneous human capital is that seldom do these two literatures meet. Another reason is that bibliometric and patenting productivity have generated more interest in policy and scholarly circles as outputs and outcomes of research collaboration. A final reason may be that past research productivity may not be a valid measure of either inputs or outcomes for team science and research centers. Cronin (2001) and Garg and Padhi (2001) for example call into question the measurement validity of research productivity as a proxies for both inputs into and outputs of collaborative research as it may occur in team science or research centers due to what they term "hypercoauthorship" wherein not all coauthors contributed expertise or human capital per se to the collaborative project and resultant article, but rather are listed as coauthors for reasons other than expertise/human capital contributions.

2.1.3 Social Capital

According to the STHC model (Bozeman et al. 2001)[1], human capital is much more than formal training or, just discussed, past research productivity, but rather is the

[1] There is to date no singular measure or scale for the scientific and technical human capital idea (and this was not the original intention of Bozeman and colleagues 2001), so the different aspects of the idea are addressed as separate human capital attributes.

summation of a number of individual attributes and experiences, including but not limited to social capital and the human capital associated with that social capital. Though there is a vast literature on social capital and its variable impacts, only the studies on the role(s) of social capital in boundary-spanning collaborations are addressed here. Because of the smallness of the literature on the role(s) of social capital specifically in boundary-spanning research collaborations, some of the general studies on social capital in collaborations generally are also included.

Much of the empirical work in this area emphasizes prior acquaintance and trust as an important input into research collaborations. Prior acquaintance as an input into new team science or research centers can enhance collaboration from the start due to decreased if not avoided transaction costs associated with engendering trust amongst collaborators from different disciplines, universities, firms, government agencies, sectors, and even age cohorts (Granovetter 1985, 1992; Marsden 1981; Williamson 1975; Commons 1970). One of the key findings from the general empirical literature on boundary-spanning collaboration (not necessarily research collaboration) is that acquaintance and the trust it engenders leads to progressively fewer and less formal structures and authorities for governing the collaboration (Gulati 1995).

Among the more interesting empirical studies of the role of trust in boundary-spanning research collaborations is one focused on inter-firm research collaboration. Dodgson (1993) addresses trust not at the interpersonal level due to the frequency of turnover in high technology companies (especially during the "tech bubble" when this study was conducted. Instead, Dodgson emphasizes interorganizational (versus interpersonal) trust characterized in two case companies by what he calls communities of interest, organizational cultures receptive to external inputs, and frequent and egalitarian communication of information about the status and purpose of the collaboration. This is perhaps one of the more interesting studies on trust and research collaboration not just because of its emphasis at the organizational level of analysis and its focus on firms (which in theory need trust less due to their ease abilities to formalize research collaboration relations relative to academic researchers and government agencies), but additionally because organizational culture is the most difficult aspect of organizations to cultivate much less change (Tolbert and Hall 2010).

Many other studies at the individual level of analysis show trust to correlate positively and significantly with collaboration processes, outputs, and outcomes (Sonnenwald 2007; Creamer 2004; Hara et al. 2003; Sonnenwald 2003; McLaughlin and Sonnenwald 2005; Knorr-Cetina 1999; Krige 1993). Trust has been a big emphasis in studies of research collaboration because without it collaboration in most cases does not happen (Olson and Olson 2002). Though their data are at the individual level of analysis, perhaps most relevant of these articles to the current study are the studies by Shrum et al. (2007) and by Zucker et al. (1995), both who show that in team science and research centers trust is most readily engendered amongst same-discipline and same-institution researchers in multi-discipline, multi-institution research collaborations. These findings point up all the more the importance of understanding how to develop a cultural "fit" at the organizational level in team science and research centers. Indeed this problem has seen as much research on problems in boundary-spanning research collaborations as on success (Boardman and Gray 2011; Gray et al. 2013).

When there is not prior acquaintance and trust, it can be very important to start the strategic planning process well before a team science or research center begins operations, i.e., during the planning phase. To avoid high transaction costs due to lack of acquaintance and trust (Kogut 1998), researchers and stakeholders present at the beginning of a boundary-spanning research collaboration can lower these costs and increase trust and acquaintance by collectively discussing and selecting additional researchers with whom to collaborate (Lipnack and Stamps 1994; Scharpf 1978; Landau 1991). These processes as they pertain to team science and research centers are addressed by way of review of many team science and research centers articles that address processes and activities empirically or with case study.

2.1.4 Career Status and Past Career Experiences

Career status and career experiences have been used as proxies for individuals' levels of expertise or human capital in a number of studies. In their recent review of university-based research collaborations with industry Bozeman and colleagues (Bozeman et al. 2013) use age as a proxy for past experience at research collaboration and suggest that it is perhaps "one of the most apparent personal factors one might expect to have an effect on collaboration." But they do not consider age explicitly as a proxy for human capital. Instead they suggest that age may have an impact on collaboration frequency and intensity because the longer one conducts research, the more collaborators she or he acquires.

The findings for age with regard to research collaboration processes, outputs, and performance are mixed. Ponomariov and Boardman (2010) find no statistically significant relationship between age and the rate or intensity of academic researchers collaborating with industrial researchers (the authors address university-industry collaboration using a variety of co-authorship measures). But there is a selection issue here insofar that academic researchers who work with and sometimes co-author with industrial researchers are not the norm and represent but a small proportion of academic researchers overall.

Other studies find age correlating positively with commercial and/or collaborative research activities and also with more traditional academic activities like publishing in the open literature. Haeussler and Colyvas (2011) find increased commercial outputs on the part of older academic researchers. Boardman and Ponomariov (2007) find similar results with regard to academic researchers' tenure status and their respective valuation of commercially relevant versus traditional academic research. Both studies suggest under the traditional academic reward template emphasizing peer reviewed publication in the open literature that the opportunity cost of engaging in more commercial research collaborations is lower for older versus younger university faculty. Both studies also suggest that not until researchers have had enough experience and productivity will they be sought out by companies, which implies a human capital dimension/interpretation of researchers' age.

Past career experiences have also been shown to have an impact on research collaboration and scientific and technical productivity. Rijnsoever and Hessels (2011) find heterogeneous research experiences to correlate positively with both disciplinary and interdisciplinary research and, similar, Aschoff and Grimpe (2011) show academic researchers who work early on in their careers with industry to be more involved with and publish more with industry based researchers later on. Ponomariov and Boardman (2010) show the rate and intensity of both interdisciplinary and university-industry co-authorship to correlate positively with academic researchers' affiliation with university-industry research centers, using a panel of bibliometric data for 57 academic researchers over the entirety of their respective academic careers. Boardman and Ponomariov (2013) use comparative case study for a purposive sample of NSF university-industry research centers to suggest (anecdotally, N=21) that past career and educational experiences in management may have an impact on how formalized and horizontally differentiated research centers are.

Other studies assess career experiences using both more and more sophisticated constructs. Dietz and Bozeman (2005) emphasize changes in job sectors throughout scientific and engineering careers and how these affect productivity in terms of both publications and patents. Using the curriculum vitae of 1,200 scientists and engineers from the USPTO (US Patent and Trademark Office) database, the authors show that diversity of career experiences leads to diversity in scientific and technical productivity. Specifically, the authors show that inter- and intra-sector job changes (i.e., university to industry and vice versa, university to university, industry to industry) leads to higher publishing and patenting rates. The authors use STHC theory to explain these findings: career transitions of academics involving collaborations with different disciplines and with industry enhance human capital and therefore productivity.

2.1.5 Motivations and Related Characteristics

In the numerous studies surveying researchers at the individual level, many control for motivations and related characteristics such as the age, gender, and ethnicity of respondents. Melin (2000) suggests that there are many personal reasons to engage in research collaborations like team science and research centers (and also acknowledges exogenous reasons as well) but emphasizes the social aspects of collaboration as a primary motivation at the individual level of analysis. Beyond the social aspects, amongst samples of academic researchers the job security that comes with tenure has been shown to affect attitudes towards collaboration. Boardman and Ponomariov (2007) find that not having tenure negatively and significantly correlates with a willingness to work with industry among a stratified random sample of academic researchers affiliated with NSF Engineering Research Centers. Using a broader data set on a national sample of academics whether they are affiliated with a research center or not, Corley and Bozeman (2004) find that tenure status does not correlate significantly with personal collaboration strategies. This contrast speaks to the selection effect of surveying just academic researchers who self-select into research centers like ERCs. A final influential motive for academic researchers joining collaborative endeavors like team science and research centers is job satisfaction (Lee and Bozeman 2005; Coberly and Gray 2013).

Age is more appropriately in our view discussed as a proxy for career status and longevity of career experiences and is discussed above (see 2.1.3). Gender and ethnicity have been shown to be an important personal collaborator attributes in the scientific community. There has been a lot of focus on women and ethnic minorities in science over the past two or so decades (especially at the NSF) due to their under-representation of women and minorities in academic science (Pollak and Niemann 1998; Johnson and Bozeman 2012).

The impact of gender on research collaboration activities and outcomes can be direct or an interaction with other individual characteristics like tenure status. Bozeman and Corley (2004) show that women tend to collaborate more than men do in academic science. And this finding holds for women at all stages of their careers (e.g., tenured or not, research group leader or not) and for different types of academic careers in science (tenure track versus research faculty). The authors also find that non-tenure track women are more likely to collaborate with other women than with their male counterparts. In a more recent yet similar study Bozeman and Gaughan (2011) seek to "break" previous models suggesting that gender matters to collaboration and specifically boundary-spanning collaboration. In this attempt they developed a new nationwide (US) survey data set including over 1,700 respondents and weighted by field and gender with an especial focus across the survey items on research collaborations with private companies and the motivations for entering these collaborations. The study showed that females collaborate more and in more ways with industry and was the first to demonstrate that the "gender effect" holds when controlling for numerous other personal attributes. Published almost simultaneously, Rijnsoever and Hessles (2011) find very similar results regarding women and the rate and intensity of interdisciplinary research collaborations (i.e., being more likely for women than men).

In contrast, the numerous studies using the "industry involvement index" (see Bozeman and Gaughan 2007) for a detailed explanation of the index, which is a weighted gradient) finds gender to have no statistically significant correlation with academic researchers' collaboration intensity with industry (Bozeman and Gaughan 2007; Gaughan and Corley 2010; Ponomariov and Boardman 2008, 2010; Boardman 2010).

Ethnic minority status has also been a factor in empirical and case based research on team science and research centers. Sonnenwald (2007) provides an extensive review not only of the relationship between participation of ethnic minorities in research collaborations but also addresses field work for alleviating some of the mistrust, misunderstanding, and conflict that can arise. In this sense minority status is yet another "boundary" that is spanned in boundary-spanning research collaborations, and like the usual suspects (i.e., disciplinary boundaries, economic/sectoral boundaries, institutional boundaries) if not managed properly these can lead to role conflict and role strain (Boardman and Bozeman 2007), distrust (Fisher and Ball 2003; Secrest et al. 2004), and a lack of informal mechanisms for coordinating diverse sets of actors like goal congruence (Boardman 2012). See Sonnenwald (2007) for a more extensive review.

Practically all of the research on the motivations and related characteristics for organizations entering research collaborations focus on private firms. A predominance of these studies provides a resource-based explanation of one sort or another (e.g., size in terms of employees and/or R&D budget). Others emphasize government incentives, geography, and leadership. The findings are quite consistent perhaps because most of these studies address private firms whose organizational environments and therefore stakeholder sets and goals are more uniform when compared to university research centers and team science.

Organizational size (usually measured as both number of employees and proportion of budget allocated to research and development) is the most frequently cited characteristic explaining which firms join industry R&D consortia and/or research collaborations with other firms. Practically all of this research finds a positive correlation between size and motivation (e.g., Angel 2002; Bayona et al. 2001; Fritsch and Lukas 2001; Santoro and Chakrabarti 2002; Kaiser 2002). But some studies show relatively unique findings. Kleinknect and Reijnen (1992) find size to decrease rather than increase the likelihood of Dutch firms collaborating with one another on research and development. Aloysius (2002) finds that firms of comparable sizes are most likely to enter into formal research collaborations with one another.

Last, some of these findings for size and motivation for firms to collaborate with one another in research may be spurious. For example, Santoro and Chakrabarti (2002) conclude that larger firms participate in university research centers to build new research capacity outside core research areas whereas smaller firms participate in centers to fulfill core research areas. But the sample of firms they use participate in different types of university research centers with very different capacities for "radical" research and development (Ettlie and Ettlie 1984; Damanpour 1996) deviating from existing knowledge and technology versus "incremental" research and development (Ettlie and Ettlie 1984; Damanpour 1996) building predominantly on existing knowledge and technology. Though Santoro and Chakrabarti acknowledge that "unique structural and contractual features distinguish university research centers" (p. 1164) and include in their analysis firms participating in centers both with and without the support of National Science Foundation centers programs, they do not emphasize theoretically or empirically the programmatic status of the centers included in the analysis, but rather focuses on firm size.

Other motivations for firms to collaborate in research and development include having common precompetitive research challenges (Ouchi and Bolton 1988; Greis et al. 1995; Sakakibara 1997; Katila and Mang 2003; Mowery et al. 1998; Hayton et al. 2013) and, related, weak competition from other firms (Sakakibara 2002); spatial proximity (Fritsch 2001) and, related, being located in a large urban area (Angel 2002); having an internal champion of inter-firm research collaboration who acts as a gatekeeper to identify firms with which to collaborate in research and development (Fritsch and Lukas 2001, Mathews 2002), as well as incentives for inter-firm research collaboration from government (Sakakibara 2001; Hayashi 2003) and, related, national culture (Steensma et al. 2000).

2.2 Materiel as Inputs and Resources for Team Science and Research Centers

This component of the framework addresses the attributes that individual researchers, including their (1) tangible capital such as equipment and infrastructure, and labor such as post-docs and graduate students and (2) prior knowledge and art including past research and technology.

2.2.1 Tangible Capital and Labor

The literature on tangible capital for university research centers and government and university team science is sparse. Most of the work emphasizing tangible capital as inputs is from the literature on firm-firm research collaborations and, to a lesser extent, on industry consortia. In our view, the lack of emphasis in the literature on tangible capital in university research centers and university and government team science is due to the transition over the past few decades of what constitutes competitive advantage in scientific and technical innovation at the university and national levels. However, a few studies focused on experimentation in high-energy particle physics emphasize tangible capital in research centers and team science that are not firm-based (e.g., Krige 1993; Galison 1997).

Focusing predominantly on firm-firm research collaborations, Hagerdoorn et al. (2000) observe the popularity of resource dependence perspective among strategic management scholars in explaining boundary-spanning research collaborations amongst private firms, which collaborate on research projects to gain access to resources and capabilities that enable them to develop and sustain competitive advantages. Others also focusing on firms (Becker and Peters 1998; Camagni 1993) emphasize the sharing of resources to reduce uncertainty and to realize cost savings as well as economies of scale and scope. Audretsch et al. (2002) count firms' network ties to universities as a tangible resource though they are really discussing the human capital in universities as much as the research laboratories and university research centers with complementary infrastructure, equipment, and critical materials.

None of this literature emphasizes access to tangible capital *alone*, but rather emphasizes access to caches or sums of human capital and social capital and labor in addition to more tangible resources like infrastructure, critical materials, equipment, and funds. In other words, whether the theory is called out explicitly or not in the literature on tangible capital in boundary-spanning collaborative research, the STHC approach driving our analysis of the literature in this study is adept for explaining the role of tangible capital in boundary-spanning research collaborations insofar that the STHC theory implies a number of important *in*tangible processes and activities as well as other types of inputs and resources, e.g., human capital, without which tangible capital cannot be implemented.

The small literature on labor in boundary-spanning research collaborations emphasizes labor as a standalone input (rather than part of a broader cache of resources) and focuses on graduate students in university-industry research collaborations. This literature is bifurcated, with some authors suggesting that graduate students' involvement with industry is beneficial to technology transfer (Ponomariov 2009; Bozeman and Boardman 2013) and also to education (Bozeman and Boardman 2013), though other authors characterizing such graduate student involvement with industry as disruptive and potentially harmful to traditional graduate education (e.g., Slaughter et al. 2002; Slaughter and Rhoades 2004).

Though we treat them as one literature here, really the two perspectives constitute separate literatures. Seldom does empirical study emphasizing graduate students roles in technology transfer address outcomes related to education, like teaching and student support, and almost as a rule does the *discourse* (typically not empirical research) (Slaughter et al. 2002; Slaughter and Rhoades 2004) on the potentially disruptive and harmful nature of student involvement with industry go unconcerned with the potential benefits of this involvement for education as well as for economic outcomes. While both sets of results (i.e., graduate students correlating positively with technology transfer in university-industry research collaborations, graduate students experiencing negative unintended consequences) can be correct in isolation, Bozeman and Boardman (2013) address both types of outcomes to demonstrate academic researchers who work with different types of university-industry research centers also to mentor and teach more graduate students. Behrens and Gray (2001) finds a null relationship comparing graduate students working in university-industry research centers to their counterparts not working in these centers or comparable arrangements. We address these studies further in Sect. 2.3 in under the "enhanced scientific and technical human capital" subheading.

2.2.2 Prior Knowledge and Technology (Field/Industry Level)

The literature on prior knowledge and technology at the field level is one that has no focused on boundary-spanning research collaborations directly, but no less it is quite important, as the state of a particular field of inquiry can have substantial impacts on the very establishment (Bozeman and Boardman 2003) and also the organization and management of such collaborations (Boardman 2012). Conceptually, prior knowledge and technology at the field level can be "radical," i.e., relatively divergent from existing knowledge and practice or it can be "incremental," i.e., focused on the application of existing knowledge and practice (Ettlie et al. 1984). There are just a few studies that address the radical-incremental dichotomy

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