Resource-Based View of University-Industry Research Collaboration

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Abstract--**University-industry research collaboration offers both parties involved recognised benefits. Universities can secure funding for students and researchers, whereas companies can gain access to science and technology to incorporate in improved products. The performance of such collaborations can be closely related to the resources available to the collaborating organisations. Therefore, this paper will examine how university-industry research collaborations can be developed and managed through applying the key concepts of the resource-based view of strategy. The research method is composed of two stages. The first stage involved a series of 32 structured interviews with representatives from companies and the academic sector, which sought to ascertain the resources required for successful university-industry collaborations. Qualitative assessment of the resources according to either being tangible, intangible or human related identified the capabilities required to underpin collaborations between universities and companies. The second stage involved a case study application of these capabilities to a major university-industry research programme. The case study investigation involved reflective analysis of how the resources and capabilities were configured and deployed during the development and management phases of the programme. This allows generation of a set of practitioner oriented recommendations for establishing university-industry collaborations.**

"Coming together is a beginning. Keeping together is progress. Working together is success", H. Ford (1863-1947).

I. INTRODUCTION

Universities are an important source of knowledge to drive forward economic development [1] and in this context university-industry collaboration can be viewed as an enabling mechanism to support innovation [2]. Companies across many industrial and high-tech sectors [3] collaborate with universities for a number of reasons. There may be a need to acquire scientific knowledge or technical insight in order to improve an existing product or service, or to contribute to new product development [4], and companies can also associate with universities in order to gain access to academic networks [5]. This basis for collaboration is predicated on the need for knowledge flow from the university to the industrial partner and the performance of collaborations can therefore be correlated with the efficiency of this knowledge flow as well as the quality and relevance of the knowledge generated [6]. Moreover, the level of any enhanced performance by the company arising from such collaborative activity will be dependent on the acquisition and deployment of knowledge outputs from the academic collaboration [7].

In this regard a company needs to first acquire the knowledge through capturing specific data and information such as from reports, journal articles and patents, or alternatively codifying tacit knowledge, such as the procedure for undertaking a particular materials modelling or simulation technique. This knowledge acquisition process will be facilitated by access to the required organisational resources (e.g. technical staff, management structures and processes as well as culture) within the company. Once acquisition has taken place, the company needs to deploy the knowledge, e.g. through incorporating the aforementioned modelling technique within an operational system such as a testing rig for mechanical structures. A company's ability to deploy this knowledge will be contingent on its level of absorptive capacity [8], which can be associated with the aforementioned organisational resources. It can therefore be discerned that the performance of industrial collaboration with universities can be related to the company's available resources, which need to be effectively configured to optimally support the knowledge acquisition and deployment process.

In terms of university participation in industrial collaborations there can be a number of motivations [9]. Universities work with companies in order to gain access to application specific data and information, such as a mechanical engineering member of faculty seeking data relating to the dynamic compression of metallic materials. Universities also work with companies to secure financial support in order to fund doctoral studentships as well as postdoctoral research positions. Collaboration with companies can provide universities with a long-term and stable platform to investigate an applied scientific area, which if supported adequately can lead to commercial development and eventual industrial application of promising technologies [10]. From the university perspective, the ability to collaborate with a company will also be dependent on the resources that can be accessed. The academic and scientific track record of the faculty member will be a key determinant as well as other resources, including physical ones such as laboratories and experimental equipment as well as organisational processes such as those related to research administration. Collectively these resources need to be harnessed in an efficient manner to underpin the collaborative process and ensure both universities and companies are able to derive mutual benefits from the collaboration and which are commensurate with the respective contributions from each party.

This research paper will focus on the role of organisational resources at both universities and companies

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and how they can be configured in order to support the collaboration process. This will include knowledge, social and process considerations, and the manner in which universities and companies develop and then manage major collaborative alliances that have the potential to ultimately lead to sustained benefits for both parties. The paper includes a comprehensive literature review of university-industry research collaboration and in this context the resource-based view of strategy is discussed. This is followed by description of the research methodology employed, which involved a series of structured interviews with collaboration stakeholders that allowed a resource-based view of university-industry collaboration to be developed, and was followed by a case study investigation of this framework. Subsequent analysis of the findings from the research study leads to conclusions and future work.

II. UNIVERSITY-INDUSTRY COLLABORATION

There has been much research on the interactions between universities and companies that is focused on the field of technology transfer [11] involving 'spin-out company' formation [12] and the role of technology licensing [13]. Academic spin-out companies are able to develop technologies that may be ultimately incorporated into industrial products and services, and patenting allows technologies to be transferred to industry under a recognised legal framework. However, studies have identified that commercialisation of intellectual property (IP) represents only a minor proportion of the total level of activity between the university sector and industrial organisations [14]. Whilst this remains an important vehicle for university research to be applied commercially, through providing the opportunity for universities (and in some cases individual faculty members) to abstract financial value from scientific work and resulting intellectual property, it is nevertheless a component of a broader range of interactions that can take place between universities and companies [15]. These broader interactions include contract research, collaborative research and technology projects, joint industry/government funded academic projects, consultancy work as well as less structured interactions such as involvement by industrialists in research meetings, seminars, conferences and other such events at universities.

Contract research is likely to involve the academic institution conducting targeted studies for industry, such as clinical trials for pharmaceutical companies, or modelling and aerodynamic testing of structures for aerospace manufacturers. Consultancy work will likely involve an academic faculty member advising a company on a technical matter, such as advice on the development of new heterogeneous catalysts for a company involved in the downstream oil refining sector, or advice on the application of data transmission algorithms to a telecommunications company.

Collaborative research undertaken between universities and companies can include a range of activities [16], such as the joint sponsorship by companies and government agencies of PhD or postdoctoral projects. There can also be collaboration where the company provides data and information from the industrial application to support the university research, which may have been funded by another source, such as government, charitable, or philanthropic. Moreover, whilst the adoption of research and technology outputs as part of the product development process can be an important motivation for companies to collaborate with universities, there can be just as much of a need to secure a competitive edge from gaining an improved understanding of a scientific or technological area [17]. Again in the context of this wider definition of collaborative working, companies may be part of university networks [18] and there could be collaboration through attendance at seminars, workshops and specific meetings to discuss scientific findings and the potential application to industrial requirements.

Considering the range of interactions that can take place as part of university-industry collaboration [19], there can be a number of instruments available to co-ordinate and govern such activities. Large-scale and strategic collaborative programmes will likely require formalised contractual mechanisms such as framework agreements, which underpin long-term programmes where projects can be administered as part of the overall contracting mechanism. Shorter projects that involve a degree of industrial funding may also be governed by contracts that include the usual provisions around the scope of work, confidentiality, exclusivity, allocation of IPR (intellectual property rights), and so on. Collaborations could also be governed through negotiation of a memorandum of understanding (MoU), or heads of agreement document that sets out the principles for collaboration and other provisions as part of a non-binding agreement. Occasional interactions may occur on an informal basis without supporting agreements in place. Additionally industrial contacts may sometimes be appointed to visiting positions at universities, or be members of advisory boards for university degree programmes. In order for more formalised agreements to be negotiated and implemented, universities need to have effective administration processes in place as well as the corresponding staff with the requisite commercial skills. It follows then that an inability to assemble these resources can significantly diminish the likelihood that a new university-industry collaborative agreement can be agreed and subsequently used to facilitate the required research work.

Indeed establishing new university-industry interactions can be subject to barriers that have the potential to prevent or limit the scope of collaboration. On this matter Bruneel et al. [20] have investigated so called orientation-related barriers (i.e. related to the differences in perspectives between universities and companies) and transaction-related barriers (i.e. related to the need for companies to deal with university administration and intellectual property policies). This study found that previous experience of collaborative research can lower such orientation barriers since both companies and universities will be more aware of the requirements (and possible deficiencies) of the other party. For example, companies may be more aware of academic needs to protect IPR, whereas universities may understand the need to negotiate licensing terms that are acceptable to companies, such as non-exclusive royalty-free (NERF) rights for foreground IP. The study also found that trust can lower both types of barriers, since relationships that have developed adequate levels of trust will be more resilient to disagreements that may arise either in the negotiation of agreements or during the delivery phase of collaboration projects. Trust is a major component of social capital [21], which has been described by many authors as an important factor for collaborative relationships [22] and social network analysis can be used as a tool to investigate the corresponding collaborative networks [23].

In order for companies to derive the necessary benefits from interactions with universities, there needs to be an appropriate fit between a company's strategic objectives and the capabilities of the university. On this matter Santoro and Chakrabarti [24] found that certain firms often establish links with more prestigious university centers in order to gain access to the collaborative networks associated with such centers and the potential broader technological awareness that can be subsequently acquired. Conversely, they also found that other firms may be more motivated by gaining knowledge to address a specific technical problem and in such a case companies may develop interactions with applied research centers. This work indicates that both universities and companies should have realistic expectations when embarking on a new collaboration and establishing a complementary fit between academic capabilities and industrial requirements (either broader networked focused, or more specific knowledge focused) will help in this regard.

Despite the potential that university-industry research collaboration offers as well as a large body of research that has already been conducted in this area there are challenges that remain [25]. A proportion of industrial investments in university activity fail to realise the original collaboration objectives and some studies have indicated that a firm's financial performance cannot be readily linked to whether there is involvement with a university [26]. Nevertheless universities are developing improved capabilities to effectively and efficiently interact with companies and conversely companies are becoming more equipped to interact with university administrative practices and corresponding cultures [27]. Gaining an improved understanding of how universities and companies can both configure their resource base and develop respective organisational capabilities will help address these challenges and the deficiencies that remain in our understanding of university-industry collaborative performance.

III. RESOURCE-BASED VIEW OF STRATEGY

The resource-based view (RBV) of strategy [28] has been used widely as a tool to examine how organisations develop competitive advantage [29, 30]. The approach is based on the premise that an organisation's performance is determined by the resources and capabilities it possesses [31]. Resources [32] can be regarded as being either tangible (e.g. physical infrastructure, equipment and materials), intangible (e.g. intellectual property, brand and culture), and human (e.g. staff and associates). Whereas capabilities can be viewed as the processes that an organisation undertakes in order to deploy and utilise its resources. The RBV approach has been used as a strategy tool in different sectors [33] and whilst there remain some detractors from this approach, it continues to offer a logical and systematic framework to help understand how successful organisational strategies are formulated [34]. There are two underlying assumptions behind the RBV framework, which is that organisations are endowed with different sets of resources and capabilities, and that resources and capabilities cannot easily be transferred between organisations without incurring cost, i.e. they are 'sticky' [35]. Furthermore, valuable resources [36] are rare (they are not common among a majority of organisations); they are imperfectly imitable (they cannot easily be copied); and they are non-substitutable (not easily changed between organisations).

Development of industrial strategy can be initially supported by the identification of resources available to the organisation [37]. There may be opportunities associated with a firm's existing resources and scenario planning can be used to identify opportunities that could be accessed if additional resources were to be acquired. In a technology context additional resources can be gained by companies undertaking collaborations with universities, which are designed to deliver the knowledge required to establish a new resource. Once an organisation, such as an automotive manufacturing company, has acquired a new resource (e.g. modelling software for combustion dynamics within an exhaust manifold), it can then be integrated with other resources in order to build capabilities as organisational routines, e.g. the aforementioned software will be used as part of the overall systems level design process for new automobile engines.

As an extension to RBV, the knowledge-based view [38] is applicable to technological situations since knowledge can be viewed as the major determinant of technical competencies and consequently an organisations accessible knowledge base is its most valuable strategic asset. In this context the competitive advantage of an organisation can be related to its ability to deploy its firm-specific knowledge to incoming resources in a unique manner. Furthermore and in terms of alliances between organisations, Grant and Baden-Fuller [39] have posited that the advantages of alliances can be related to enhanced efficiencies in accessing knowledge, and this theory attempts to describe how knowledge acquisition alone does not account for alliance performance.

The resource-based view perspective has been previously applied to strategic alliances [40] and also collaboration involving not-for-profit organisations [41]. This latter work identifies that the resource-based view has traditionally been applied to commercial organisations pursuing competitive advantage and there has been very little coverage of non-for-profits, which do have to compete for funding from government agencies and other sources as well as competing with peer organisations for partnerships. RBV is viewed as being complementary to social network theory and there is detailed consideration of collaboration networks representing relational resources available to collaborating partners. Moreover, participation in networked structures can provide organisations with a channel to engage strategic assets [42]. In the case of university-industry collaboration in the pharmaceutical sector, a university may be collaborating with a pharma company as part of the pre-clinical validation of lead drug compounds. In this example the pharma company is able to gain access to the latest clinical data from patients at the university hospital, whereas the university can access data on new chemical entities (NCEs) from the company's pre-clinical compound library. This leveraging of strategic assets can therefore be seen as providing the organisational fit for projects where the collaborating partners have complementary capabilities.

Applying the RBV to individuals involved in collaboration has been used to highlight how participation in internal and external networks can influence an academic researcher's career development [43] and this can be further related to a number of independent variables, such as length of career, career experience and individual personality. This work reinforces the basis for applying RBV to collaborative activities, since the acquisition of new knowledge by those involved in research and technology can be associated with the development of new or enhanced resources that are required by both universities and companies to be successful. Moreover, other studies have also focused on the individual level, including research using the scientific and technical human capital approach [44] to explore university research centers and the industry involvement of academic researchers. Collectively these studies point to the often non-linear and complex nature of collaboration that can be categorised through different perspectives and which yield a range of different findings. Nevertheless investigation of the role of resources and capabilities and crucially an examination of specifically how they are configured and deployed provides both an academically rigorous and practitioner relevant framework to consider university-industry research collaboration.

University-industry research collaborations can be viewed as forms of alliances that provide platforms for learning [45]; with the learning derived from either the generation and subsequent application of knowledge outputs from the research that is undertaken, or alternatively from knowledge that is developed through the social interactions between the collaborators in each of the organisations. The application of the resource-based view of strategy to university-industry collaborations therefore provides a framework to consider which resources are required to support the value appropriation process, i.e. generating research outputs that can be applied to industrial applications.

IV. RESEARCH STUDY

The empirical research methodology involved two main components. The first component was based on a series of 32 structured interviews with representatives from companies and the academic sector. This investigation sought to ascertain the resources required by both universities and companies for successful university-industry research collaborations. Qualitative assessment of the resources according to either being tangible, intangible or human related was extended to allow development of the commercial, technical and social capabilities required to underpin effective collaborations between universities and companies. The second component of the research study involved a case study application of these capabilities to a major industry funded collaborative research programme at the university (Imperial College London). The case study investigation involved reflective analysis by the author of how the resources and capabilities were configured and deployed during the development and management phases of the programme.

The two main empirical components of the research study are depicted in the framework in Fig. 1, which is adapted from Grant [32, p. 175]. The framework includes firstly identification of collaboration resources through the resource audit (i), followed by secondly assessment of the linkages between resources and processes to determine the primary capabilities for collaboration (ii). Then thirdly there is examination of how resource and capabilities contribute to successful collaboration through the case study (iii), followed by fourthly analysis of the case study findings to provide strategy implications and practitioner recommendations (iv).

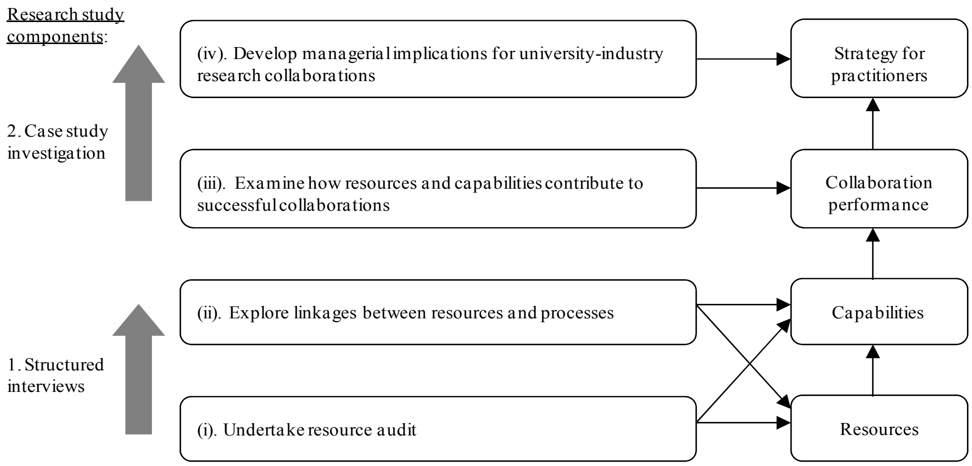

Fig. 1. Framework for analysing resources and capabilities, adapted from Grant [32, p. 175].

The structured interviews were held with a cross-selection of representatives from both the academic and industrial sectors including the following individuals: seven members of academic faculty from different departments at the university (from engineering and natural sciences departments as well as the business school); thirteen professional services staff from the university including business management, contracts and leadership staff; twelve members of staff from different industrial companies in the United Kingdom including both technical and management staff. The interviews included open questions to ascertain the interviewees' perspectives on what constitutes effective university-industry research collaboration, and also questions to identify the resources needed by both universities and companies to develop and manage such collaborations. Since according to the RBV resources can be regarded in terms of either being tangible, intangible, or human-related, Table 1 provides a summary of the interview responses according to these three categories. These responses provide a comprehensive assessment of the resources required by both universities and companies to establish and deliver effective collaborations that generate value for both parties. Although many of the resources are naturally required by the university, which can essentially be viewed as a supplier, it can be observed that the company (i.e. the customer) also needs to have a number of often complementary resources to facilitate collaboration. Through building on the findings from the resource audit it is possible to conceptualise the required organisational capabilities in terms of either being technical, commercial, or social based. These capabilities can be viewed as the groups of resources and accompanying processes that support successful university-industry research collaboration. Rather than examine these capabilities for each of the collaborating organisations (i.e. for the university and the company), it is useful to consider such capabilities for the overall collaboration. Therefore, Fig. 2 provides a summary (affinity diagram) of these collaboration capabilities.

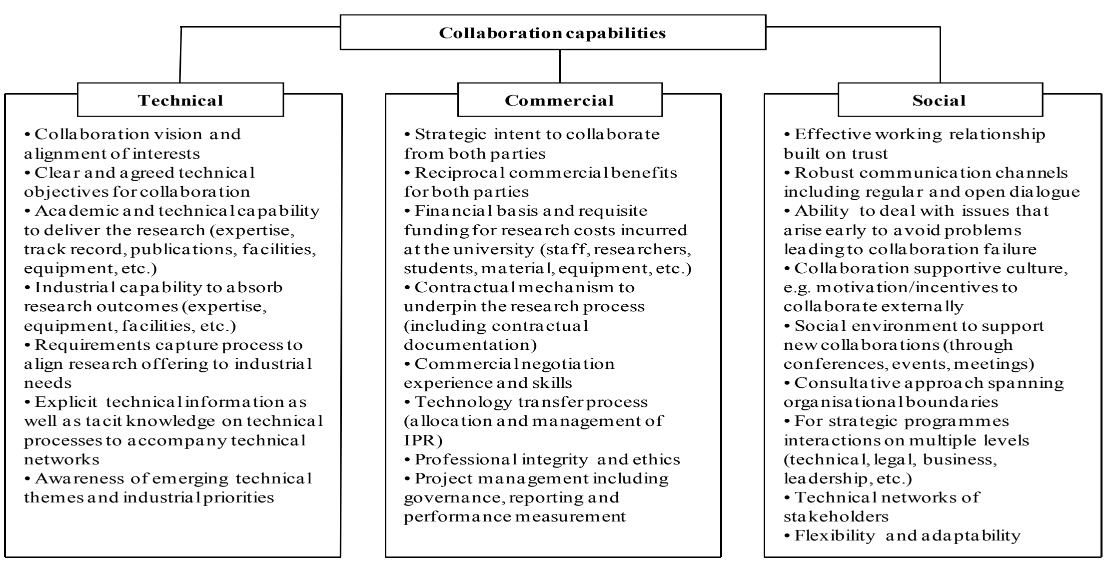

Fig. 2. Capabilities for university-industry research collaborations.

TABLE 1. SUMMARY OF INTERVIEW RESPONSES FOR IDENTIFICATION OF RESOURCES REQUIRED FOR SUCCESSFUL UNIVERSITY-INDUSTRY RESEARCH COLLABORATIONS.

Resource type	University	Company
Tangible	Scientific laboratories including experimental equipment, e.g. laboratories and spectrometry equipment for synthetic organic chemistry experiments	Financial resources to fund or participate in academic research
	Computing facilities including high-performance computing (HPC), modelling and simulation software	Technical facilities to assess research outcomes and establish technology development programmes
	General research and education facilities associated with a university such as lecture rooms	Potential access to manufacturing facilities to incorporate arising technologies into new product development
	Geographical accessible location of university site	
Intangible	Intellectual property and accompanying patent portfolio	Industrial data and knowledge to contribute to academic studies
	Focused research capability (value proposition)	Clear industrial requirements for research
	Track record of principal investigator and academic team, including measures of esteem (e.g. invited presentations, awards, etc.)	Experience of working with universities
	Available communication channels with company (regular meeting and where appropriate teleconferencing/videoconferencing)	Available communication channels with university (regular meeting and where appropriate teleconferencing/videoconferencing)
	University brand and reputation for leading academic research	Industrial reputation for technology development and incorporating research from external sources into company's technology portfolio
	Adequate understanding of the technical problem space, and appreciation of industrial drivers for research	Appreciation of how academic research can address industrial priorities
	Corporate knowledge of how to engage with companies in different industrial sectors	Knowledge within the company of which universities to work with and in which priority areas
	Flexible approach to commercial negotiations (including project scope, price and intellectual property rights)	Flexible approach to commercial negotiations (including project scope, price and intellectual property rights)
	Understanding of collaborative research frameworks and contracting practice	Understanding of collaborative research frameworks and contracting practice
	Professional integrity	Business ethics
	Knowledge of arising industrial opportunities	Knowledge of emerging scientific areas and trends
	Research project management skills	Project management skills
	Supporting culture that promotes interactions with industry (e.g. such work is not penalised in favour of teaching responsibilities)	Supporting culture that promotes interactions with universities (e.g. such work is not penalised in favour of other activities)
	Social environment that helps facilities new collaborations (e.g. conferences, partnering events, open lectures, research meetings, etc.)	
	Technical networks of academic, industry and government stakeholders for a particular scientific area or thematic area/sector, e.g. healthcare, energy, or environment	
	Multidisciplinary approach to research and for strategic programmes an ability to integrate teams from different academic departments	
	Management skills associated with project governance, project reporting, and measuring the performance of collaborations	
Human-related	Academic expertise (scientific experience, track record, publications, international profile, etc.)	Technical vision for how academic research can be deployed in company
	Academic leader (principal investigator), post-doctoral research staff, and postgraduate students (PhD or MSc)	Technical leader from company and where appropriate senior-level sponsor (board level) of major research programmes
	Commercial and business staff with expertise to negotiate industrial contracts	Effective contracts staff with expertise to negotiate academic contracts
	Technology transfer office to lead on the commercialisation of IP	Company legal/contracts department
	Open and regular dialogue with company leading to trusting relationship	Open and regular dialogue with university leading to trusting relationship
	Communication skills of academic and research team	Communication skills of industrial technical team
	Adaptability of academic and research team as well as responsiveness to changes in industrial requirements	
	Business skills to manage industrial research opportunities and meet company's commercial requirements	

One of the main criticisms of the resource-based view is the apparent lack of parameterization of value [46] or the difficulty in translating strategic direction into operational implications. Indeed although the structured interviews allowed a resource audit to be conducted for university-industry research collaboration, in order to properly assess how resources are deployed within collaborations there is a need for greater contextual analysis. Consequently, a case study investigation was undertaken involving reflective analysis by the author, who was personally involved in the direction of a major five-year university-industry collaborative programme established at the university. The case study relates to an industry supported research institute at a university in the United Kingdom. The institute conducts research and education in the area of shock physics, and it was established in 2008 following a substantial investment by a UK industrial organisation. In order to provide background material for the case study, Fig. 3 shows the institute's schedule (schematic version) for the five-year collaborative programme.

The case study investigation involved analysis of how the collaboration capabilities and supporting resources were configured as part of the institute's development and resulting management cycle. Previous research has identified four main stages involved with the development and management of industry support institutes, which are the design, initiate, deliver and sustain stages [47]. This management system (see Fig. 4) provides an appropriate framework to structure the case study investigation and therefore description of how the three collaboration capabilities have been deployed is provided according to these four stages.

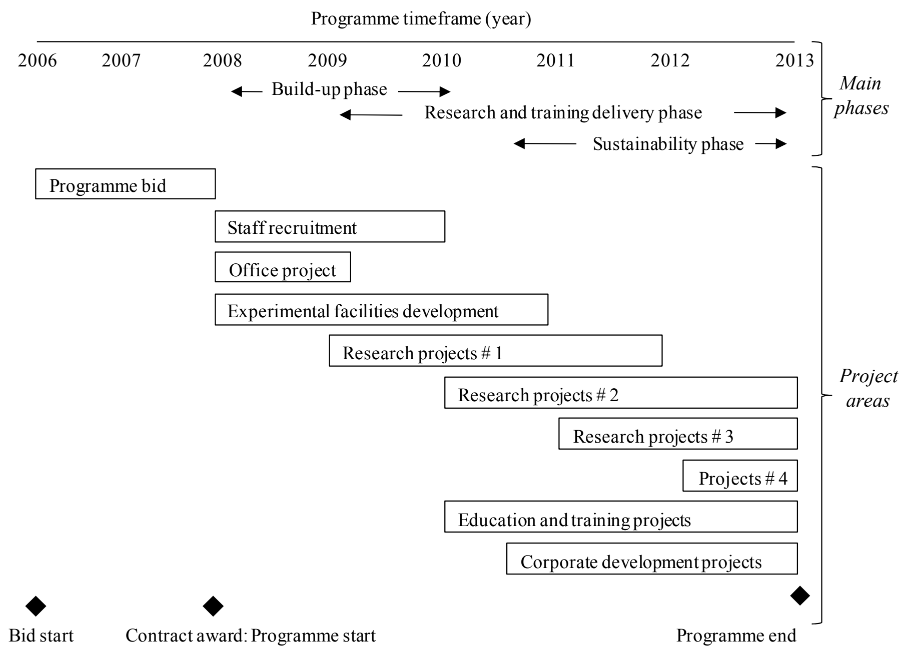

Fig. 3. Five-year schedule for university-industry collaborative programme.

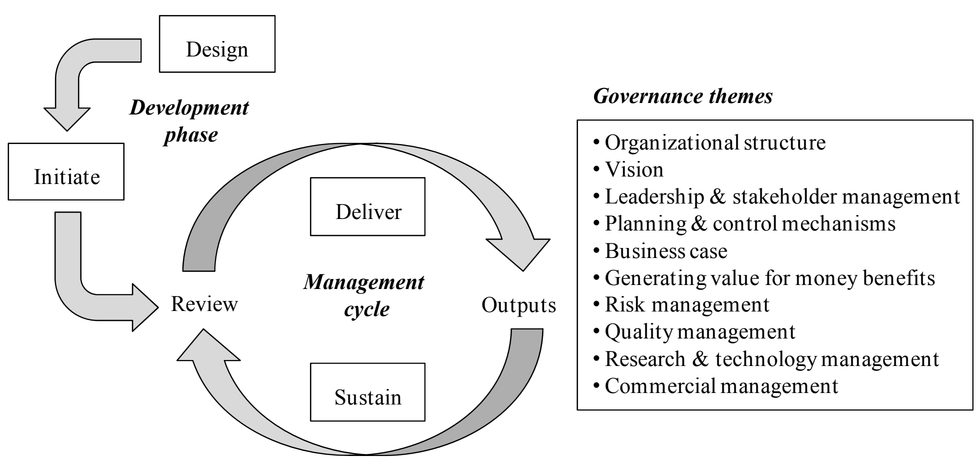

Fig. 4. Institute management system [47].

A. Design stage

The design stage involved establishing the technical vision and objectives for the university-industry collaboration, which was borne out of the company's industrial requirements to develop an improved understanding of how materials behave when subjected to high pressures. Realising this technical vision was predicated on alignment between the industrial requirements and the academic capability at the university, including the technical facilities and equipment, and academic faculty expertise and track record (as codified in research publications, such as journals, conference proceedings and patents). During the design stage there was development of an initial technical capability based on bringing together previously disparate areas of shock physics, including plasma physics and pulsed power driven shocks, dynamic compression of materials under plate impact and static high-pressure research. The technical remit of the collaboration was developed so that knowledge outputs would be generated in all the core areas of shock physics and whilst these areas represent fundamental scientific studies (i.e. corresponding to a low technology readiness level) they are nevertheless broadly aligned with the overall industrial requirements.

Design of the commercial capability rested on development of the funding and contracting mechanism to support the institute but there was also consideration of how the collaborative programme would be governed. Governance was achieved through a joint industry/university operations board that meets quarterly to review institute progress and respond to arising issues, such as any delays in the appointment faculty members. There was also a strategic board chaired by an independent academic with a remit to oversee long-term development and sustainability of the institute. Although the university was required to competitively bid for the industrial programme funding, there were existing technical and managerial interactions with the company. This level of connectivity provided the corresponding initial level of social capital that helped facilitate the university engagement with the company. As the collaboration progressed further, social interactions and capabilities were enhanced through the regular and open dialogue as well as the trust that was established.

B. Initiate stage

The initiate stage involved the formal start-up of the institute and the corresponding collaborative programme, which included a number of research and education projects (such as a new MSc degree in shock physics as well as various short courses). The technical capabilities deployed in this stage included appointment of the institute director (professorial) as well as other academic faculty that collectively had the required expertise and track record to attract the industrial funding. In addition to the professorial institute director, there was also appointment of the programme director who had responsibility for the administration of the institute including overseeing financial management, commercial activities, facilities management and business development. Conversely the institute director had responsibility for the overall technical programme and for managing interactions with other external organisations. This separation of responsibilities by the founding directors of the institute ensured the collaborative programme was delivered to meet the industrial needs and the requirements of the university administration functions were met in a satisfactory manner.

The commercial capabilities deployed in the initiate stage can be related to the framework agreement that was agreed. This framework agreement allowed for an initial baseline programme of work along with an enabling (or tasking element) where additional projects (or tasks) could be enabled throughout the five-year term of the programme. This mechanism gave the university a guaranteed level of funding so that it was able to commit further resources (such as staff, students and new laboratory facilities) to help establish the collaborative programme. But it is also provided the industrial collaborator with a degree of control since a proportion of the research projects would be authorised gradually throughout the programme. The collaborative programme was also supported by a business case that identified leveraged financial benefits in addition to the scientific or knowledge outputs.

C. Deliver stage

Delivery of the collaborative programme followed the design that was described previously and this allowed integration of the technical, commercial and social capabilities from both the university and the company to underpin the collaboration process. The overall programme was managed according to recognised project management standards, including project scheduling, financial budgeting and cost control as well as risk management activities. Individual project budgets were delegated to principal investigators thereby allowing programme finances to be managed centrally.

Technical capabilities delivered were based on the academic strengths of the university. In this regard individual research projects were proposed by the principal investigators and this 'bottom-up' approach ensured academic faculty were confident in the research areas and that crucially findings could be published in journals of appropriate standing. In terms of acquisition of the arising knowledge, the industrial collaborator was involved in the joint supervision of individual projects (where the industrial supervisor may be appointed to a visiting position, such as a visiting researcher or visiting professor). This direct connection with academic projects helped to strengthen the knowledge acquisition process. Indeed a number of staff members from the company registered for postgraduate degrees (e.g. MSc) at the university as well as doctoral (PhD) projects and this was also a major part of knowledge acquisition. It can be observed that this technical and social based capability allows companies to efficiently gain knowledge from university collaborations since explicit knowledge is generated in research articles and crucially staff involved also acquire tacit knowledge of how the research is conducted and interpreted.

Performance of the overall collaborative programme was measured through the design and implementation of a bespoke performance measurement system based on the balanced scorecard [48], which included a holistic view of collaboration performance including financial, institute capability, training and education, and research output metrics. Data and information was collected on a quarterly basis for submission to the industrial collaborator, and was also used by the institute management team to track performance.

D. Sustain stage

In terms of the collaborative programme, the sustain stage relates to the need for activities to be undertaken that underpin the long-term development of the institute's programme. Technical capabilities are supported by new experimental equipment that has been commissioned, including a new large-bore gas gun facility that allows plate impact shock physics research to be carried out. This new facility supports training of industrial staff on the equipment which helps augment knowledge gained from taught courses. The new experimental facility also provides a technical platform to contribute to submission of joint industry/university proposals for funding by the UK government funding agencies. The facility was established through joint-working by the university and the company, which included full project life cycle considerations from conceptual and planning stages, through to design, manufacture, testing and installation stages as well as assembling the safety case for the experimental infrastructure [49]. This joint working further highlights the strengths of relations between the company and university that underpinned establishment of this major new facility.

Furthermore, through the close working relationship that is supported by various joint university-industry activities (e.g. collaborative projects, management board meetings, training courses, research meetings, conferences, etc.), the social capabilities of the collaboration have been gradually strengthened. Increased social capital arising from the regular and open dialogue and also from joint decision-making thereby contributes to the sustainability of the collaboration through a shared vision for the long-term development of the programme. This sustainability is accompanied by commercial capabilities developed including additional funding secured as well as the use of financial leverage as a mechanism to demonstrate 'value for money' for industrial investment in academic research. This financial leverage is detailed in the aforementioned balanced scorecard, which allows this metric alongside others to be tracked in a timely and convenient fashion by both key customer contacts in the company as well as by the institute's management team.

V. CONCLUSIONS

This paper has described how the resource-based view (RBV) of strategy can be used as a framework to consider how university-industry research collaborations can be successfully developed and managed. These collaborations are important across a raft of industrial and high-tech sectors, such as pharmaceutical and healthcare, defence and aerospace, engineering and telecommunications. Companies collaborate with universities to gain access to specific knowledge outputs [50], such as promising research areas that can be developed further to enhance industrial competitiveness. But companies also collaborate with universities to participate in science and technology networks in order to gain spillover benefits [51] from wider external interactions. This paper has provided a thorough treatment of the merits of university-industry research collaboration and this has been studied through a number of illustrative mechanisms and theoretical lenses.

The resource-based view of strategy has provided a framework to analyse how university-industry research collaborations can be configured and the paper has employed two main empirical lines of enquiry in order to explore the matter. Structured interviews with 32 people heavily involved in university-industry collaboration has provided a rich set of resources needed by both universities and companies, and these resources have been refined into the technical, commercial and social capabilities required for collaborations. This view has been examined further by assessing how these capabilities were deployed during a five-year industry supported collaborative programme at a university institute. Through building on this work, the following practitioner oriented recommendations are summarised for university-industry research collaborations:

A. Universities

- *Technical*: The need for leading science and technology (as demonstrated by publications, citations, etc.) coupled with an awareness of how it relates to industrial requirements in a given area; Agreement with industrial partner on clear technical objectives; Supporting experimental infrastructure and equipment required.
- *Commercial*: Experience and commercial skills to negotiate and administer industrial research contracts, including negotiation of intellectual property rights (IPR); Project management skills; Professional integrity.
- *Social*: Academic leadership and for major collaborative projects there can also be a need for an administration leader; Regular and open dialogue with the industrial partner; Trusting relationship that allows problems and issues to be addressed; Flexibility and adaptability in regard to modified industrial requirements; Consultative approach including negotiation skills.

B. Companies

- *Technical*: The need for awareness of academic capabilities and how they can be integrated with product development opportunities; Data and information on industrial requirements that can be shared with academia; Technical facilities to develop the research outputs from collaboration.
- *Commercial*: Collaboration funding (where appropriate); Experience and commercial skills to negotiate and administer academic research contracts, including negotiation of intellectual property rights (IPR); Project management skills; Professional integrity.
- *Social*: Leadership within the company of the academic relationship including technical management of the collaboration; Trusting relationship that allows problems and issues to be addressed; Flexibility and adaptability in regard to modified academic considerations; Consultative approach including negotiation skills.

Collaboration with companies can offer universities opportunities to develop research findings ultimately towards commercial application, e.g. through technology transfer (IP licensing). In the engineering sciences, such as civil engineering, development of new construction management techniques can help engineering faculty to influence future engineering practice for new buildings. In the medical sciences area, clinical academics working on assessment of lead development compounds collaborate with pharma companies in order to validate the fundamental clinical research. Consequently, the ability to demonstrate the commercial application of research can be a strong motivator for academic faculty to work with companies. Indeed within the UK the current governmental assessment scheme for research quality, the Research Excellence Framework [52], places a high value on demonstration of the impact of research and this includes commercial impact.

The findings reported in this research highlight that whilst tangible assets such as laboratories and equipment are required for university-industry collaborations, many of the resources and capabilities are either intangible or human-related, such as academic track record and expertise, or experience by both universities and companies in contracts negotiation and accompanying commercial skills. Certainly in the case of academic knowledge this can be regarded as being 'sticky', i.e. difficult to imitate, or to transfer between organisations without incurring cost. Collaborations between companies and universities allow industry to gain some of the knowledge benefits of such academic expertise through the collaboration mechanism, which may of course have a financial value attached to it. Nevertheless, this could well be less costly compared to a company setting up its own experimental facilities and employing the required technical staff. Even in this scenario, the specific knowledge held by the university may not be acquired. Collaboration with universities can be financially attractive in connection to this research cost avoidance [53] and especially when viewed in an open innovation framework [54], where companies are seeking new ideas and technologies from external sources.

Embarking on a new collaboration for purely financial benefits may however be a somewhat narrow pathway to follow that does not realise the required objectives. More sensible would be the pursuit of collaborative activity as part of an overall approach to learning and where companies have positioned university collaboration within an overall knowledge management system, there will be a greater likelihood that sustained benefits (including financial benefits) can be acquired from the collaboration. Furthermore, these benefits can be associated with the companies' absorptive capacity [55], i.e. the ability to successfully utilise the research findings from the collaboration within the company. This absorptive capacity will require staffing, organisational processes and crucially a supporting culture that places value on academic research. Without this supporting environment then collaborative research with universities is unlikely to become sustainable or indeed profitable. Companies may also acquire knowledge benefits through spillover effects from participation in collaborative networks [56] but again an ability to absorb the arising knowledge is crucial.

In regard to the management skills associated with university-industry collaborations, they necessarily involve more than one organisation, and so an ability to manage across organisational boundaries [57] can be a key skill-set for those involved. These skills could include a flexible and consultative approach, where stakeholders are engaged, and the need to accommodate the perspectives from staff involved in the collaboration from both the university and the company. No more will these skills be needed than by the principal investigator of the collaboration at the university, who needs to bridge the university-industry interface in order to ensure the collaboration is successful. For example, with the establishment of a new research centre or institute, the founding academic director would also need such intangible skills to be in abundance as well as the necessary academic credentials of course.

The paper has assembled a detailed view of how resources and capabilities can be configured to underpin successful university-industry collaborations. The resource-based view of strategy has provided a framework to allow resources and capabilities for collaboration to be considered. Although a critique of the RBV approach is the reported difficulties in translating strategy into real world managerial insight as well as the lack of operational validity [58]. The contextual analysis of university-industry research collaboration and the accompanying case study investigation has addressed this critique through providing practitioner focused implications for the management of research collaborations involving universities and companies. Furthermore and in metaphorical terms, collaboration can be viewed in terms of an automotive vehicle and its journey: the journey's destination would represent the development of new technical capabilities and hence the goal of the collaboration; the vehicle's engine represents the commercial capabilities to deliver the collaboration; and the fuel in the vehicle represents the social capabilities (including trust) to support the collaboration. This paper has attempted to expand on the current view of university-industry research collaboration and the benefits that can arise for the parties involved through, in the context of the vehicle and the journey, developing a systems level analysis of the vehicle and its automotive engine along with an improved understanding of the direction of travel. The RBV approach is therefore an illustrative framework that can help both practicing managers and theorists to examine how research collaborations can be developed and managed in terms of both structural and process considerations.

The weaknesses of this paper lie in the qualitative approach and the reflective nature of the case study investigation by the author. However, the empirical methodology employed incorporates the findings from structured interviews with a varied collection of individuals involved with collaboration, including people from various backgrounds and with different perspectives. The case study investigation allows contextual examination of the resulting resources and capabilities. An extensive literature review has been undertaken and this helps to augment the findings provided in this paper.

Future work is suggested on development of structured processes to provide universities and companies with a tool-set to help establish and then manage collaborations so that benefits are optimised for both parties. Larger-scale studies that assess best practice across different universities and companies involved in collaboration are suggested, including consideration of factors for geographical, industry sector and collaboration scope considerations. Furthermore, development of an appropriate taxonomy of different types of university-industry collaboration would help determine best practice for different organisational situations.

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