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Science-based innovation via university spin-offs: the influence of intangible assets

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University spin-offs (USOs) have attracted significant attention from scholars and policy-makers as an important mechanism for science-based innovation. The debate on how USOs generate innovation outcomes has often focused on tangible assets, while the role of *intangible assets* has been less explored and remains loosely defined. Yet emerging research suggests that intangible assets, especially in the early stages of a USO's lifecycle, have a critical influence on its survival and future success, highlighting a need for a better understanding of how intangible assets enable science-based innovation through USOs. Drawing from several streams of literature, we define intangible assets in the context of science-based innovation through USOs: *an intangible asset is a resource that is non-physical, non-financial, has long life, and has potential to provide future benefits to the owner.* Based on this working definition, we conduct a systematic literature review of the leading innovation management journals and inductively derive a framework outlining the antecedents, processes, and outcomes of science-based innovation through USOs, focusing on the influence of intangible assets. The framework identifies the categories of resources which can enhance or hinder science-based innovation through USOs. Such categorization reveals fruitful directions for future research such as a deeper examination of societal outcomes. We conclude by offering

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recommendations for scholars, practitioners, and policymakers to better leverage intangible assets to enhance science-based innovation.

1. Introduction

Governments across the globe support university research to spur innovation, yet innovation scholars highlight the challenges of translating public funding into science-based innovation[1] (Arora et al., 2020; Guzman and Stern, 2020). Consequently, university spin-offs (USOs), have received increasing attention in the technology management literature as an important mechanism for science-based innovation. USOs stimulate economic and social growth by creating novel products and services, attracting talent, and enriching regional and national innovation ecosystems (Roberts et al., 2019; Bolzani et al., 2021).

Much of the extant research on USOs and their innovation outcomes is centered around *tangible assets* such as venture capital financing, government funding, and equipment. These tangible assets are typically used in empirical studies (Agarwal et al., 2004; Hayter, 2015; Siegel and Wright, 2015), as they are relevant and easier to quantify and operationalize. However, *intangible assets*, such as intellectual property, human, knowledge, and relational capital, are increasingly recognized as critical inputs to the science-based innovation process (Kramer et al., 2011; Crema and Nosella, 2014; Grimaldi et al., 2017).[2] Crucially, investment in intangible assets is accelerating across the OECD countries (Aizcorbe et al., 2009; Price, 2019; Hazan et al., 2021) but the link between intangible asset investment and commercialization is not well understood. While research is nascent on the role of intangible assets in science-based innovation (hereafter also referred to as 'science innovation'), there are indications that intangible assets play critical roles in USO survival and success, especially in the early stages.

For example, in the biotechnology sector, the individual-level intangible assets of academic cofounders, such as their research excellence, and the novelty and breadth of their patents, inform strategic, path-dependent decisions even *before* USO founding (Thomas et al., 2020; Park et al., 2022, 2023). These early decisions heavily influence the development of downstream resources and capabilities, such as prioritizing markets and developing a business model, that contribute to future USO success (Park et al., 2023). As another example, Fini et al. (2022) find that STEMM scientists' research quality and patent activity significantly predict the likelihood of establishing science-based ventures. As these examples show, emergent research suggests that intangible assets have a critical influence on the success of USOs, but the link between intangible assets and USOs remains understudied in the innovation management literature.

Therefore, a richer understanding of the role intangible assets play in the success of USOs can enhance science innovation and improve efficiencies in the translation of public funding to desired economic and societal outcomes through USOs. Hence, we pose the research question, *what role do intangible assets play in science-based innovation through university spin-offs?*

To answer this question, we must first address a gap in the extant research, namely that existing definitions and examples of intangible assets vary across different streams of literature. This is largely due to the fact that intangible assets are less identifiable than tangible ones and therefore they are difficult to define and measure. For example, intangible assets in accounting focuses on quantifiable resources owned by a company, while the management perspective of intangible assets focuses on human and intellectual capital. This lack of convergence in the definition of intangible assets makes it difficult to conduct a systematic review of their influence on science innovation. Thus, this paper first aims to combine the strengths of these disparate treatments of intangible assets and synthesizes a novel, conceptual definition of intangible assets in the context of science innovation. Next, using this new definition, we address the research question by conducting a systematic literature review of the current body of research on science innovation *via* USOs, where one or more intangible assets are studied as a variable of interest.

This paper offers four contributions. First, we provide a novel, concrete, and actionable definition of intangible assets in the context of science innovation through USOs, which can be used by both innovation and management scholars. Second, using this definition, we conduct the first

[1]We define science-based innovation as the commercial exploitation (i.e., development of new or improved products and services) of a patented invention or unpatented scientific expertise derived from university-based research (Perkmann et al., 2013; Shane and Ulrich, 2004; Fini et al., 2018).

[2]As an example of how intangible assets can influence the development and success of a USO, the academic-entrepreneur founder of AbCellera leveraged an intangible asset (their social capital, specifically their international network) to shape his research and to enhance market potential while the technology was still in the lab (Park et al., 2023).

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systematic review of science innovation through USOs, focusing on the influence of intangible assets. This systematic review reveals patterns in past research, outlining the antecedents, processes, and consequences of science innovation through USOs across multiple levels and contexts, and identifying interesting paths for future work.

Third, by synthesizing the literature, we propose a processual framework for science innovation through USOs. This framework highlights the process through which intangible assets influence USO performance. Fourth, we identify key knowledge gaps in the field, namely, a lack of sophisticated measures of USO innovation and a poor understanding of why USOs fail. We conclude by offering recommendations to address these gaps and to enhance the translation of science innovation within a university context.

2. Conceptual background

Scholars have increasingly focused on the university as an initiator of breakthrough innovations and an important actor to develop new business activities (O'Shea et al., 2007; Fini et al., 2011; Klofsten et al., 2019; Bolzani et al., 2021; Thomas et al., 2020). In particular, USOs can play a critical role in the knowledge transfer and innovation process, by converting novel science into economic outputs and broader societal benefits (Miranda et al., 2018). The many mechanisms through which USOs can create value include generating new business ideas, opportunities, and activities, creating high-skilled and knowledge-intensive jobs, diversifying economies, increasing the value of exports, and maintaining regional and national ecosystem richness. Thus, numerous studies have explored policy interventions to encourage academic scientists to translate their inventions to science innovation through USOs (Benneworth and Charles, 2005; Lockett et al., 2005; Mustar and Wright, 2010; Vincett, 2010; Arora et al., 2020; Fini et al., 2020).

However, in terms of understanding *how* USOs enable successful science innovation, many of the empirical studies in this field focus on *tangible assets* as both dependent and independent variables. For example, venture capital funding is a frequently used variable to study the antecedents and outcomes of successful USOs (Zhang, 2009; Hayter, 2013; Rodríguez-Gulías et al., 2018). Numerous empirical studies related to USOs focus on other tangible assets such as cash flows, direct funding, equity amounts, and laboratory equipment (Johansson et al., 2005; Savva and Taneri, 2015; Meoli and Vismara, 2016).

However, *intangible assets*, such as a scientist's reputation and entrepreneurial capabilities, also play critical roles in unlocking scientific innovation (Buigues et al., 2000; Seo and Kim, 2020), as evidenced by the rapidly increasing investments into intangible assets by the US and other OECD countries (Aizcorbe et al., 2009; Price, 2019; Hazan et al., 2021). While the specific definitions of tangible vs. intangible assets have been debated, researchers generally agree that tangible assets deal with monetary and physical resources (e.g., investment funding, cash balances, raw materials, equipment, infrastructure, mainframes, and developed products) and intangible assets include human, knowledge, and relational capital (e.g., scientist prestige, intellectual property, research excellence, experience, alliances, and team makeup) (Heirman and Clarysse, 2007; Greco et al., 2013; Grimaldi et al., 2017). However, there is a lack of consistency in how intangible assets are operationalized and the concept is poorly defined, which we expand upon in the next subsection.

To conduct a systematic review of science innovation through USOs, focusing on the influence of intangible assets, we need a working definition of intangible assets to enable our bibliographic study. In the following subsections, we review the several streams of literature that either directly or indirectly elucidate the nature of intangible assets and synthesize these various treatments into a new working definition. We use this working definition of intangible assets to conduct our systematic review. The motivation of our paper is not to study intangible assets more broadly, rather, it is to study how intangible assets facilitate science innovation through USOs. The following subsections synthesize several bodies of research to derive a new definition of intangible assets.

2.1. *Defining intangible assets: integrating the literature*

Disparate streams of research have their own treatments of intangible assets, and we have yet to see a convergent definition. Most definitions of intangible assets consist of lists and examples (Corcoles, 2010), with no conceptual description of what they actually are that can be built upon by other researchers in different contexts. While we do not attempt to derive a universal definition of intangible assets, we need a workable definition for our systematic review of science innovation through USOs, focusing on the influence of intangible assets. Thus, we assess disparate streams of research to produce a definition of intangible assets relevant to the context of science innovation.

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2.1.1. Accounting

Quantitative representations of intangible assets are frequently seen in the accounting literature, where methods have been proposed to operationalize intangible assets into numerical and financial variables such as R&D expenditures and counts of innovative property and computerized applications, that are then included on firm and government balance sheets (e.g., Corrado et al., 2005, 2009). While these operationalizations are useful, because of the need to quantify intangible assets in most empirical work in this field, more nuanced, less quantifiable intangible assets such as entrepreneurial capabilities are often understudied in this space. In other words, the accounting literature tends to favor metrics that represent easily quantifiable and established firm assets such as R&D expenses and computer applications, and focuses less on fuzzier firm assets such as individual networks, research expertise, and the novelty, breadth, and market potential of patents. These fuzzier assets can play crucial roles in science innovation, early USO formation, and eventual venture success (Thomas et al., 2020; Park et al., 2022, 2023).

2.1.2. Human and intellectual capital

In the management literature, intangible assets that focus on the founder or scientist are often captured in the human and intellectual capital streams of research and tend to be fuzzier, or less easily quantified than in accounting research. In the context of USOs and science-based start-ups, human capital can be broadly defined as a scientist's knowledge, skills, abilities, experiences, and level of prestige, and has been shown to be positively associated with firm success (Baum and Silverman, 2004; De Cleyn et al., 2015; Klofsten et al., 2019). The concept of intellectual capital overlaps with human capital and is broadly defined as the knowledge stored within a firm or individual (Nahapiet and Ghoshal, 1998; Dietz and Bozeman, 2005). It has also been shown to have influence on the development and success of USOs and science-based firms (Baum and Silverman, 2004; Link and Ruhm, 2011; Secundo et al., 2017).

We suggest that both treatments of intangible assets (accounting and human/intellectual capital) have their strengths, and they should be considered together to appropriately investigate the role of intangible assets in science innovation. This sentiment has been shared previously. For example, The United States Bureau of Economic Analysis (BEA) notes that when studying intangible assets, quantifiable metrics such as R&D investment dollars should indeed be included but, 'methodological issues (will) still remain', since intangible assets should also include less easily quantified 'investments in human capital' (Aizcorbe et al., 2009).

The amalgamation of the two streams of literature broadens the scope and definition of intangible assets and we suggest that this expanded scope more accurately represents such assets. Scholars have noted the need to broaden economic concepts by incorporating managerially relevant, human capital constructs: 'these (economic) evaluation methods tend to be too narrow in defining the unit of analysis…focusing generally on…a monetary translation of scientific and technical outputs. It is not what is in these methodologies that is the problem, it is what has been left out' (Bozeman et al., 1999, p. 7). Combining these streams of research not only reduces the possibility of important constructs being 'left out' but also enables a broader conceptual definition, addressing the problem of most definitions of intangible assets simply being lists or examples.

2.1.3. A new definition of intangible assets

By combining these streams of research, we construct a new working definition of intangible assets, which we then use to conduct our systematic review of science innovation through USOs, focusing on intangible assets. A prior conceptual definition of intangible assets that we identified is provided by Corcoles (2010), who argues that intangible assets generally share the following properties: non-tangible, long life, provide future benefits, identifiable or non-identifiable, controlled by an entity. We draw from this definition but modify *non-tangible* to *non-physical and non-financial*, as the latter is more descriptive; also, defining an intangible asset as non-tangible is obvious. We modify *identifiable* to *quantifiable*, as the latter term is clearer and better describes the difference between certain human capital variables such as years of education (quantifiable) and scientist prestige (less easily quantified). Finally, we make a subtle replacement: *owner* in favor of *controlled by an entity*. This is because the entity and the nature of the control may change, such as tacit knowledge or patents being transferred from a scientist to a firm. We proceed to augment our conceptual definition with examples of quantifiable variables often seen in the accounting literature and the less easily quantified variables often seen in the human/intellectual capital literature. Therefore, in the context of science innovation through USOs, we suggest the following definition of intangible assets:

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An intangible asset is a resource that is non-physical, non-financial, has long life, and has potential to provide future benefits to the owner.

Intangible assets can include quantifiable proxies of firm capabilities and value such as R&D expenditures, patents, and highly qualified personnel (HQP) metrics, and other constructs that are less easily quantified yet are highly relevant to USOs including entrepreneurial capabilities, technological capabilities, creativity, and scientist prestige.

This definition and its supporting description have three key characteristics that together, lead to a novel treatment of intangible assets: (1) it starts with a conceptual definition, (2) this conceptual definition is augmented with a list of elements that have been recognized as intangible assets, and (3) it integrates both the accounting and human/intellectual capital streams of research. We provide this definition as a starting point for our systematic review of science innovation through USOs, focusing on intangible assets.

2.2. Systematic review

While we identified several bibliometric analyses on USOs more generally (Mustar et al., 2006; O'Shea et al., 2007; Rothaermel et al., 2007; Mars and Rios-Aguilar, 2010; Miranda et al., 2018; Mathisen and Rasmussen, 2019), we aim to provide the first systematic review of the influence of intangible assets on science innovation through USOs. The primary focus of our systematic review is to uncover the inputs, outputs, and processes that enable science innovation through USOs by identifying and analyzing empirical innovation management papers that incorporate intangible assets.

We note that this systematic review does not broadly cover intangible assets, rather it focuses on the influence of intangible assets on science innovation through USOs. It is also important to note that our study is driven by relevant papers that are found specifically in the innovation management literature (the journals that comprise our systematic review are listed in Section 3.1). While some of the intangible assets we have discussed, such as entrepreneurial capabilities, are also examined in adjacent fields of research, such as entrepreneurship, these fields do not necessarily focus on innovation management, and may only study phenomena at the individual level. While there may be overlapping topics of interest such as entrepreneurial mindset and team dynamics between these adjacent fields and ours, we are mainly interested in how intangible assets affect science innovation through USOs. Therefore, we focus our study on the innovation management domain.

3. Methodology

This section presents the methods used to conduct our systematic review of the literature related to the role of intangible assets on science innovation through USOs. We loosely follow some of the bibliographic methods employed by Perkmann et al. (2013, 2021) in their systematic literature review of academic engagement.

3.1. Search terms and data source

The unit of analysis for our study is articles published in the leading Technology and Innovation Management journals. We selected 13 journals based on a meta-analysis conducted by Huang et al. (2019). In their study, the authors compared five extant papers (Linton, 2006; Thongpapanl, 2012; Yang and Tao, 2012; Lee, 2015; Hall, 2016) which independently ranked and produced a list of the top Technology and Innovation Management journals based on numbers of publications, citations, and impact factors.

As expected, some of the journals appeared more than once across the five lists. As an example, *Research Policy* appeared on all five lists, but *Asian Journal of Technology Innovation* only appeared in Hall's (2016) list. Huang et al. (2019)[3] identified the journals that appeared at least twice across the five lists, which resulted in the following 13 journals from which we draw our sample of papers: *IEEE Transactions on Engineering Management, Industrial and Corporate Change, Industry and Innovation, International Journal of Technology Management, Journal of Engineering and Technology Management, Journal of Product Innovation Management, Journal of Technology Transfer, R&D Management, Research Policy, Research-Technology Management, Technological Forecasting and Social Change, Technology Analysis & Strategic Management*, and *Technovation*.

The source of data was the Web of Science database. It is a scientific citation indexing service that enables researchers to conduct comprehensive citation searches for multiple journals. While Web of Science and Scopus are both popular indexing services, we choose Web of Science as it prioritizes scholarly journals (as opposed to a broader range of outlets, including consumer-oriented publications),

[3]Huang et al. (2019) provides a synthesis of the key Technology and Innovation Management journal rankings that had been conducted to that point, making it a suitable aggregated meta-report from which to identify articles for our study.

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Table 1. Search query and results

Web of science query	Number of publications
((TS = ((universit* OR academi*) AND sci* AND innovat* AND spin* AND (entrepreneur* OR determinant* OR success* OR performance* OR obstacle* OR barrier* OR inhibitor*))) AND TS = (patent* OR network* OR publication* OR capabilit* OR employee* OR staff* OR training OR database* OR project* OR assignment* OR teaching* OR visiting OR conference* OR intangible asset OR knowledge OR trade secret* OR information capital OR relational capital OR know-how OR brand OR advertising OR reputation OR culture OR human capital OR experience* OR talent OR prestig* OR creativity OR R&D OR knowledge management system* OR data management OR customer management system* OR external relationship* OR organizational capital OR structural capital OR organizational capital OR sharing of information OR firm strategy OR firm mission)) AND SO = (Journal of Product Innovation Management OR Research Policy OR Research-Technology Management OR R&D Management OR IEEE Transactions on Engineering Management OR Technological Forecasting and Social Change OR International Journal of Technology Management OR Technovation OR Technology Analysis & Strategic Management OR Journal of Engineering and Technology Management OR Journal of Technology Transfer OR Industrial and Corporate Change OR Industry and Innovation)	74
Filter by only empirical studies, with at least one intangible asset variable	63

and has some more field tags, enabling flexibility in advanced searches (Singh et al., 2021). We extracted the full bibliographic records of innovation and USO-related papers in our selected journals through a Boolean logic search query on wild-card search terms related to universities, entrepreneurs, science, spin-offs, and innovation. We then added a list of keywords to the search query related to intangible assets by aggregating the ontologies and taxonomies on intangible assets curated by Leitner (2005), Corcoles (2010), and Cozzarin (2021) (see Appendix A for full details). Next, we filtered the results by papers that were published in the above-mentioned 13 Technology and Innovation Management journals. This query produced 74 results. Finally, we manually reviewed the full text of each article and removed any paper that did not have empirical data or did not contain at least one variable including an intangible asset, leading to a final list of 63 papers. The full query and the corresponding results are provided in Table 1.

3.2. *Data analysis and theme mapping*

We read and analyzed the 63 papers, compiling the following data into a table: analysis type, independent variables (i.e., inputs), mediators/moderators (i.e., processes, or a construct that influences the conversion of inputs to outputs, which is also the definition used in Brown and Svenson (1988) in their bibliographic review of R&D productivity) and dependent variables (i.e., outputs). For each variable we identified its level of analysis (individual, firm, intermediaries, ecosystem) and whether it was an input, process, or output variable. We then mapped each variable to broader innovation themes, to aid in our analysis. For example, firm-level independent variables such as 'team size', 'team heterogeneity' and 'team age' were grouped under the subcategory, 'firm capabilities' as these variables are frequently employed as proxies for firm capabilities. The full categorization schema is provided in Table 2.

We note that a few of the variables studied in these papers are actually *tangible assets*. This is because we identified papers that studied at least one intangible asset, but did not exclude papers that also studied tangible assets. For example, a selected paper that has an intangible asset as an independent variable (e.g., strategic alliances) may also have a tangible asset as a dependent variable (e.g., firm revenues). Tangible assets have been labeled as such in Table 2. Also note that some variable categories, and their associated variables span multiple levels, as shown in Table 2. For example, for the variable 'patents' in the 'Technological capabilities' category, a patent can be assigned to either the individual scientist or the firm, therefore the variable spans both levels.

We then analyzed our tabulated and aggregated data according to the variable categories in Table 2 in a graphical format, separating the variable categories for each of the inputs, processes, and outputs and by levels of analysis (individual, firm, intermediaries, and government/ecosystem). Finally, we used the graphical representation of the results of our bibliographic review to create a stylized model, or framework, outlining the various antecedents of the role of intangible assets on innovation through USOs at multiple levels, along with the key processual mediators and outputs.

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Table 2. Variable categorization schema

Variable type	Variable category	Level of analysis	Related variables in papers
Independent	Scientist capabilities – research and entrepreneurial characteristics of the individual scientist	Individual	Consulting activities Role models Years at academic institution Entrepreneurial orientation Collaborative research Contract research Entrepreneurial capabilities Researcher characteristics Publications
	Technological capabilities – characteristics of the invention or product itself	Individual and Firm	Technology readiness level Research type Patents
	Firm capabilities – characteristics of the team or company	Firm	Team size Team heterogeneity Team age Science based Identification of market need Market strategy Firm creation Firm characteristics
	University capabilities – support and resources from the university	University	Business training Teaching capital TTO access University support Industry partnerships Department size University type
	Government and ecosystem support – resources from local and national governments, and other actors within the commercial or research environment	Ecosystem	Highly qualified personnel Science park access Networks Government support Geography – culture Incubators
Dependent	Scientist growth and impact – changes in scientist capabilities and perspective	Individual	Entrepreneurial intentions Patents Socialization (conferences, informal conversations) New research Collaborative research
	Economic Performance – commercial improvements or changes to the firm, or the local network of other firms and stakeholders	Firm and Ecosystem	Spin-offs Non USO start-ups Ip revenues[1] Abandonment Firm revenue[1] Firm size External financing[1] New products[1] Number of customers Survival Licensing
	Knowledge Translation Impact – conversion of scientific invention to commercial benefits to the local network of firms and stakeholders	Ecosystem	University–industry interactions Knowledge transfer

(Continues)

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Table 2. (Continued)

Variable type	Variable category	Level of analysis	Related variables in papers
Process/Moderator	Firm/Entrepreneurial Strategy – decisions made by the scientist or firm that led to science-based innovation	Individual and Firm	Entrepreneurial self-efficacy Entrepreneurial capabilities Network centrality Researcher excellence IP strategy Strategic alliances
	Innovation Intermediaries – other actors or institutions that contributed to science-based innovation	University and Incubators	Department characteristics Connectedness of TTOs Incubator support University support
	Innovation Policy – the effect of policy interventions aimed at translating science-based inventions and technologies to commercial outputs	Government and Ecosystem	University–industry linkage Effective filtration Geography Ecosystem richness Policy and programs Funding structure

[1]Tangible assets.

4. Results

This section presents the results of the systematic review. Each subsection details a specific component of the current body of research related to science innovation through USOs, focusing on intangible assets.

4.1. *Descriptive view of the field of intangible assets and university spin-offs*

We observe that the first set of papers on this topic was published in the late 1990s, with a relatively low and steady rate of publication until the early 2010s. The number of publications peaked between 2012 and 2015 and has remained relatively steady since (Figure 1). This rise in publication activity in the last decade is likely due in part to the increasing interest in management research on intangible assets more generally (Kramer et al., 2011; Crema and Nosella, 2014; Grimaldi et al., 2017).

We find that the top three journals in terms of number of publications, *Technovation*, *Journal of Technology Transfer*, and *Research Policy*, dominate research in this field, accounting for nearly 74% of all articles (Table 3). The countries with the most research on this topic are the UK (13 articles) and Italy (16 articles) (Table 4). Finally, most research in this field is quantitative (64% of papers) with most of the remaining papers being qualitative, and one paper being a network analysis (Table 5).

4.2. *Inputs, outputs, and processes*

This sub-section presents the thematic mapping of variables for the inputs, outputs, and processes (i.e., factors that help convert inputs to outputs) used in the papers.

4.2.1. Inputs

At the individual level, the characteristics of the academic scientist, including their education and prestige (Boardman and Ponomariov, 2009; Bonardo et al., 2010; Criaco et al., 2014; Thomas et al., 2020), their entrepreneurial background (Visintin and Pittino, 2014; Ramaciotti and Rizzo, 2015; Thomas et al., 2020), and the presence role models (Prodan and Drnovsek, 2010; Di Paola, 2021) all influence the innovative capacity of USOs. In general, these studies suggest that many of these inputs positively influence USO success. Some studies provide counterintuitive findings, such as negative relationships between prior industry experience and USO survival (Criaco et al., 2014) and third-party funding and USO formation (Ramaciotti and Rizzo, 2015). Also, the characteristics of the early technologies these scientists produce while still in their academic labs are important factors in determining the outcomes of innovation through USOs, including their market-readiness (Battaglia et al., 2021) and the number and quality of patents related to those technologies (Lindelof and Lofsten, 2005; Prodan and Drnovsek, 2010; Ramaciotti and Rizzo, 2015; Radko et al., 2023).

Firm-level characteristics are also frequently examined. USO team heterogeneity appears

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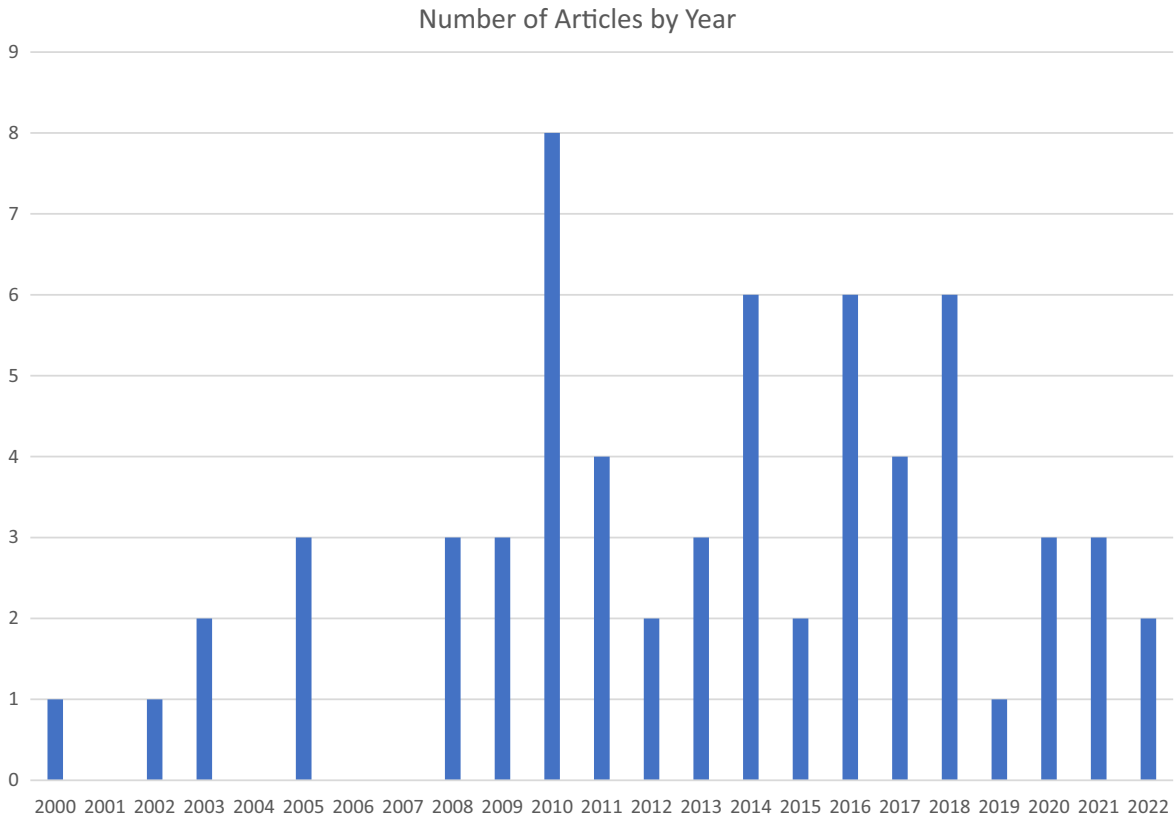

Figure 1. Frequency of publications on science innovation through USOs, focusing on intangible assets. [Colour figure can be viewed at wileyonlinelibrary.com]

Table 3. Number of publications by journal

Journal	Number of publications
Technovation	22
Journal of Technology Transfer	17
Research Policy	8
Technological Forecasting and Social Change	5
R&D Management	3
Technology Analysis & Strategic Management	3
International Journal of Technology Management	2
Journal of Product Innovation Management	1
IEEE Transactions on Engineering Management	1
Industrial and Corporate Change	1

to positively influence innovation (D'este and Perkmann, 2011; Visintin and Pittino, 2014; Battaglia et al., 2021), but it appears to vary according to other characteristics such as team size (Battaglia et al., 2021). Firms that have strategically aligned their technologies to viable and near-term market opportunities tend to produce more economically desirable outcomes (Soetanto and Jack, 2016; van Stijn et al., 2018; Thomas et al., 2020). Relatedly, the capabilities and characteristics of USOs such as their technology intensity and ability to pivot influence their innovation outcomes. (Carayannis and Roy, 2000; D'este and Perkmann, 2011; van Stijn et al., 2018)

The level and type of support from universities is a frequently researched topic. University support is generally positively correlated to desirable USO outcomes (Nosella and Grimaldi, 2009; Bradley et al., 2013; Beyhan and Findik, 2018; Messina et al., 2020). However, one paper by Bathelt et al. (2010)

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Table 4. Number of publications by country

Country	Number of publications
Italy	16
England	13
Spain	9
France	8
Netherlands	8
USA	8
Sweden	5
Portugal	4
Belgium	4
Germany	3
Canada	3
Russia	2
Switzerland	2
Norway	2
China	2
Turkey	2
North Ireland	2
Brazil	1
Australia	1
Slovenia	1
Taiwan	1
Wales	1

Table 5. Number of publications by analysis type

Type of analysis	Number of publications
Quantitative – regression	21
Quantitative – difference in means	3
Quantitative – descriptive	4
Quantitative – other	6
Qualitative – case	14
Qualitative – interviews	7
Qualitative – comparative analysis	7
Network analysis	1

found that in the University of Waterloo ecosystem in Canada, start-ups reported that the influence of the university on firm success was marginal. The effectiveness of university technology-transfer offices (TTOs) has also been investigated, with Caldera and Debande (2010) finding that in Spain, TTOs have little influence on the creation of USOs, while others (Rasmussen et al., 2014; Radko et al., 2023) suggesting that TTOs can be helpful by providing tailored support for the firm.

The role of intangible assets on innovation related to USOs has also been explored at the ecosystem level, where various other stakeholders in the innovation ecosystem are studied as input variables. Government support, both in terms of funding and facilitative policies for USO creation and growth are often positively associated with desirable innovation outcomes (Kroll and Liefner, 2008; Malo, 2009; Gilsing et al., 2010; Vincett, 2010; Scaringella and Chanaron, 2016). The richness of networks, which include alliance partners who can add complementary capabilities to the USO also positively contributes to USOs (Perez and Sánchez, 2003; Chang, 2017; Fischer et al., 2018; Thomas et al., 2020). A listing of each paper in our review, along with the independent variables, is organized by theme and provided in Table 6.

4.2.2. Outputs

The outputs, or dependent variables observed in the papers of our systematic review can be thematically grouped into scientist/entrepreneur growth and impact, economic performance, and knowledge translation impact. One-way scientist growth and impact have been explored is by using new academic research as an outcome variable. Various papers note that USOs not only influence scientists entrepreneurially but can also be helpful in providing them with funding streams and new ideas for more lab-based research (D'este and Perkmann, 2011; Chang, 2017; Battaglia et al., 2021). Network-based metrics such as increased socialization (i.e., through conferences or informal conversations) and research collaborations are used as output measures but have interestingly also been used as inputs, showing a positive influence on USOs (Perez and Sánchez, 2003; Boardman and Ponomariov, 2009; Malo, 2009; Abreu and Grinevich, 2013; Barbieri et al., 2018).

The most prevalent indicators of innovation in our dataset are related to the USOs themselves. Specifically, the number of USOs formed and their survival were the most common proxies for innovation activity. The factors that influence these metrics include government policy interventions, and papers on this topic suggest that policies that support industry linkages tend to lead to favorable USO outcomes (Goldfarb and Henrekson, 2003; Malo, 2009; Gilsing et al., 2010). Another factor is university support, and research on this topic shows that it tends to be more effective if the university exhibits strong connectedness to the regional industry ecosystem (Nosella and Grimaldi, 2009; Fini et al., 2011; Prokop, 2021). Another factor is the richness of local ecosystems, and relevant studies show that being situated in such an ecosystem is not sufficient for spin-off success, rather, other variables such as early ties to commercial actors are needed for firm success (Kroll and

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Liefner, 2008; Bathelt et al., 2010; Salvador, 2011; Scaringella and Chanaron, 2016; Messina et al., 2020).

Innovation outputs related to USOs have also been studied at the ecosystem level, where the dependent variables include constructs such as knowledge translation and university-industry linkages (Caldera and Debande, 2010; Treibich et al., 2013; Díez-Vial and Montoro-Sánchez, 2016; Fernández-Esquinas et al., 2016; Fischer et al., 2018). These outcomes are enabled by co-location and openness with influential commercial entities, and are also associated with scientist prestige (Vincett, 2010; Calcagnini and Favaretto, 2016; Wu et al., 2018). Papers that focused on knowledge translation impact had to create their own definitions of what knowledge translation entails, and the definitions can starkly differ (e.g., Caldera and Debande (2010); Treibich et al. (2013)). This points to an opportunity to further develop this concept, as we have done with intangible assets. A listing of each paper in our dataset, with labels indicating which theme the paper's dependent variables were categorized under, is provided in Table 6.

4.2.3. Processes

We are also interested in analyzing and categorizing the process variables that enable the conversion of the input variables to outcomes in science innovation through USOs, focusing on intangible assets. The majority (79%) of papers in our dataset include a process-based variable (usually in the form of a mediator or sometimes a moderator) in their analysis or discuss their importance of them. For example, a set of papers investigated the role of entrepreneurial or firm strategy in the science innovation process: many recent papers attribute agency to the individual scientist-entrepreneur (as opposed to the firm) and suggest that their capabilities and decisions are key enablers in the translation of the input variables to innovation outcomes. Examples of such capabilities include IP protection (Carayannis and Roy, 2000; Thomas et al., 2020), self-efficacy (Würmseher, 2017; Di Paola, 2021), founding team formation (Visintin and Pittino, 2014; Thomas et al., 2020), and network curation (Lindelof and Lofsten, 2005; Del Giudice et al., 2017; Thomas et al., 2020).

Innovation intermediaries are also relevant to the conversion of the inputs to science innovation outcomes. For example, several papers investigated various university supports such as research funding, generating brand awareness, and generous IP policy as mediators that influence desirable innovation outcomes (Van Burg et al., 2008; Bonardo et al., 2010; Caldera and Debande, 2010; Riviezzo et al., 2019; Prokop, 2021). Another intermediary of interest as a processual enabler is incubators, where authors such as McAdam et al. (2010) note the effectiveness of university science park incubators as test beds for proof-of-concept technologies. Tang et al. (2014) on the other hand, question whether government-supported incubators in China are helpful in overcoming innovation market failures. Compared to the other process variables, intermediaries are less studied, and thus it is not surprising that we see conflicting results among papers, and so there is much opportunity to elucidate their roles in the science innovation process.

The final grouping of studies that focus on process is innovation policy. These papers primarily explore the role policy interventions play in translating lab-based inventions and technologies to commercial outputs, in the USO context. Many of these papers use comparative methods between countries, examining intellectual property and commercialization incentive policies. Canada, Sweden, France, UK, US, and China garner the most interest in these studies (Goldfarb and Henrekson, 2003; Kroll and Liefner, 2008; Rasmussen, 2008; Mustar and Wright, 2010; Vincett, 2010). In general, there seems to be agreement that less restrictive, non-punitive policies that still have enough protection for novel intellectual property, are associated with enabling science innovation. A listing of each paper in our review, along with the variables that are studied as processes in the conversion of input to output variables, is organized by theme and provided in Table 6.

5. Concluding discussion

This section presents a conceptual framework for science innovation through USOs, focusing on intangible assets, by distilling the findings of our systematic review and identifying under-researched areas. We observe critical weaknesses in the field, including a lack of sophisticated measures of scientific innovation and a poor understanding of why USOs fail. We incorporate recommendations for scholars, scientist-entrepreneurs, and policymakers on how to address these knowledge gaps.

5.1. A framework for innovation through USOs, focusing on intangible assets

Based on our analysis, we propose a novel framework for how intangible assets influence science

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Table 6. Variables analyzed in the papers that make up the systematic review

Paper	Scientist cap.	Tech. Cap.	Firm cap.	Univ. cap.	Govt. and Ecosys. Support	Sci./Ent. Growth and impact	Econ. Perf.	Knowledge translation impact	Firm/Ent. Cap./Strat.	Innovation Intermed.	Innovation policy
Abreu and Grinevich (2013)	x		x	x	x	x	x		x	x	
Åstebro et al. (2012)	x						x			x	
Ayoub et al. (2017)					x		x			x	
Barbieri et al. (2018)	x					x			x		
Bathelt et al. (2010)				x			x			x	
Battaglia et al. (2021)	x	x	x			x	x		x	x	
Beyhan and Findik (2018)				x			x			x	
Boardman and Ponomariov (2009)	x			x		x		x	x		x
Bonardo et al. (2010)	x		x				x			x	
Bradley et al. (2013)				x				x			x
Calcagnini and Favaretto (2016)	x							x			x
Caldera and Debande (2010)				x				x			x
Carayannis and Roy (2000)			x			x	x		x	x	
Chang (2017)			x		x	x			x		
Criaco et al. (2014)	x						x			x	
D'este and Perkmann (2011)	x		x	x		x	x	x	x	x	x
Davey et al. (2016)				x	x		x			x	
Del Giudice et al. (2017)					x		x			x	
Di Paola (2021)	x			x		x			x		
Díez-Vial and Montoro-Sánchez (2016)			x			x	x	x	x	x	x
Fernández-Esquinas et al. (2016)		x	x	x	x			x			x
Fikirkoca and Saritas (2012)					x		x			x	
Fini et al. (2011)				x			x			x	
Fischer et al. (2018)	x			x	x	x		x	x		x
Fontes (2005)		x	x				x	x		x	x
Gilsing et al. (2010)					x		x			x	
Goldfarb and Henrekson (2003)	x			x			x	x		x	x
Kroll and Liefner (2008)					x		x			x	
Lindelof and Lofsten (2005)			x		x		x			x	
Löfsten and Lindelöf (2005)			x	x	x		x			x	

(Continues)

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Table 6. (Continued)

Paper	Scientist cap.	Tech. Cap.	Firm cap.	Univ. cap.	Govt. and Ecosys. Support	Sci./Ent. Growth and impact	Econ. Perf.	Knowledge translation impact	Firm/Ent. Cap./Strat.	Innovation Intermed.	Innovation policy
Malo (2009)				x	x	x	x		x	x	
McAdam et al. (2010)	x				x			x			x
Messina et al. (2020)				x	x		x			x	
Munari and Toschi (2011)	x		x	x			x			x	
Mustar and Wright (2010)							x			x	
Ndonzuau et al. (2002)	x						x	x		x	x
Neves and Franco (2018)			x	x			x			x	
Nosella and Grimaldi, 2009				x	x		x			x	
Ortín-Ángel and Vendrell-Herrero (2014)			x				x			x	
Perez and Sánchez (2003)					x	x	x		x	x	
Prodan and Drnovsek (2010)	x	x		x	x	x			x		
Prokop (2021)	x						x			x	
Radko et al. (2023)		x		x	x		x			x	
Ramaciotti and Rizzo (2015)	x	x		x	x		x			x	
Rasmussen et al. (2014)				x			x			x	
Rasmussen (2008)								x			x
Riviezzo et al. (2019)	x					x	x		x	x	
Rodríguez-Gulías et al. (2020)			x			x			x		
Salvador (2011)					x		x			x	
Scaringella and Chanaron (2016)					x	x	x	x	x	x	x
Scuotto et al. (2020)	x							x			x
Soetanto and Jack (2016)			x	x			x			x	
Soetanto and Van Geenhuizen (2015)				x	x		x			x	
Styhre (2014)					x		x			x	
Tang et al. (2014)					x	x		x	x		x
Thomas et al. (2020)	x	x	x		x		x			x	
Treibich et al. (2013)			x			x	x	x	x	x	x
Van Burg et al. (2008)							x			x	
van Stijn et al. (2018)			x	x			x			x	
Vincett (2010)			x		x			x			x
Visintin and Pittino (2014)	x		x				x			x	
Wu et al. (2018)			x	x				x			x
Würmseher (2017)	x							x			x

Note: Columns with no shade, light shading, and dark shading denote inputs, outputs, and process variables, respectively.

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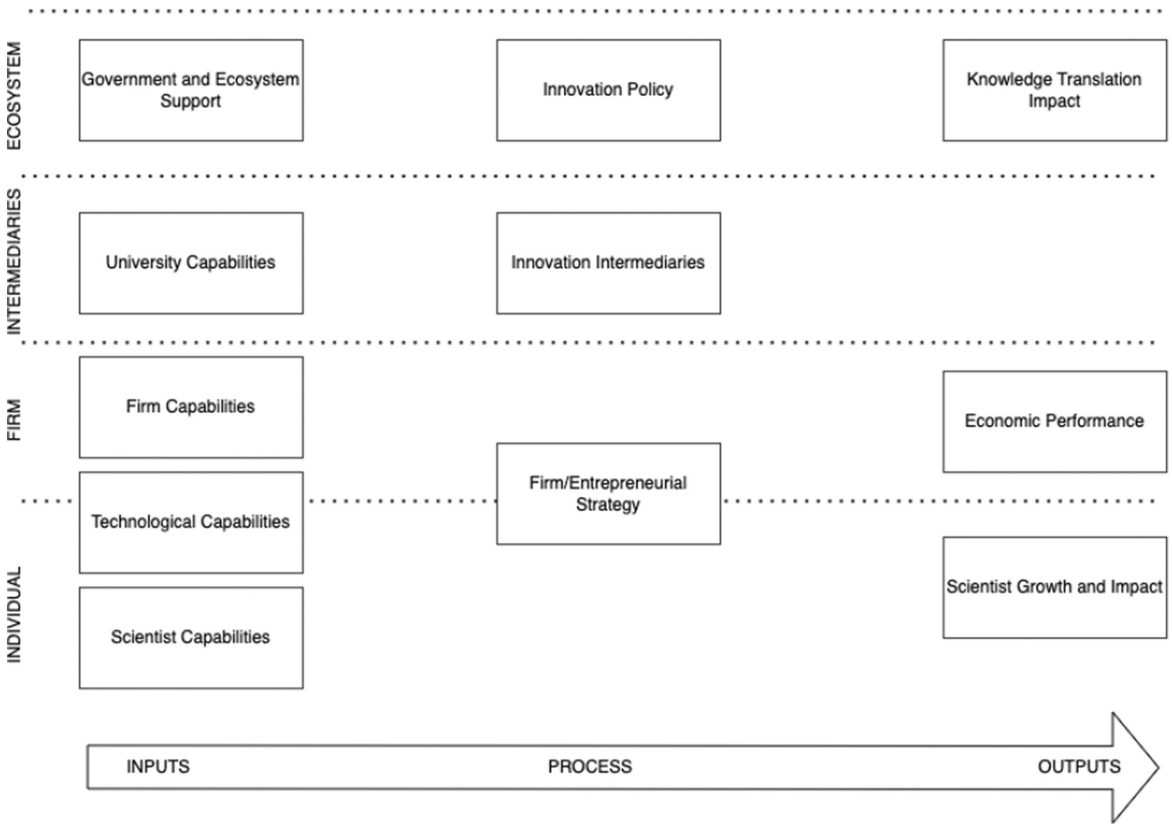

Figure 2. A framework on science innovation through USOs, focusing on intangible assets. See Table 2 for a description of each box.

innovation in the USO context, shown in Figure 2. The framework illustrates this phenomenon in terms of inputs, processes, and outcomes. Moreover, the science innovation process, as it relates to intangible assets and USOs, is a multi-level phenomenon determined by individual, firm, intermediary, and ecosystem-level factors.

The initial phase of the framework reflects *inputs* of the science innovation process as it relates to USOs and intangible assets. In the literature, there is a reasonably even focus across the various levels of input to the science innovation process, with a slight emphasis on firm, university, and ecosystem-level factors. However, many recently published papers have brought agency back to the scientist-entrepreneur, as evidenced by the recent emergence of papers related to entrepreneurial self-efficacy, mindset, and capabilities (e.g., Thomas et al., 2020; Di Paola, 2021; Prokop, 2021) that may indicate a shift in interest towards the individual.

Consequently, the latter phase of the process relates to *outputs* resulting from the science innovation process. The outputs encompass scientific advancements, economic performance, and knowledge translation. While benefits across these three outcomes are not mutually exclusive, as evidenced by several papers analyzing multiple variables and levels as outputs (e.g., Díez-Vial and Montoro-Sánchez, 2016; Radko et al., 2023), there appears to be an established practice of using simple metrics related to USO survival and the number of USOs formed as a measure of innovation success.

The center of our framework is the translation process itself, whereby the conversion of inputs (e.g., lab-based invention) to outputs (e.g., commercial value) is enabled by firm/entrepreneurial strategy, innovation intermediaries, and innovation policy. Firm/entrepreneurial strategy encompasses the alignment of tensions between technology and market requirements and the decisions made by the entrepreneur, both in selecting the vehicle for translation (i.e., USO) and the development of the scientific invention itself. Several papers note that the ability of academic scientists to make effective decisions relates to their entrepreneurial capabilities and strategy (Van Burg et al., 2008; Treibich et al., 2013; Thomas et al., 2020). Yet others find that firm strategy, such as those related to intellectual property management, is the key link between inputs and targeted outcomes (e.g., Carayannis and Roy, 2000).

Innovation intermediaries relate to the institutional support, internal and external to the university, that

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can be leveraged to affect the translation of scientific invention to innovation. The least explored in our dataset, questions related to this mediator include the role of these intermediaries, the timing and phase of their engagement in the translation process, and their fit as part of the entrepreneurial strategy. In our context, consensus around the effectiveness of intermediaries is tenuous and sometimes shows conflicting results, highlighting the developing nature of this field.

Lastly, innovation policy encompasses the governmental ambitions and objectives associated with public research funding and the economic and emerging societal challenges that require response. Our research shows nuances in the evaluation of the effectiveness of public funding. For example, Ramaciotti and Rizzo (2015) observe that USO experience and access to a TTO heavily moderate the usefulness of public funds, and Tang et al. (2014) find that, surprisingly, government-funded incubator support is ineffective at helping attract private financing. Such nuances suggest that key questions remain unanswered, including how to optimize the public funding of breakthrough technologies to ensure a 'fair share' appropriation of value by society, rather than allowing the private industry to disproportionately benefit, relative to the exploration risks taken on by public funding entities (Mazzucato, 2011).

5.2. Recommendations for scholars

Based on this systematic review, we suggest that the field requires a much more sophisticated understanding of what constitutes science innovation success through USOs. A simple tally of the number of USOs created does little to advance our knowledge of how intangible assets can be leveraged to enhance economic and societal outcomes. This is in line with calls to better understand the 'third mission' of the university, where the university can serve as a translation layer between novel research and benefits to the industrial sector and society (Visintin and Pittino, 2014; Hossinger et al., 2020). We note that looking outside Technology and Innovation Management journals may contribute some meaningful insights into broadening the methodological rigor of how outputs are represented. For example, in the entrepreneurship field, Fini and Toschi (2016) and Fini et al. (2012) investigate what determines corporate entrepreneurial *intentions*, instead of the simpler 'number of firms founded' metric that is commonly seen in innovation management.

We also note that overwhelmingly, the papers in our dataset are focused on what contributes to and constitutes innovation *success*, with the few studies that deeply examine failures mostly revolving around more abstract and high-level constructs such as government policy and ecosystem configurations (Fikirkoca and Saritas, 2012; Tang et al., 2014; Battaglia et al., 2021). By applying the same intellectual rigor but focusing on USO failure cases, there may be a research opportunity to add new dimensions to our understanding of the science innovation process through USOs. Like any innovation system, a degree of failure is inevitable and even desirable, given the complexity and uncertainty involved. Without such failure and the subsequent learning, discovery research will tend towards incremental as opposed to frontier breakthroughs and science inventions will lack the necessary novelty to deliver outcomes that solve grand challenges.

Relatedly, we encourage the incorporation of less easily quantified variables such as societal impacts, as suggested by Fini et al. (2018). Such nuanced variables, while they require more effort to operationalize, drive management scholarship forward more meaningfully. Given that R&D is a common construct of interest in the papers that comprise our dataset, we invite the readership and scholars of *R&D Management* to explore more nuanced intangible assets in future empirical papers on science innovation. Again, bridging various streams of scholarship (e.g., between R&D/technology/innovation management and entrepreneurship, or even management and the hard sciences) may be helpful in broadening research concepts and operationalizations and allow the field to move away from overly simple proxies of science innovation.

5.3. Recommendations for practice

Drawing from our findings, we offer practical recommendations for scientist-entrepreneurs and policymakers to enhance the science innovation process.

Most academic scientists are motivated by making a positive impact with their scientific inventions, such as through a USO. However, their specialized scientific training and experience seldom prepare them to make the strategic entrepreneurial decisions that lead to realizing that vision. With the long timelines in commercializing breakthrough science, the decisions an academic scientist makes in the research lab regarding what research funding to pursue, experiments to run, technology attributes to explore, and intellectual property to protect, will have long-lasting consequences for future USO formation and development. Many university scientists assume that a business co-founder will make all the business decisions, however, well-endowed

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USOs can often trace their success to intangible assets and entrepreneurial decisions made in the research lab, prior to firm formation (Thomas et al., 2020; Park et al., 2022, 2023).

Our framework and the research landscape that informs it suggest that the academic community places significant importance on the mediating role of innovation policy on the translation of intangible assets to desired economic and societal outputs. We recommend that policymakers support science innovation by (1) investing in specialized entrepreneurial training for scientists through awareness and education programs, such as Invention to Innovation (Mitacs, Beedie, Simon Fraser University) and I-Corps (US National Science Foundation) and (2) de-risking breakthrough university inventions by funding commercialization post-doctoral fellows and providing access to facilities for process scale-up (e.g., Cyclotron Road, Berkeley National Laboratory).

Additionally, policymakers can play an important role in resolving the information asymmetry between emergent ventures that require capital to grow and venture capitalists who are unable to determine whether the venture is going to succeed. Policymakers can bridge this gap by encouraging universities to aid their spin-off ventures by signaling the quality of the ventures to outside investors through research assessments, research evaluations, and strategic intellectual property (Hsu and Ziedonis, 2008; Rasmussen et al., 2020; Thomas et al., 2020).

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Ethics statement

Not applicable.

Data availability statement

Data available on request from the authors.

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APPENDIX A

The search terms used to identify papers related to USOs and science-based innovation include: university*, academi*, sci*, innovat*, spin* and entrepreneur*. The wild card character (*) provides the flexibility to retrieve results that include any character(s) in its place. For example, papers whose titles or abstracts contain words such as academic entrepreneur, science-based firm and entrepreneurship would be captured in the results. Additional tangentially related terms were also included (which can only add to the results since we use an OR operator for these) based on a USO-related bibliometric analysis by Mathisen and Rasmussen (2019), including determinant*, success*, performance*, obstacle*, barrier*, inhibitor*.

We use the following search terms to capture terms related to intangible assets based on ontologies and taxonomies provided by Leitner (2005), Corcoles (2010), and (Cozzarin (2021): patent* OR network* OR publication* OR capabilit* OR employee* OR staff* OR training OR database* OR project* OR assignment* OR teaching* OR visiting OR conference* OR intangible asset OR knowledge OR trade secret* OR information capital OR relational capital OR know-how OR brand OR advertising OR reputation OR culture OR human capital OR experience* OR talent prestig* OR creativity OR R&D OR knowledge management system* OR data management OR customer management system* OR external relationship* OR organizational capital OR structural capital OR organizational capital OR sharing of information OR firm strategy OR firm mission

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