University ambidexterity: assessing the nature of interdependence between knowledge exchange and knowledge creation in UK universities

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University ambidexterity: assessing the nature of interdependence between knowledge exchange and knowledge creation in UK universities

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Abstract
The concept of university ambidexterity has been advanced to capture the simultaneous pursuit of exploration (research) and exploitation (knowledge exchange). While ambidexterity can enhance organisational performance, tensions and barriers have been identified suggesting it is far from straightforward to achieve. In light of this, it has been proposed that universities follow a 'twisting learning path' that alternates between exploration and exploitation. However, this violates the idea that innovation activities are persistent in nature. In order to assess the nature of the ambidexterity of UK universities, we use data from the UK Higher Education Business & Community Interaction survey to examine the temporal dynamics of the relationship between research and KE. Through estimating a suite of Panel Variance Auto Regressive models, our results suggest that university ambidexterity has three key characteristics: (1) a determinant temporal 'path dependent' effect, whereby research and KE activities exhibit a significant autoregressive component; (2) an inter-temporal bi-directional relationship between research and KE activities; and (3) short time lags between the implementation of research and KE coupled with the dissipation of the relationship over time that is indicative of a persistent relationship between the two. Consequently, we propose an alternative model of university ambidexterity by highlighting the continuous interdependency of research and knowledge exchange within UK universities and its persistent nature.

Keywords Knowledge exchange · University ambidexterity · Persistence · Knowledge creation · Innovation

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1 Introduction

An emerging theme within the extant literature on university Knowledge Exchange (KE) is that these activities are not independent from research but undertaken concurrently (Chang et al., 2016; García-Hurtado et al., 2022; Marzocchi et al., 2019; Sengupta & Ray, 2017; Thomas et al., 2023). Consequently, the concept of university ambidexterity has been advanced to capture the simultaneous pursuit of a broad range of activities including new knowledge creation, technology transfer, industrial collaboration, and commercialisation activities such as licensing and patenting, as well as building science parks and supporting spin-offs and start-ups (Ambos et al., 2008; Centobelli et al., 2019; Compagnucci & Spigarelli, 2020). Two key themes emerge from this literature; firstly, research and KE are interdependent, and second, 'bi-directionality' is important, with research inputs and outputs positively related to KE activities and vice versa (Johnston et al., 2023; Sengupta & Ray, 2017).

However, interest in organisational ambidexterity is not new as scholars have long been examining this concept and its role in organisational performance (Ali et al., 2022; Guerrero, 2021; He & Wong, 2004; Junni et al., 2013; Roth et al., 2024; Tushman & O'Reilly, 1996). Indeed, this literature shows that ambidexterity promotes flexibility, learning, and adaptation within organisations (Alcade-Heras et al., 2019; Saleh et al., 2023; Audtretsch & Guererro, 2023). Consequently, recent work has suggested that ambidexterity is the 'missing link' between entrepreneurship, management, and innovation' (Audretsch & Guerrero, 2023). Yet, while ambidexterity can enhance organisational performance, the existence of tensions and barriers means it is far from straightforward to achieve in practice (Andriopoulos & Lewis, 2010; Senaratne & Wang, 2018). As such, in a university context, Centobelli et al (2019) propose a'twisting learning path' model whereby ambidexterity is achieved over time but due to tensions between exploration and exploitation the university alternates between one and the other.

However, the idea of the twisting learning path violates the idea that innovation activities are persistent in nature. Indeed, the extant literature proposes three key ideas to support the persistence of innovation. First, it is argued that 'success breeds success' (Flaig & Stadler, 1994), meaning that innovation can be understood as a virtuous cycle (Le Bas & Scellato, 2014). Second, the existence of sunk costs promotes persistence (Peters, 2009; Antonelli et al., 2013; Mañez & Love, 2020). Third, innovation is persistent in nature as is underpinned by long-term knowledge accumulation (Latham & Le Bas, 2006; Le Bas & Scellato, 2014). Therefore, while the twisting learning path implies a tumultuous relationship and a trade-off between the two, the persistence of innovation implies a more constant and steady relationship.

To establish empirically whether ambidexterity is characterised by persistence or a twisting learning path in the context of UK universities, this paper uses data from the UK Higher Education Business & Community Interaction (HE-BCI) survey to estimate a suite of Panel Variance Auto Regressive (PVAR) models examining the dynamics of the relationship between knowledge creation and KE activities. The paper makes a new contribution to the literature by illustrating that the persistence of research and KE activities induces a determinant temporal 'path dependent' effect. Therefore, we offer an alternative to Centobelli et al's (2019) 'twisting learning path' model, instead proposing that university ambidexterity is characterised by a persistent continuous interdependent relationship between research and knowledge exchange within UK universities.

The paper is structured as follows: Sect. 2 outlines the conceptual and theoretical basis of the paper. Section 3 outlines the data and analytical methods used. Section 4 presents the findings, while Sect. 5 discusses their implications. Finally, Sect. 6 concludes.

2 Conceptual and theoretical background

2.1 University knowledge exchange

While universities make significant contributions to the economy through their traditional missions of teaching and research (Goddard et al., 2014; Hermannsson et al., 2017; Jaffe, 1989), it is the 'third mission' of knowledge exchange (KE), i.e. business engagement and knowledge commercialisation activities, that has attracted the attention of scholars and policymakers over the past two decades (Le et al., 2022; Østergaard & Drejer, 2022).

Importantly, the KE activities that underpin these paradigms are contingent on what have been described as the 'entrepreneurial' and 'engaged' characteristics of universities (Breznitz & Feldman, 2012; Marzocchi et al., 2019; Philpott et al., 2011). Given this approach, universities have been conceptualised in terms of the focus of their KE activities. For example, the 'entrepreneurial university' is proposed as an exemplar of a university with a focus on KE activities that exploit knowledge through what have been termed 'hard' activities such as generating patents, licensing technology to users, and creating spinouts (Etzkowitz, 2003; Kirby et al., 2011; Metcalfe, 2010). Conversely, 'softer' activities such as collaborative research, consultancy, and CPD have been highlighted as the domain of the 'engaged university', (Johnston et al., 2023; Perkmann et al., 2013; Philpott et al., 2011; Sanchez-Barrioluengo & Benneworth, 2019.) In addition, the engaged university is also regarded as having a social focus, not only contributing to regional development through these activities (Breznitz & Feldman, 2012; Thomas & Pugh, 2020; Trippl et al., 2015), but also being embedded into the regional ecosystem allowing an understanding of the needs and requirements of other actors (Breznitz & Feldman, 2012; Sanchez-Barrioluengo & Benneworth, 2019).

However, conceptualising KE activities as dichotomous through focusing on either 'hard' or 'soft' activities fails to capture the nuances of these activities, particularly as universities are heterogenous when it comes to KE activities and strategies (Kitagawa et al., 2016; Sánchez-Barrioluengo et al., 2019; Sengupta & Ray, 2017). Indeed, many differing KE strategies and activities have been identified with respect to the research activities, teaching activities, and location (Abreu et al., 2016; Hewitt-Dundas, 2012; Huggins et al., 2012; Sánchez-Barrioluengo et al., 2019). For example, universities where research grants form a higher proportion of total revenues exhibit differing patterns of KE activities than those that generate a higher proportion of revenues from teaching activities (Abreu et al., 2016; Hewitt-Dundas, 2012). In addition, these universities tend to have a greater spatial reach and work with larger firms, while more teaching focused universities have a more local focus (Huggins et al., 2012). However, KE is not necessarily the exclusive domain of research focused universities as the sheer diversity of these activities means that universities may pursue these in different ways (Kitagawa et al., 2016; Sánchez-Barrioluengo et al., 2019). As such, presenting KE activities as a spectrum of activities appears to be a better way of understanding (Philpott et al., 2011), rather than attempting to capture the KE activities of a university in terms of an isomorphic and static ideal type.

2.2 University ambidexterity

Despite earlier suggestions that universities face a trade-off between undertaking research and KE (Dasgupta & David, 1994), there is evidence that the two are not independent but interdependent (Hughes & Kitson, 2012; Sengupta & Rossi, 2023). For example, greater knowledge creation activities through higher levels of research grants are positively related to higher levels of knowledge exchange activity in terms of industry engagement and the creation of spinout firms (Marzocchi et al., 2019; Perkmann & Walsh, 2009; Sengupta & Ray, 2017; Wright et al., 2008). Furthermore, there is evidence that some KE activities such as patenting are positively related to research activity (Perkmann et al., 2013).

Likewise, not only are KE and research activities interdependent but the relationship has been found to be bi-directional. Therefore, KE activities are not just driven by research activities but also influence the research activities undertaken and the outputs produced by universities (Johnston et al., 2023; Sengupta & Ray, 2017). For example, Sengupta and Ray (2017) find that research outputs are positively related to higher levels of industry collaboration. In addition, Johnston et al (2023) find that research income in high-technology sectors is higher where the university generates higher levels of income from KE activities such as licencing, patenting, collaborative research, and contract research. Therefore, research activities influence KE activities and vice versa.

This interdependence has led to the examination of universities through the lens of organisational ambidexterity (Ambos et al., 2008; Centobelli et al., 2019; Chang et al., 2009; Sengupta & Ray, 2017). Ambidexterity typically refers to the degree in which exploration and exploitation are concurrently undertaken within the organisation (Lavie & Drori, 2012). Indeed, ambidexterity is a key tenet of the organisational learning and innovation literatures and outlines the ability to undertake a range of complementary, yet distinct, tasks simultaneously (Audretsch & Guerrero, 2023; Gibson & Birkinshaw, 2004; Jansen et al., 2006; March, 1991). In summary, this literature stresses the fact that ambidexterity underpins organisational adaptation and promotes competitive advantages (O'Reilly & Tushman, 2008). O'Reilly and Tushman (2008) outline three distinct types of ambidexterity: sequential, structural, and contextual. Sequential ambidexterity captures the switching or oscillation between periods of exploration and exploitation as organisational capabilities evolve and can more easily switch between the two as these develop (Boumgarden et al., 2012; Brown & Eisenhardt, 1997; O'Reilly & Tushman, 2008). Furthermore, this switching tends to be found among smaller firms lacking the resources to pursue exploration and exploitation concurrently (Tempelaar & Van de Vrande, 2012). Structural ambidexterity involves the simultaneous pursuit of exploration and exploitation through different business units coupled with the use of "different competences, systems, incentives, processes, and cultures (ibid, pg. 192). This division therefore enables an organisation to achieve excellence in both activities and improve its performance (Jansen et al., 2006). Finally, contextual ambidexterity focuses on the simultaneous pursuit of exploration and exploitation across the whole business coupled with adaptive management that identifies and reacts to external changes (Gibson & Birkinshaw, 2004).

In a university setting, the nature of ambidexterity is contested. In simple terms, ambidexterity is recognised as undertaking both exploration focused knowledge creation and commercialisation focused exploitation activities simultaneously (Ambos et al., 2008; Chang et al., 2009; Sengupta & Ray, 2017). The result is that ambidexterity

results in a 'bi-directional' relationship between research and knowledge commercialisation where undertaking one supports the other and vice versa (Degl'Innocenti et al., 2019; Johnston et al., 2023; Sánchez-Barrioluengo et al., 2019; Sengupta & Ray, 2017). However, an alternative viewpoint is proposed by Centobelli et al (2019) who define exploration as the management of *internal* knowledge to support teaching, research, and commercialisation activities and exploitation as the management of *external* knowledge to support teaching, research, and commercialisation. The ability to create dual structures and organisational flexibility are highlighted as the key to pursuing an ambidextrous approach to KE and research within a university (Ambos et al., 2008; Chang et al., 2016). Therefore, ambidextrous universities can be viewed as rooted in a positive feedback loop to produce relevant knowledge, making them the ideal 'knowledge transceiver' (Huggins et al., 2008). This allows them to create relevant knowledge and disseminate it into the innovation ecosystem, while also reacting to the demands of the ecosystem to produce relevant knowledge. Therefore, higher levels of ambidexterity within universities suggest they are more likely to be engaged in a virtuous circle, where its embeddedness in the innovation system, as characterised by higher levels of industrial engagement, enables it to understand and react to the demands of the industrial base and create and commercialise new knowledge (Perkmann et al., 2011, 2013, 2021).

Furthermore, the nature of ambidexterity has implications for inter-temporal relationships between research and KE and how each may influence one another over time. Indeed, scholars have begun to examine the dynamics and inter-temporal changes in research and KE activities within a university (Sengupta & Rossi, 2023). Importantly, a bi-directional concurrent relationship research and KE activities does not imply any cross-fertilisation is instantaneous. For example, in healthcare and science, it has long been recognised that time lags exist between the creation of knowledge and its translation into tangible outcomes in terms of products, or interventions (Hanney et al., 2015; Hering, 2018; Morris et al., 2011). Additionally, the nature of ambidexterity will influence whether the temporal dynamics of the relationship between KE and research are transient, indicating an effect that dissipates through time, or persistent, leading to the emergence of 'growth effect' characteristics.

Two key factors must also be noted. The first is that university ambidexterity is typically examined in terms of sequential and structural ambidexterity (Chang et al., 2009). Second, a concurrent focus on exploitation and explorations results in the existence of tensions that arise from the demands of each activity (Ambos et al., 2008; Centobelli et al., 2019). These tensions are manifest through differing incentives to pursue research and commercialisation activities within universities (Friedman & Silberman, 2003; Lach & Schankerman, 2008), and while some academics may work seamlessly between the two, others struggle to do so (D'Este & Perkmann, 2010; Zucker & Darby, 2001). Given these tensions between exploration and exploitation activities, ambidexterity is far from straightforward to achieve (Centobelli et al., 2019).

Consequently, Centobelli et al (2019) propose the existence of a'twisting learning path' model whereby ambidexterity is achieved over time but due to tensions between exploration and exploitation the university alternates between one and the other, analogous Brown and Eisenhardt's conceptualisation of sequential ambidexterity. Indeed, as Sánchez-Barrioluengo et al. (2019) highlight, the changing nature of knowledge exchange activities among universities outline the fact they are not static. Furthermore, Marzocchi et al's (2019) finding that the previous period's teaching and research endowments are negatively related to the turnover of university start-ups in the present period lends some credence to a model of ambidexterity as an oscillation between exploration and exploitation. Conversely, Sengupta and Ray (2017) find that research outputs are positively related to knowledge

exchange activity from the previous period suggesting that ambidexterity should be captured in terms of a steady state of concurrent activities as research is feeding directly into knowledge exchange activities.

Given this latter evidence, we draw on the literature on innovation persistence to offer an alternative conceptualisation of university ambidexterity as relying on a steady relationship between research and KE. In short, innovation persistence is underpinned by three key ideas. Firstly, it is suggested that 'success breeds success' (Flaig & Stadler, 1994) whereby innovation promotes further innovation in a virtuous cycle (Le Bas & Scellato, 2014). Second, persistence is driven by path dependency and the existence of sunk costs in that R&D is a long-term undertaking that requires substantial upfront preparation and planning (Peters, 2009; Antonelli et al., 2013; Mañez & Love, 2020). Third, as innovation is underpinned by knowledge accumulation, whereby organisations build up expertise through learning, this continuity implies persistence (Latham & Le Bas, 2006; Le Bas & Scellato, 2014). Therefore, given that research and KE are essentially innovation and R&D activities it is natural to extend the idea of innovation persistence to universities. Consequently, this approach is analogous to Gibson and Birkinshaw's (2004) contextual ambidexterity where organisations have "the behavioural capacity to simultaneously demonstrate alignment and adaptability across an entire business unit" (p.209). This then enables individuals to pursue either exploitation or exploration activities as they deem appropriate.

In common with other organisations innovation activities, university research and KE activities are dynamic and occur over time. While in a firm sense the idea that 'success breeds success' enables further innovation by providing the resources, knowledge and financial, to fund new pursuits; for a university, successful research and KE activities enhance the credibility of the institution and individual academics (Johnston & Huggins, 2018; Zucker & Darby, 2001). In addition, there are substantial sunk costs associated with university research and KE activities for both the organisation and the individuals involved. These are manifest in terms of obtaining equipment, developing facilities, and recruiting personnel which take both time and resources as well as experience and expertise in obtaining funding for research grants or KE collaborations, which typically account for experience and past records of the investigators. Consequently, as with the firm-level literature, experience matters, and this may act as a significant barrier to entry for those universities into either research or KE where the relevant knowledge and expertise is not possessed. Therefore, from a university perspective, the persistence of innovation suggests does not imply discontinuity but continuity.

Furthermore, the bureaucratic nature of universities means they may simply not be organisationally agile enough to, pivot, re-allocate resources efficiently or quickly, and change direction to take a discontinuous approach to their research and KE activities (Geiger & Sá, 2007; Moutsios, 2023). Any oscillation between exploration and exploitation may therefore result in academics competing for resources without a clear strategic direction supporting their work, creating a "bureaucratic web" of insecurity (Moutsios, 2023, pg. 381). Consequently, university bureaucracy may simply be insufficient to support an oscillating approach to research and KE (Maassen & Stensaker, 2019). Therefore, we suggest that university ambidexterity is underpinned by *both* the interdependence of research and knowledge exchange and the existence of a steady state of concurrent activities as they support one another. These arguments lead us to test the following hypothesis:

Hypothesis 1 University ambidexterity is manifest as a steady state of concurrent exploration and exploitation.

Another consideration is the fact that KE is an umbrella term for a wide range of activities; indeed, it is widely accepted that KE covers a wealth of formal activities including collaborative research, contract research, courses to support continuing professional development, use of facilities and equipment, the granting of patents, and issuing of licences for technology (Johnston et al., 2023; Sánchez-Barrioluengo, 2014; Sánchez-Barrioluengo et al., 2019; Sanchez-Barrioluengo & Benneworth, 2019; Sengupta & Rossi, 2023). In terms of university ambidexterity, the extant literature reveals that this diversity equates to many differing relationships between KE and research. For example, Sengupta and Ray (2017) find a positive relationship between research outputs and industrial collaboration in general (Sengupta & Ray, 2017). In addition, Sengupta and Rossi (2023) suggest that higher levels of research income lead to more diversified KE activities. Finally, Johnston et al (2023) identify a positive relationship between research income in high-technology sectors and income from licensing, patenting, contract research, and consultancy projects (Johnston et al., 2023). Conversely, a negative relationship between the diversity of KE and CPD income is noted (Sengupta & Rossi, 2023). As such, university ambidexterity is complicated by the existence of multiple channels of KE.

Furthermore, the relationships that underpin KE must be considered when assessing the nature of university ambidexterity. As Centobnelli et al. (2019) note, as exploitation involves external knowledge it will involve relationships with actors within organisations outside the university. As such, while research activities may focus on internal expertise, i.e. predominantly driven by actors within the university, and obtaining funding via the quality of a research proposal, for KE there is a relational aspect to consider (Ankrah & Al-Tabbaa, 2015). Indeed, the process of university-industry collaboration is regarded as socio-technical in nature, relying on closeness in terms of both interaction and understanding for linkages to form and function effectively (Ankrah and Al-Tabba, 2015; Johnston, 2022). Given this, the fact that undertaking KE is a relatively long-term endeavour suggests that while Centobelli's et al.'s (2019) statement that university ambidexterity "seems to be achieved over time" (pg. 188) is valid, the oscillation process that is key to their model appears to undermine the formation socio-technical proximities that are required for university's successful engagement in KE (Johnston & Huggins, 2021).

Given that the numerous KE activities have differing influences on research there is a need to understand these pathways in more detail. Reference to 'exploitation' activities may overly simplify this understanding. In addition, we suggest that simply characterising university ambidexterity as the simultaneous pursuit of KE and research activities overlooks the nuances of the relationships between individual KE activities and research outlined in the extant literature. Indeed, to understand the dynamics of the relationship between the two in more detail requires examining each the relationship between individual KE pathway and research. Given this, the temporal relationship between individual KE activities and research may also vary, giving clues as to the nature of ambidexterity in term of persistence or discontinuity. Therefore, if university ambidexterity is characterised by persistence, then short time lags in the relationships between KE and research should be observed as research and KE activities will continuously interact with one another. This argument is tested through Hypothesis 2.

Hypothesis 2 University ambidexterity is characterised by short time lags in the relationships between research and KE activities.

Finally, as the extant literature is clear that universities are not isomorphic (Fuller et al., 2019; Kitagawa et al., 2016), variations in university ambidexterity may exist. Indeed, as research and KE are ultimately driven by the capabilities of the university (Sengupta & Rossi, 2023) then variations in these will lead to variations in the level of research and KE undertaken. Furthermore, given the persistence literature suggests that 'success breeds success' (Flaig & Stadler, 1994), and as KE is ultimately underpinned by the research undertaken, then research intensity should be an important driver of ambidexterity (Hewitt-Dundas, 2012; Sánchez-Barrioluengo et al., 2019). This observation leads to the proposition that stronger relationships between research and KE should exist in research intensive universities as higher levels of research intensity provide more opportunities for KE to occur leading to greater interdependencies between the two (Sengupta & Rossi, 2023). Conversely, universities with lower endowment of knowledge resources may require more time to build up the knowledge to utilise in KE. This argument is formalised for testing through Hypothesis 3.

Hypothesis 3 University ambidexterity is positively related to research intensity.

3 Context, data and analysis

3.1 Data specification

To test our hypotheses, we utilise data from both the Higher Education Business & Community Interaction (HE-BCI) survey and UK Research and Innovation's (UKRI) Gateway to Research database. The HE-BCI survey is an annual survey of business collaboration activities undertaken by UK universities completed by technology transfer officers. As universities are legally obliged to complete it, it provides a detailed and reliable insight into the industrial collaboration activities of UK universities. The data used (summarised in Table 1) follows the extant literature in utilising income from research, licencing IP, consultancy, contract research, collaborative research, continuing professional development (CPD) activities, firms' utilisation of equipment and resources within the university, and regeneration activity, as well as the size of the university's patent portfolio, and number of spinouts created (Johnston et al., 2023; Rossi & Sengupta, 2022; Sanchez-Barrioluengo & Benneworth, 2019; Sánchez-Barrioluengo et al., 2019; Sengupta & Ray, 2017).

In addition, the model is augmented through identifying the strategic intent of each university towards industrial collaboration using data from Part A of the HE-BCI survey which asks about the primary focus of a university's external engagement strategy (businesses or otherwise), the existence of strong incentives within the university for academics to engage with businesses, the existence of a majority owned subsidiary for the commercial exploitation of knowledge, and whether the university has an on campus business incubator facility (Soetanto & Jack, 2016). Accordingly, dummy variables are included to capture the strategic intent of each university, coded as 1 where businesses were named as the primary focus of external engagement (non-commercial social, community and cultural organisations, the public sector, or other), where the university reported they had strong incentives in place to encourage engagement (as opposed to no incentives or only some incentives in place), where the university operated an majority owned subsidiary, and where the university operated an incubator.

Table 1 Overview of endogenous and exogenous variables

Variable	Description
Total Research Grants in High Technology Fields (RESEARCH)	Total income from grants from UK funding councils in projects in the following areas: Robots; Artificial Intelligence; Driverless Cars; Space and Satellite Technology; Clean Energy; Healthcare; Medicine; and Battery Technology
Contract Research (CONT)	Income from projects undertaken with a non-academic partner
Collaborative Research (COL)	Income from projects utilising both public grants and a financial contribution from a non-academic partner
CPD Income (CPD)	Income from designing and implementing training and career development programmes
IP Income (IP)	Income generated through possessing Patents, Copyrights, trademarks or granting licences to utilise technology owned by the university
Spinoffs (Spin)	Number of start-up firms registered each year by the university from 2006/07–2016/17
Patent portfolio (PAT)	Number of patents either registered to the university or licensed to a third party in each year
Business Focus (BUS)	Binary variable establishing whether businesses the primary focus of the university's external engagement or otherwise
Strong Incentives for Commercialisation (STRONG)	Binary variable establishing whether the university regards itself as having in place strong incentives for academics in terms of pecuniary rewards for business engagement activities or otherwise
Existence of Subsidiary for Commercialisation (SUB)	Binary variable establishing whether the university has a majority or wholly owned subsidiary responsible for commercialisation of knowledge or otherwise
Presence of Incubator (INC)	Binary variable establishing whether the university has created an incubator facility for new start-ups or otherwise

Therefore, the dataset captures in-depth details of income from knowledge exchange activities of 149 UK universities between 2006/2007 and 2016/2017. We focus on all universities to gather a complete picture of university ambidexterity rather than consider universities as dichotomous, i.e. either entrepreneurial or not. Therefore, we seek to understand the relationship between research and KE for all institutions rather than a subset. This period was selected to cover a long period and also one where all projects were completed prior to the onset of the Covid 19 pandemic in March 2020 which changed research funding priorities in the UK. In order to focus on knowledge that is relevant to industry and lends itself to commercial outcomes, we collected data on research income through creating a unique database of grants from high technology research projects in fields of: robots; artificial intelligence; driverless cars; space and satellite technology; clean energy; healthcare; medicine; and battery technology, identified through searching the Gateway to Research website (www.Gtr.ac.uk).. In total, the 5532 projects identified accounted for over £2.4bn of research funding between 2006/2007 and 2016/2017. These projects were broken down as follows: robots 242;

Artificial Intelligence 238; Driverless Cars 20; Space and Satellite Technology 606; Clean Energy 140; Healthcare 1515; Medicine 2173; and Battery Technology 598.

3.2 Empirical model and estimation strategy

In this paper, we employ an advanced econometric technique known as the Panel Variance Auto Regressive (PVAR) using generalized method of moments (GMM) estimations developed by Abrigo and Love (2016) to control for the endogeneity of knowledge creation. To examine the bidirectional association among multiple variables is a challenging task, hence we employ the PVAR technique to create empirical differentiation in the transformation mechanism of economic activity (Abrigo & Love, 2016; Lin et al., 2019). The panel VAR model is a widely recognized method for quantification of the bidirectional relationship between target variables in multiple observations (Canova & Ciccarelli, 2009) as it can not only ameliorate the endogeneity issue of simultaneity, but also accommodate potential interaction and heterogeneity across universities to profile the increasingly integrated and interrelated nature of HE knowledge creation.

We define the PVAR model functional form as follows:

$$y_{it} = \sum_{j=1}^{p} \beta_j y_{it-j} + \delta z_{it} + \varphi_t + \gamma_i + \varepsilon_{it}$$

where y_{it} is the matrix of categorised endogenous variables that account for income from research and KE activities across unit i and time t; y_{it-j} where the j order lag is determined through Andrews and Lu (2001) criterion; p yields the lag order; β_j is the parameter estimation matrix; δ is the parameter estimation matrix on the first difference of a matrix of exogenous variables z_{it}. We use income in each category to capture a university's activity, with higher levels of income representative of higher levels of each. While some authors use research outputs as the basis for analysis e.g. Sengupta and Ray (2017), we follow Sánchez-Barrioluengo et al. (2019) in utilising income as a measure of both research and KE as it represents the value of these activities for each university. Therefore, using income as a measure of research and KE activities provides a good proxy for levels of these activities in each university at a fixed point in time. We focus on the date the income was awarded to the university as an indication of when the research or KE activity was initiated. While it is recognised that research projects may span multiple years, the awarding of a grant or contract represents the time when the idea was formulated prior to it being pursued formally. This is analogous to the way a research output may not typically be created at time of publication but is the result of work that has taken place in the period leading up to its publication. Therefore, by examining income levels for research and KE activities at a particular time we capture the time the project was initiated and the basic knowledge to pursue the project was in place.

Due to the temporal and spatial unevenness of university funding in the priority technologies (Johnston & Wells, 2020), we control for both yearly time fixed effect φ_t and spatial fixed effects γ_i at the NUTS-1 regional level; ε_{it} is the random error term. We specify and estimate models with the inclusion of a matrix of endogenous y_{it} which captures an array of unit and time variant university characteristics, activities, and knowledge creation. We further integrate strictly exogenous z_{it} variables categorised by each university strategic orientation. Table 2 provides a summary of the endogenous and exogenous matrices for each model specification. Descriptive statistics are presented in Table 3.

Table 2 PVAR model specification

Model	Lag order	Endogenous variable vector	Contemporaneously exogenous variable vector
1	1	RESEARCH; IP, COL, CONT, PAT, CPD, SPIN	Regional fixed effects; time fixed effects
2	1	RESEARCH; IP, COL, CONT, PAT, CPD, SPIN	Regional fixed effects; time fixed effects; SUB, BUS, STRONG, INC

Table 3 Descriptive statistics

Variable	Min	Max	Mean	SD	Time	
RESEARCH (Ln)	−2.30	17.78	4.14	8.01	2006–2017	N: 1639 n: 149 T: 11
CONT (Ln)	−2.30	12.66	6.79	2.85	2006–2017	N: 1639 n: 149 T: 11
COL (Ln)	−2.30	11.85	5.94	4.19	2006–2017	N: 1639 n: 149 T: 11
CPD (Ln)	−2.30	10.74	6.34	3.19	2006–2017	N: 1639 n: 149 T: 11
IP (Ln)	−2.30	11.07	2.47	3.84	2006–2017	N: 1639 n: 149 T: 11
Spin	0.0	104	8.58	14.51	2006–2017	N: 1639 n: 149 T: 11
PAT	0.0	3357	108.55	295.46	2006–2017	N: 1639 n: 149 T: 11
INC (1/0)	0.0	1.0	0.718	0.450	2006–2017	N: 1639 n: 149 T: 11
BUS (1/0)	0.0	1.0	0.577	0.494	2006–2017	N: 1639 n: 149 T: 11
STRONG (1/0)	0.0	1.0	0.194	0.390	2006–2017	N: 1639 n: 149 T: 11
SUB (1/0)	0.0	1.0	0.436	0.496	2006–2017	N: 1639 n: 149 T: 11

4 Empirical results

4.1 Stochastic properties and lag length selection

We first check the stochastic properties of our data to avoid spurious inference. We perform the Augmented Dickey–Fuller (ADF) unit root test and Phillips-Perron (PP) test for each variable to check whether each measure is stationary (Pesaran, 2015). Results for the ADF & PP tests are presented in Table 4. Panel unit root test results indicate that the null hypothesis of non-stationarity (unit roots present for all variables) is strongly rejected in all level variables. We therefore estimate via forward orthogonal deviations. Given that all variables reject the null of nonstationary, panel cointegration testing is not necessary and we proceed without first differencing transformation.

In choosing our model optimal lag length, we rely on a set of consistent moment and model selection criteria (Andrews & Lu, 2001). The Andrews and Lu's (2001) methodology is based on Bayesian information criteria (MBIC), Akaike information criteria (MAIC), and Hannan–Quinn information criteria (MHQIC) to check consistency and asymptotic normality of the data, whilst balancing against the need to maintain degrees-of-freedom. We employ first-to-third-order PVAR sets by using the initial three lags of all endogenous variables. According to those criteria, our models should be estimated using 1 lag.

4.2 PVAR model selection and estimation

4.2.1 Baseline PVAR model

Our first specification consists of a baseline PVAR model built to specify the endogenous structures between university research income and KE income. This yields a model which estimates the general structural interdependence without interference from strategic mandates of the university. By utilising a PVAR methodology, we are able to investigate the

Table 4 Unit root tests

Variable	Level ADF	Level PP
Ln(RESEARCH)	−8.6334 (0.000)	−19.022 (0.000)
SPIN	−8.4551 (0.000)	−11.953 (0.000)
ln(COL)	−7.5607 (0.000)	−11.304 (0.000)
ln(CONT)	−7.3906 (0.000)	−10.703 (0.000)
ln(IP)	−8.2243 (0.000)	−11.99 (0.000)
ln(CPD)	−7.7861 (0.000)	−14.148 (0.000)
ln(FAC)	−8.3825 (0.000)	−12.846 (0.000)
SUB	−7.0034 (0.000)	−9.9766 (0.000)
BUS	−6.044 (0.000)	−8.9489 (0.000)
STRONG	−7.1486 (0.000)	−10.335 (0.000)
INC	−6.5993 (0.000)	−9.6433 (0.000)

p value are in parentheses. Z-statistics are reported for the Augmented Dickey Fuller (ADF) test and Phillips–Perron (PP) test in levels. Null hypothesis = non-stationarity

Table 5 PVAR Model (1)

Model 1	Response on						
Response from (endogenous variables)	*RESEARCH*	*IP*	*COL*	*CONT*	*PAT*	*CPD*	*SPIN*
$RESEARCH_{t-1}$	0.2688*** (0.0488)	0.0129 (0.0079)	0.0096 (0.0070)	0.0202* (0.0079)	0.0111* (0.0043)	−0.0088 (0.0091)	0.0459 (0.0483)
IP_{t-1}	0.0563 (0.1322)	0.7177*** (0.0392)	−0.0020 (0.0323)	−0.0310 (0.0366)	0.0127 (0.0140)	0.0448 (0.0344)	0.1015 (0.1411)
COL_{t-1}	0.2792*** (0.0793)	0.0126 (0.0232)	0.8055*** (0.0303)	0.0212 (0.0320)	0.0058 (0.0102)	0.0058 (0.0102)	−0.1194 (0.1337)
$CONT_{t-1}$	0.2573* (0.1138)	−0.0433 (0.0297)	−0.0144 (0.0419)	0.6695*** (0.0589)	−0.0104 (0.0180)	0.0861* (0.0409)	0.1046 (0.1516)
PAT_{t-1}	0.8817*** (0.2349)	0.1911*** (0.05620	0.1552* (0.0747)	0.1062 (0.0729)	0.8733*** (0.0283)	−0.0166 (0.0490)	0.1146 (0.3131)
CPD_{t-1}	−0.2092* (0.0984)	0.0016 (0.0244)	−0.0163 (0.0345)	0.1134* (0.0498)	−0.0025 (0.0114)	0.6670*** (0.0411)	0.1274 (0.2300)
$SPIN_{t-1}$	0.0457 (0.0241)	0.0155** (0.0058)	0.0053 (0.0040)	0.0094 (0.0068)	0.0093** (0.0034)	0.0035 (0.0058)	0.8239*** (0.0561)

Regional and time fixed effects included but not reported; ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; a lag-length of 1 as determined by the AIC and BIC criterion; estimation via GMM Forward Orthogonal Deviation

dynamic structure of the existing relationship between research income and its determinants within universities, across universities, and time. One of the advantages over a traditional VAR is the possibility to include important fixed effect coefficients to account for time invariant characteristics innate to each university. The estimates of Model 1 are presented in Table 5.

The results highlight that KE income across various activities in the previous period have a significant and positive effect on research income in the current period. Thus, research income from in period t is positively related to the level of income from collaborative research ($\beta = 0.273, P < 0.001$), income from contract research ($\beta = 0.257, p < 0.05$), and total number of patents held ($\beta = 0.882, p < 0.001$) in period t-1. Furthermore, research income is also positively related to the previous period's research income ($\beta = 0.269, p < 0.001$), suggesting a reinforcing cycle. Conversely, income from CPD in the previous period has a significant and negative effect on research income in the current period ($\beta = -0.209, p < 0.05$). In terms of magnitudes, we observe different size effects across all variables, with patents having the largest effect

Importantly, we find an inter-temporal bi-directional relationship exists between some KE activities and research income. For example, we find a positive bi-directional relationship between research income and income from contract research ($\beta = 0.020, p < 0.05$) and number of patents held ($\beta = 0.011, p < 0.05$). Importantly, the size of these coefficients highlights the fact that the influence of KE is stronger on research than vice versa.

Furthermore, we find evidence that KE activities are also inter-linked as several significant relationships are observed. For example, IP income in the current period is positively related to patents held ($\beta = 0.191, p < 0.001$) and spinouts created ($\beta = 0.016, p < 0.01$) in the previous period, while contract research income in the current period is positively related to income from CPD in the previous period ($\beta = 0.113, p < 0.05$), and number of patents held in the current period is positively related to the number of spinouts created in the previous period ($\beta = 0.009, p < 0.01$).

Finally, we find evidence of the auto-regressive nature of all variables, both KE income and research income, in that income in the previous period displays a significant and positive relationship with income in the previous period. Therefore, there appears to be a virtuous cycle of income generation in one period promoting continued income generation in the next. Given these findings, we accept hypothesis 1 as this represents a constant manifestation of university ambidexterity with the interdependence of each a concurrent occurrence.

4.2.2 Controlling for strategic orientation

Our second specification extends the baseline PVAR model (Model 1) through controlling for the strategic orientation of the university, which is often over-looked in terms of their effects on knowledge generation activities (Giuri et al., 2019; Johnston et al., 2023). To control for the heterogeneous nature of university strategic orientation, we estimate the baseline PVAR model with the addition of four proxies for university strategic orientation (z_{it}). These are entered as exogenous variables given the binary construction of these variables and mandated nature of strategy. The results of Model 2 are presented in Table 6. As can be seen, the significance and intertemporal direction of the endogenous variables does not alter upon the inclusion of strategic proxies. The PVAR baseline remains robust to various specifications of university characteristics. Consequently, the findings are consistent with Model 1, while also highlighting the importance of strategy.

Table 6 PVAR Model (2)

Model 2	Response on						
Response from (endogenous variables)	*RESEARCH*	*IP*	*COL*	*CONT*	*PAT*	*CPD*	*SPIN*
$RESEARCH_{t-1}$	0.2695*** (0.0469)	0.0136 (0.0081)	0.0118 (0.0078)	0.0216** (0.0080)	0.0128** (0.0048)	−0.0071 (0.0096)	0.0589 (0.0489)
IP_{t-1}	0.0773 (0.1365)	0.7178*** (0.0393)	−0.0016 (0.0349)	−0.0242 (0.0393)	0.0143 (0.0160)	0.0377 (0.0327)	0.1618 (0.1430)
COL_{t-1}	0.3023*** (0.0826)	0.0102 (0.0236)	0.7903*** (0.0310)	0.0112 (0.0341)	−0.0051 (0.0130)	0.0094 (0.0293)	−0.1575 (0.1434)
$CONT_{t-1}$	0.2753* (0.1155)	−0.0440 (0.0312)	−0.0292 (0.0430)	0.6582*** (0.0602)	−0.0216 (0.0201)	0.0686 (0.0395)	0.0693 (0.1378)
PAT_{t-1}	0.9335*** (0.2407)	0.1806*** (0.0547)	0.1027 (0.0859)	0.0733 (0.0810)	0.8464*** (0.0314)	−0.0447 (0.0561)	0.0248 (0.0248)
CPD_{t-1}	−0.2004* (0.0959)	−0.0049 (0.0233)	−0.178 (0.0331)	0.1139* (0.0512)	−0.0066 (0.0125)	0.6521*** (0.0436)	0.1241 (0.2382)
$SPIN_{t-1}$	0.0508* (0.0249)	0.0152** (0.0058)	0.0031 (0.0042)	0.0074 (0.0067)	0.0084** (0.0032)	0.0038 (0.0054)	0.8217*** (0.0576)
Response from (exogenous variables)							
BUS	−0.4074 (0.4784)	0.0264 (0.1034)	0.3197** (0.1142)	0.1822 (0.1421)	0.1993** (0.0650)	−0.0479 (0.1233)	0.5574 (0.5457)
STRONG	−0.0067 (0.4942)	0.1085 (0.0981)	−0.0007 (0.1090)	−0.0637 (0.0991)	0.0023 (0.0522)	0.0723 (0.1076)	0.1687 (0.4415)
SUB	−0.5737 (0.3767)	−0.0180 (0.0809)	0.1630 (0.0940)	0.2225* (0.0864)	0.0902 (0.0482)	0.0566 (0.1015)	0.4569 (0.4013)
INC	−0.6068 (0.5391)	0.2036 (0.1358)	0.4060* (0.1667)	0.3585 (0.1864)	0.1546 (0.0898)	0.4961** (0.1776)	0.3051 (0.4490)

Regional and time fixed effects included but not reported; ***$p<0.001$; **$p<0.01$; *$p<0.05$; a lag-length of 1 as determined by the AIC and BIC criterion; estimation via GMM Forward Orthogonal Deviation

The results show that a business focused external engagement strategy is positively associated with higher levels of income from collaborative research ($\beta = 0.320, p < 0.001$) and a larger patent portfolio ($\beta = 0.199, p < 0.01$). Furthermore, where the knowledge transfer office is a wholly owned subsidiary of the university, higher levels of contract research are observed ($\beta = 0.223, p < 0.05$). Finally, the presence of a university incubator has a positive effect on collaborative research income ($\beta = 0.406, p < 0.05$), and income from CPD activities ($\beta = 0.496, p < 0.01$).

To test the stability of our PVAR models we analyse whether the roots of the companion matrix were less than 1 (Sigmund & Ferstl, 2021). The values of the roots of all the companion matrixes of the two models are within the unit circle, demonstrating the model's stability and allowing for simulation analysis. The Eigenvalue stability conditions are also met, confirming that the estimated PVAR's are stable (Lütkepohl, 2005).

4.3 Generalised impulse response functions (GIRFs) & forecast-error-variance decompositions (FEVDs)

To examine the time dynamics within the models, we assessed the response characteristics of the endogenous variables in the following ten periods (years) through the estimation of Generalised Impulse Response Functions (GIRFs). This assessment enables us to observe the changing characteristics of the endogenous variable's response over time and also yields intertemporal visualisation. The GIRF's for Model 2 are presented in Fig. 1. From the panels it appears that shocks to both growth rates of research income generation are transitory: the effects of any shock therefore dissipate over time. Consequently, our results suggest that university ambidexterity is characterised by short lags in the cross-effects between research and KE. As such, we confirm hypothesis 2.

While GIRFs examine the responses of a variable to other variables' innovations, forecast-error-variance decompositions (FEVDs) indicate the contribution of each variable to the determination of other variables' forecast error variances. This is a good indicator of economic significance out of sample and to evaluate the relative cumulative contribution of each variable to the overall behaviour of our model. The FEVDs proportions after 10 years are given in Table 7. The variance decomposition shows the longer terms effects of various KE activities on research income, for example, patent profiles respectively explain approximately 8 per cent of the fluctuations of research income across the forward-looking time horizon.

4.4 Granger causality tests

To validate the dynamics between the underlying variables, we perform Granger causality tests. We test the direction of causality for both the whole sample and two subsamples according to their share of high technology research income. To assess this, we divide out the two subsets on a basis of research income volume. We classify universities into two panels on a basis of the quantity of their income generation as following the transformation:

$$PanelA = \left[\mu_i + 0.5 * \sigma\right] < Research_i$$

$$PanelB = \left[\mu_i + 0.5 * \sigma\right] > Research_i$$

where μ_i is the mean panel value of IS for country i and σ is the standard deviation of IS. Subset A proxies for those universities which are 'research intensive', with Subset

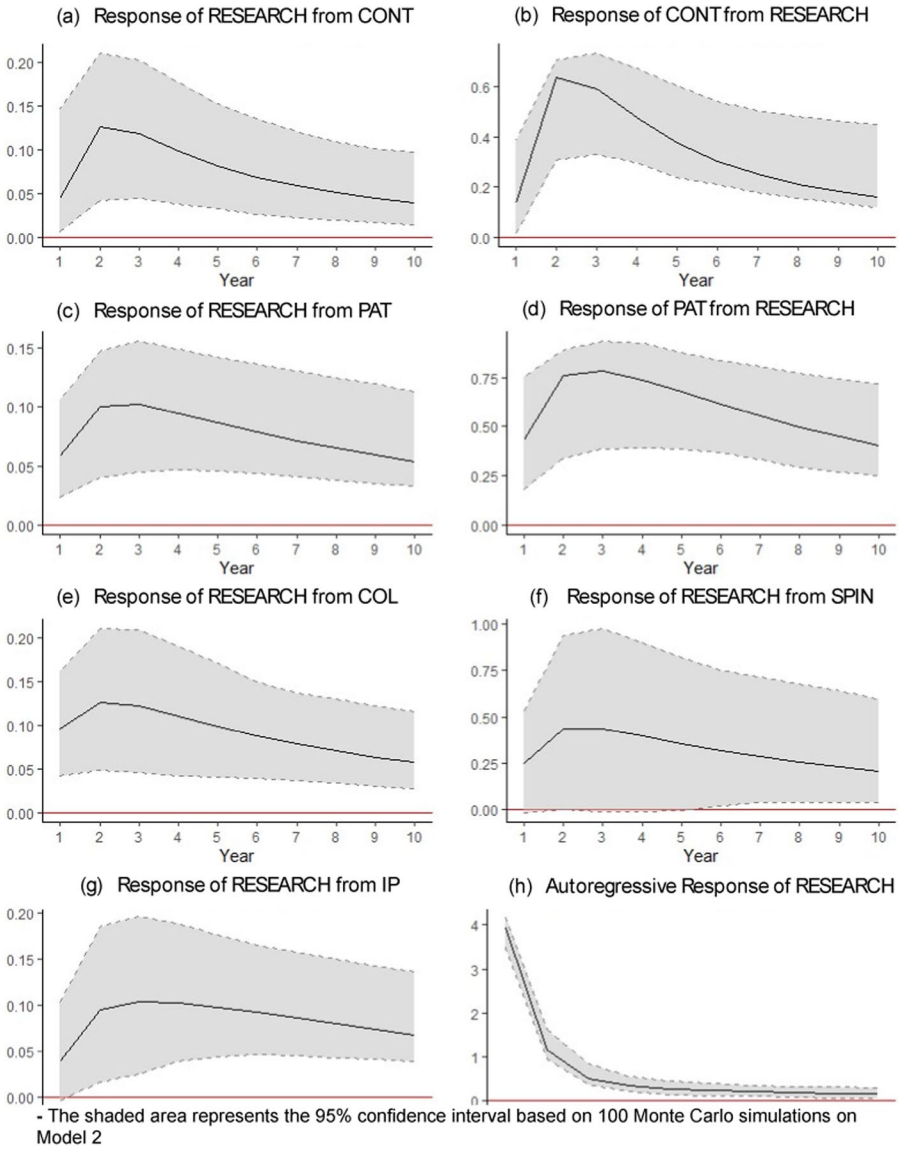

Fig. 1 Generalised impulse response functions

B otherwise. Subset A represents approximately 20% of universities. A variable is said to Granger cause another variable if there is enough evidence to reject the null hypothesis that the coefficients on the lags of the vector of variables y_{it-j} in the PVAR equation of y_{it} are all equal to zero. The results of this test reported in Table 8, provides evidence of causality among the key directions, suggesting that these variables should be treated as endogenous. Importantly, we confirm the bidirectional relationships between RESEARCH→PAT→RESEARCH and RESEARCH→CONT→RESEARCH, demonstrating that research income generation is endogenous and virtuous (as positive feedback

Table 7 Forecast-error variance decomposition analysis

	Variation in the row variable explained by column variable (in %, n years ahead)						
	Years ahead	*RESEARCH*	*IP*	*COL*	*CONT*	*PAT*	*CPD*	*SPIN*
RESEARCH	1	100	0	0	0	0	0	0
	2	94.9	0.32	1.4	1.1	1.1	0.39	0.53
	5	82.7	1.1	4.2	2.5	5.3	0.76	3.1
	8	76.9	1.5	4.8	2.7	7.6	0.79	5.4
	10	76	1.7	4.8	2.7	8.4	0.79	6.6

Percent (in unitary values) of variation in the variable explained by column variable for 1, 2, 5, 8 and 10 periods ahead

effects are apparent). The one-way causal relationships of the PVAR are also confirmed, suggesting the key importance of income from CPD activities and number of spinouts created in the intertemporal generation of research income in high technology fields.

Furthermore, as this result is consistent between the two subsets, demonstrating that the bidirectional relationships are constant irrespective of the category of university, we reject Hypothesis 3 that research intensity determines university ambidexterity. However, we note that the causal magnitude between research income and patent portfolio weakens within the intensive university subset while the direction remains the same. As the Granger tests are not sensitive to tests on varied subsets, this supports the view that the PVAR coefficients on predictive relations are neither spurious nor inconsistent. These causal relationships further support the feedback effect evidenced by our GIRF's in Fig. 1.

5 Discussion and conclusions

Given the twin trends of examining both innovation and university research and knowledge exchange through the lens of organisational ambidexterity (Audretsch & Guerrero, 2023; Centobelli et al., 2019; Sengupta & Ray, 2017), the analysis presented in this paper examined the simultaneous pursuit of research and KE in UK universities over a decade long period to assess the extent to which this relationship can be characterised as a 'twisting learning path' or a steady state underpinned by persistence (Bercovitz & Feldman, 2006; Centobelli et al., 2019; Thomas et al., 2023). The results suggest that university ambidexterity has three key characteristics: (1) a determinant temporal 'path dependent' effect, whereby research and KE activities exhibit a significant autoregressive component; (2) an inter-temporal bi-directional relationship between research and KE activities; and (3) short time lags between the implementation of research and KE coupled with the dissipation of the relationship over time that is indicative of a persistent relationship between the two. Consequently, given these results, we propose an alternative perspective to Centobelli et al's (2019) 'twisting learning path' model by highlighting the continuous interdependency of research and knowledge exchange within UK universities and highlight the persistent nature of university ambidexterity.

Furthermore, as university ambidexterity is unrelated to research intensity, the ability to undertake research and KE simultaneously is unrelated to the amount of research being undertaken by a university. Consequently, lower levels of research and KE activity are no

Table 8 Panel granger causality test

	PAT→ RESEARCH	RESEARCH →PAT	CONT→ RESEARCH	Research →CONT	COL→ RESEARCH	CPD→ RESEARCH	SPIN→ RESEARCH
Full sample							
Z-statistic	1738.1***	32.871***	1407.8***	38.665***	1123.1***	109.04***	1463.5***
p value	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Subset A: Research intensive universities							
Z-statistic	35.329***	1.1435	120.44***	14.374***	15.839***	4.000***	89.473***
p value	0.000	0.252	0.000	0.000	0.000	0.000	0.000
Subset B: non Research-intensive universities							
Z-statistic	960.89***	7.4177***	637.63***	24.762***	675.55***	139.98***	340.89***
p value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Results of a lag order of 1 presented; ***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

barrier university ambidexterity. In addition, through examining KE in terms of its constituent parts (Compagnucci & Spigarelli, 2020), we highlight the complexity of the relationship between exploration and exploitations activities. Therefore, university ambidexterity is not simply a matter of looking at two broad types of activities but rather understanding the intricacies of the interrelationships of many different activities. These are outlined in Fig. 2, which illustrates the interrelationships of research and KE activities; for example, research activity positively influences future KE activities such as collaborative research and patenting. In return, current research is positively influenced by contract research, patenting, and spinouts created in the previous period, and negatively influenced by the previous period's CPD activities.

Therefore, the findings presented in this paper, in line with the extant literature, reaffirm that ambidexterity is an important characteristic for the pursuit of universities' research and KE activities as each underpins the other (Johnston et al., 2023; Rossi & Sengupta, 2022; Sengupta & Ray, 2017). Finally, while KE requires knowledge to be created through research to be applied to external contexts, research activity is also dependent upon KE.

5.1 University ambidexterity: Turning a super tanker?

Given the concurrent nature of the research and KE processes that underpin university ambidexterity, we advance a theory of university ambidexterity that is continuous in nature and places persistence at its centre as an alternative to Centobelli et al.'s (2019) 'twisting learning path'. While persistence has been widely explored with respect to firms (Latham & Le Bas, 2006; Le Bas & Scellato, 2014), it has not previously been applied to universities, therefore by drawing on this literature we extend current understanding of university ambidexterity by incorporating both time dynamics (Sánchez-Barrioluengo, 2014; Sánchez-Barrioluengo et al., 2019) and persistence.

Importantly, the continuous interdependency of research and KE suggests that there are considerable sunk costs involved. Indeed, the nature of research and its reliance on the accumulation of knowledge and expertise in a discipline highlights the reality of these sunk costs. In parallel, additional sunk costs are added by the socio-technical nature of KE

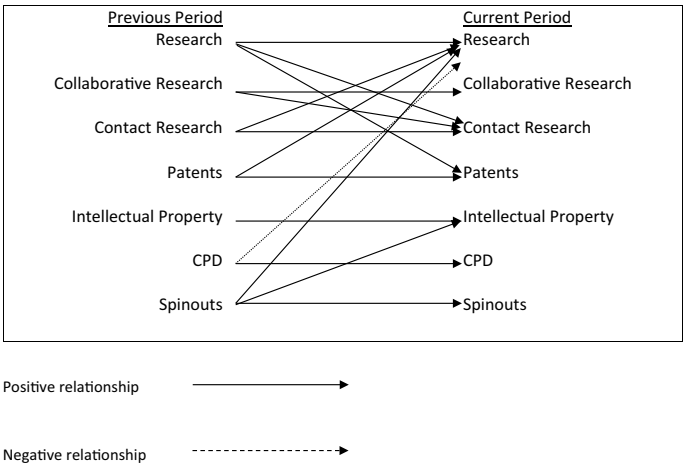

Fig. 2 Temporal relationships between research and knowledge activities

(Ankrah & AL-Tabbaa, 2015), whereby connections and understanding among the individuals involved is a key driver that underpins formation and function (Johnston, 2022). In light of both of these arguments, the persistence of these relationships is perhaps inevitable, making oscillation less achievable or even optimal.

While the existence of sunk costs underpins persistence, it also implies a level of inertia. Indeed, as universities are often bureaucratic in nature, persistence may in fact be reinforced by their organisational set-up (Moutsios, 2023). Yet, we do not suggest that where university ambidexterity is driven by persistence then no change is possible. Instead, we utilise the analogy of turning a super tanker to illustrate how persistence underpins university ambidexterity but still permits change to occur. As such, a university changing its pathway in terms of research and KE is much like a super tanker changing course; it is possible to achieve but it only does so slowly. Importantly, this is not interpreted to mean that universities are ponderous and unresponsive; more that changing direction requires foresight, a clear idea of a new direction, patience, and persistence. These factors are not necessarily conducive to a twisting path characterised by oscillation but instead the following of a continuous direction where any changes in this direction must be planned and are executed slowly and deliberately. Therefore, the importance of persistence in university ambidexterity does not imply unresponsiveness to external shocks and stimuli.

Given these arguments, we suggest that this theoretical approach to university ambidexterity draws most closely on contextual ambidexterity (Gibson & Birkinshaw, 2004), which importantly brings the role of the individual into focus. Gibson and Birkinshaw (2004) suggest that ambidextrous individuals are characterised by alertness to opportunities, cooperative, brokers of new linkages, and multitaskers. These characteristics firstly reinforce the relational aspect of KE, highlighting the importance of those whose work can span the knowledge and business ecosystem (Clarysse et al., 2014) but also brings the micro foundations of university ambidexterity to the fore (Felin et al., 2012; Perkmann et al., 2021). Given this, we call for more work to explore the management of university ambidexterity and how the complementarities between KE and research activities are manifest in terms of the actions of individual academics (D'Este & Perkmann, 2010; Link et al., 2007). Indeed, as Audretsch and Guerrero (2023) regard ambidexterity as the 'missing link between management, innovation, and entrepreneurship' this offers fertile ground to examine the multiple functions of universities.

Importantly, as university ambidexterity is independent of size effects it is equally possible to be ambidextrous with lower levels of research and KE activities. As such, the requirement for ambidexterity to be realised requires a university to be utilising research and KE concurrently regardless of magnitude. Therefore, ambidexterity is not contingent on larger levels of research or KE income, nor is it necessarily contingent on organisational size. Furthermore, the temporal determination of university ambidexterity is independent of the innate features of each university and, as income generation attains multiplier qualities, suggests it can be explained by momentum effects (Cefis & Orsenigo, 2001). Consequently, the fact that university ambidexterity is partially determined by the historical profiles of the universities research and KE activities it is therefore possible that it can have different characteristics within different universities, with different KE activities coming to the fore. In addition, the development path of a university is important for its future trajectory in terms of which are of KE they wish to specialise; the persistence of university ambidexterity suggests that specialisms in one area of KE is likely to be reinforced and institutionalised in the long term.

Furthermore, as universities have long been recognised as promoters of innovation and economic development, the results have important policy implications (Agasisti et al.,

2019; Goddard et al., 2012; Pugh et al., 2022). Firstly, the autoregressive nature of the KE activities suggests that a strength in one area is likely to lead to continued success in that domain. As suggested by Flaig and Stadler (1994) 'success breed success', suggesting any Triple Helix approach to economic development should examine the current research and KE strengths of local universities when seeking to build these activities into policies to boost innovation. In addition, the importance of persistence in university ambidexterity and the fact that any changes in direction require careful planning mean that universities cannot be expected to change the course of research and KE activities quickly to support economic development.

Finally, the paper suggests several practical implications. First, as university ambidexterity can result from one or many elements of KE academics and technology transfer personnel should prioritise any of these activities in which an individual university has a strength. Furthermore, given that all universities can pursue an ambidextrous approach to research and KE regardless of the size of their portfolios, university leaders should encourage the practice in order to embed this into strategies. As universities increasingly combine research and KE activities more formally, this could be complimented by resourcing and encouraging academics to work simultaneously on research and KE activities so that the two are inter-twined rather than treated as separate endeavours. However, given that academic pursuits, outcomes, and outputs tend to be prioritised (Hockaday, 2020; Reymert & Thune, 2022) this may entail a cultural shift as well as reducing barriers (Galan-Munros & Plewa, 2016).

While the paper has delivered several new insights, it is not without its limitations. Firstly, as with many studies in this field, the single country focus means that the findings are context specific. Therefore, we suggest that other contexts should be explored, of course dependent upon data availability (Hemmert et al., 2014). In addition, undertaking the analysis at the organisational level does not capture the individual behaviours that generate these outcomes and therefore require more attention (Rajalo & Vadi, 2017). In terms of future research avenues, we advocate an examination of the processes that underpin these findings though the eyes of individual academics. Thirdly, while this analysis captures formal pathways and income generating activities, we acknowledge that many alternate, informal, pathways to KE may exist and should be examined further (Hayter et al., 2020). Finally, as recent work has highlighted the importance of clustering to supporting ambidexterity (Mendes et al., 2023), an examination of links between universities and clusters may yield new insights into whether universities may support ambidexterity in their surrounding milieu and whether the existence of ambidexterity within the surrounding milieu may influence university ambidexterity.

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