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A new perspective on open innovation: established and new technology firms in UK bio-pharmaceuticals

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The aim of this paper is to explore open innovation (OI) implementation and its impact on firm innovation performance in sectors experiencing technological discontinuities. The paper employs the framework of inbound, outbound and coupled OI to identify processes reflecting sourcing, externalising and exchanging knowledge across organisational boundaries on upstream and downstream innovation activities and explores their impact on the innovation performance of new and established technology firms. The empirical setting is the UK bio-pharmaceuticals sector during 1991 and 2001, a paradigmatic era of discontinuous change and intensified OI implementation. First, our findings show that new technology firms (NTFs) and established technology firms (ETFs) differ in their extent and patterns of inbound, outbound and coupled OI, reflecting that they implement OI to manage their competences in light of technological change. Second, we identify a complex and multifaceted relationship between OI and patenting performance, with NTFs experiencing enhanced performance from some OI processes while ETFs experiencing challenges. The paper suggests that delineating OI into inbound, outbound and coupled, along upstream and downstream activities, offers a deeper understanding of the role of OI in innovation, guiding selective implementation in pursuing enhanced innovation performance during periods of discontinuous technological change.

1. Introduction

External actors make an important contribution to firm innovation and open innovation (OI) offers a means for theorising, analysing and exploring the impact of various firm practices to link internal and external ideas, knowledge and resources (Chesbrough, 2006; Chesbrough et al., 2008; Dahlander and Gann, 2010; Huizingh, 2011; West and Bogers, 2014). Open innovation is: ‘... both a set of practices for profiting from innovation,

and also a cognitive model for creating, interpreting and researching those practices’ (Chesbrough, 2006, p. 286) and offers a comprehensive framework that captures organisational efforts to attract external knowledge and to use internal knowledge externally (Chesbrough et al., 2008).

The aim of this paper is to analyse how both new and established (or incumbent) technology firms (hereafter NTFs and ETFs, respectively, see: Rothaermel and Boeker, 2008) in sectors experiencing discontinuous change implement OI and

how in turn it affects their innovation performance. Technological change can be competence enhancing/destroying (Tushman and Anderson, 1986) and it can affect the core and the complementary knowledge (Teece 1986, 1992). To analyse how NTFs and ETFs implement OI and the implications on innovation performance we develop hypotheses on the impact of sourcing (inbound OI), externalising (outbound OI) and exchanging (coupled OI) (Gassmann and Enkel, 2004) knowledge on upstream and downstream innovation activities (Bianchi et al., 2011, 2014). The bio-pharmaceuticals sector is an apposite setting because during the 1990s there is extensive use of collaborative R&D and alliances for technology sourcing and commercialisation (Cainarca et al., 1992), a clear identification of upstream and downstream activities and of NTFs and ETFs (Rothaermel, 2001a, 2001b; Rothaermel and Boeker, 2008; Hopkins et al., 2013; Dutta and Hora, 2017; Birkinshaw et al., 2018). The paper contributes to existing debates on OI and innovation performance by: first, extending existing research on the role of OI in organising innovation, the exploitation of new technologies and adaptation of ETFs to discontinuous technological change (West et al., 2008; Dahlander and Gann, 2010; Huizingh, 2011; West et al., 2014); second, developing a set of hypotheses that can guide research in other sectors undergoing technological change that share similarities to biotechnologies (Eggers and Francis Park, 2018); third, by employing the comprehensive framework of inbound, outbound and coupled OI (Gassmann and Enkel, 2004) and operationalising OI with a practice-oriented approach (Huizingh, 2011; Alexy et al., 2016; Zobel et al., 2016) it offers a comprehensive, longitudinal exploration of OI (Dahlander and Gann, 2010; Huizingh, 2011; West et al., 2014) which complements existing research focusing on inbound OI (West and Bogers, 2014).

The remainder of the paper is structured as follows: Section 2 provides the background to this work by discussing existing research on discontinuous technological change, collaboration and innovation performance of NTFs and ETFs in the context of the bio-pharmaceuticals sector. Section 3 discusses inbound, outbound and coupled OI on upstream and downstream innovation activities and develops hypotheses on their role in the innovation performance of NTFs and ETFs. Section 4 provides information on the sample and data sources and Section 5 discusses empirical constructs. Section 6 presents methods and results and Section 7 discusses the findings and concludes the paper.

2. Discontinuous technological change, collaboration and innovation in the bio-pharmaceuticals sector

Technological discontinuities influence the value of resources underpinning established production and innovation processes (Tushman and Anderson, 1986). Technological change brings in industrial change, with new technology firms, exploiting and commercialising the new technology entering established sectors and established firms responding by reconfiguring resources and capabilities to bridge the gap between existing and new value maximising configurations (Lavie, 2006; Eggers and Francis Park, 2018). The majority of research focuses on technological change that challenges core/upstream (R&D based) knowledge rather than complementary/downstream capabilities (e.g. manufacturing, marketing, product development) (Teece 1986, 1992; Cozzolino and Rothaermel, 2018). Under such conditions, NTFs and ETFs can mutually benefit from collaboration by leveraging new upstream knowledge and downstream competencies, respectively (Rothaermel, 2001a, 2001b; Cozzolino and Rothaermel, 2018).

Biotechnologies extended the scientific paradigm underpinning pharmaceuticals, and while challenged upstream-core capabilities in product discovery, reinforced the value of competences around complementary/downstream activities. Other characteristics of biotechnologies are high commercial uncertainty (Hopkins et al., 2013), long era of ferment (Eggers and Francis Park, 2018) and long gestation periods due to the stringent regulations in pharmaceuticals. Most research on the role of alliances in innovation in the bio-pharmaceuticals sector, focuses on alliances for technology commercialisation, where NTFs and ETFs combine their complementary competences in new product discovery and development (Rothaermel, 2001a, 2001b; Rothaermel and Boeker, 2008). In such alliances, the division of labour is facilitated by a strong appropriability regime and IP protection provides a framework for technology sharing and openness (Arora and Gambardella, 2010; Cozzolino and Rothaermel, 2018).

Research in the US bio-pharmaceuticals sectors shows ETFs to enhance their NPD and financial performance when they form alliances with NTFs to acquire new core knowledge on product discovery, while leveraging their complementary resources (Rothaermel, 2001a). US ETFs in bio-pharmaceuticals focus most of their alliances on leveraging complementary competencies, rather than on acquiring upstream knowledge; the former type of alliances exhibits a higher impact on NPD performance than

the later (Rothaermel, 2001b). The relationship between the aggregate number of alliances formed by ETFs and their NPD performance is curvilinear, reflecting potential inefficiencies in managing an increasing number of alliances (Rothaermel, 2001b). NTFs in the US bio-pharmaceuticals sector enhance their innovation performance (both patents and NPD) from alliances exploiting their core technologies (Shan et al., 1994; Fernald et al., 2015) and upstream alliances with universities (Dutta and Hora, 2017). Similar to ETFs, diminishing returns are identified between the overall alliance activity of NTFs and their NPD performance (Deeds and Hill, 1996; Rothaermel and Deeds, 2006).

This literature demonstrates a fragmented view on the role of openness in the innovation performance of NTFs and ETFs. This paper aims to offer a comprehensive exploration of OI implementation by examining the role of sourcing, externalising and exchanging knowledge and resources across organisational boundaries in the innovation performance of both NTFs and ETFs.

3. Inbound, outbound and coupled open innovation: hypotheses development

Gassmann and Enkel (2004) developed a framework to systematically explore OI by delineating three core processes: inbound (outside-in), outbound (inside-out) and coupled. They can be pursued through various informal practices and formal collaborative agreements. Inbound OI captures practices, such as licensing and technology acquisition, that enrich a firm's knowledge base by accessing and internalising ideas and knowledge from external sources, such as universities and users (Gassmann and Enkel, 2004). Outbound OI includes practices that channel, exploit and commercialise internal ideas and technologies externally in different markets and with different partners, such as licensing out and selling intellectual property (Gassmann and Enkel, 2004; Grant and Baden-Fuller, 2004; Arora and Gambardella, 2010). Coupled OI links inbound and outbound OI in knowledge and resource exchange agreements, such as cross-licensing, joint research, product development and commercialisation, joint manufacturing, co-marketing and joint ventures (Gassmann and Enkel, 2004).

Existing research on OI focuses on technology sourcing, or inbound-upstream OI, but firms can also internalise, outsource, buy-in, sell-out and cooperate with external actors along downstream activities (Vanhaverbeke and Cloudt, 2008; West

et al., 2008, 2014; Chesbrough and Chen, 2013; Chesbrough et al., 2014; Stanko et al., 2017). Downstream activities can be outsourced to specialist service providers; outsourcing clinical trials to specialist organisations facilitates time efficiency and effectiveness (Gassmann et al., 2008; Howells et al., 2008). In new drug development upstream and downstream activities can be clearly identified: drug 'discovery' (upstream), encompassing target identification and lead optimisation and drug 'development' (downstream), entailing pre-clinical and clinical tests and post-approval activities, such as manufacturing, marketing and distribution (Arora and Gambardella, 2010; Bianchi et al., 2011; Cozzolino and Rothaermel, 2018).

3.1 Inbound open innovation and firm innovation performance

Inbound OI refers to internalising ideas, technologies and expertise that complement and supplement a firm's knowledge base, involving linking with external actors and organisations which are at a comparative advantage. Inbound OI may lower the risks and costs of exploring emerging technologies, enhancing firm flexibility, time to market and NPD performance (Leone and Reichstein, 2012; Wang et al., 2012). It can be used to internalise pre-competitive research from universities, in-license technologies protected by intellectual property and other proprietary production methods and to access specialist or geographically distant knowledge. Upstream inbound OI is particularly relevant in high-tech sectors experiencing high technical and scientific churn, as firms face higher pressure to keep abreast of external developments. Inbound OI requires searching and evaluating suitable partners, investing in processes for knowledge transfer, knowledge matching and project management (Lakemond et al., 2016), in diffusing and storing external knowledge and re-adjusting internal practices (Lavie, 2006).

With inbound OI firms can access downstream competences to complement existing activities (e.g. Dutta and Hora, 2017), improving performance through economies of scale and scope, achieving efficiencies and reducing costs by soliciting user feedback in new product development, trials and customisation (Dahlander and Gann, 2010). ETFs can benefit from such scale economies and efficiencies, while NTFs, as they are less likely to be vertically integrated, can benefit from accessing complementary downstream competences (Rothaermel and Deeds, 2004; Dutta and Hora, 2017). ETFs with a broad knowledge base are expected to enhance their

innovation performance by both upstream and downstream inbound OI (Rothaermel, 2001a, 2001b). For ETFs facing technological discontinuities that challenge core knowledge, upstream inbound OI will have a bigger impact on innovation performance than downstream inbound OI (Eggers and Francis Park, 2018). Following existing research we propose that upstream and downstream inbound OI can complement the narrow expertise of NTFs enhancing their innovation performance (Khilji et al., 2006; Fernald et al., 2015; Dutta and Hora, 2017); the impact will be stronger for downstream inbound OI as engaging in further product development and commercialisation encourages learning that is underdeveloped internally. The following hypotheses are proposed:

H1a: *Intensifying upstream and downstream inbound open innovation processes positively affects the innovation performance of new technology firms; downstream inbound open innovation has a bigger effect than upstream.*

H1b: *Intensifying upstream and downstream inbound open innovation processes positively affects the innovation performance of established technology firms; upstream inbound open innovation has a bigger effect than downstream.*

3.2 Outbound open innovation and firm innovation performance

Outbound OI captures knowledge outflows from a firm's innovation process and includes all systematic activities aimed at exploiting firm-specific knowledge and resources, and products and services stemming from intermediate NPD stages (Gassmann and Enkel, 2004; Dahlander and Gann, 2010). Outbound OI can improve time to market, facilitate the diffusion of technologies influencing industry standards (Dahlander and Gann, 2010). Participating in external markets for technology provides a stream of profits, helps to timely recoup investments in R&D and to efficiently manage IP portfolios by benefiting from marginal and peripheral technologies (Arora and Gambardella, 2010; Natalicchio et al., 2014). Pursuing outbound OI is challenging due to the intangible nature of knowledge, imperfections in evaluating ex ante its future value, the need to identify suitable partners and the higher risks of opportunism and increased future competition (Arora and Gambardella, 2010; Natalicchio et al., 2014). Exploiting technologies both internally and through licensing, can have a negative impact on profit margins, due to costs associated with the need for close coordination to avoid

cannibalisation and safeguard against increased future competition from licensees (Bianchi et al., 2014). Licensing out is not free from disadvantages, especially when licensing across different industries, as it can divert a firm's focus outside its core product and customer base, diluting its attention and potentially harming long-term innovation performance (Leone and Reichstein, 2012). Particularly for technologies distant from the core, licensors offer greater support to licensees, as the threat of competition from leapfrogging is not direct. Often, licensors use grant-back clauses to ensure that improvements in licensed technologies are transferred back, enabling future appropriation and eliminating the threat of direct competition (Leone and Reichstein, 2012; Bianchi et al., 2014; Laursen et al., 2017). Grant-back clauses can facilitate learning and are more likely in licensing agreements of core rather than peripheral technologies (Laursen et al., 2017).

NTFs, due to their specialist technological expertise and need to recoup investments in R&D are likely to pursue upstream outbound OI to exploit their core technologies in different applications. Due to the liability of newness (Rothaermel and Boeker, 2008), NTFs are less powerful in negotiating learning from licensing out and the rise of future competition can negatively affect their inventiveness in the long run. ETFs with upstream outbound OI can effectively manage their technology portfolio, benefiting from exploiting peripheral and underutilised technologies; because grant-back clauses are less likely when licensing non-core technologies, we expect upstream outbound OI to have a less pronounced effect on their innovation performance compared to downstream. With outbound OI firms can leverage unique downstream competences, underutilised resources and excess production capacity, enhancing flexibility and efficiency, positively influencing innovation performance and competitiveness. Leveraging complementary downstream capabilities in alliances provides ETFs with wider access to new markets enhancing both their NPD and financial performance (Rothaermel 2001a, 2001b). NTFs in biotech leverage downstream capabilities with outbound OI when providing specialist services related to clinical trials (Bianchi et al., 2011). The above lead to the following hypotheses:

H2a: *Intensifying upstream and downstream outbound open innovation processes enhances the innovation performance of new technology firms; upstream outbound open innovation has a bigger effect than downstream.*

H2b: *Intensifying upstream and downstream outbound open innovation processes has a positive effect on the innovation performance of established technology firms; downstream outbound open innovation has a bigger effect than upstream.*

3.3 Coupled open innovation and firm innovation performance

Coupled OI captures knowledge and resources exchange and sharing, the co-occurrence of inbound and outbound OI (Gassmann and Enkel, 2004; Enkel et al., 2009; West and Bogers, 2014) and co-creation with external actors (Piller and West, 2014; West et al., 2014). Firms are likely to use coupled OI to coordinate distributed, complex and overlapping tasks, to share the risks and costs of uncertainty in joint research, creating value by sharing complementary and supplementary resources. In coupled OI, partners are likely to experience high degrees of reciprocal interdependence, which requires close interaction and communication to manage complexity in coordinating joint tasks. Both partners have incentives to invest in both relationship specific assets and knowledge sharing routines to enhance joint value creation (Dyer and Singh, 1998; Dyer et al., 2018). The ability of partners to capture a portion of the common value created in such agreements depends on their bargaining power (Dyer et al., 2008, 2018). Partner ex ante bargaining power depends on the scarcity and value of resources that they contribute to the agreement, with the partner making the most critical contribution being more likely to appropriate a higher share of the common value (Dyer et al., 2008).

Investments in relationship specific assets and knowledge sharing routines dynamically co-evolve increasing the potential common value. Such investments may not be easily re-deployable which creates appropriation concerns, motivating partners to intensify investments in value capture mechanisms (Dyer et al., 2018). Partners with greater technological experience and a larger internal resource base, which creates opportunities for private value creation from alliances (Dyer et al., 2008), make higher investments in value capture mechanisms and often use power-seeking tactics (Arora and Gambardella, 2010; Panico, 2017). We expect that due to their larger resource base, ETFs will be more likely to have control over a greater set of resources and as a result to enjoy a better negotiating position and higher bargaining power, enabling potential capture of greater value in alliances (Rothaermel, 2001a, 2001b). NTFs with a focused range of competences and resources are likely to have control over a narrow

set of resources and because of their liability of newness, to suffer from weaker negotiating and bargaining power. Relative bargaining power in alliances is influenced by the criticality of resources that firms contribute to the agreement. Due to the characteristics of biotech and its impact on core and complementary competences, we expect that, overall, NTF bargaining power will be stronger in upstream coupled OI agreements compared to downstream, while the reverse will be the case for ETFs. It should be noted that the criticality of resource contributions, at firm-level, may be difficult to be judged ex ante, especially when such resources involve knowledge and techniques related to emerging technologies of uncertain commercial potential (e.g. Hopkins et al., 2007). We formulate the following hypotheses:

H3a: *There is a negative relationship between intensifying upstream and downstream coupled open innovation processes and innovation performance for new technology firms; this impact is more pronounced for downstream compared to upstream coupled OI.*

H3b: *There is a positive relationship between upstream and downstream coupled OI and innovation performance for established technology firms; this impact is more pronounced for downstream compared to upstream coupled OI.*

Table 1 provides an overview of our hypotheses.

4. Sample and data sources

To identify the population of firms in the UK bio-pharmaceuticals sector we consulted two consecutive editions (2000 and 2002) of the UK Biotechnology Directory (Coombs and Alston, 2000, 2002), and extended this list with information from membership to the UK Bio-Industry Association. The 1980s marked the first decade of NTF entry in UK bio-pharmaceuticals, as the scientific paradigm in pharmaceuticals embraced biotechnologies (Orsenigo, 1989; Howells et al., 2008), with a successive wave of higher NTF entry during the 1990s, associated to a more supportive environment due to institutional changes in both drug regulation and finance (Hopkins et al., 2013). The turn to 2000s is not only characterised by a significant shift in finance supporting start-ups in biotech, but the entire decade witnessed consolidation, with ETFs merging with other ETFs and acquiring NTFs (Gottinger, 2010; Hopkins et al., 2013; Cozzolino and Rothaermel, 2018). For the purposes of this study, we focus on the period between 1991 and 2001, as there is a

Table 1. Overview of hypotheses for the role of inbound, outbound and coupled OI on NTF and ETF innovation performance in the bio-pharmaceuticals sector

Open innovation processes	New technology firms	Established technology firms
Inbound		
Upstream	Hypothesis 1a Positive	Hypothesis 1b Positive (bigger than downstream)
Downstream	Positive (bigger than upstream)	Positive
Outbound		
Upstream	Hypothesis 2a Positive (bigger than downstream)	Hypothesis 2b Positive
Downstream	Positive	Positive (bigger than upstream)
Coupled		
Upstream	Hypothesis 3a Negative	Hypothesis 3b Positive
Downstream	Negative (bigger than upstream)	Positive (bigger than upstream)

clear identification of NTFs and ETFs, an upsurge in OI activity (Hagedoorn and Roijakkers, 2006) and a gradual internalisation of biotechnologies by ETFs through collaboration (Hopkins et al., 2007; Birkinshaw et al., 2018). The commercial potential of biotechnologies started becoming clearer post 2000s (Hopkins et al., 2007; Birkinshaw et al., 2018); collaborating for R&D and technology sharing are common during early stage development of other technologies (Cainarca et al., 1992) which broadens the impact of the insights drawn from studying this sector during this time period.

We identified 110 UK-based independent firms, including the UK subsidiaries of MNEs. As data collection was retrospective, we identified all firms active in 2003, which may omit firms active during 1991–2001 that seized operation before 2003. Following existing research in this sector (Rothaermel and Boeker, 2008) we identify ETFs, firms imprinted under technologies prior to biotech, having primary SIC codes in Pharmaceuticals (including a few firms in Chemicals)¹ and NTFs as the dedicated biotechnology firms, with core operations in Biotechnology.²

We capture open innovation processes by observing practices for OI in formal collaborative agreements and alliances with independent actors (Chesbrough, 2006; Hung and Chou, 2013) reported in ReCap and BioScan.³ We identified that out of the 110 firms, 66 ETFs and NTFs formed alliances; 2,077 alliances

were initiated between 1991 and 2001, with full information on content provided for 1,983. Starting from 1980s and extending beyond 2000, there is considerable variety across ETFs in the extent and time period they embraced biotechnologies, if they did at all (Birkinshaw et al., 2018). To capture innovation performance, we collected firm-level data on patents from the UKPTO, and to explore our hypotheses we use information on company accounts from FAME and Thomson's Analytics, R&D investments from Thomson's Analytics and the UK DTI's R&D Scoreboard.

5. Data analysis and variables

5.1 Inbound, outbound and coupled open innovation processes in collaborative agreements

To operationalise OI we adopt a practice-oriented approach (Alexy et al., 2016) and identify inbound, outbound and coupled OI based on the content of collaborative agreements as provided by ReCap and BioScan. Analysis of content is an emerging research practice, leading to rich information, enabling a comprehensive exploration of the relationship between OI and firm innovation performance (Huizingh, 2011; Zobel et al., 2016). We identify the three OI processes at both upstream and downstream activities (Vanhaverbeke and Cloudt, 2008; Zobel et al., 2016). We proceed by allocating each agreement to one of the six categories: upstream/downstream inbound, outbound and coupled OI. We generate six variables for each firm with a value equal to the number of agreements under each category and year to capture the extent of openness. The allocation focuses on the role that the firm in our sample assumes in the agreement (e.g. licensee vs licensor) and uses information on both its type (i.e. licensing, cross-licensing and so on) and description (e.g. testing a protein sequence, clinical trials and so on). A sample of the allocated agreements was shared with a biologist to discuss and check the coding process. To avoid inaccurate allocations, we removed agreements with incomplete content.

5.2 Remaining variables

5.2.1 Firm innovation performance

Patents are an effective measure of innovation performance in science-based sectors (e.g. Ziedonis, 2008) and employed widely in literature capturing firm innovation from alliances (e.g. Deeds and Hill, 1996; Sampson, 2007). We collect patent data from

the UK Patent and Trademarks Office (UKPTO) via Esp@cenet as we focus on UK-based firms. Patents are identified by matching both the name and the address of firms in our sample with those of the patent assignees (Arora et al., 2011). Multinational enterprises may assign patents at the HQ level. When the MNE HQ is outside the UK, we examine information on inventor location, as it can signal the location(s) of invention, and then, moved on to assign any patents with UK-based inventors to the UK-based subsidiary in our sample. To allocate patents over time we use the filing rather than publication dates as they more closely reflect the time of new knowledge creation.

5.2.2 Factors affecting firm innovation performance

We collect data on firm-specific characteristics influencing innovation performance, such as investments in R&D and firm size, to account for the amount of investments in innovation and resource endowments, respectively. Firm size is captured by number of employees, as due to the nature of the technology and long gestation periods, firms may not immediately generate sales (Rothaermel and Boeker, 2008; Birkinshaw et al., 2018; Moeen and Mitchell, 2020).

5.2.3 Experience in managing collaborative agreements

Experience in managing alliances can improve firm efficiency in managing collaborative tasks (Anand and Khanna, 2000; Wang and Rajagopalan, 2015), and could be linked to efficient OI management. We measure firm collaborative experience with the aggregate number of alliances, considering that on average each alliance lasts for 5 years (Kogut, 1988). We use 1 year lagged values of this measure to reflect that it takes on average 1 year for firms to transfer any learning from past experience to current implementation of OI (Lavie et al., 2011). We use logarithmic transformations due to diminishing returns in alliance experience accumulation (e.g. Sampson, 2005).

6. Analysis and results

6.1 Analysis

The analysis is based on a panel observing 66 firms using biotechnologies between 1991 and 2001, with 32 ETFs and 34 NTFs. First, we examine statistical differences across the six OI processes (OIPs), exploring whether our analytical constructs capture distinct approaches to OI. A *t*-test, together with

bootstrap for robustness (99% confidence interval) show statistically significant differences across all OIPs.

Table 2 shows average values for all OIPs for ETFs and NTFs, respectively. For ETFs, on average, upstream inbound (2.3) and upstream coupled (1.2) are the most frequently used, reflecting a tendency to in-source knowledge around early NPD stages. NTFs focus on upstream activities forming on average 1 (outbound), close to 0.8 (coupled) and 0.6 (inbound) OIPs, reflecting that they mainly use OI for external knowledge outflows at early drug discovery stages, and secondary for knowledge exchange or joint creation. Table 2 compares the two groups and shows that there are statistically significant differences across all OIPs with the exceptions of outbound (both upstream and downstream). Overall the comparisons show that ETFs and NTFs employ different OI processes, reflecting differences in their competences and use of OI to manage and redeploy them in light of the technological change.

To examine the role of OIPs on firm innovation performance we carry out regression analyses separately for ETFs and NTFs similar to relevant research on firm groups (Vahter et al., 2014). Table 3 provides correlation coefficients and Table 4 presents the results. The panel is considerably unbalanced, mainly due to firm entry after 1991, with 20 NTFs being established after 1995 (this pattern is consistent with Hopkins et al., 2013). Since our dependent variable is a count variable and due to overdispersion we conclude that the Negative Binomial model is better suited⁴ to Poisson.⁵

The Wald χ^2 statistic shows that the interpretative power of the Random Effects (RE) specification is significant for ETFs but not for NTFs. We examine joint significance for groups of variables for NTFs as follows: first, only for controls, second, for all OIP variables together, third, only for the two OIP variables that appear to be significant in the initial model (upstream coupled and downstream inbound, see Table 4). Joint significance is confirmed only in the third case ($\chi^2 = 7.61$, prob = 0.022) showing a positive and significant association between upstream coupled and downstream inbound OIPs and NTF innovation performance. Results for ETFs show a significant and negative association between downstream inbound, downstream outbound and innovation performance which is counter to our expectations (part of hypotheses 1b and 2b). We examine curvilinearity but do not find support. Comparisons on the relative impact of upstream and downstream OIPs are

Table 2. Comparisons of ETFs and NTFs across upstream and downstream open innovation processes: non-parametric tests

	Upstream open innovation processes			Downstream open innovation processes		
	Inbound	Outbound	Coupled	Inbound	Outbound	Coupled
ETFs (N = 208)						
Mean	2.3	0.89	1.19	1	0.63	0.53
Median	1	0	0.5	0	0	0
St. Dev.	3.201	1.325	1.980	1.469	1.144	1.067
Min	0	0	0	0	0	0
Max	14	7	11	8	6	7
NTFs (N = 184)						
Mean	0.61	1	0.78	0.29	0.53	0.18
Median	0	1	0	0	0	0
St. Dev.	0.873	1.572	10.322	0.619	0.975	0.507
Min	0	0	0	0	0	0
Max	6	10	8	3	5	3
Statistics: Kolmogorov–Smirnov						
ETFs	0.254	0.274	0.288	0.285	0.361	0.392
NTFs	0.324	0.288	0.303	0.459	0.392	0.502
Significance	0.000	0.000	0.000	0.000	0.000	0.000
Comparisons						
Mann–Whitney (U)	12.933	19.827	17.095	13.838	18.553	15.871
Standardised test statistic	−5.895	0.671	−2.004	−5.578	−0.626	−4.020
Significance	0.000	0.502	0.045	0.000	0.532	0.000

not carried out due to insignificance for one of the two variables across models. The following sections discuss our results for ETFs and NTFs.

6.2. Open innovation and the innovation performance of ETFs

Our results show a significant and negative association between downstream inbound, downstream outbound and ETF innovation performance. The findings contradict the experience of US ETFs in bio-pharmaceuticals which enhance both NPD and financial performance by leveraging downstream competences in alliances with NTFs (Rothaermel, 2001b). The following provide an interpretation of why our results differ. ETFs faced high complexities and costs in integrating biotechnologies with existing complementary downstream capabilities and the need to invest in supporting organisational innovations (Hopkins et al., 2007). The use of genomics introduced complexities in clinical trials, product approval and development, while Hopkins et al. (2007) suggest that from early 1990s to early 2000s biotechnologies proved to be less successful than anticipated and they mainly focused on established targets and treatments contributing

less to novel therapies than after 2000 (Hopkins et al., 2007; Birkinshaw et al., 2018). These may provide an explanation for the negative impact we observe on patents as they capture novelty.

Our results reflect the difficulties in identifying suited technologies under technological uncertainty and of integrating unfamiliar external sources of knowledge that may be disconnected with existing thinking and processes (Lavie, 2006; Hopkins et al., 2007; Stanko et al., 2017). They also reflect that adapting complementary capabilities to the exploitation of new technologies requires closer coordination and communication across their interface, which is more effectively organised through tighter coordination (Moeen and Mitchell, 2020). The negative association between downstream outbound and ETF innovation performance reflects the barriers in disentangling and externalising intermediate outputs of the NPD process that are interrelated with other NPD projects. This is particularly the case for ETFs externalising compounds that are interlinked within therapeutic areas (Chesbrough and Chen, 2013).

Broadly our results reflect the challenges facing ETFs when substituting and transforming embedded capabilities which are interdependent with other NPD stages (Lavie, 2006). Furthermore, effective

Table 3. Summary statistics and correlation matrix for ETFs and NTFs, respectively

	Mean	St. Dev.	1	2	3	4	5	6	7	8	9
ETFs											
Number of patents	0.520	1.775									
Upstream inbound	2.298	3.201	0.022								
Upstream outbound	0.894	1.325	-0.073	0.020							
Upstream Coupled	1.188	1.980	-0.070	0.384	0.144						
Downstream inbound	0.995	1.469	-0.157	0.425	-0.086	0.376					
Downstream outbound	0.625	1.144	-0.141	0.251	0.268	0.471	0.118				
Downstream coupled	0.529	1.067	-0.089	0.402	0.010	0.307	0.282	0.178			
Number of employees	4,100.066	12,513.690	0.173	0.476	-0.201	0.143	0.382	-0.068	0.298		
R&D expenses	144.970	363.246	0.386	0.254	-0.249	0.036	0.204	-0.127	0.083	0.703	
Collaboration experience (ln)	2.136	1.609	0.004	0.607	0.155	0.489	0.471	0.398	0.268	0.266	0.182
NTFs											
Number of patents	0.168	0.699									
Upstream inbound	0.614	0.873	-0.014								
Upstream outbound	1.000	1.572	0.020	0.083							
Upstream coupled	0.777	1.322	0.196	0.022	0.031						
Downstream inbound	0.293	0.619	0.083	0.296	0.026	0.077					
Downstream outbound	0.533	0.975	0.024	0.145	0.089	-0.126	0.138				
Downstream coupled	0.179	0.507	-0.025	0.136	0.216	0.008	0.207	0.107			
Number of employees	280.986	769.338	-0.014	-0.029	-0.127	-0.034	-0.015	-0.008	0.088		
R&D expenses	9.362	12.606	0.058	0.120	0.057	0.181	-0.007	0.012	0.179	0.458	
Collaboration experience (ln)	1.527	1.252	0.046	0.237	0.186	0.209	0.291	0.167	0.257	-0.045	0.407

Table 4. Negative binomial panel data model estimates, random effects specification (dependent variable: number of patents)

	ETFs		NTFs	
	Coefficients	Standard errors	Coefficients	Standard errors
<i>Independent variables</i>				
Upstream inbound	0.085	0.099	-0.101	0.282
Upstream outbound	0.164	0.208	0.177	0.201
Upstream coupled	0.034	0.092	0.266**	0.125
Downstream inbound	-0.425**	0.188	0.645**	0.330
Downstream outbound	-0.720*	0.383	0.243	0.210
Downstream coupled	-0.106	0.232	-0.354	0.397
Number of employees	0.000	0.000	0.000	0.001
R&D expenses	0.002	0.002	0.001	0.029
Experience in collaboration	-0.338	0.412	0.122	0.350
Constant	0.851	1.328	0.136	1.402
Observations	132		83	
Firms	24		20	
Wald Chi ²	39.04		10.07	
Prob > Chi ²	0		0.3451	
Log Likelihood	-108.532		-64.990	

Significance levels: * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

implementation of OI may require reorganising internal processes and systems of communication to develop absorptive, desorptive and multiplicative capabilities, broadening R&D personel skills on OI management (Gassmann and Enkel, 2004; Spithoven et al., 2011; Bianchi et al., 2015) and the development of processes for value creation and capture in OI (Chesbrough et al., 2018).

6.3 Open innovation and the innovation performance of NTFs

Our results can have important implications for NTFs suggesting that innovation performance can be enhanced when they simultaneously implement upstream coupled and downstream inbound OIPs. For instance, this can reflect a combination of agreements for joint research and for internalising external expertise on further product development and commercialisation. This is in line with Dutta and Hora (2017) showing that when NTFs form exploratory alliances to in-source knowledge from universities together with alliances for commercialisation with ETFs, they enhance both their invention and commercialisation performance. Our results echo research showing that NTFs which engage in commercialisation alliances better understand market needs, which enhances in turn their success in patents (Shan et al., 1994; Khilji et al., 2006; Fernald et al., 2015). Broadly this reflects the need for close coordination between upstream and downstream activities for effective communication and

technology commercialisation (Moeen and Mitchell, 2020). Our results confirm part of hypothesis 1a (inbound downstream OI) and contradict part of hypothesis 3a (coupled upstream). The positive impact of coupled upstream OIPs, showing that NTFs overcome negotiation and appropriation barriers in such agreements, could be interpreted through the science-base nature of biotechnologies and the close links of NTFs with universities and publicly funded research, which we believe reflect most coupled upstream OI (Orsenigo, 1989; Hopkins et al., 2013). Overall, NTFs wishing to effectively pursue such an OI strategy of linking coupled with inbound OIPs upstream and downstream, would need to develop an integrative view across absorptive, desorptive and relational capabilities to support their simultaneous implementation (Spithoven et al., 2011; Chesbrough et al., 2018).

7. Discussion and conclusions

The paper develops hypotheses on the role of inbound, outbound and coupled OI on upstream and downstream activities in the innovation performance of ETFs and NTFs when technological change challenges upstream competences of ETFs. The UK bio-pharmaceuticals sector between 1991 and 2001 provides an aposite setting for this exploration. Findings show that, contrary to expectations, ETF innovation performance is negatively associated with downstream inbound and outbound OI. Results for NTFs support our expectations

that downstream inbound OI enhances innovation, but this is only in combination with upstream coupled OI, with the latter being positive, contrary to our hypothesis. Our findings are limited to the specific sector and time period. Subsequent changes in the sector, led to what was initially breakthrough biotechnologies becoming integral part of the underpinning scientific disciplines, to the close interlacing of ETFs and NTFs, with backward and forward integration, respectively, by some major firms in the sector driven by the desire to capture greater value (Lavie, 2006; Hopkins et al., 2013; Cozzolino and Rothaermel, 2018). There is firm heterogeneity and variety in their paths of evolution that should be acknowledged as a limitation of our analysis of groups of ETFs and NTFs (e.g. Birkinshaw et al., 2018).

Our findings show that a deeper understanding is needed on the interplay between internal innovation processes, OI and firm processes to build internal capabilities and reconfigure competences in light of technological change (Lavie, 2006; Eggers and Francis Park, 2018). Indeed, our results show, particularly for NTFs, the need to understand how firms interrelate and manage different OI processes across upstream and downstream activities. For ETFs results suggest that a deeper exploration is required to understand the range of inefficiencies and costs associated with OI, and the nature of capabilities supporting efficient OI implementation and management (Gassmann and Enkel, 2004). Identifying and internally developing upcoming and uncertain external technologies challenges ETFs' innovation performance. So does their attempt to externally exploit downstream capabilities in an attempt to reconfigure existing capabilities and achieve greater efficiencies. Deploying and reconfiguring downstream capabilities in alliances to commercialise externally sourced technologies entails challenges stemming from coordinating their interface, lowering transaction costs and internalising economies of scale. The subsequent (post 2000) backward integration to biotechnologies by most major pharmaceuticals firms provides further testament to our conjectures (Arora and Gambardella, 2010). Our results for both NTFs and ETFs reflect the efficiency and innovation benefits of a close coordination between upstream and downstream activities.

The paper is limited to a specific time period and sector; however, it shows that delimiting between inbound, outbound and coupled OI is instrumental in understanding the relationship between OI and firm innovation performance, highlighting the influential role of the Gassmann and Enkel's (2004) framework in guiding effective in-sourcing, externalising and exchange of knowledge and resources. Employing the OI framework on upstream and downstream activities,

sheds light on how ETFs and NTFs in sectors experiencing technological change can use OI to manage and develop their competences. Distinguishing between upstream and downstream activities adds to Gassmann and Enkel's (2004) framework, by highlighting that OI can make a different impact depending on the context of its application; for instance, inbound OI appears with a different sign for upstream compared to downstream activities for both ETFs and NTFs. Our findings are aligned with existing research showing that external sourcing strategy depends on the nature of competences sources, technical or complementary (Moeen and Mitchell, 2020).

Because the period explored is a paradigmatic example of how emerging technologies develop through OI, our findings can be of relevance for sectors experiencing technological change with similar characteristics to biotech, as suggested in Eggers and Francis Park (2018). The hypotheses developed in this paper and their partial support call for further research in sectors similar in nature to the early stages of biotechnology development. Future research can modify the expectations put forward in this paper, to facilitate research on the use and impact of OI on ETF and NTF innovation performance when technological change unsettles complementary (downstream) rather than core ETF knowledge (Cozzolino and Rothaermel, 2018).

This paper reinforces the need for future research on the OI framework (Gassmann and Enkel, 2004), on the barriers to fully benefit from OI (Dahlander and Gann, 2010; Stanko et al., 2017) and on the processes that enable value creation and capture in OI (Chesbrough et al., 2018). The latter is the cornerstones of OI capabilities and envelopes capabilities for new product development, innovation and alliance management (Wang & Rajagopalan, 2015; Spithoven et al., 2011; Chesbrough et al., 2018).

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Notes

- ¹Specifically the US SIC codes are: 2833 ‘Medicinal Chemicals and Botanical Products’; 2834 ‘Pharmaceutical Preparations’; 2835 ‘Diagnostic Substances’; 2836 ‘Biological Products, Except Diagnostic’.
- ²Specifically the US SIC code is: 8731 ‘Commercial Physical and Biological Research’.
- ³ReCap and BioScan are both notable for their scope, completeness of information for their consistency and reliability and provide information on all types of formal agreements aiming at discovering and developing bio-pharmaceutical products, draw on press releases,

sector specific magazines, US Securities and Exchange Commission (SEC) filings, and company annual reports, with information dating back to 1979.

⁴STATA estimates the ‘alpha’ parameter for the pulled cross-section and time-series dataset, and it is equal to 5.48 and 1.92 for Pharma and BFs, respectively, suggesting overdispersion in both datasets (LR test values: LR = 118.87 and LR = 18.15, respectively, and Prob \geq Chibar2 = 0.000 in both cases).

⁵As the fixed effects estimation relies on first-differencing, a number of observations were automatically dropped as for a number of firms there were no changes in the dependent variable over time. Specifically, the total number of observations for the fixed effects specification is substantially reduced (59 and 41 observations for Pharma and BFs generated by nine and eight firms, respectively), severely affecting degrees of freedom and reliability of estimates. Therefore, Table 4 presents only random effects estimates.

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