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Technology transfer challenges in asymmetric alliances between high-technology and low-technology firms

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ABSTRACT

Low-technology firms face an increasingly disruptive innovation landscape as new legislation and changing market demands force them to dramatically reduce emission levels to become more sustainable. However, successfully developing and implementing sustainable technologies frequently presupposes alliances between low-technology firms (such as process industry companies) and high-tech firms (such as their specialized technology providers). Such alliances are asymmetric and problematic because of differences in approaches to learning, knowledge bases, collaboration routines, and high cognitive distance between high- and low-technology firms. Against this background, we performed a multiple case study of six asymmetric alliances operating in the food and food packaging sectors in the UK. The analysis reveals that technology distance asymmetry, technology integration complexity, and innovation capability incompatibilities prohibit technology transfer effectiveness. By mapping these themes across three phases of technology transfer, we identified a total of nine unique problems that hamper technology transfer effectiveness and, therefore, risk delaying or distorting the implementation of novel sustainable technology. The paper provides theoretical implications for the literature on innovation in LMT firms and for the literature on sustainability alliances along with practical implications for improving technology transfer between high-tech and low-tech firms considering climate change.

1. Introduction

The environmental crisis is quickly approaching a tipping point (IPCC, 2022). Low and medium technology[1] (LMT) firms, such as those in the process industries, are particularly at odds as they account for a large proportion of total greenhouse gas emissions (Hellsmark et al., 2016). Therefore, responding to climate change is of particular importance for LMT firms and doing so requires significant innovation in their technological base (Kamalaldin et al., 2021; Turnheim and Nykvist, 2019; Markard et al., 2012). For example, the food sector is the largest industrial sector in most countries and, hence, it is responsible for a significant environmental impact. Innovation can play an important role by reducing food and packaging waste and improving the sustainability of production (Simms et al., 2020; Trott and Simms, 2017).[2]

However, LMT firms face significant challenges in shifting to new technological regimes. Integrating new technologies into existing production systems is a challenge (Kuokkanen et al., 2018; Kemp et al., 1998). Path dependency and lock-in further inhibit the introduction of new technology (Hellsmark et al., 2016; Markard et al., 2012; Ahman and Nilsson, 2008). Together, these forces often lead to incremental sustainability improvements, which fail to address the radical advancement required (Markard et al., 2012). Indeed, LMT firms have been slow in improving sustainability (Hansen and Coenen, 2017; Hellsmark and Söderholm, 2017).

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[1] The typology of industrial sectors proposed by the OECD (Hatzichronoglou, 1997), distinguishes between four classes of firm: (i) high technology; (ii) medium-high technology; (iii) medium-low technology; and (iv) low technology. Low-technology firms are, hereafter, referred to with the abbreviation LMT (low and medium technology), which is commonly used in the innovation literature (Robertson et al., 2009; Trott and Simms, 2017).

[2] In the food sector, estimates suggest that between 15 % and 30 % of food is wasted, and the sector is responsible for approximately 19 million tons of plastic waste in Europe alone (see Simms et al., 2020). Food also accounts for around a quarter of global greenhouse gas emissions (Richie and Roser, 2021).

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To overcome these challenges, LMT firms frequently seek collaboration with high-tech firms. The linkages between high-tech and LMT industries are a key driver of growth and change (Pavitt, 1984). In the literature on innovation in LMT industries, the importance of externally generated knowledge, embodied technologies, and advanced manufacturing technologies originating from high tech industries is given a central role in product and process innovation (Fitjar and Rodríguez-Pose, 2013). Whilst supply chain collaborations are predominant (Tether, 2002; Hutcheson et al., 1995, 1996), alliances beyond a firm's existing supply chain with partners that possess unique and complementary scientific and technological knowledge are critical (Vega-Jurado et al., 2009; Faems et al., 2005).

Sustained innovation in LMT firms relies on continuous incorporation of new knowledge and embodied technologies originating from high-technology firms, and their subsequent adaptation to the requirements of existing products and production processes. When done successfully, the transfer and subsequent application of technology from high-tech firms into LMT firms has led to a number of radical innovations, including the growth of active and modified atmosphere packaging (to reduce food waste), novel replacements for single use plastics packaging, and production technologies that could reduce emissions drastically (see Ahvenainen, 2003; Dainelli et al., 2008; Wyrwa & Barska, 2017a & 2017b; Raconteur, 2018; Heldman et al., 2018).

We refer to collaboration between LMT and high-tech firms as alliances. Broadly defined, alliances are inter-organizational relationships where two or more organizations pool resources to achieve some common objective (Shipilov and Gawer, 2020). Alliances between low-technology firms and their high-technology partners are of particular importance in addressing the unfolding environmental crises (Söderholm et al., 2019). Technology transfer problems between high-tech and LMT firms often arise in such alliances (Lager and Frishammar, 2010).

Alliances between LMT and high-tech firms take place in contexts characterised by an underlying divergence in the nature of knowledge and in learning approaches (Grillitsch et al., 2019; Trott and Simms, 2017; Jensen et al., 2007a). In high-tech firms, the STI-based innovation mode dominates – namely, scientific and technologically based codified and analytical knowledge (Martin and Moodysson, 2013; Jensen et al., 2007a; Asheim et al., 2007). By contrast, LMT firms' knowledge is closer to the DUI mode – namely, learning by doing, by using, and by interacting, which gives first-hand knowledge that is synthetic, tacit, and applied – employing well-trained and experienced engineers to drive innovation (Parrilli and Heras, 2016; Asheim and Hansen, 2009; Jensen et al., 2007a). With these differences as the backdrop, we conceptualize high-tech to LMT firm alliances as *asymmetric* and define them as: "*Collaborations involving the transfer and application of technology originating from a high-technology firm, where the STI innovation mode is predominant, to a low-technology alliance partner, where the DUI innovation mode is predominant.*"

Prior research has illuminated different types of asymmetric alliance. However, each of these is different from the focus of the present study of alliances between high-tech and LMT firms, which involve firms with inherently distinct knowledge base types (STI versus DUI). Firstly, asymmetric alliances between small to large firms present problems that stem from a small firm's relative lack of accumulated knowledge, small budgets, and limited resources (e.g.,Madrid-Guijarro et al., 2009; Pihkala et al., 2002). Secondly, asymmetries in university-to-industry alliances reveal problems rooted in different institutional logics, objectives, attitudes, and cultures, but not necessarily knowledge base type or learning mode dissimilarities (e.g., Schartinger et al., 2001; Bruneel et al., 2010), such as when scientists in a university communicates with scientists in a high-tech firm. Finally, alliances at high cognitive distance (measured by industry code, such as a collaboration between a firm in the chemicals industry and a cosmetics firm) but not specifically involving the high-tech to LMT collaboration that we study, present problems resulting from a divergence in the specific content of scientific or technological knowledge involved (Enkel and Gassmann, 2010; Gilsing et al., 2008; Nooteboom et al., 2007). Yet, once again the inherent knowledge bases and learning modes may not necessarily be dissimilar. Hence, none of the aforementioned literatures are primarily concerned with the divergence in knowledge base type and learning mode (STI versus DUI) that is present in asymmetric alliances between LMT and high-tech industries (Jensen et al., 2007a; Thomä, 2017), which is the focus of the current study.

To be successful, asymmetric alliances presuppose effective technology transfer between high-tech and LMT firms (Heidenreich, 2009; Robertson et al., 2009). In fact, the sustained success of both types of industry is dependent on effective transfer of technology between them (Robertson et al., 2003; Robertson and Patel, 2007). Notably, studies have demonstrated the significance of combining different knowledge bases with innovation performance (Haus-Reve et al., 2019, 2023; Jensen et al., 2007a). In the case of our study, this requires combining different internal (DUI) and external (STI) knowledge bases for innovation. The significance of this further underpins the rationale of our study. To illustrate the potential importance of such types of technology transfer, whilst biotechnology applications were initially adopted by the pharmaceutical industry, greater payoffs were eventually achieved from their application in LMT firms (Robertson et al., 2009; Lipsey et al., 2005).

The phenomenon we are after – technology transfer through asymmetric alliances between LMT and high-tech firms – has mainly been discussed in two parallel literatures. First, the literature on innovation in LMT firms has underscored the significance of collaboration between LMT and high-tech firms and has called for a better understanding of the combination of internal–external engineering and utilization of different scientific knowledge bases (Haus-Reve et al., 2019; Grillitsch et al., 2019). To date, the combination of non-uniform knowledge bases in technology transfer (e.g., Helfat, 2015) has been scarcely researched (Manniche et al., 2017; Manniche, 2012; Asheim et al., 2017). Hence, whilst access to high-tech STI technology may exist, its transfer and successful implementation far from always follow (Alhusen and Bennat, 2021). We argue that these shortcomings in the literature have resulted in a lack of distinction between the different knowledge bases and the learning characteristics possessed by partners in asymmetric alliances and, specifically, how these differences influence technology transfer. Understanding technology transfer requires a perspective that moves beyond the pure proximity of firms' knowledge bases and R&D investments (Mendonça, 2009; Nooteboom et al., 2007). Thus, we respond to calls to concentrate on the problems associated with technology transfer between high-tech and LMT sectors, which result in comparatively slower rates of technological change in LMT industries (Robertson et al., 2009). Our primary contribution to the literature on innovation in LMT firms is, therefore, to uncover the combinative effects of different internal (DUI) and external (STI) knowledge (Haus-Reve et al., 2019; Grillitsch et al., 2019) and its implications for technology transfer, from a high-tech firm into an LMT firm.

Second, in the alliance literature, Lumineau and Oliveira (2018, p.440) suggested that studies still "…*overlook core features of interorganizational relationships*". Studies tend to assume single valence in relationships, meaning that most prior studies examine either a positive valence (e.g., cooperation) or a negative valence (e.g., conflict), which arguably ignores the inherent heterogeneity of high-tech and LMT collaboration. We seek to contribute to the alliance literature (Lumineau and Oliveira, 2018) and specifically to the emerging literature on environmental alliances (Niesten and Jolink, 2020). Environmental alliances are more complex than regular ones because they have both economic and environmental objectives (Niesten and Jolink, 2020). Such alliances tend to display much higher levels of partner heterogeneity and uncertainty (Stadtler and Lin, 2019; Meschi and Norheim-Hansen, 2020). Prior research into environmental alliances has laid an important foundation by describing different types (Wassmer et al.,

2014) as well as motives for or antecedents to engaging in such alliances (Niesten and Jolink, 2020; Stadtler and Lin, 2017). We contribute to the literature on alliances – and, in particular, environmental alliances – by studying positive valence (e.g., cooperation among actors) and negative valence (e.g., conflicts, problems, and challenges in technology transfer), enabling us to uncover the challenges in technology transfer over the different phases of asymmetric alliances.

This leads us to the following research question*: How do different types of inter-organizational dissimilarities between high-tech and LMT firms impact technology transfer in asymmetric alliances?* Adopting a multiple case study, our research presents an analysis of six asymmetric alliances where development and subsequent transfer of sustainable technology was at the forefront. By illuminating the specific problems that arise in LMT and high-tech firm collaboration, and by showing that these are phase specific, we add a contingency perspective to better manage technology transfer in such alliances. Our findings, therefore, move beyond solely identifying differences in each type of firm knowledge, approach to learning, or differences in collaboration routines to illustrate how these differences are manifested over the different phases of an asymmetric alliance.

The remainder of our paper proceeds as follows. Firstly, we review the literature to establish key sensitizing concepts to guide the analysis. The following chapter provides details on our case study, sampling, and data analysis. The results chapter presents our findings, followed by a discussion and analysis. Finally, we present our conclusions, implications, and recommendations for future research.

2. Theoretical background

2.1. Sustainable innovation in LMT industries

Achieving radical improvements in sustainability often requires firms to move outside their existing technological paradigm (Dosi, 1982; Castellacci, 2008) because incremental improvements to existing technologies and production systems will be insufficient (Van den Bergh et al., 2011). However, achieving more radical leaps in sustainable innovation is complex (Ekins, 2010; Kemp, 1994). Indeed, switching to a new technological paradigm requires new scientific knowledge, advances in engineering, and material technology. Often, digitalization is a driver of such sustainability in LMT sectors (Kamalaldin et al., 2021).

Moving to a new technological paradigm necessitates the mobilization of knowledge and capabilities from other value chains and industries (Jakobsen and Clausen, 2016; Mossberg et al., 2021). This brings about increased complexity and requires the active involvement of a more diverse range of actors in comparison to 'conventional' innovation (Cainelli et al., 2012; Horbach et al., 2012). Marzucchi and Montresor (2017) suggest that this implies a combination of STI and DUI based innovation modes. Yet, significant problems in combining these different modes across organizational boundaries exist. This is partly because sustainability problems are systemic in nature (Frishammar and Parida, 2019) and, therefore, require collaboration by organizations with diverging agendas, organizational logics, and cultures (Quélin et al., 2017). In practice, such collaboration materializes via technology transfer between the companies involved.

2.2. Technology transfer between high-tech and LMT firms

Innovation is an iterative process involving new combinations of components, processes, and ideas (Fleming, 2007). This combinatory logic highlights the importance of externally generated knowledge (Kogut and Zander, 1992). Indeed, collaborative innovation and subsequent transfer of technology are critical for breakthrough innovations and science plays a key role (Fleming, 2007) – for example, when pursuing so-called environmental alliances to replace incumbent dirty technology (Niesten and Jolink, 2015). Firms need to create new combinations of external and internal resources when engaging in this process, which is often challenged by its tacitness and complexity (Koruna, 2004; Kogut and Zander, 1992).

In studying LMT industries, prior research highlights the importance of both external (disembodied) technology and externally developed (embodied) technologies to sustained innovation, with technology from high-tech industries of growing importance (Fitjar and Rodríguez-Pose, 2013; Grimpe and Sofka, 2009; Heidenreich, 2009; Robertson et al., 2009; Santamaría et al., 2009). LMT firms are frequent users of external engineering and scientific knowledge (Hirsch-Kreinsen et al., 2003). This external STI knowledge compensates for internal R&D shortages (Hirsch-Kreinsen et al., 2006; Maskell, 2004; Heidenreich, 2009). Thus, external knowledge inflows contribute to developing the internal knowledge base (Hirsch-Kreinsen et al., 2003; Hansen and Serin, 1997). Hence, the combination of different internal–external knowledge bases is recognised as a potential driver of innovation (Haus-Reve et al., 2019, 2022; Jensen et al., 2007a), but studies are yet to examine this at the alliance level. However, the benefits of doing so are not automatic. For example, the findings of Haus-Reve et al. (2019) highlight that firms involved in supply chain collaboration may experience problems in benefitting from engagement with scientific partners. The different forms of HT and LMT alliances are visualized in Fig. 1, where the current study focuses on the asymmetric alliances in the upper left quadrant.

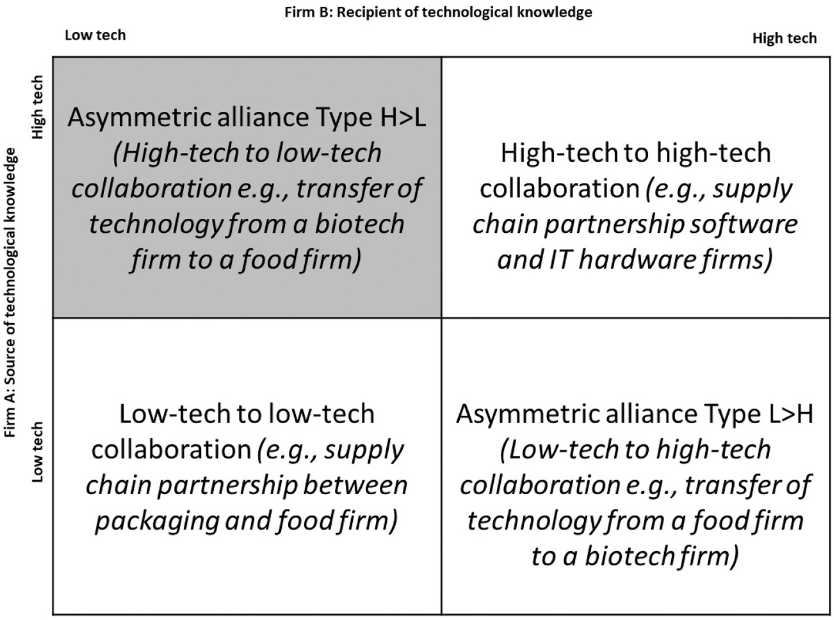
Technology is used in idiosyncratic ways (Mendonça, 2009; Garibaldo and Jacobson, 2005), so it must be tailored to recipients' specific requirements (Metcalfe, 1988; Rosenberg, 1976; Robertson and Patel, 2007). This presupposes effective technology transfer. However, despite the best of intentions, transfer is often challenging. To provide a conceptual background to the potential problems and challenges faced in asymmetric alliances between LMT and high-tech firms, our literature review is grounded in two complementary literatures. Firstly, building on Haus-Reve et al. (2019) and others, we identify differences in the *learning and knowledge building approaches* and *knowledge base characteristics* of high-tech and LMT firms. This literature highlights the different knowledge bases that predominate and the mode of innovation in high-tech and LMT firms (Fitjar and Rodríguez-Pose, 2013; Parrilli and Heras, 2016). Therefore, it helps shed light on potential technology transfer problems and challenges. Whilst this literature identifies factual differences in each firm type, it does not go as far as to uncover how these influence actual collaboration in asymmetric alliances. Therefore, we review a second area of literature centering on dissimilarities in alliances, via the concepts of *high cognitive distance* and problems in *cooperation and sequencing.*

2.3. Dissimilarities in learning and knowledge building approaches and knowledge bases

Due to differences in knowledge bases and approaches to learning, asymmetric alliances between high-tech and LMT firms present important challenges (Grillitsch et al., 2019; Jensen et al., 2007a; Fleming, 2001). Our review of prior studies on innovation in LMT firms, including the literature on STI and DUI knowledge bases and combinatorial knowledge dynamics, enabled us to outline two key dimensions of difference (see Table 1).

The first dimension distinguishes between the different *learning and knowledge building approaches* of high-tech and LMT firms. In high-tech firms, the scientific and technology innovation mode (STI), embedded in formal R&D, is more pronounced (Jensen et al., 2007b). Making knowledge explicit and converting it to codified form is central to the STI mode, with formal learning of scientific and technological principles of fundamental importance (Thomä, 2017). Therefore, partners must possess relevant capabilities to understand the associated prior scientific research and technological principles, methods, and language. If not, technology transfer effectiveness will suffer.

In contrast, the DUI mode is more pronounced in LMT firms (Jensen et al., 2007a; Thomä, 2017). Here, the creation and use of tacit knowledge and know-how is central. This "techne" knowledge is highly



		Firm B: Recipient of technological knowledge	
		Low tech	High tech
Firm A: Source of technological knowledge	High tech	Asymmetric alliance Type H>L *(High-tech to low-tech collaboration e.g., transfer of technology from a biotech firm to a food firm)*	High-tech to high-tech collaboration *(e.g., supply chain partnership software and IT hardware firms)*
	Low tech	Low-tech to low-tech collaboration *(e.g., supply chain partnership between packaging and food firm)*	Asymmetric alliance Type L>H *(Low-tech to high-tech collaboration e.g., transfer of technology from a food firm to a biotech firm)*

Fig. 1. Conceptualisation of two types of supply chain alliances and two types of asymmetric alliances (grey box dictates the type of alliance studied in this paper).

context specific and strongly related to practice (Johnson et al., 2002; Simon, 1969). Experienced-based learning, which occurs "on the job" through doing, using, and personal interaction, is central (Lundvall and Borrás, 2005). The emphasis of the DUI mode is on solving concrete problems with specific applications (Grillitsch et al., 2019). This knowledge base, combined with limited internal R&D, often leads to an emphasis on incremental innovation (Hervas-Oliver et al., 2015; Parrilli and Heras, 2016; Manniche, 2012; Asheim et al., 2017).

Whilst fundamental differences exist between high-tech and LMT firms, and their associated innovation modes (STI vs. DUI), we do not claim they are perfectly dichotomous in nature (Alhusen and Bennat, 2021). Indeed, the STI and DUI learning modes should be viewed as *ideal types*, with firms having some degree of each (Thomä, 2017). For example, high-tech firms also draw on DUI for their long-term success (Santamaría et al., 2009). Likewise, some LMT firms spend relatively more on R&D as a percentage of turnover, which brings them closer to the STI mode (e.g., Thomä, 2017). However, there is a trade-off between investing in one type of activity or the other (Haus-Reve et al., 2019 & 2022). This is particularly pertinent to LMT firms, with their limited resources for innovation. Moreover, some recent studies have begun to distinguish between internal and external DUI – for example, emphasising the difference between internal and external "learning by interacting" (Alhusen et al., 2021; Haus-Reve et al., 2023). So, not all DUI activities need be within the internal boundaries of a LMT firm. But that said, when entering asymmetric alliances, we argue that the inherent differences in firms' knowledge bases and learning styles present clear challenges to technology transfer.

A second dimension relates to the inherent *knowledge base characteristics* embedded in high-tech and LMT firms. External knowledge reflects the context from which it was created and transmitted, which is frequently different to that in which it is received (Robertson, 1998; Morone and Taylor, 2010). Consequently, the way a firm builds knowledge will have a direct influence on its resulting knowledge base (e.g., Alhusen et al., 2021; Jensen et al., 2007a). The pronounced "stickiness" of context-specific knowledge and engineering expertise in LMT firms may pose a challenge in technology transfer with high-tech partners. The STI knowledge that is more dominant in high-tech firms is typically codified and tends to be more independent (e.g., Asheim and Hansen, 2009; Martin and Moodysson, 2013; Gilsing et al., 2011). Yet, the disembodied and embodied STI knowledge coming from HT firms frequently does not arrive in immediately usable form, with integration into LMT firms requiring it to mesh with existing and new product and production technologies that are largely tacit, context specific, and strongly related to on-site practice (Robertson et al., 2009; Pavel and Pavitt, 1987; Rosenberg, 1963). Hence, knowledge does not stand alone and is often intertwined (Gilsing et al., 2011). The nature of the systemic change may add to the complexity within the technology transfer process.

2.4. *Dissimilarities in cognitive distance and cooperation and sequencing*

The literature on high-tech and LMT firms does not in itself provide a sufficient theoretical lens through which to examine problems in technology transfer via asymmetric alliances. It identifies differences in firms, but only alludes to these as potential sources of problems in technology transfer. Therefore, we draw upon studies of innovation at high cognitive distance and alliances involving firms with dissimilarities in cooperation and sequencing. This literature can be viewed against a backdrop of absorptive capacity studies that underscore the cumulative nature of knowledge absorption based on prior learning, which influences the ability to understand new related knowledge. Similarities in partner skills, knowledge and technologies, and cognitive structures have been found to influence success (Lane and Lubatkin, 1998; Lane et al., 2006; Azadegan and Dooley, 2010). It seems reasonable to assume that the inherent LMT/high-tech firm differences regarding DUI and STI knowledge-building approaches and knowledge bases can cause high cognitive distance as well as significant differences in cooperation and sequencing (though the prior literature is largely tacit on this).

Firstly, a stream of studies in the alliance literature examining cross-industry collaboration highlights the implications of cognitive distance for collaboration. Cognitive proximity is typically based on similar technological knowledge or closely related industry-standard classifications (Enkel and Gassmann, 2010; Gilsing et al., 2008; Nooteboom et al., 2007), and distance is, therefore, the conceptual opposite. Studies here highlight the importance of alliance partners with whom firms would not usually collaborate (Granovetter, 1973), particularly for exploratory innovation (Enkel and Heil, 2014; Enkel and Gassmann, 2010; Gassmann et al., 2010). Few studies have examined innovation at high cognitive distance, which underscores the need for further research (Enkel et al., 2018; Dingler and Enkel, 2016; Enkel and Heil, 2014; Enkel

Table 1
Learning and knowledge building approaches and knowledge base characteristics of high-tech and LMT firms.

	Characteristics	LMT firms	High-tech firms
i) Learning and knowledge building approach	*R&D intensity*	R&D expenditures typically less than 2 % or 2.5 % of sales depending on criteria applied (see Legler and Frietsch, 2007; Kirner et al., 2009; Galindo-Rueda and Verger, 2016)	R&D expenditures often over 5 % of sales (Legler and Frietsch, 2007; Kirner et al., 2009; Galindo-Rueda and Verger, 2016)
	External knowledge acquisition patterns	Search patterns primarily within the supply chain (Grimpe and Sofka, 2009)	Search patterns engage with basic science and technological knowledge bases (Grimpe and Sofka, 2009)
	Type of knowledge workers	Innovation primarily driven by DUI and non-R&D workers and well-trained engineers; from university or engineering colleges and with extensive on-the-job training (Heidenreich, 2009; Lee and Walsh, 2016; Grillitsch et al., 2019)	Innovation primarily driven by R&D workers, scientists, and technologists with high levels of academic and scientific training (e.g., Heidenreich, 2009; Lee and Walsh, 2016; Miörner et al., 2018; Grillitsch et al., 2019)
	Learning orientation for R&D and innovation	R&D inappropriate innovation measure, firms possess limited or no independent R&D capacities. Innovation primarily driven by doing, using, and interacting (Hirsch-Kreinsen, 2008; Jensen et al., 2007a)	R&D appropriate measure of innovative activity, with innovation primarily driven by Science and Technology (STI) logic (Jensen et al., 2007a; Hirsch-Kreinsen, 2008; Manniche, 2012)
	Processes of knowledge and technology creation	Context specific learning and practice related, involving the creation of practical solutions through doing, using, and interacting (Manniche, 2012). Largely inductive processes, through observation of specific incidents and problem solving (Manniche, 2012; Asheim and Hansen, 2009; Manniche and Testa, 2010)	Generation based on cognitive and rational processes, through the application of methods and formal models; through scientific principles and technology (Manniche, 2012). Deductive processes, based on formal models, generalisation, and codification (Manniche, 2012; Asheim and Hansen, 2009; Manniche and Testa, 2010)
	Origins of technology and knowledge for innovation	Application or novel combination of existing knowledge and technologies (Dougherty, 2004; Asheim and Coenen, 2006; Manniche, 2012)	Creation of new knowledge and technologies (Asheim and Coenen, 2006)
ii) Knowledge base characteristics	*Dominant knowledge type*	Implicit and tacit knowledge and practical skills (Asheim and Coenen, 2006; Cowan et al., 2001; Johnson et al., 2002; Jensen et al., 2007a; Parilli & Heras, 2014)	-Codified and explicit knowledge, codifiable, in patents and publication (Parilli & Heras, 2014; Cowan et al., 2001; Johnson et al., 2002; Jensen et al., 2007a; Parrilli and Heras, 2016; Asheim and Coenen, 2006) -Analytical knowledge (science-based) knowledge base (Laestadius, 1998; Asheim and Hansen, 2009; Asheim and Gertler, 2005)
		Synthetic knowledge (experience based) base (Laestadius, 1998; Asheim and Hansen, 2009; Asheim and Gertler, 2005) Applied knowledge (Marsili, 2001), “know how” and “know who” (Jensen et al., 2007a; Lundvall and Johnson, 1994)	-Basic and applied knowledge (Marsili, 2001), ‘Know what’ and ‘know why’ (Jensen et al., 2007a; Lundvall and Johnson, 1994)
	Location of knowledge	More tied to space/place, resulting in more geographically confined collaboration (e.g., Asheim and Hansen, 2009).	Localisation and geographical distance of limited importance (e.g., Asheim and Hansen, 2009; Martin and Moodysson, 2013)
	Differentiation of technological and knowledge base	Systemic and interdependent knowledge, with new knowledge embedded in existing systems and forming part of a larger system of integrated knowledge often stemming from different disciplines (see Gilsing et al., 2011; Asheim and Hansen, 2009; Robertson et al., 2009)	Stand-alone, relatively independent pieces of knowledge (see Asheim and Hansen, 2009; Martin and Moodysson, 2013; Gilsing et al., 2011)
Primary innovation outputs		Primarily incremental improvements to products and processes (Thomä, 2017)	Radical innovation more common and the novelty of products is often high (Thomä, 2017)

and Gassmann, 2010). However, extant studies have identified some of the challenges presented by high cognitive distance, which creates problems in utilising external knowledge (Gilsing et al., 2008; Nooteboom et al., 2007). Broadly, higher distance increases the levels of uncertainty, ambiguity, and complexity (Enkel and Heil, 2014; Datta and Jessup, 2013; Nooteboom et al., 2007).

Collaborative innovation at high cognitive distance is also challenged by the development of new competencies, and learning is slow and costly (Buckley et al., 2009; Gilsing et al., 2008; Nooteboom et al., 2007). Technology transfer is dependent on both partners' ability to express and learn new knowledge (Buckley et al., 2009; Dhanaraj et al., 2004; Håkanson and Nobel, 2000). Prior research focuses on the challenges stemming from distance, based on differences in technological knowledge. In our study, we argue that such differences could be compounded by a more fundamental divergence in the type of knowledge base possessed by each firm (e.g., DUI vs. STI). In other words, knowledge base characteristics have an influence on cognitive distance and, thus, challenge transfer and joint learning. For example, as recipients of STI knowledge from a high-tech firm, the embedded tacit knowledge base and systems of LMT firms are likely to heighten challenges, resulting in lengthy periods of learning to understand how to apply new technology (de Solla Price, 1984; Semmelweis and Murphy, 1981). Likewise, difficulties are often experienced in understanding why a technology does not work in production (Bonnin Roca et al., 2017). Innovators struggle to model production conditions in laboratory experiments (Pisano, 1996) and problems must be overcome through “learning by trying” (Fleck, 1994) or “learning by doing” (Arrow, 1962).

Secondly, in the alliance literature, a further stream of studies highlights a fourth dimension of dissimilarity – that of *coordination and sequencing* – further elucidating the problems faced (Estrada et al., 2016; Gulati et al., 2012). Underpinning the challenges depicted in this literature is that alliance management activities are contingent on the particular phase in the alliance life cycle (e.g., Das and Teng, 2002). Studies have highlighted that challenges often arise from differences in routines and orientations between partners, which leads to problems in managing new partnerships due to a lack of familiarity with goals, expectations, and routines (Doz, 1996; Inkpen and Currall, 2004). Routine dissimilarities imply differences in how an alliance should be conducted, whereas orientation dissimilarities reflect the rationale or scope of the alliance (Estrada et al., 2016). Therefore, differences in the learning styles and knowledge building approaches of each type of firm will result in challenges in coordination and sequencing. Such differences have been found to inhibit alliance development and the ability of each partner to effectively learn, coordinate, and cooperate (Weber and Mayer, 2014; Lavie et al., 2012; Lioukas and Reuer, 2015). This creates problems in coordinating efforts and sequencing collaborative activities and learning (Wilkof et al., 1995; Gulati et al., 2012; Zollo et al., 2002). Critically, differences can result in interpretive conflicts, differences in the interpretation of events, diverging assumptions, and the lack of a shared vision (Weber and Mayer, 2014; Barnett, 2008; Smith and Barclay, 1997). However, extant studies of these dissimilarities provide limited insights into the evolution of an alliance (see Estrada et al., 2016). Furthermore, prior studies have not addressed high-tech to LMT collaboration and the influence of their dissimilar innovation modes.

2.5. Conceptual framework

Whilst extant studies provide relevant insights into how dissimilarities between alliance partners influence technology transfer and the potential outcomes that may result, they fail to explain the specific problems in technology transfer between high-tech and LMT firms. More empirical studies are required in this area (e.g., Robertson et al., 2009).

Fig. 2 constitutes the research framework and is an attempt to visualize our theorizing. The framework captures the critical inter-organisational differences between high-tech and LMT firms that our study is concerned with. Firstly, the figure pinpoints the dissimilarities between high-tech and LMT firms in two respects: i) their approaches to learning and knowledge building, and ii) the characteristics of their knowledge bases (STI vs. DUI). Secondly, the figure identifies how these are intertwined with the dissimilarities regarding iii) cognitive distance, resulting largely from differences in knowledge bases, and (iv) cooperation and sequencing, resulting largely from differences in learning and knowledge building approaches. Finally, it conveys that external technology (embodied or disembodied), originating in a HT firm over time, is transferred to a LMT firm and subsequently combined with existing technology and production systems (T-0 to T-1).

We utilise these four related dimensions as sensitizing concepts to guide our empirical investigation and subsequent analysis. That is to say, they provide a conceptual foundation and a direction of where to look for the specific types of dissimilarities or problems that arise in asymmetric alliances between high-tech and LMT firms. It seems inherent in the literature on LMT firms that significant knowledge base and learning differences would result in cognitive distance and differences in cooperation and sequencing, yet how these inter-organizational differences play out in asymmetric alliances has not been examined by empirical studies. The next chapter describes the methods deployed for doing so.

3. Methods

3.1. Empirical setting: sustainable innovation in the food packaging sector

We selected the food packaging sector based on its economic and environmental significance across both developed and developing countries (Simms et al., 2020; Trott and Simms, 2017; Notarnicola et al., 2012). In the food packaging sector, improvements in sustainability require innovation in a variety of different domains, including traceability, emission control, logistics, production and processing, lifecycle assessment, waste management, and packaging (Herrero et al., 2020; Li et al., 2014). Alliances between firms help address such challenges (Arcese et al., 2015) – for example, in emerging science and engineering fields, such as ICT, smart materials, and biotechnology – by the blending of new and old technological capabilities (Mendonça, 2009; Robertson and Patel, 2007). Such technologies, which emanate from high-tech firms, are critical in solving environmental problems (Söderholm et al., 2019). Furthermore, whilst new technologies and innovation can speed up transitions (Herrero et al., 2020), challenges stemming from low levels of investments in R&D, low margins, technological lock-in, and deficient supply chain integration prevail (Simms et al., 2020; Trott and Simms, 2017).

3.2. Research strategy and sampling

Our paper adopted a multiple case study approach (Edmondson and McManus, 2007; Eisenhardt, 1989). The research process was non-linear with data collection and analysis overlapping (Eisenhardt, 1989, 2021). Our rationale for adopting the multiple case study approach was twofold. Firstly, it allowed us to answer "how" questions involving complex and contemporary events (Eisenhardt, 1989; Yin, 2003; Dodgson et al., 2008), of which technology transfer between high-tech and LMT firms is an example (Aaboen et al., 2012). Secondly, it allowed a theory-guided yet open-ended inquiry into a phenomenon still in its nascent

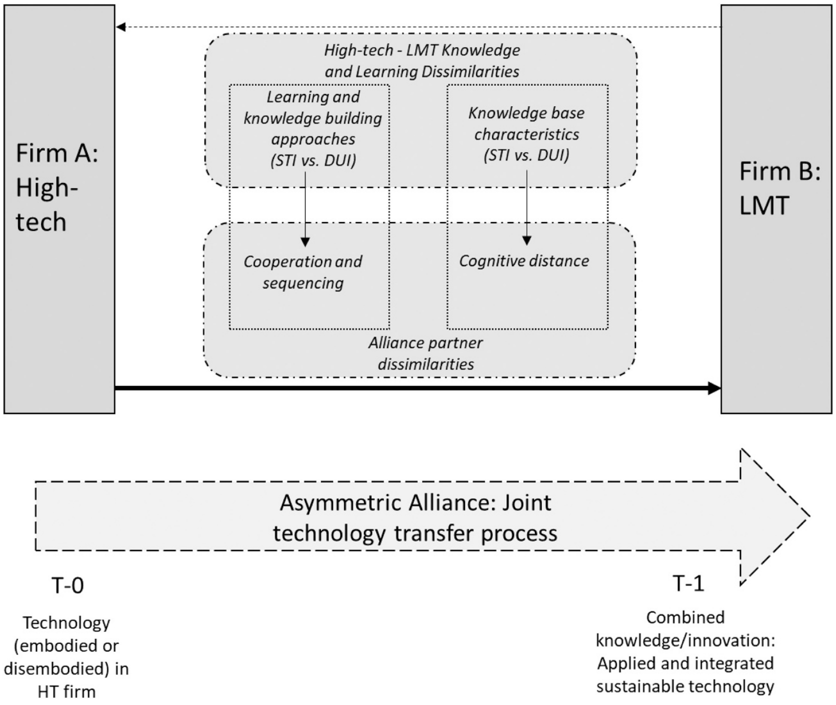


Fig. 2. Sensitizing concepts and key inter-organizational differences in asymmetric alliances between LMT and high-tech firms influencing joint technology transfer.

Table 2
Summary of Cases, Interviewees, and Sustainability Impact of Each Case.

	A: Coating to decrease water and oil permeability *02/2016–01/2022* *(version 1 completed, ongoing development for expanded applications)*	B: Coating to create oxygen barrier *04/2016–10/2011* *(version 1 completed, ongoing development for expanded applications)*	C: Printed electronics *01/2011–09/2018*	D: Microwave technology for baked goods *03/2011–09/2018*	E: Recyclable plastic film with high barrier properties *01/2018–11/2022*	F: Metal packaging with unique scannable code on underside of table *05/2010–02/2019*
Overview of Case Firm Core Knowledge Base (Knowledge Recipient)	Top 4 International paperboard and cardboard packaging manufacturer and processor with knowledge in printing and ink application.			Top 15 European food processor with knowledge in specialist baking and mixing.	Top 10 International plastics packaging manufacturer with expertise in processing laminated plastics.	Top 4 International metal packaging manufacturer with knowledge in coatings and printing.
Summary of case study	*Aim:* Printable coating made from natural inks that can be directly applied onto existing board materials as a surface coating to decrease water and oil permeability, enabling paper-based packaging to be used on liquid products and those that contain or excrete liquids or oils. *Project constraints:* To be delivered with little or no added unit cost. Preferably with minimal changes to existing production equipment, but with possibility of new production line to deliver project. If new CAPEX required, need for investments to also support Alliance Project B. *Intended applications:* paperboard and paper.	*Aim:* Printable coating made from natural inks that can be applied directly onto existing board materials as a surface coating to provide an oxygen barrier and thus create a packaging format for products that require protection from oxygen in order to maintain shelf stability. *Project constraints:* To be delivered with little or no added unit cost. Preferably with minimal changes to existing production equipment, but with possibility of new production line to deliver project. If new CAPEX required, need for investments to also support Alliance Project A. *Intended applications:* paperboard and paper.	*Aim:* Smart packaging for consumer interactivity by using printed electronics on the packaging, providing consumers with ready access to information, whilst also ensuring the packaging remains recyclable. *Project constraints:* To be delivered with little or no added unit cost with minimal changes to, or investments in, the production line. *Intended applications:* paperboard and carboard.	*Aim:* To utilise microwave cooking technologies within an existing production line context to improve the final product quality and consistency, whilst reducing the energy requirements of the baking process. *Project constraints:* To be integrated into an existing production line, with microwave module to be inserted within a hot oven and thus having to withstand high temperatures. *Intended applications:* Baked goods.	*Aim:* To remove nylon from a novel 11-layer extruded plastic film to enable the film to be recyclable, whilst maintaining high barrier properties. *Project constraints:* To utilise a newly installed innovative production line. *Intended applications:* plastics packaging for food and pharmaceuticals applications.	*Aim:* Development of unique printable QR and data matrix codes. Unique laser marked code printed on underside of the tab on a beverage can to be read by phone-camera scanning. *Project constraints:* Need to apply the unique laser imprint to the packaging and check/read the imprint at production line speed.
High-tech partners involved in each collaboration (Key knowledge Donor)	Eight firms initially involved to explore the potential to adapt existing technologies to the project's requirements, later narrowed down to a single partner.	Five firms initially involved to explore the potential to adapt existing technologies to the project's requirements, later narrowed down to a single partner.	Specialist printer of circuit boards across a number of electronics sectors (e.g., toys, cars, industrial equipment).	Electronics and microwave technology supplier.	Specialist plastics resin manufacturer/supplier.	Three laser beam manufacturers initially (ultimately reducing to one), laser technology research institute, specialist consultancy firm/IT (app) developer.
Firm Interviewees (LMT knowledge recipient)	[I1] VP Innovation Europe (4), [I2] VP Innovation Group, [I3] R&D Manager UK (3), [I4] R&D Executive Group, [I5] Head of Production Operations UK, [I6] Production Line Manager Site I, [I7] Technical Production Manager UK Site i, [I8] Production Line Manager UK Site ii, [I9] Head of Operations UK, [I10] R&D Technician (Coating and Inks Specialist)			[D1] Production line engineer, [D2] R&D manager (UK) (2)	[E1] New product development manager (4), [E2] Head of new product development, [E3] Production line manager.	[F1] Breakthrough innovation manager (2), [F2] New product development manager, [F3] Site production manager.
Archival Resources	Initial project brief (all projects), 10 selected key internal presentations (projects A & B), project reports (all projects, total eight).			Initial project brief, 7 annual internal progress presentations, five key project reports.	Initial project brief, 8 bi-annual internal presentations, four project reports.	Initial project brief, production reports, 9 annual internal presentations.
Case Alliance High-tech Partner interviewees	[I11] R&D Technician Chemical Supplier A (2), [I12] Scientist Chemical Supplier B, [I13] UK Head of R&D Chemical Supplier B.	[I14] R&D Technician Chemical Supplier C, [I15] Scientist Chemical Supplier C, [I16] Head of R&D Chemical Supplier D.	[I17] R&D Manager Electronics Firm E, [I18] Product Developer Electronics Firm E.	[D3] Founder/director of advanced manufacturing technology consultancy and engineer, [D4] Consultant/engineer from advanced manufacturing technology consultancy, [D5] R&D Manager microwave technology supplier.	[E4] Chemical resin manufacturer R&D technician (3).	[F4] Sales agent from laser supplier (2). [F5] Technical consultant on integration/app development.
Sustainability alliance aim[a]	-Alternative to single use plastics bottles/	-Replacing single use plastic bags for cereals	-Providing information through	-Use of less energy in manufacturing	Enable high barrier plastics flexible	Providing information through printed codes

(continued on next page)

Table 2 (*continued*)

	A: Coating to decrease water and oil permeability *02/2016–01/2022* *(version 1 completed, ongoing development for expanded applications)*	B: Coating to create oxygen barrier *04/2016–10/2011* *(version 1 completed, ongoing development for expanded applications)*	C: Printed electronics *01/2011–09/2018*	D: Microwave technology for baked goods *03/2011–09/2018*	E: Recyclable plastic film with high barrier properties *01/2018–11/2022*	F: Metal packaging with unique scannable code on underside of table *05/2010–02/2019*
	bags. -Enabling recyclability of low- or non-permeability packaging through removing the requirement for multiple layers of materials. -Natural materials ensure sustainability.	and potato crisps with a coated paper bag that is 100 % recyclable or compostable.	printed electronics that instructs consumers on the recycling of paperboard packaging. -Enabling printing of electronic circuits onto paperboard whilst maintaining recyclability.	processes for baked goods.	packaging films to be recycled through removal of nylon layers from extruded 11-layer film.	that encourage recycling and link this to user competitions and/or rewards schemes. Ensuring packaging remains recyclable whilst inserting printed code.

[a] Classified based on Ellen MacArthur Foundation Circular Economy Framework (Ellen MacArthur, 2013, p. 24).

stage (Edmondson and McManus, 2007).

We sampled six asymmetric alliances between LMT food and food packaging firms and partners from high-tech industries (see Table 2). Five cases were from packaging firms, whereas one case was from a firm producing packaged foods. The sample was constructed by deploying the typology of industrial sectors (Hatzichronoglou, 1997). We followed Heidenreich (2009) to distinguish between "higher technology" (incorporating high and medium-high) and "lower technology" (incorporating medium-low and low) industries. Prior studies demonstrate that the STI and DUI modes of innovation are predominant in higher and lower technology companies, based on both industry classification and each company's R&D spending (e.g., Heidenreich, 2009; Hatzichronoglou, 1997). To create alignment between our theorizing and data, for each firm in each alliance, we checked that spending on R&D was consistent with the definitions of an LMT firm and a high-tech firm, which it was. Moreover, we paid close attention to the nature of activities conducted in each type of firm. Here, the second-order themes identified in our data collection within each firm were consistent with activities that could be classified as STI and DUI. To control for extraneous variation, our theoretical sampling (Eisenhardt, 1989) deployed the following sampling criteria: i) each case was an asymmetric alliance between a high-tech and LMT firm where all LMT firms were from similar types of supply chain; ii) all cases had a clearly defined project scope to transfer a novel technology; iii) each "sender" of technology was a high-tech firm outside the existing supply chain of the focal LMT firm; and iv) each case involved the development of an innovative solution where sustainability was a central objective.

All six alliances were completed, but two of them had generated "spun-off" activities where additional application areas for project results and technology were explored (see Table 2). By sampling completed alliances, respondents were able to retrospectively reflect on events and problems that unfolded. Whilst each of the cases differed in their individual timing and duration, the overall timeline of the data collection extended over a period of seven years (see Table 2).

3.3. *Data collection*

We conducted 43 interviews in the six alliances, which ranged from one to three hours each. Protocols were created (see Appendix 1) to properly document the findings, and these were subsequently adapted for each case and interview (Yin, 2009). Our initial discussions with senior managers, and the interviews that followed, helped to identify the key informants pertinent to each alliance (Miles and Huberman, 1994). We triangulated the interview data with observations from meetings, documentary data (such as project schedules), written reports and briefs, and minutes taken during project meetings (Yin, 2009) (see Table 2). Thus, we followed the principles of triangulation (Eisenhardt, 1989; Yin, 2003) where data from archival sources informed the primary data collection, such as identifying areas for additional probing questions, comparing insights, and checking accuracy. For example, by comparing, we were able to identify and clarify differences in the unfolding of events as described by our informants. Our access to the case firms enabled us to observe each alliance as it unfolded, including the problems that aired in the collaboration process (McDonald, 2005; Schultze, 2000). Triangulation enabled us, therefore, to validate the interview data gathered and, in doing so, minimise the risk of potential biases or inaccuracies in the recalling of events (Maxwell, 1996).

3.4. *Data analysis*

We utilised each of the dimensions identified in our conceptual framework (Fig. 2) as sensitizing concepts, which helped us to focus the data analysis and give it direction (Blumer, 1954). This made the analysis theoretical (Braun and Clarke, 2006) in so far as the research question was pre-defined and the sensitizing concepts were used to shed light on it. That said, data collection and analysis overlapped along with repetitive reading of the literature (Eisenhardt, 1989; 2021). To mitigate position bias, and to remain open to ideas emerging from the data, the analysis was undertaken by two researchers.

Data analysis followed the principles proposed by Braun and Clarke (2006). Firstly, the recorded interviews were transcribed and read repeatedly, which assisted familiarisation, and a list of initial ideas were documented. An example of an idea was that technical and engineering knowledge seemed vastly different from scientific knowledge. Secondly, utilising the sensitizing concepts, we generated initial codes from the preliminary patterns in the data. The codes characterised the problems observed in the studied alliances resulting from both the differences between type of firm and the LMT context itself. For example, causal ambiguity of LMT firm production processes frequently frustrated their HT partners but was not at all perceived as problematic by LMT workers. In contrast, limited access to pilot testing and using equipment complicated technology transfer, which seems to be rooted directly in the LMT context (rather than in inter-firm differences). The development of these initial codes supported the organisation of subsequent data, whilst allowing the identification of new codes as they emerged.

Thirdly, initial codes were clustered into categories, and drafts were developed to uncover how the categories related to theoretical themes. For example, multiple codes centred on differences in thought worlds and cognitive schemas of HT and LMT workers. This was first labelled "Cognitive differences among groups of employees" and later revised to "Representational gaps between scientists and engineers", which more accurately described its contents. At this point, patterns began to emerge with respect to both the problems identified and how these materialized across three key identified phases in the technology transfer process. In this coding process, we uncovered the specific relationships between those sensitizing concepts relating to knowledge and learning dissimilarities and those relating to alliance partner dissimilarities – for example, the linkages between the knowledge base of the firm and how this played out in specific problems related to cognitive distance.

With respect to the three phases, across each case, we identified commonalities in the presence of an (early) initial planning and exploratory phase of the alliance, a subsequent (mid) joint development and testing phase, and finally (late) attempts to understand how to embed and deploy the developed technology in the context of the firm, and particularly the production line. Hence, we utilised these phases to map the problems uncovered. The three phases broadly align with the alliance formation literature (Kale and Singh, 2007). This literature reveals that alliances are initially formed, with partners focusing on establishing the required technologies, aligning goals, and assuring complementarity and fit (Ireland et al., 2002; Spekman et al., 1998a). Following this, each party adheres to their defined responsibilities, with governance being critical alongside the mutual management of expectations (Gulati et al., 2012; Contractor and Reuer, 2014). Finally, relationships between partners must be actively managed, with trust and conflict management at the forefront as each firm attempts to complement and reinforce one another to deliver desired outcomes (Brattström and Faems, 2020; Doz, 1996). Moreover, the phases we identify are consistent with definitions of innovation that emphasise key activities in technology transfer (e.g., Zawislak et al., 2012).

Through the process of elaborating the meaning, differences, and similarities between individual codes and categories, a draft thematic map was created (i.e., a visual representation of the data structure in different hierarchical levels). The thematic map was completed in two steps – firstly, with a subset of the data and, subsequently, with the complete data set to ensure validity and completeness. The map identified three main types of dissimilarity in the alliances. These were mapped across the three phases of technology transfer that were identified. Finally, we further improved the thematic map to ensure it was clearly defined and coherent. A key task was to assure that themes worked in relation to coded extracts. Another key task was rephrasing codes and removing ambiguous codes or any overlap in identified concepts. For example, "Variance in the rate at which innovation teams can respond to development requirements" is an example of a code that was removed as it overlapped with other similar codes. We also worked to assure that the names of themes were clear, and that the overall story of the analysis was consistent.

4. Results

Fig. 3 provides a visual overview of the data structure. The three overarching themes are used to structure the results section. Tables 3 to 5 provide representative quotations in support of Fig. 3, whilst power quotations are provided in the text.

The joint contributions of both the high-tech and LMT firms were central to the success of each alliance. Yet, the firms experienced multiple problems during collaboration because of their inherent dissimilarities. Our analysis led us to classify these dissimilarities into three main dimensions: i) technology distance asymmetry, ii) technology integration complexity, and iii) innovation capability incompatibilities. We subsequently uncovered and linked these to the three main phases of the high-tech to LMT technology transfer process.

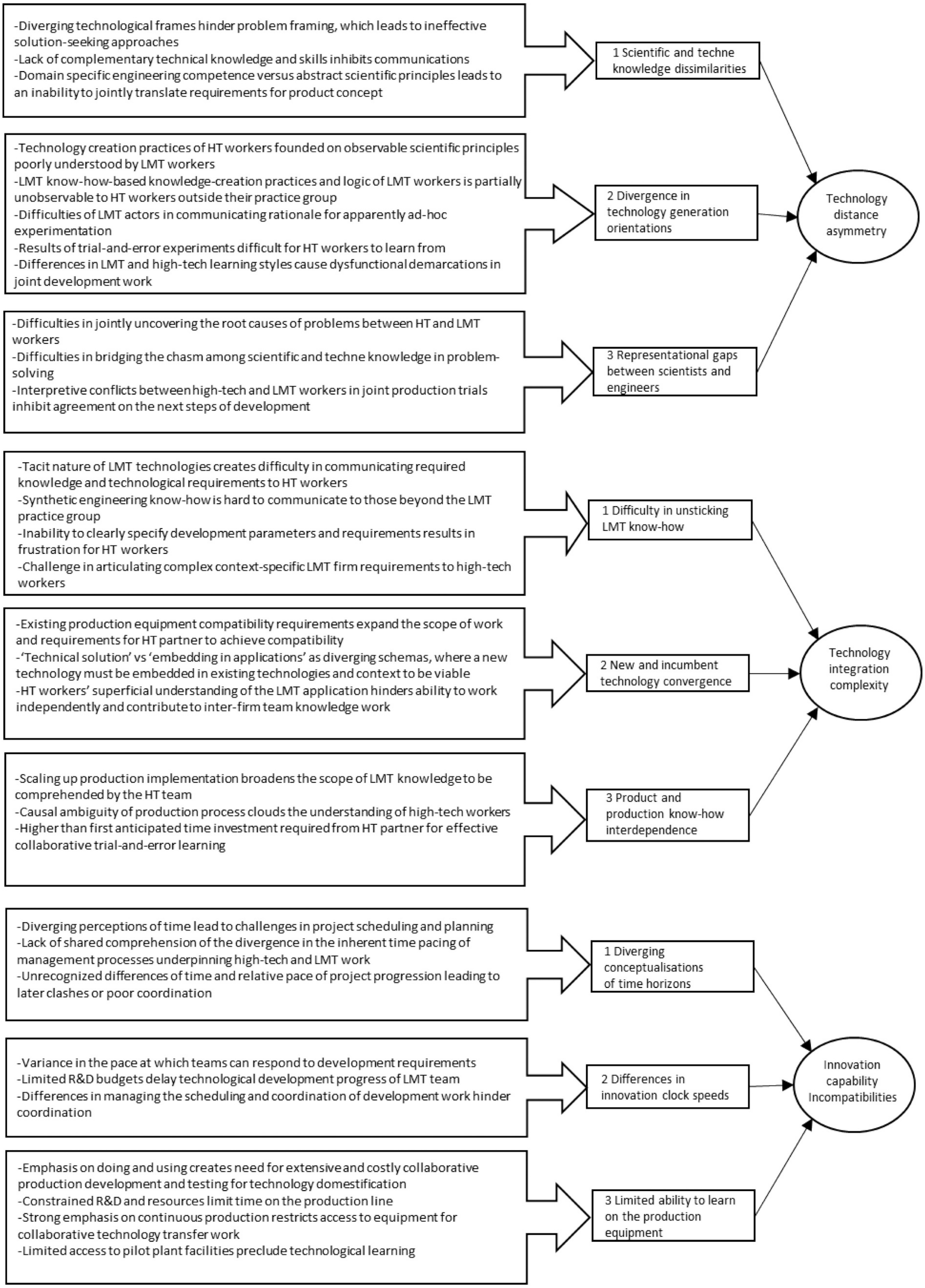
The three themes for each dimension characterise how the main dimensions play out in the alliances studied. The three phases capture the key early, middle, and later phases of the dissimilar alliances. These were reflected in three main types of activity: i) technical problem-framing activities in which we observed attempts by intra-firm teams to establish their roles and uncover what the requirements were for the new technology, how to create it, and plan for how this would be subsequently managed; ii) technology customisation in which the technology was created for the LMT application, involving the taking on of development responsibilities and extensive development work; and iii) technology fusion where we observed the collaborating firms attempting to successfully embed the new technology and scale it up by integrating it into their systems and production. This finding takes into account that alliance activities are contingent on the particular phase in the alliance life cycle (Das and Teng, 2002). Together, this led us to identify a total of nine specific problems that characterise the challenges faced.

The following sections describe each of the dimensions and the themes that characterise them. In initially describing each dimension, we link to prior findings from the literature on dissimilarities in cognitive distance and collaboration and sequencing (the lower part of our conceptual framework). Subsequently, in describing the themes, we link these to dissimilarities in the DUI and STI learning and knowledge building approaches and knowledge bases of high-tech and LMT firms (the upper part of our framework). In doing so, the sections that follow demonstrate how our findings on the problems experienced in asymmetric alliances link to, build on, and extend prior findings in each of the sensitizing concepts.

4.1. Technology distance asymmetry

Our first dimension captures how communication, collaboration, and team working between high-tech and LMT firms were hindered by a lack of common knowledge, skills, and differences in approaches to how new technologies were generated and understood. In the initial alliance activities, these underlying differences in knowledge and learning hindered the development of a shared understanding, collaborative working, and the achievement of a shared understanding on how to proceed (e.g., low fidelity and quality of communication). Hence, the resulting problems were subsequently evident in each phase of technology transfer. Broadly, this dimension reflects problems stemming from a lack of cognitive proximity (e.g., Enkel and Heil, 2014; Nooteboom et al., 2007; Boschma, 2004). However, differences extended beyond differences in technical knowledge alone and were compounded by more fundamental dissimilarities in the nature of knowledge and learning between workers.

Scientific and Techne Knowledge Dissimilarities. The first theme captures how fundamental dissimilarities in high-tech and LMT workers' knowledge hindered their ability to jointly define key technical problems and understand how to develop the new solutions required. Firstly, the technological knowledge of each firm's workers diverged, with little shared understanding of the features, parameters, performance, and use of the others' technologies. For example, knowledge of coatings and their prior application in plastics was of limited use when attempting to comprehend their potential application to the paperboard domain. Attempts to bridge this gap in understanding were hindered by a broader lack of common background training, knowledge, and skills (e.g., Heidenreich, 2009; Grillitsch et al., 2019) between workers with predominantly scientific or engineering expertise. This inhibited communication and shared understanding. Specifically, we found that the formal training and understanding of scientific principles evident among high-tech workers contrasted with the context-bounded techne engineering competencies of LMT workers, which had often been developed "on the job". Furthermore, the predominantly production-processing knowledge of LMT workers was unfamiliar to their high-tech counterparts. LMT workers lacked the scientific knowledge to translate their requirements into clear technical specifications, whilst high-tech workers lacked the domain-specific knowledge that characterised LMT development and which was necessary in comprehending how to develop appropriate solutions. For instance, LMT workers' deficient understanding of the scientific principles underlying the knowledge of high-tech workers frequently hindered them from understanding codified knowledge in documented results. Such problems



-Diverging technological frames hinder problem framing, which leads to ineffective solution-seeking approaches
-Lack of complementary technical knowledge and skills inhibits communications
-Domain specific engineering competence versus abstract scientific principles leads to an inability to jointly translate requirements for product concept

-Technology creation practices of HT workers founded on observable scientific principles poorly understood by LMT workers
-LMT know-how-based knowledge-creation practices and logic of LMT workers is partially unobservable to HT workers outside their practice group
-Difficulties of LMT actors in communicating rationale for apparently ad-hoc experimentation
-Results of trial-and-error experiments difficult for HT workers to learn from
-Differences in LMT and high-tech learning styles cause dysfunctional demarcations in joint development work

-Difficulties in jointly uncovering the root causes of problems between HT and LMT workers
-Difficulties in bridging the chasm among scientific and techne knowledge in problem-solving
-Interpretive conflicts between high-tech and LMT workers in joint production trials inhibit agreement on the next steps of development

-Tacit nature of LMT technologies creates difficulty in communicating required knowledge and technological requirements to HT workers
-Synthetic engineering know-how is hard to communicate to those beyond the LMT practice group
-Inability to clearly specify development parameters and requirements results in frustration for HT workers
-Challenge in articulating complex context-specific LMT firm requirements to high-tech workers

-Existing production equipment compatibility requirements expand the scope of work and requirements for HT partner to achieve compatibility
-'Technical solution' vs 'embedding in applications' as diverging schemas, where a new technology must be embedded in existing technologies and context to be viable
-HT workers' superficial understanding of the LMT application hinders ability to work independently and contribute to inter-firm team knowledge work

-Scaling up production implementation broadens the scope of LMT knowledge to be comprehended by the HT team
-Causal ambiguity of production process clouds the understanding of high-tech workers
-Higher than first anticipated time investment required from HT partner for effective collaborative trial-and-error learning

-Diverging perceptions of time lead to challenges in project scheduling and planning
-Lack of shared comprehension of the divergence in the inherent time pacing of management processes underpinning high-tech and LMT work
-Unrecognized differences of time and relative pace of project progression leading to later clashes or poor coordination

-Variance in the pace at which teams can respond to development requirements
-Limited R&D budgets delay technological development progress of LMT team
-Differences in managing the scheduling and coordination of development work hinder coordination

-Emphasis on doing and using creates need for extensive and costly collaborative production development and testing for technology domestification
-Constrained R&D and resources limit time on the production line
-Strong emphasis on continuous production restricts access to equipment for collaborative technology transfer work
-Limited access to pilot plant facilities preclude technological learning

Fig. 3. Data structure.

Table 3
Representative quotations: Technology distance asymmetry.

Knowledge distance asymmetry	
Scientific and techne knowledge dissimilarities	"*I sometimes think we need an interpreter. It's like they have this understanding of the chemical and we know all about metals and processing the material, but then there is this big gap between us, and we aren't really communicating on the same plane. It's difficult to know what is required.*" [F2] "*It's difficult to achieve an integrated understanding. Because they know so little about the technology and have such a different set of knowledge … this really hindered us from jointly understanding what was needed and agreeing how to move forward.*" [I3] "*Microwaves were really new to our partner [food firm], whilst we hadn't really worked closely on a product like this and did not really understand what the requirement would be for our technology to work under such heat … we also did not know what impacts on this type of product and how it performs. We don't have experience of baking, it's far from our area of expertise. So, it's hard to communicate with them effectively to decipher what's needed.*" [D5]
Divergence in Technology Generation Orientations.	"*It's hard for them not to end up just standing on the sideline in testing, as they find it hard to understand our rationale for development. We might start with a plan of testing things in a particular order, but typically after initial tests you are just drawing on your experience and skipping tests as you kind of know what will and will not be likely to improve outcomes … that process is hard for them to comprehend or interpret.*" [I2] "*When we are testing on production equipment you rely on your prior experience and what you know tends to work or not work, but then that is hard for them to understand your rationale and that limits your ability to work together and develop a shared understanding of the problems you experience … they kind of end up on the periphery when we are undertaking tests.*" [F3] "*The problem is they basically ended up watching our work on the production line huddled in a little group away from us. We are there trying various different settings and changes and just doing it on the basis of what we expect to happen, but it's hard for them to understand our logic. But then you come out of the test and its harder to learn from that …. Whereas they tend to follow a more formal process, which is quite different to our workers.*" [F1]
Representational Gaps Between Scientists and Engineers.	"*There's like this big gap between us and it's hard to bridge… Despite months of iterations, we are left struggling to make progress as neither of us can fully grasp what is going wrong or what needs to be done … They want further work on the formulation, but from our perspective the problem appears to be in its application.*" [I16] "*After several experiments with different formulations they sent through, I knew that this new version would not work that well from the basic formulation, I felt that I recognised a pattern of what did and did not seem to produce the right results … The formulation we tested around three months ago was the best, despite several iterations, and I knew that would be the case before the test. But I do not have the understanding of chemicals to really make detailed recommendations and suggest what would work …. Having run trials on the line, we couldn't get the right appearance, but we couldn't understand why as we lacked knowledge of the chemicals. So, we were telling them that there was a problem. They struggled to grasp the differences of applying their chemical into an extruded ten-layer film.*" [E1] "*They know the theory of chemistry and believe that more or less of a chemical component should produce a result. The problem is that it doesn't work like that in practice when processing it … So, in theory, it should happen, but it doesn't, but then we have to decipher how to adjust things and what to change.*" [E3]

for high-tech partners are evident in the following:

> "*We do not possess the knowledge of their production process, the way their material works and have no real prior understanding to draw upon … It's very frustrating that they do not have any real knowledge of the basic principles of the components we are dealing with when attempting to tailor our formulation.*"
>
> [I13]

Hence, the lack of symmetry in skills and knowledge hindered the workers from establishing a clear direction for joint development.

Divergence in Technology Generation Orientations. The second theme captures how differences in new technology-generation and problem-solving orientations of high-tech and LMT workers to create new technology diverged, thereby challenging collaboration between actors because the technology was developed and tested for the LMT context. High-tech workers' practices of technology creation were founded on observable scientific principles and natural laws (Manniche, 2012; Asheim and Hansen, 2009; Manniche and Testa, 2010), which underpinned their cognitive processes and relatively structured approach to designing experiments. Yet, LMT workers lacked the scientific knowledge to comprehend them. By contrast, LMT workers' activities and routines were based largely on practical experience (e.g., Manniche, 2012; Asheim and Hansen, 2009). The logic underpinning their practices was inherently based on reasoning that was only partially transparent to those outside the firms' internal practice community. For example, in smaller-scale benchtop work prior to scaling up, LMT workers' decisions on the tests to be run and how to progress experiments appeared to their external partners to be largely ad hoc, and they experienced difficulty in communicating their intuitive rationale. These ad-hoc trial-and-error processes were in stark opposition to the systemic approaches of high-tech workers and created results that were hard for high-tech workers to interpret and thus learn from. For example, an unsuccessful test would lead LMT workers to move to a different line of experimentation based on know-how and without a clearly articulable reasoning. For example:

> "*Their logic for testing formulations on the production line was difficult to understand. They do not follow a logical and systematic process, and they try to explain what they are doing…. But it's like if you are not in the 'in group' of engineers that do this on a day-to-day basis you cannot really understand their rationale … But then we have ended up not really participating and, with these results [referring to seemingly ad-hoc procedures], it becomes harder for us to interpret the results at the end of the day.*"
>
> [I14]

Where work was intended to be jointly conducted, the diverging nature of the practices of high-tech and LMT workers in their learning sometimes resulted in dysfunctional demarcations in joint development work. Each firm's workers struggled to establish common ground on which they could jointly collaborate to develop the new technology for the intended application – hence, the result was separation. Our results reveal how differences in approaches to knowledge generation hindered the ability to learn through participation. Consequently, joint learning and development was hampered.

Representational Gaps Between Scientists and Engineers. As the alliances progressed to the application of technologies and attempts to embed them into the production systems of the LMT firms, we observed challenges in jointly understanding and resolving problems. Frequently, the innovative technologies developed did not perform as anticipated in production scale up or pilot plant trials (Roca et al., 2017). We observed

Table 4
Representative quotations: Technology integration complexity.

Technology integration complexity	
Difficulty in Unsticking LMT Know-how.	"*Our application is very specific and it's hard for them to develop that in-depth understanding that's needed to then meet the requirements. They didn't really grasp the differences in laminating in five layers, as opposed to eleven, the gauge of the material, and they were also working with a blown extrusion technology, which works differently to our extrusion process. Differences are evident in the properties of the final product.*" [E1] "*I think they struggled to get that understanding upfront that was needed, we just couldn't get them to fully grasp our needs … They were not used to working to the specifications and requirements that we use in food packaging. Their proposals often produced what seemed to them to be a strong adhesive strength, but for us it was insufficient. They would be achieving a level of three, which in many contexts would be considered strong, but we required a minimum strength level of ten.*" [E2] "*It is very hard to actually specify what is needed, you aren't just trying to achieve something new, technologically, which the food firm understands what performs in practice they are not able to unpick the bits that matter, let alone to articulate and translate that practical understanding into something meaningful for the supplier. We have worked on a lot of projects like this and have kind of learnt the importance of spending a lot of time on this and trying to find and transfer this kind of understanding … but it's tough.*" [D3]
New and Incumbent Technology Convergence.	"*So, they went away and did this work but, because they only have a superficial understanding of our technologies and particularly our process, much of what they did didn't really take things in the right direction. Working separately is difficult for this reason.*" [F1] "*They hear we need to put it on the machine and apply it thinly, but do not understand the subtle nuances required … coating thickness, drying time, ability to apply it onto board through the rollers … They also do not really comprehend the relative ranking or weighting of factors and decisions on trade-offs.*" [I1] "*… they suggested adding more water to make the formulation work … no one in our team would have made such a suggestion, it reflected their inability to grasp the fundamental relationships involved in processing inks on paperboard.*" [I5]
Product and Production Know-How Interdependence.	"*… It has to work in the existing process and that adds an additional but integral consideration. That knowledge is held within the production team.*" [D1] "*They have a large portfolio of chemicals but struggled to know which would be best for our application and production process. They struggled to grasp the interrelated requirements of extruding the film, the interactions between the layers and how they form together, and how this functions in the production process.*" [E3]. "*They find it hard to input into our development as they do not know the line, the equipment, and the process is new to them. There is a lot of knowledge to be grasped in order to transfer an existing technology and make it viable for our requirements.*" [I7]

Table 5
Representative quotations: Innovation capability incompatibilities.

Innovation capability incompatibilities	
Diverging Conceptualisations of Time Horizons.	"*When they consider development speed and work on a project, their understanding of the timescale is fundamentally different to ours.*" [I17] "*We think we are doing something really quickly, but then you realise that their definition of quick is completely different to ours. We are using a stage-based process, and they are working in short agile sprints … We were totally out of from the beginning and didn't even realise it, our whole discussions I think were predicated on a different understanding of how we would be able to progress the project.*" [F2] "*We were able to use our experience on working on projects with food firms [working alongside high-tech partners] and recognise there is a need to manage expectations and progress for each firm. Otherwise, it can lead to disillusionment on both ends … but I think particularly for the technology suppliers, they work in a different way and often do not understand the delays on the end of the food firm.*" [D3]
Differences in Innovation Clockspeeds.	"*They are able to work much faster than us, and it's hard to integrate our efforts. It's more like we are working in parallel than working together as a team.*" [E2] "*We mostly do 'D' and not much 'R', we are focused on developing and using things, not developing new materials* (e.g., *chemicals). Therefore, our processes for more advanced projects are much less refined and much slower, we also do not have the funds to progress at such a rate.*" [I3] "*… their ability to adapt and respond is much slower. We were changing parts of our formulation over a two-week period, but little had happened on their end in that time. We are often waiting for their input for weeks or months, their ability to respond and adapt is much slower.*" [I12]
Limited Ability to Learn on the Production Equipment.	"*We need to conduct trials to prove buying the process is worth the investment, but we cannot conduct trials without access to an appropriate process. This formed the key problem when we were trying to figure out how the coating would actually work for us and what development was required.*" [I1] "*Testing restricts us in building understanding. Trialling with three different settings when you have access can take half a day.*" [F3] "*Not many of our lines are available for testing, but then even if you can find time you are asking the production team to run something new and largely untested on the line and you get a lot of resistance. Sometimes, you are also wanting to synchronise this with the external supplier's team visiting for the tests, which makes it even harder … The combination of these factors slows you down … getting time on the line can really slow you down.*" [E1]

interpretive conflicts (Weber and Mayer, 2014; Barnett, 2008; Smith and Barclay, 1997), where attempts to address such challenges were hindered by diverging perceptions of the problems and how best to solve them. At this point in the technology transfer process, it was evident that, between the different knowledge workers (e.g., Heidenreich, 2009; Lee and Walsh, 2016; Grillitsch et al., 2019), a significant gap in understanding was present. This gap hindered them from developing a shared understanding of the problem and the root causes of the technology failing to perform as expected. As a result, diverging opinions were evident on how these problems should best be addressed. Hence, there was evidence of representational gaps in problem solving, with interpretive conflicts between the high-tech and LMT workers. This was particularly evident in joint scale up production trials – for example, where the lack of a shared understanding constrained teams in framing problems and potential solutions. Such problems are evident in the following:

> "*When the new samples arrived, I was pretty sure they would not be as effective as those delivered to us three months ago. That was looking from the chemical specification sheet and reflecting on the other tests we have done since. That turned out to be the case … The problem is, whilst I have grasped some basic understanding, I do not really know enough about their chemicals to advise … I do not have the background or training.*"
>
> [E1]

The inability of workers to draw a common conclusion resulted in disagreements over, for example, whether problems should be resolved through fundamentally changing the scientific or technological solution, thus requiring further work from the high-tech firm, or through its implementation and use on production equipment, thus requiring further work from LMT workers. Hence, reaching an agreement on the next steps of development was challenging.

4.2. Technology integration complexity

Our second dimension reflects the integral role of high-tech partners in the creation of the new technology for the specific context of the LMT application. Technologies had to be integrated into existing product and production systems, whilst limiting the cost of doing so. As a result, reflecting the two-way nature of learning (Buckley et al., 2009; Håkanson and Nobel, 2000; Dhanaraj et al., 2004), it was critical for the high-tech firm to develop knowledge of unfamiliar LMT technologies, production processes, and systems. Yet, this knowledge was tacit and context specific and, therefore, hard to transfer. Thus, learning was costly, due both to the unfamiliar nature of technologies (Buckley et al., 2009; Gilsing et al., 2008; Nooteboom et al., 2007) and to their inherent sticky nature.

Difficulty in Unsticking LMT Know-how. The first theme captures how, in the initial phase of the alliance, the underlying nature of embedded LMT knowledge and technologies resulted in difficulties in articulating and communicating to high-tech partners the requirements and necessary understanding for the forthcoming development. The high-tech partners possessed little or no prior understanding of the LMT partners' technological or production application and context in which their knowledge would be applied. Yet, in the early phases of the alliances, developing their understanding of these often subtly nuanced requirements proved problematic, such as those related to an individual material and its processing requirements. The tacit nature of LMT "know-how" (Jensen et al., 2007a; Lundvall and Johnson, 1994) also hindered the documentation and clear up-front specification of development parameters and transfer requirements. For high-tech workers, acquiring this understanding was challenging and costly (e.g., Asheim and Hansen, 2009; Martin and Moodysson, 2013) and, in some cases, development parameters were not fully comprehended in the early activities undertaken. LMT workers explained that they possessed the understanding pertinent to stipulating the project specifications, based on prior experience. Yet, they themselves often did not fully comprehend, and could not explain, why past solutions had worked or had failed to work. Hence, their inability to articulate the context-specific nature of "what works" coupled with their failure to convey a higher level of knowledge frustrated their high-tech partners in attempting to understand what needed to be created:

> "*We have a way of finding solutions, but I am not sure we always know how we find them or reached that conclusion. You just kind of know based on what did or did not work before. Trying to communicate that is pretty challenging … so trying to say upfront what will be needed to be successful is pretty challenging, but they want that kind of clear spec[ification].*"
>
> [I1]

Hence, LMT knowledge was unlike a textbook and, therefore, hard to document or translate. Complex interactions between different material, technological, and processing factors that would influence the outcome were difficult to simply encode and communicate. The combination of these factors increased the probability of development parameters critical to success failing to be comprehended by high-tech partners, and the application's requirements remained ambiguous from the outset.

New and Incumbent Technology Convergence. The nature of technology transfer in the context of LMT firms necessitated integration with established and incumbent technologies. Gilsing et al. (2011) and Robertson et al. (2009) emphasized that knowledge may be independent or systemic. This alliance challenge reflects the implications of the broad issue of DUI knowledge being systemic and intertwined (Gilsing et al., 2011; Asheim and Hansen, 2009; Robertson et al., 2009) as the alliance progressed. This challenge was illustrated in alliance F where a laser technology had to work on existing drink cans and tabs and operate on the existing production line with minimal capital costs. Nor could it impede line efficiency or speed. Achieving compatibility with existing equipment increased the scope of development work, yet the restricted resources in LMT meant this compatibility had to be achieved with limited cost implications. In this customisation stage, the invisible nature of interactions between different elements of LMT knowledge posed an additional challenge for high-tech workers to comprehend. Achieving compatibility resulted in expanding the scope of the work when creating the new technological solution, yet we also observed divergence in the interpretive schema between high-tech and LMT workers that challenged this. Whilst embedding the technology in existing systems and processes (embedding in applications) was considered central to the alliance work for LMT workers, for their high-tech counterparts, the development of a technical solution was considered the main scope of their work. Hence, production viability and cost effectiveness were less of a priority and beyond the scope of their work.

Related to the complex and invisible nature of LMT knowledge, we also observed in this phase that high-tech workers failed to fully grasp the workings of the application. Despite significant efforts, as newcomers to the context, they only ever achieved a superficial understanding and did not comprehend the deep underlying relationships among different elements. This resulted in problems in individually executed development work, which often demonstrated low validity and fidelity. For example, high-tech firms often undertook R&D and provided their partners with prototype samples of their results. Subsequent evaluation of the prototypes would then reveal distinct problems in the development undertaken, which was inappropriate and reflected a lack of understanding of the underlying technological requirements of the LMT context. Hence, independent task execution and knowledge work was challenged by a superficial understanding. Likewise, in inter-firm joint work, this superficial understanding led to suggested solutions that were considered naive:

> "*They suggest different outputs, speeds, temperatures etcetera, when they send through samples, but they are rarely appropriate, and we are trying to convert them and establish what would be appropriate. But then you are sending back the results based on different testing settings to those they anticipated, and they are struggling to interpret the results.*"
>
> [I3]

The increased scope of various considerations, and the additional development work this created, ran the risk of the alliance being deprioritised by high-tech partners.

Product and Production Know-How Interdependence. The third theme stems from the need to integrate technologies into full-scale production systems and manufacturing in the final alliance activities. This theme reveals how the systemic nature of knowledge (Gilsing et al., 2011; Robertson et al., 2009) further impacted on technology transfer, in particular the influence of existing production systems of LMT firms were of critical importance to technology transfer success, presenting further problems. Notably, in all but one alliance, the new technologies had to be applied to an existing production line. Hence, in this implementation phase, the breadth of knowledge required to achieve full incorporation spanned from the product to its production and processing (e.g., NPD, production, engineering) and was distributed across a wider variety of actors. Furthermore, where problems were experienced in scaling up, not only were a complex variety of factors at play but also the interrelations between them were ambiguous. When interactions between different aspects were invisible, the understanding of high-tech workers was clouded:

> "*… where you are processing it. They need to understand the machine design, the influence of heat, extrusion diameter, and the screw … It has to work in the existing process and that adds an additional but integral consideration. That knowledge is held within the production team.*"
>
> [E2]

This integration phase and the associated, extensive trial-and-error learning often proved more time consuming than first anticipated by high-tech teams, which created a disincentive. Indeed, it was noted that the low margins in many LMT firms resulted in long payback on new technologies and, thus, the time investment required posed a significant challenge that led to disillusionment.

4.3. Innovation capability incompatibilities

Our final dimension captures dissimilarities in the innovation capabilities of high-tech and LMT firms and reflects additional challenges facing LMT firms, which slowed their relative pace of technological development activities and their ability to progress their internal development. These dissimilarities reflect difficulties in the routines, coordination, and sequencing of the alliance project work (Estrada et al., 2016; Gulati et al., 2012) in the specific LMT context, and they impeded the successful management of their progression. Hence, this dimension reveals how the interorganisational differences between the firms and their knowledge bases specifically result in problems in coordination and sequencing between them.

Diverging Conceptualisations of Time Horizons. In the initial alliance activities, when knowledge workers from each firm first began to work together, we observed a divergence in the assumptions of time between high-tech and LMT knowledge workers. Such differences in the framing of time challenged scheduling and planning, where high-tech workers tended to think in comparatively shorter time scales and faster progression. Contributing further to this divergence theme, we noted that the underlying management of innovation activities often differed between types of firm. High-tech firms were typically more flexible and showed an ability to plan work to shorter time horizons, which contrasted with LMT firms who were less flexible and their management was more sequential in nature. Furthermore, in some cases, such differences in time pacing were not uncovered in the initial phases of the alliance, remaining unrecognized and resulting in problems later in development:

> "*The project was a priority for us, and we communicated that to [HT partner name removed], and we thought that we were both working on it as a project with a high rate of development … However, it became evident that our understanding of fast was quite different to theirs, we thought we were going fast but they were able to advance development at a rapid rate that we hadn't even comprehended.*"
>
> [D2]

Therefore, a failure to uncover and address such problems in the initial alliance phases exerted an impact on subsequent management and the ability of each firm to collaborate and coordinate in the following phases.

Differences in Innovation Clock Speeds. The second theme identifies how the differences in the pace of each team's innovation activities impacted the joint creation of technologies to service the needs of the LMT application. Here, differences in the resources and development budgets (see Legler and Frietsch, 2007; Kirner et al., 2009; Galindo-Rueda and Verger, 2016), combined with the routines and processes in each type of firm, created a diverging pace of activities. The greater emphasis on R&D and technological change in high-tech firms, contrasted with the emphasis on efficiency, incremental development, and day-to-day operations in LMT firms. Hence, LMT firms' development was delayed in relative terms. This was combined with differences in how the firms actually managed the scheduling and coordination of work on an ongoing basis, where the slower and sequential processes of LMT firms frustrated their more agile and flexible high-tech partners. The respective management approaches to innovation challenged the joint management of alliances and scheduling of activities between the partners. For example:

> "*The problem is they are using an agile approach, and we are using stage gate … they are working at a completely different speed to you and using a completely different pacing, and that causes a lot of problems in scheduling and organizing work.*"
>
> [F1]

These differences in the pace of development not only challenged scheduling and joint coordination but also the slower pace of the LMT firm often frustrated the high-tech partners.

Limited Ability to Learn on the Production Equipment. The third theme reflects the problems experienced in gaining access to production equipment to test new technologies in a LMT firm. The significance of production implementation, combined with LMT workers' emphasis on extensive learning about the novel technologies through their use, created the need for extensive production testing (Trott and Simms, 2017). This was a costly time investment, but important in understanding how technologies functioned to scale at the end of the alliance life cycle. Yet, we observed difficulties in gaining access to equipment. This was due to limited R&D and resources (see Legler and Frietsch, 2007; Kirner et al., 2009; Galindo-Rueda and Verger, 2016), combined with an emphasis on the day-to-day running of the factory. The perceived risk of testing novel, unproven, and unfamiliar technologies further contributed to this. Moreover, our interviews revealed that this limited access restricted opportunities for joint learning with workers from the high-tech firm. For example, delays of several months until time was available on a production line were not uncommon and frequently halted progress. Hence, a strong emphasis on continuous production restricted collaborative work. Not only was internal equipment difficult to access but the LMT firms often experienced problems in accessing pilot plant equipment. Pilot plants were identified as prohibitively costly to use in the alliance work due to limited R&D budgets. For example:

> "*I do not think the pilot plant facilities are set up with our kind of industry in mind. They are just too expensive for our R&D budgets.*"
>
> [I1]

Thus, a lack of opportunities to learn in the production environment impeded technology transfer and the successful embedding of technologies, which was fundamental to their ultimate commercial exploitation. Ultimately, progress was further delayed, to the frustration of the high-tech partners.

5. Discussion

Our study was conducted against a background of a critical need to improve linkages between high-tech and LMT industries to enable the transfer and subsequent adoption of science and technology (STI) knowledge by the less R&D-intensive (DUI) type of firm (Jensen et al., 2007a; Thomä, 2017). This typically involves the combination of different internal–external knowledge bases, which holds the potential to be a driver of innovation (Haus-Reve et al., 2019, 2023; Jensen et al., 2007a). Little is currently known about technological diffusion and adaptation processes between high-tech and LMT industries (Robertson et al., 2009). Our study, therefore, centred on the transfer of technology between high-tech and LMT industries. Considering the mounting environmental problems society faces, improvements in the sustainability of manufacturing across many LMT industries are of critical importance. Such problems are particularly acute in the process industry setting. However, the existing literature on LMT industries and alliances has so far failed to provide a micro-level understanding of the problems faced by such collaborations (e.g., Haus-Reve et al., 2019; Grillitsch et al., 2019; Lumineau and Oliveira, 2018; Manniche et al., 2017). Our study has addressed this gap by conducting a detailed analysis of asymmetric alliances between high-tech firms and firms in LMT industries. The findings from these alliances, whose central aim was improvements in sustainability, highlighted problems experienced in moving from purely recognizing the potential value of new technologies to transforming them into something useful that could be applied to existing products and processes.

Fig. 4 presents our key findings in the form of a framework that reveals how the nine problems play out over the life cycle of an asymmetric alliance. The three alliance characteristics on the left side reflect the dimensions identified in our data, whilst the knowledge integration stages reflect the three main phases over which alliance activities unfold (e.g., Gulati et al., 2012; Brattström and Faems, 2020; Contractor and Reuer, 2014; Ireland et al., 2002). The figure visually represents how each of the nine problems, in the centre of the figure, unfold as an asymmetric alliance progresses. Each problem had a centre of gravity within the alliance life cycle where it was most pertinent or acute. Whilst not all the problems highlighted in our study are exclusive to LMT industries, we have uniquely characterised how these problems in combination, if not addressed, hinder LMT firms from exploiting technology from high-tech firms.

5.1. Theoretical contributions

The primary contribution is to augment studies of innovation in the LMT industries. Firstly, our results reveal how the differences between each type of firm's knowledge base and learning characteristics influence technology transfer. Haus-Reve et al. (2019), Grillitsch et al. (2019), Heidenreich (2009), and Robertson et al. (2003) each identified the different types of knowledge base but did not examine their combination at the alliance level, leading them to call for an improved understanding of the transfer of technologies from high-tech to LMT industries. Critically, this technology transfer necessitates the combination of internal–external DUI and STI knowledge bases (e.g., Haus-Reve et al., 2019; 2022; Jensen et al., 2007a). We responded to these calls by delineating three main overarching types of challenge faced in alliances between high-tech and LMT firms, specifically: i) technology distance asymmetry; ii) technology integration complexity; and iii) innovation capability incompatibilities. In doing so, our paper provides a contribution to the literature by outlining the challenges that result when combining different learning and knowledge building approaches, and knowledge bases, in the technology transfer process. Whilst prior studies have identified the differences between the two firm types and their respective learning modes (DUI vs. STI), they have not progressed sufficiently to uncover how these differences actually influence and play out in a technology transfer process. For example, with respect to theme one, whilst the prior literature recognises broad differences in the type of worker employed in each firm type, it has not captured how fundamental differences in their training and the nature of knowledge that each possess thwart the development of a shared understanding of how to develop new solutions at the commencement of an alliance, how to jointly frame the innovation problem effectively, and how to move towards solving it.

Specifically, our results enabled us to map these overarching

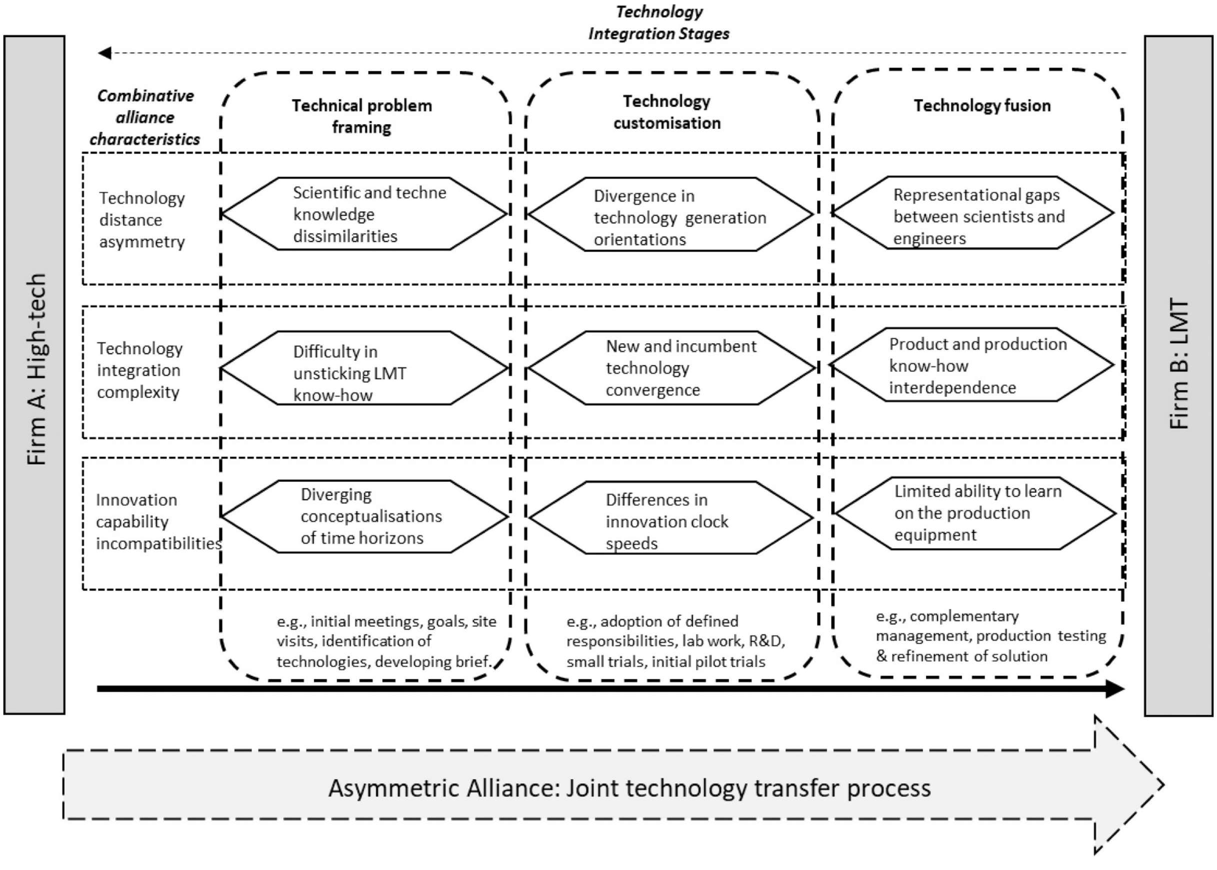


Fig. 4. Problems of technology transfer and implementation in asymmetric alliances between high-tech and LMT firms.

challenges across three main phases of the technology transfer process (e.g., Gulati et al., 2012; Brattström and Faems, 2020; Contractor and Reuer, 2014; Ireland et al., 2002), revealing how they play out over the technology transfer process. This allowed us to develop a novel framework that dynamically captures the nine problems faced in technology transfer in asymmetric alliances (Fig. 4). The specific problems identified have not previously been uncovered in the LMT or knowledge base literatures (e.g., Haus-Reve et al., 2019; Grillitsch et al., 2019; Manniche et al., 2017), due to a lack of studies examining high-tech to LMT technology transfer. Each of the problems uncovered demonstrate how the interorganisational differences between high-tech and LMT firms, and their inherent, predominant modes of innovation (STI and DUI), create specific problems within the different phases of technology transfer in an asymmetric alliance. For scholars, our framework adds to the literature by highlighting how differences in each type of firm play out in the process of a technology transfer. These findings provide one explanation as to why firms that are primarily engaged in supply chain collaborations may fail to reap the full benefits when engaging with scientific partners (e.g., Haus-Reve et al., 2019).

Secondly, Robertson et al. (2009) and Robertson and Patel (2007) have highlighted the relatively low rates of technological diffusion from high-tech to LMT industries. Whilst the work of Christensen et al. (2013) provides one explanation, due to the challenges incumbent companies face in pursuing major change and lock-in effects, our work provides an additional explanation. The findings captured in the three dimensions illuminate how the differences in each type of firm impede aspects of collaboration, such as teamwork, the transfer of technology, and cooperative work. Likewise, prior studies identified the influence of lock-in effects, based on existing resources and commitments, and highlighted how this hinders change (Tripsas and Gavetti, 2017; Tushman and Anderson, 1986). Whilst it is known that traditional LMT firms face the challenges of lower R&D budgets and lock-in effects, our study uncovered how they play out in asymmetric alliances. Similarly, in a process industry context, Lager et al. (2013) identified the problems of inertia and idiosyncratic investments, where firms expect to run for decades on their investment with minor changes achieved through learning by doing and by using over time, but they lack receptivity to new technologies. But what is not known is the technology transfer implications of those features in the high-tech to LMT collaboration. Thus, we move the literature forward by providing new specific explanations for the slow and challenging transfer of technologies between these two types of firm, revealing the factors that contribute to slower rates of adoption as a result of the differences between firms. In doing so, we respond to the lack of scholarly attention given to LMT industries and their relationship to high-tech industries (Heidenreich, 2009; Hirsch-Kreinsen et al., 2005; Von Tunzelman and Acha, 2005).

We contribute to the alliance literature by moving beyond describing types and motives for environmental alliances (Wassmer, 2014; Niesten and Jolink, 2020; Stadtler and Lin, 2017) to uncovering the micro dynamics of technology transfer problems over each main phase as an alliance unfolds. Environmental alliances are more complex than regular ones as they have dual purposes – they have both economic and environmental objectives. By illuminating the specific problems that arise in LMT and high-tech firm collaboration and pinpointing the centre of gravity of each problem to a specific phase of the alliance, we add a contingency perspective to the management of technology transfer in such alliances. These findings contribute to the literature on alliances (Lumineau and Oliveira, 2018) and, more specifically, to the emerging literature on environmental alliances (Niesten and Jolink, 2020). By studying collaboration between high-tech and LMT firms as well as conflicts and challenges that arise in technology transfer, we have combined positive and negative valence and uncovered the specific problems in adapting technological knowledge possessed by high-tech firms to the requirements of LMT firms. The prior alliance management literature has shown that key activities are contingent on the particular phase of the alliance life cycle (Das and Teng, 2002; Spekman et al., 1998b). For the environmental alliance literature, these insights reveal a need to further consider the activities required and how firms should perform them.

5.2. Managerial implications

LMT firms and high-tech firms often collaborate under significant inter-firm differences regarding knowledge bases, approaches to learning, cognitive distance, and collaboration and sequencing routines. These differences, which are rooted in asymmetry, frequently lead to practical challenges in transferring and integrating technology. This signals a highly challenging context for collaboration and technology transfer, which is manifested in the nine unique problems that our data analysis uncovered, and which hampers technology transfer effectiveness over the three phases of an asymmetric alliance, if not thoroughly dealt with. On a broad level, our framework delineates the problems that might negatively influence collaboration activities and offers a systematic way to think about them. Managers should, to the extent possible, attempt to reduce or mitigate the influence of each within the technology transfer process. So how can this be done?

Problems stemming from *technology distance asymmetry* calls for the exchange of "rich" information, which can resolve conflicting interpretations and allow parties to approach a shared understanding. This demands social support from the managers involved. In practice, this may imply regular face-to-face meetings over the life cycle of the alliance, joint problem-solving sessions, etcetera, which allow the participants in the alliance to converge on the meaning of potentially equivocal cues and then define better common solutions. Frame-of-reference training is another method that has proved effective in settings with high collaboration complexity (Hollenbeck and Jamieson, 2015). The firms involved can also make use of liaison devices – namely, dedicated staff who transcend organizational boundaries. Such persons (project managers or specialists) can help overcome knowledge asymmetries in the form of representational gaps, for example. Furthermore, this problem provides additional evidence of the benefits of LMT firms enhancing their STI mode of innovation to enhance absorptive capacity.

Problems stemming from *technology integration complexity* are fundamentally different. Challenges in unsticking LMT know-how calls for externalization (Nonaka and Takeuchi, 1995) – that is to say, a clear expression of largely tacit knowledge, which allows it to be better understood by others. Techniques centring on figurative language (such as metaphors and analogies) or deductive/inductive reasoning can be helpful in this regard. In contrast, the need to fuse with legacy technologies and the reciprocal relationships between product and production know-how clearly calls for better absorptive capacity on the part of the LMT firm and better desorptive capacity on the part of the high-tech firm. For the specific type of asymmetric alliance we studied – namely, transfer of technology from a high-tech to a LMT firm – absorptive capacity centres on the receiving firm and urges managers to invest in routines and activities to better value information, assimilate it, and apply it effectively. In contrast, desorptive capacity urges the high-tech firm to develop similar routines but for outward transfer – that is, to become a better "teacher".

Finally, problems centering on *innovation capability incompatibilities* can be addressed by better synching development processes and logics. In practice, the alliance work tasks can be executed by deciding up front on following, for example, the stage-and-gate process logic of the LMT firm. By agreeing up front on phases, development activities, timing, and decision-making points, problems stemming from the diverging conceptualization of time horizons and differences in innovation clock speeds can be mitigated. The limited ability to learn by doing and by using on equipment is different, though. This problem requires managers to balance the day-to-day needs of production with tomorrow's need for new product and process concepts. In practice, this problem can be addressed through an internal policy at the LMT firm, which encourages testing and access to production facilities close to planned maintenance stops.

5.3. Policy implications

Clearly, high-tech and LMT firms can do much to improve technology transfer on a voluntary basis and without any policy interventions. That said, the process industries, to which the food and food packaging industries belong, account for large greenhouse gas emissions and negative externalities (Richie and Roser, 2021; Simms et al., 2020), which makes the policy discussion relevant. Our analysis at the alliance level does not lend itself to proposing specific policy mixes, but it is, nevertheless, applicable to broader policy recommendations. To improve technology transfer and address some of the associated problems, such as the limited opportunities for learning by doing, we see two policy initiatives as worthy of consideration and elaboration.

Firstly, there seems room for *economic transfers,* which policy makers can use to strengthen linkages between high-tech and LMT industries, where R&D and absorptive capacity may be limited (Thomä, 2017). This could include “in block” public support via R&D programmes directly to industry, perhaps in combination with funding for industrial research. Such economic instruments influence primarily the development and diffusion of new products and processes from the supply side. Given the fact that some innovations and applications developed elsewhere may yield greater payoffs when subsequently applied in LMT firms (Robertson et al., 2009; Lipsey et al., 2005), R&D programmes and public support could be geared to stimulate technology transfer not only between LMT and high-tech firms but also between LMT and high-tech firms in different industries.

Secondly, economic transfers can be combined with so-called “soft instruments” (Borras and Edguist, 2012) – in particular, public–private partnerships that share costs, benefits, and risks for critical infrastructure. For example, our analysis revealed limited ability to learn by doing and by using through access to production equipment. In part, this could be offset by investment in publicly funded pilot and demonstration plants. Such plants can allow production line testing and facilitate training programmes for LMT firms on novel equipment. They may also improve understanding and collaboration between high-tech and LMT firms when joint demonstration projects are undertaken.

5.4. Limitations and future research

Our research strategy of case-study theory building naturally has its limitations and, hence, provides opportunities for future research. The findings of our study offer a number of future research avenues. Firstly, based on Fig. 1, we suggest a need to examine and compare different types of alliances between high-tech and LMT firms, as well as comparing findings across different types of alliances including LMT to high-tech, high-tech to high-tech, and LMT to LMT. This would help us further understand dissimilarities and their influence. Secondly, studies should explore different types of asymmetries in alliances, such as university to industry and company size differences. Thirdly, we suggest that studies should build on the insights presented here and further examine the element of time as a means to explore the evolution of challenges and potential opportunities associated with dissimilarities across the phases of asymmetric alliances. For example, researchers could look at the positive and negative valences of dissimilarities and how these may change across alliance phases from beneficial to detrimental. Furthermore, studies should more fully examine the potential interplay between different types of dissimilarities across the alliance phases.

Fourth, our study was conducted in the food and packaging sectors. As with all industries, it has its idiosyncrasies, and our findings may, therefore, not be directly generalized to other settings. Consequently, we suggest there is a need to examine other LMT industries and to explore the differences between process and assembly LMT industries. Fifth, each of the nine problems identified should be examined further to enhance the initial understanding developed in our study. Finally, we suggest the need to explore country contexts beyond the food packaging sectors – for example, in our study, difficulties in accessing pilot plants formed one key challenge but, in other industries or countries, this may differ. Likewise, government grant and incentive schemes to promote technology transfer and to support collaboration may vary from country to country.

CRediT authorship contribution statement

Christopher Simms: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Johan Frishammar:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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