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Make-or-buy decisions for industrial additive manufacturing

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Abstract

Much of the potential of industrial additive manufacturing (AM) is said to lie in the digital specification of components that can be transmitted seamlessly and unambiguously to partners fostering flexible outsourcing. In industry, we observe nuanced AM supply chain governance structures that result from make-or-buy decisions, with a tendency to implement AM in-house. Thus, there is a discrepancy between what is discussed in the literature and implemented in practice. We apply a multiple-case study approach to investigate *why* and *how* AM impacts the make-or-buy decision of manufacturing firms. We identify four decision profiles demonstrating the spectrum of specific governance structures and develop a framework to explain the underlying rationales. We find strong arguments for in-house AM including firms' perceived need to protect their digitally encapsulated intellectual property, reevaluation of their core competencies, commitment to internal learning, and senior management's enthusiasm for AM. By using transaction cost economics and the resource-based view, we contribute to the understanding of how arguments of these general theories are modified by the digital and emerging traits of AM. We reveal contradicting guidance in the theories' argumentation for the case of AM and provide managers a clear perspective on alternative strategies for their AM implementation process.

KEYWORDS

3D printing, case study research, digital supply chain, industrial additive manufacturing, outsourcing, supply chain governance

INTRODUCTION

Industrial additive manufacturing (AM) is one of the biggest technological breakthroughs in recent years. The fundamental game changer of AM technologies is that parts are manufactured layer-by-layer directly from the digital design file without product-specific setup and tooling (Olsen & Tomlin, 2020). Following recent technological advances, manufacturing firms have started to adopt industrial AM and implement it in their supply chains (Holmström et al. 2016; Holmström & Partanen, 2014). The make-or-buy decision for AM is one essential decision in their AM implementation process (Ruffo et al. 2007). Firms must decide whether they commit resources, including assets and competencies, to in-house AM or if they outsource the AM design and manufacturing process to specialized suppliers, termed AM service bureaus (Hedenstierna et al. 2019).

The specific characteristics of AM are expected to affect or even have a "radical impact" on the make-or-buy decision and, hence, the selected AM governance structure (Rehnberg & Ponte, 2018, p. 59). Yet, limited research exists that explicitly investigates manufacturing firms' make-or-buy decisions for AM. Overall, the broader operations and supply chain management (OSCM) literature puts the vision forward that the digital traits of AM foster flexible, dynamic outsourcing compared with traditionally "analog" manufacturing technologies (Berman, 2012; Hedenstierna et al. 2019; Meyer et al. 2021; Verboeket & Krikke, 2019).

In contrast, current "lighthouse" implementations of AM demonstrate that manufacturing firms opt for more nuanced governance structures than solely short-term outsourcing as proposed by literature: Ernst & Young found in a cross-industry survey of 900 firms that 40% have installed in-house AM technologies compared with 26% that outsource to AM service bureaus and 34% that do not make use of one of the two options yet (EY, 2019). Furthermore, the survey highlighted that 34% of the firms expect that AM will enable the reintegration of outsourced parts and thereby enhance their competitiveness. Indeed, there are famous examples of firms that believe in in-house AM. General Electric has additively manufactured fuel nozzles for its LEAP aircraft engines since 2014 (Kover, 2018). Besides, firms indicate that outsourcing AM is not their long-term strategy. Daimler Buses, for instance, started purchasing spare parts for its buses from AM service bureaus, but recently internalized these parts and established a new AM spare parts business model for cross-industry customers (Automotive World, 2021). In addition, some firms appear to continuously rely on the same outsourcing partners. For example, Boeing contracted an AM service bureau to manufacture FAA-approved structural titanium parts for the 787 Dreamliner on a long-term basis (Scott, 2017).

These examples from practice suggest that some firms pursue in-house (e.g., General Electric and Daimler Buses) and long-term outsourcing strategies (e.g., Boeing) for industrial AM. Hence, their decisions may not be reflected by the arguments for short-term, flexible outsourcing in existing research. Our study is motivated by this discrepancy and the lack of knowledge on why manufacturing firms opt for specific governance structures for AM. Our objective is to gain an in-depth understanding of *why* and *how* AM, as an example of emerging digital manufacturing technologies, impacts the governance choices of manufacturing firms. We address three research questions:

1. Which governance structures do manufacturing firms select to implement industrial AM in their supply chains?
2. *Why* do manufacturing firms opt for these specific AM governance structures?
3. *How* do digital and emerging traits of AM affect firms' governance choices?

In light of the scarcity of previous work on the AM make-or-buy decision, we opted for a multiple-case study research approach. Our collected data reveal four decision profiles for industrial AM characterizing manufacturing firms' current behavior. Beyond a tendency to outsource AM (Waverers), we identify strong efforts to invest in in-house AM (Pioneers), to simultaneously combine in-house AM and outsourcing (Combiners), and an intention to combine in the future (Planners). To investigate the rationales of manufacturing firms (*why*), we draw on two established theories broadly used in the OSCM literature to explain make-or-buy decisions in the "analog" age—namely, transaction cost economics (TCE) and the resource-based view (RBV) (Tsay et al. 2018). We develop a framework to elaborate their established explanations for make-or-buy decisions in the nascent context of industrial AM. Based on this framework, we demonstrate *how* two contextual factors—the digital product specifications and emerging stage of AM—modify general TCE and RBV argumentation and lead to the outcome of the governance decision.

Our findings provide three theoretical contributions. Foremost, we understand our study to be one of the first to investigate manufacturing firms' make-or-buy decisions for industrial AM. Our study contributes to the OSCM literature by structuring and characterizing the four make-or-buy decision profiles and providing insights into the rationales of manufacturing firms, outlined in a set of propositions. Our study thus serves as a reference point for quantitative decision-support models. Second, our study applies a middle-range theorizing (MRT) approach as proposed by Stank et al. (2017), Craighead et al. (2016), and Soltani et al. (2014) for the OSCM community. We contextualize TCE and the RBV to show how the established arguments of these extant theories must be adapted and refined for the novel context of make-or-buy decisions for emerging digital AM technologies, validated with our collected empirical data. Third, our study identifies and characterizes the AM make-or-buy decision as a setting wherein TCE and RBV arguments provide contradicting guidance. We contribute to the understanding of the combination of TCE and the RBV by deriving alternative strategies that manufacturing firms can pursue to resolve the conflict.

From a managerial perspective, our study provides decision makers in manufacturing firms with a clear perspective on the spectrum of governance choices for industrial AM and raises awareness for alternative implementation paths. Overall, we demonstrate interfaces with the innovation literature and address that our findings are transferable to industries with similar make-or-buy decisions.

The remainder of this paper is structured as follows. First, we embed our study in the extant OSCM literature on industrial AM and combine TCE and the RBV to establish our theoretical lens. Next, we explain the methodology of our multiple-case study approach. Subsequently, we present the four make-or-buy decision profiles of manufacturing firms and use the developed framework to explain their rationales and formulate propositions. The following discussion delineates our contributions to theory and provides managerial insights before we present our conclusions.

BACKGROUND

Industrial additive manufacturing context

Our study uses AM as a prominent example of the shift from traditional manufacturing to direct digital manufacturing (Holmström et al. 2016; Holmström & Partanen, 2014). AM comprises multiple manufacturing technologies. We focus on industrial AM, which refers to the professional application of AM, particularly for metal and high-quality polymer parts. Industrial AM differs from 3D printing, which commonly denotes the consumer side of the technologies (Thomas-Seale et al. 2018). New parts, spare parts, prototypes, tools, and jigs and fixtures are typical applications for industrial AM (Gartner, 2019). With a recent 10-year market growth rate of 25.7% (2011–2020) (Wohlers Associates, 2021), AM is currently in the emerging stage of becoming an early mainstream market (Gartner, 2019). This stage is characterized by high technological uncertainty referring to the inability to accurately predict technological requirements and environmental effects (Geyskens et al. 2006; Song & Montoya-Weiss, 2001). AM requires two sets of activities, the design processes and the manufacturing processes themselves. Manufacturing processes include data transfer of the digital product specification to the AM machine and pre-processing, the actual manufacturing process, and post-processing (Eyers & Potter, 2015).

Literature on the additive manufacturing make-or-buy decision

Previous work extensively discusses the decision to adopt AM versus traditional manufacturing technologies (e.g., Oettmeier & Hofmann, 2017; Schniederjans, 2017; Yeh & Chen, 2018) and identifies barriers to implementation in different industries (e.g., Dwivedi et al. 2017; Mellor et al. 2014; Thomas-Seale et al. 2018). In contrast, the focus of our study lies on manufacturing firms that have already adopted or at least decided to adopt AM and are choosing their implementation paths.

We identified studies that recognize the relevance of the AM make-or-buy decision (Holmström et al. 2017; Rehnberg & Ponte, 2018; Ryan et al. 2017) and that advise firms to carefully assess trade-offs involved in this decision (Verboeket & Krikke, 2019). Berman (2012, p. 157) highlights the "ability to share designs and outsource manufacturing, and the speed and ease of designing and modifying products" as a fundamental benefit of AM. In a similar vein, Manda et al. (2018, p. 2) refer to the outsourcing of AM as a "faster, less expensive and easier route."

However, the literature that investigates AM make-or-buy decisions remains very limited as of now. Meyer et al. (2021) identify in their review that the AM sourcing literature lags behind practice. From the perspective of manufacturing firms, Hedenstierna et al. (2019) propose a novel bidirectional partial outsourcing model for AM and demonstrate the economic benefits of this governance structure. Their results indicate that the general-purpose characteristics of AM (i.e., no product-dependent setup and tooling) are ideal for flexible outsourcing and facilitate dynamically trading production capacities between alternating contractors and subcontractors. Ruffo et al. (2007) find that in-house AM can be economically advantageous because profit margins and additional warehousing and logistics costs of the outsourcing partner can be avoided by on-demand, in-house AM, whereas Baldinger et al. (2016) calculate comparable market prices and in-house costs. Furthermore, Rogers et al. (2016), Chaudhuri et al. (2019), and Holzmann et al. (2020) take the perspective of AM service bureaus as predestined outsourcing partners for AM and classify their services. They emphasize that AM service bureaus offer individual service bundles of design for AM, manufacturing, and various auxiliary services such as consulting and training to manufacturing firms. Outsourcing of AM is assessed as a means to eliminate risks (e.g., of technological obsolescence) and is not expected to differ in terms of contractual risks from a "standard manufacturer–supplier relationship" (Rogers et al. 2016, p. 892).

Thus, we note that the extant literature is aware of the AM make-or-buy decision but provides only a few insights into the rationales of manufacturing firms specifically. Nevertheless, many arguments raised in the broader AM research in the OSCM literature have implications for the AM make-or-buy decision and we will interpret them in light of our theoretical lens.

Theoretical lens

We focus on the fundamental decision between conducting AM in-house hierarchically (make) versus outsourcing on the free market (buy). The governance structure for AM transactions, market or hierarchy, is the outcome of make-or-buy decisions (McNally & Griffin, 2004; Williamson, 2008). Thus, we purposely omit "hybrid" arrangements like joint ventures, alliances, and acquisitions. Building an understanding for the two polar governance structures, market or hierarchy, is a prerequisite for understanding more complex variants and intermediate forms (see Conner & Prahalad, 1996). Tsay et al. (2018) provide a summary of TCE and the RBV in their review of outsourcing research in production and operations management literature; and we briefly touch on some main points below.

The focus of TCE lies on the efficiency of governance structures. It postulates that governance structures need to be aligned with transaction attributes (Williamson, 1975). Key attributes of transactions are *asset specificity*, *uncertainty*, and *frequency* (Williamson, 2008). Asset specificity refers to the degree an asset can be diverted to other uses. With high asset specificity, the bilateral dependency of the actors involved in a transaction increases along with the potential for opportunistic behavior (Carney, 1998). High risk of opportunism causes contractual arrangements to become expensive, difficult to enforce, and incomplete, forcing firms to implement activities in-house. In the presence of a certain level of asset specificity, high uncertainty requires administrative control and amplifies the trend toward hierarchical governance (David & Han, 2004). However, a number of studies argue that specifically high technological uncertainty encourages firms to remain flexible. Hence, specific types of uncertainty may also result in the need for flexibility that drives firms toward market governance (e.g., Balakrishnan & Wernerfelt, 1986; Folta, 1998; Geyskens et al. 2006). Furthermore, TCE considers the case that asset-specific transactions occur with a high frequency. If so, they require constant and intense monitoring efforts in the market and may be governed more efficiently in a hierarchy (Williamson, 1979).

The RBV takes an alternative perspective on governance structures in arguing that the sustained competitive advantage of a firm results from its individual and superior combination of resources (Barney, 1991). This reasoning implies that firms have largely heterogeneous resources, including all firm-owned assets, capabilities, and knowledge. The RBV suggests that firms are able to create and sustain a competitive advantage with *valuable*, *rare*, imperfectly *imitable* resources and an *organization* that is ready to exploit these resources (Barney, 1995). The concept of core competencies (Prahalad & Hamel, 1990) builds on the RBV and argues that resources which provide a sustained competitive advantage to a firm should not be outsourced to third parties.

It is common and widely accepted that the combination of TCE and the RBV enhances the understanding of the vertical boundaries of a firm (e.g., Hitt et al. 2016; Holcomb & Hitt, 2007; Jacobides & Winter, 2005). Williamson (1999, p. 1098) acknowledges that both theories deal with "partly overlapping phenomena" and emphasizes that firms need to consider their pre-existing strengths (core competencies) and weaknesses in addition to the efficiency of governance structures. Starting from such complementation, Conner and Prahalad (1996) and McIvor (2009) identify scenarios in which both theories stand in conflict. They suggest that given certain combinations of potential for opportunism and resource positions, TCE and the RBV may be contradictory and call for further research to identify real-world settings and gain insights into their implications for theory and practice. Our findings indicate that industrial AM is caught in exactly such a contradictory situation as we will demonstrate in the discussion of our results.

Broader literature in light of the theoretical lens

The broader OSCM literature on AM provides arguments that have implications for the AM make-or-buy decision. Table 1 summarizes these arguments and interprets them in the light of TCE and the RBV. When interpreted from a TCE perspective, the arguments speak in favor of outsourcing AM. On an aggregated level, this interpretation is based on the assessment of AM machines as general-purpose equipment, location-independence of AM, interchangeability of partners, and high technological uncertainty resulting from the emerging stage of AM. It must not go unnoticed, though, that the wider literature emphasizes adequate protection of firms' intellectual property (IP), which is a concern that comes with outsourcing. Considering arguments that relate to the RBV, the broader literature establishes the differentiation between the physical resources for additively manufacturing a part and the digital resources required for AM design activities. While the former argues in favor of outsourcing the manufacturing process, the latter suggests conducting design activities in-house.

Across the arguments raised in past research, we observe strong points for outsourcing AM activities, even though few aspects are mentioned that warrant in-house operations. Hence, the governance of AM appears to be a scenario wherein TCE and the RBV are mostly complementary, both arguing for outsourcing. However, this anticipation

TABLE 1 Aggregated arguments from the broader OSCM literature on AM

Topic	Arguments with implications for the AM make-or-buy decision	Key references	Interpretation with the theoretical lens
General-purpose equipment	AM machines are inherently flexible to manufacture different designs (no product-dependent setup and tooling)	Holmström and Partanen (2014), Hedenstierna et al. (2019), Chen et al. (2021)	TCE: The general-purpose equipment for AM suggests low physical asset specificity
	The investment in AM machines is not specific for any customer or product	Scott and Harrison (2015), Hedenstierna et al. (2019)	
	AM service bureaus can easily achieve economies of scale at fixed setup costs (e.g., for machine warm-up) by maximizing the utilization of AM machines with pooling orders from multiple customers	Holmström et al. (2010), Gibson et al. (2015), Sasson and Johnson (2016), Baumers et al. (2016), Öberg (2019)	
Location-independence	Low location requirements for the AM process (ideally only the AM machine and a single basic raw material are necessary at the manufacturing location)	Mellor et al. (2014), Durach et al. (2017), Chan et al. (2018), Verboeket and Krikke (2019), Tziantopoulos et al. (2019)	TCE: The location-independence of AM suggests low manufacturing site specificity, but providing a secure digital infrastructure is a practical challenge
	Transportable AM machines with low space requirements; AM facilitates outsourcing to AM service bureaus close to the point of demand	Eyers and Potter (2015), den Boer et al. (2020), Kumar et al. (2020), Westerweel et al. (2021)	
	Digitally encapsulated product specifications can be seamlessly stored, transferred, and shared with partners	Berman (2012), Baumers and Holweg (2019), Hedenstierna et al. (2019)	
	AM requires secure and robust information and communication technology for adequate IP protection	Yampolskiy et al. (2014), Holland et al. (2018), Lacity (2018), Kurpjuweit et al. (2021)	
Interchangeability of partners	Required know-how for the AM process is not specific	Chekurov et al. (2018), Verboeket and Krikke (2019)	TCE: The interchangeability of partners for AM suggests low human asset specificity
	Manual intervention for pre- and post-processing is currently necessary; future increase in automation is expected to further reduce the requirements	Khajavi et al. (2014), Roca et al. (2019)	
	No dependency on the AM expertise and skills tied to AM service bureaus; partners become interchangeable which facilitates flexible, short-term outsourcing relationships	Holmström et al. (2016), Zijm et al. (2019), Meyer et al. (2021)	
Emerging stage	High risk of obsolescence associated with the novelty of AM technologies; requires cautious investments in in-house equipment	Rogers et al. (2016), Hedenstierna et al. (2019)	TCE: The emerging stage of AM suggests high technological uncertainty
	Uncertain investment in in-house AM is a burden especially for SMEs	Strong et al. (2018)	
	Outsourcing allows manufacturing firms to access AM without initial high and uncertain investments (e.g., for AM machines, equipment, training of operators)	Conner et al. (2014), Mellor et al. (2014), Ford and Despeisse (2016), Rogers et al. (2016)	

(Continues)

TABLE 1 (Continued)

Topic	Arguments with implications for the AM make-or-buy decision	Key references	Interpretation with the theoretical lens
Digital nature	Ease of sharing, modifying, and reusing digital files enabled by AM reduces the costs of monitoring a single transaction	Berman (2012)	TCE: The digital nature of AM suggests low dependency on transaction frequency
	Flexible integration of new outsourcing partners; on an occasional or recurrent basis as long as the digital design file is available	Ruffo et al. (2007), Delic and Eyers (2020)	
Available production skills and knowledge	Easy-to-acquire skills and knowledge for additively manufacturing a part	Ben-Ner and Siemsen (2017), Chekurov et al. (2018), Fontana et al. (2019)	RBV: Available production skills and knowledge suggest that no competitive advantages are obtained with additively manufacturing a part
	Little labor input for the manufacturing process	Gibson et al. (2015), Chan et al. (2018)	
	Accessibility of AM for firms without prior manufacturing background (e.g., logistics service providers and retailers)	Holmström and Partanen (2014), Durach et al. (2017), Arbabian and Wagner (2020), Chen et al. (2021)	
	Low market entry barriers for AM service bureaus	Rogers et al. (2016), Ford and Despeisse (2016), Holmström et al. (2016)	
Rare design and software skills and knowledge	Importance of digital assets and competencies for AM; focus on AM design/engineering and software skills	Rylands et al. (2016), Holmström et al. (2016), Massimino et al. (2018), Ben-Ner and Siemsen (2017)	RBV: Rare design and software skills and knowledge suggest that competitive advantages are obtained with designing a part for AM
	Knowledge and skills for AM design are rare; a novel set of skills and rethinking of traditional design are necessary	Mellor et al. (2014), Thomas-Seale et al. (2018)	
	AM service bureaus are experienced and capable of offering design-related services coupled with manufacturing services	Rogers et al. (2016), Chaudhuri et al. (2019)	
Core competencies	Outsourcing of the AM process is an opportunity to specialize and concentrate on core competencies other than AM	Ruffo et al. (2007), Rogers et al. (2016), Holmström et al. (2017), Manda et al. (2018)	RBV: If AM does not affect core competencies, it should be outsourced

contrasts with prominent examples of in-house AM in industry (e.g., General Electric and Daimler Buses). We start from this thought to identify AM make-or-buy decision profiles of manufacturing firms and investigate their rationales for selecting these profiles with a MRT approach.

METHODOLOGY

Research design

Our MRT research design builds on the *mechanism + context = outcome* framework as it aims at generating a context-specific understanding, following Stank et al. (2017) and Pellathy et al. (2018). This study is positioned in the growing research field of industrial AM with a need for exploration. It makes use of TCE and the RBV to investigate rationales for make-or-buy decisions in this specific empirical context. We opted for a case study approach that allowed us to explore the novel phenomenon of AM make-or-buy decisions and to continuously interact between TCE, the RBV, and our context-specific data. This constitutes an abductive approach, as suggested by Ketokivi and Choi (2014). We chose a multiple-case, holistic case study design (Yin, 2014). Multiple cases enabled us to draw comparisons, increase the abstraction level, and derive more robust and grounded insights (Eisenhardt & Graebner, 2007).

We defined manufacturing firms, both for components and end products, as our units of analysis as they are confronted with make-or-buy decisions for AM. We aimed at building a deep understanding of the make-or-by decision mechanism directly from the perspective of manufacturing firms. Furthermore, we opted to enhance this understanding by extending and refining the case insights with industrial AM domain knowledge collected from AM-specific supply chain actors. Data collected from the AM domain provided us a rich background and nuanced, context-specific understanding to balance and reflect our case study findings.

Case selection

We embedded our study in the context of industries with challenging industrial AM needs. Hence, we focused on regulated industries with high safety concerns, including rail and road transportation, aerospace, and machinery and equipment. All firms involved in our study are located in Europe; mostly Germany. According to Wohlers Associates (2021), Germany is recognized as a strong contributor to the AM industry, with prominent producers, especially for metal AM systems, being located in Germany. To identify suitable firms, we conducted web searches and contacted a large AM industry network.

We applied replication logic to carefully select the cases of manufacturing firms. Since we focused on the two polar governance choices (market vs. hierarchy), we chose manufacturing firms that we expected to contribute to the emergence of contrasting (theoretical replication) patterns of AM make-or-buy decisions (Eisenhardt & Graebner, 2007; Siggelkow, 2007; Voss et al. 2002). Moreover, we used snowball sampling—namely, following up on interviewees' recommendations—to purposefully integrate cases with extensive experience in industrial AM that we expected to share rich insights into AM make-or-buy decisions, as suggested by Pratt (2009) and Small (2009). The final sample consists of 12 cases of component and end-product manufacturers. All firms are involved in AM and willing to share their insights. As sharing success is easier than sharing failure, we may well over-represent successful AM implementation attempts. Furthermore, the sample contains ten large firms and two SMEs, as a reflection of the novelty of the market (Evangelista et al. 1997; Marzi et al. 2018). Table A1 includes further information on the cases.

In addition, we selected 14 firms from the AM domain based on their competitive positions in the nascent industrial AM market. These included eight potential suppliers of manufacturing firms for in-house AM (i.e., AM machine manufacturers, AM material suppliers, and AM software and platform providers), four AM service bureaus as predestined outsourcing partners for AM, and two AM industry experts, all detailed in Table A2.

Data collection

We collected data via semi-structured interviews between February 2019 and April 2020. Following Dubois and Gadde (2002), we abductively developed an interview protocol (see Appendix B) based on the extant literature on AM and first observed AM implementations from industry. As our main interest rests in manufacturing firms' AM make-or-buy decision and rationales, our interview protocol focused on these topics. We initially developed the interview protocol for our primary interviews with manufacturing firms. As we progressed in our case study, we started to conduct context-specific interviews with actors from the AM domain and successively adapted the interview protocol to their perspectives. All interviewees had to be directly engaged with AM and hold a management position that allowed them to contribute to their firms' AM make-or-buy decisions or reflect as AM-specific actors on such decisions from a strategic perspective.

Interviewees were contacted via e-mail and/or phone. A letter of introduction was sent to the interviewees in advance (Yin, 2014), allowing them to prepare for the interview. We conducted one in-depth interview per firm generally with a single interviewee (see Appendix A). In light of the current emerging stage of industrial AM, we are convinced that we identified key informants in the selected firms. The interviews lasted between 30 and 90 min (51 min on average). Fifteen interviews were conducted face to face at the firms' locations, and 11 interviews were conducted via phone or video call. Two authors were present during seven interviews to increase the conformity of their interview techniques; the authors conducted the other interviews individually. Moreover, some of the interviewees provided additional documents (see Appendix A), which we used, along with supplemental data from publicly available sources (firms' websites, press releases, and articles), to triangulate the interviews.

Data analysis

The interviews were recorded, transcribed by the authors, enriched with data from secondary sources, and stored in a case study database. The transcripts were sent to the interviewees to verify the content and to rule out misunderstandings and misinterpretations and were revised if necessary by the authors. The iterative data analysis process overlapped with data collection. In total, we analyzed 419 single-spaced pages of interview and supplemental data applying the three fundamental types of coding from grounded theory—open, axial, and selective coding according to Corbin and Strauss (2015). Two authors conducted the data analysis independently using the qualitative data analysis software MAXQDA. Coding was discussed extensively among the authors, and conflicts were resolved. The described coding approach allowed us to gradually increase the level of abstraction while shifting from analyzing the individual make-or-buy decisions of each manufacturing firm to analyzing across all our cases to gain an in-depth and reflective understanding of their rationales. In this way, decision patterns emerged from multiple steps of analysis and multiple perspectives, in line with what Eisenhardt (1989) proposes for within- and cross-case analysis.

To be more specific, we identified 31 individual make-or-buy decisions by the manufacturing firms and we found three dimensions characterizing these decisions: the pursued strategy (*in-house*, *outsourcing*, *mixed*), the maturity level of the make-or-buy decision (*tentative*, *established*), and the AM application with its associated quality requirements (*new parts*, *spare parts*, *prototyping and tooling*, *education and research*). In addition, we distinguished the applications with respect to the materials (*metal* (*M*), *polymer and others* (*P*)) since metal AM is oftentimes considered to be more technologically challenging than polymer AM. We classified the identified make-or-buy decisions according to the three dimensions as illustrated in Figure 1. Note that the firms commonly make various complementary AM make-or-buy decisions, for instance, for multiple products or business divisions. By graphically comparing similar and contrasting characteristics (see Figure 1), we arrived at four distinct AM make-or-buy decision profiles of manufacturing firms and used them to structure the results of our within-case analysis.

Following this classification, we developed a conceptual framework across all cases that enabled us to capture the rationales for AM make-or-buy decisions and investigate the explanatory power of TCE and RBV arguments in the context of industrial AM. In doing so, we followed a top-down MRT approach, as suggested by Craighead et al. (2016). We started with general TCE and RBV arguments and used our collected data to substantiate how the industrial AM context modifies the general arguments. In this phase of the analysis, the additional data collected from AM-specific actors was essential to recognize nuances and deepen our contextual understanding of the rationales.

Throughout the process of case selection, data collection, and data analysis, we accounted for rigorous case study design (see Table 2), commonly assessed with four criteria: internal validity, construct validity, external validity, and reliability (Cook & Campbell, 1979; Gibbert et al. 2008).

FINDINGS

We first present the four make-or-buy decision profiles of manufacturing firms (within-case analysis) before investigating across all cases the rationales leading to the observed behavior in light of TCE and RBV arguments (cross-case analysis).

Make-or-buy decision profiles of the manufacturing firms

We identified four make-or-buy decision profiles covering the spectrum of manufacturing firms' behavior for industrial AM: *Pioneers*, *Combiners*, *Planners*, and *Waverers*. Figure 2 positions the four profiles according to the three derived dimensions with a focus on the pursued strategy (in-house, outsourcing, mixed). The following discusses the characteristic behavior of each of the four profiles individually.

Pioneers and *Combiners* characterize manufacturing firms that homogenously pursue established strategies. Their governance choices appear to be deliberate and focused on demanding AM applications with high-quality requirements (see Figure 2). *Pioneers* are end-product manufacturers that substitute traditional manufacturing steps with AM. These firms benefit from their early entry into the AM market and operate at the edge of technology by focusing on utilizing AM for the serial production of new parts. Pioneers have identified AM use cases, built the necessary design and manufacturing skills in-house, and are beginning to implement standard processes for AM. These firms now additively manufacture some parts in-house that used to be traditionally outsourced, thereby increasing vertical integration. Based on their expertise and reputation, Pioneers have also established third-party AM businesses dedicated to winning new customers. As of now, Pioneers do not intend to outsource AM in the future.

Combiners benefit from combining both in-house AM and outsourcing for specific applications—that is, they apply a make-and-buy strategy. Jacobides and Billinger (2006, p. 249) coined the term "permeable vertical boundaries" for this type of strategy. Besides one SME from the aerospace industry (C8), Combiners consist of large component manufacturers (see Appendix A). These firms rely on extensive experience in industrial AM and have recorded increased vertical integration due to AM. By orchestrating secure firm-owned networks of AM machines and developing specialized units for AM, Combiners demonstrate high integration of AM in their organizations. We observed that Combiners' in-house capacity is reserved for demanding IP-sensitive applications, whereas they outsource to selected, audited AM service bureaus to gain access to specialized and/or rare AM technologies or to overcome peaks in demand that exceed their own AM machine capacity. Combiners plan to expand the mixed strategy in the future. Long-term collaboration with AM service bureaus, just as it is common with traditional suppliers, is their aspired goal for expanding the mixed strategy.

In contrast, *Planners* (partly) and even more so *Waverers* (entirely) represent cases that pursue tentative strategies mostly for AM applications with medium- and low-quality requirements. Their AM make-or-buy decisions are not fully developed yet; therefore, Figure 2 shows their status quo and future intentions. *Planners* are end-product manufacturers focused on outsourcing AM. They have established initial relationships with AM service bureaus for pilot applications, but the current use cases do not affect Planners' core business yet. Nevertheless, Planners already have (E1) or are in the process of successively implementing transaction routines (E4) with their initial partners (e.g., for outsourcing metal samples). The initial partners were commonly approached based on geographic proximity or a very preliminary search. However, Planners have a clear vision of establishing strategic outsourcing relationships once their value-creating AM applications are fully identified. They plan to carefully select AM service bureaus for serial production using a tendering process. We further observed Planners' intention to complement outsourcing with in-house AM in the future. Specifically, they initially invested in polymer 3D printers to gain experience and then build their in-house AM expertise from there. Thus, Planners may well develop a mixed strategy in the future.

Waverers are smaller component manufacturers than Combiners (see Appendix A). These firms have only recently started AM implementation and pursue a tentative mixed strategy. Apart from prototyping, these firms have not (yet) decided to permanently outsource AM. Waverers work with AM service bureaus on pilot studies, often combined with consultancy for use-case identification and (re)design for AM. Such initial collaborations may be hindered by financial and time constraints. For example, one component manufacturer indicated, "We did a training with an AM service bureau to qualify our staff in assessing parts for AM, but it was a bit too expensive and time-consuming." Furthermore, Waverers might invest in

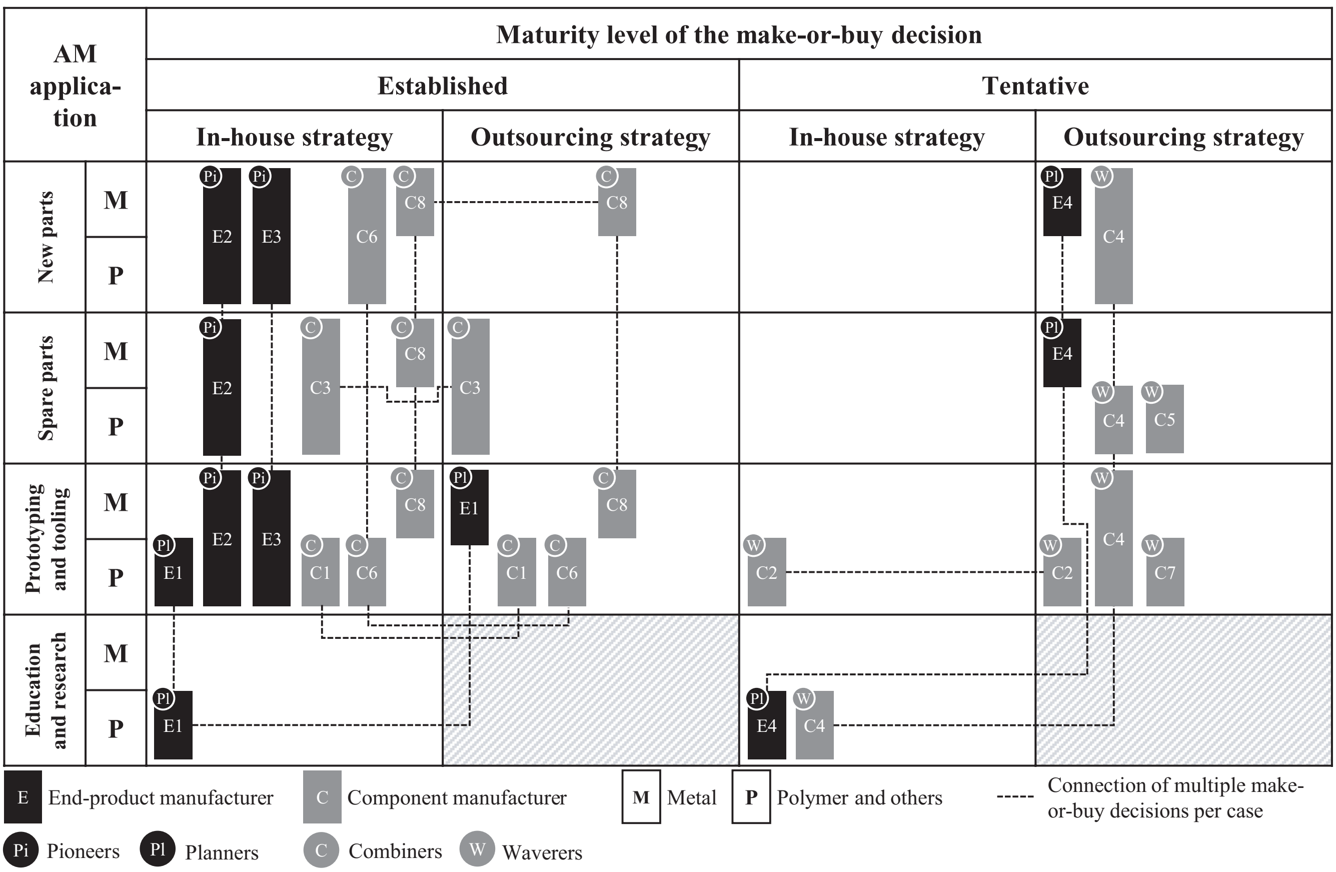

FIGURE 1 Classified make-or-buy decisions of the manufacturing firms

in-house polymer 3D printers for education purposes and to build trust and acceptance, but they believe developing in-house expertise for demanding applications is not currently feasible. Their reluctance to in-house AM is partly based on disappointing first AM experiences. For instance, one of the Waverers reported that profitable in-house AM for their customers failed, leading to a stagnated usage of the AM machine for internal purposes and no further involvement in AM. Hence, we found Waverers to consider an AM outsourcing strategy as a future direction.

Overall, the four profiles suggest a broad spectrum of governance choices among the manufacturing firms in our sample. All the interviewees from manufacturing firms reflected and argued that their strategy was suitable for their specific situation. Pioneers and Combiners *actively* increase their vertical integration in the transition from traditional manufacturing technologies to AM. Moreover, Combiners benefit from in-house AM and outsourcing. While their demanding IP-intensive applications are governed by hierarchy, more diverse and less demanding (polymer) applications are governed by both, hierarchy and market, with carefully selected outsourcing partners. Combiners and Planners already have or intend to develop long-term outsourcing relationships with qualified partners, which is similar to traditional manufacturing. Waverers tend to outsource AM although they are hesitant to commit to a permanent AM governance structure, partly due to financial constraints and unfulfilled expectations for initial in-house AM attempts.

Framework for additive manufacturing make-or-buy decisions

As a next step of the analysis, we reviewed the perspectives collected across the cases to develop a framework outlining the rationales for AM make-or-buy decisions. For the framework development, we considered the domain knowledge provided by the AM-specific actors. Overall, we extracted multiple consistent influence factors and structured them on two levels, as presented in Figure 3. General factors directly lead to the AM make-or-buy decision, and the manufacturing firms' viewpoints can be explained using TCE and RBV argumentation. The general factors include *core competencies*, *IP concerns*, *capacity and skill investment*, and *dependency*. What is more, we observed contextual factors that are specific for AM as emerging digital manufacturing technologies: the *digital product specifications* and *emerging stage of AM*. The contextual factors do not affect the make-or-buy decision directly but do alter firms' emphasis on and understanding of the general factors. In the following discussion, we analyze the effect of the general factors and develop propositions on how the contextual factors modify manufacturing firms' perception of the general factors when it comes to the AM make-or-buy decision. In addition, we reflect the applicability for the four identified make-or-buy decision profiles.

Core competencies

General effect

Interviewees pointed out that radically different and innovative design skills are required to realize the potential of AM supporting literature-based reasoning (see Table 1) on manufacturing firms' digital resource position (e.g., Rylands et al. 2016; Thomas-Seale et al. 2018). For example, one component manufacturer shared, "I see design as the value-creating process because all the know-how is linked to design." As suggested by Mellor et al. (2014), the interviewees emphasized that engineers with experience in traditional manufacturing need to acquire new skills for AM design; thus, investments in education for building AM capabilities are required.

Following Prahalad and Hamel (1990) and the RBV logic, the interviewees stressed that they would not be willing to outsource AM design activities that are considered core competencies. We observed that the firms generally do not consider traditional design to be a core competency but tend to consider AM design to be such a competency. Indeed, AM design capabilities are a source of sustained competitive advantage, particularly when design improvements (e.g., lightweight structures, complex geometries, or increased functional integration) are achieved. One component manufacturer pointed out, "The competencies for AM design are rare, and that is why you can differentiate from the market." Following the RBV argumentation, manufacturing firms develop and use design capabilities internally.

Contextual modification by digital product specifications

Digital product specifications are central to the AM process. Indeed, the manufacturing firms reported that all their AM knowledge and expertise are encapsulated in digital files. We observed that the perceived relevance of digital product specifications affects the manufacturing firms' core competencies. For example, an end-product manufacturer explained, "The game is decided more on digital than on physical soil." In other words, digital product specifications have led the firms to reevaluate their core competencies.

Most notably, the interviewees emphasized that digital product specifications contain not only design files but also specific AM material and manufacturing-process

TABLE 2 Quality measures

Criterion	Fulfillment	Recommendations from the literature	Measures implemented in this study
Internal validity	Plausible causal relationships and logical reasoning are sufficient to defend research conclusions (Gibbert et al. 2008)	Clear research framework (Yin, 2014) and discovery of underlying theoretical reasons (Eisenhardt, 1989)	Focus on the two polar governance structures (market vs. hierarchy); navigation within TCE and the RBV as grand theories to elaborate context-specific aspects of make-or-buy decisions for industrial AM (MRT approach)
		Pattern matching of empirically observed patterns and predicted or established patterns in previous studies (Eisenhardt, 1989)	Positioning of findings in the extant OSCM literature, as derived in the background section
Construct validity	Data-collection process leads to the accurate observation of reality (Denzin & Lincoln, 2017)	Clear chain of evidence (Yin, 2014)	Review of transcripts by authors and verification by interviewees; transcript revision by authors; coding and intensive discussion of codes among authors; classification and framework development based on the coded data
		Data triangulation — use of different data-collection strategies (Yin, 2014)	Collection of data about the cases of manufacturing firms from multiple sources (12 semi-structured interviews); triangulation with internal data and supplemental data (firms' websites, press releases, and articles)
External validity	Case study allows for analytical generalization from observations to theory (Gibbert et al. 2008; Yin, 2014)	Cross-case analysis of multiple cases (Eisenhardt, 1989) or a nested approach of multiple cases within a firm (Yin, 2014)	Analysis of multiple cases of manufacturing firms with a transparent and identical approach; classification of the individual behavior of manufacturing firms to four distinct AM make-or-buy decision profiles (within-case analysis) and investigation of the rationales across the cases (cross-case analysis)
		Reasoning for case study selection and details on the context (Cook & Campbell, 1979)	Scarcity of previous work on the AM make-or-buy decision and resulting need for exploration; embedding of case study in industries with an expected need for industrial AM and a broad spectrum of make-or-buy decisions; additional collection of data from actors from the industrial AM domain to reflect the case-study findings and develop a context-specific understanding
		Replication logic (Yin, 2014)	Selection of cases for predicted contrasting AM make-or-buy decisions; complementation with a snowballing approach

(Continues)

TABLE 2 (Continued)

Criterion	Fulfillment	Recommendations from the literature	Measures implemented in this study
Reliability	Absence of random errors (Gibbert et al. 2008) and repeatability of results (Lincoln & Guba, 1985)	Transparency by documentation (Yin, 2014)	Development of an interview protocol and standardized data-collection and storing process
		Replication by storing processed data in a case study database for later retrieval (Yin, 2014)	Use of the software MAXQDA to store the case study data and development of a coding system

information (e.g., layer thickness, speed, and manufacturing temperature). As an extension of previous work (e.g., Holmström et al. 2016; Rylands et al. 2016; Thomas-Seale et al. 2018), we found that valuable, rare, and highly protected digital design resources for AM only facilitate superior-quality AM parts when they are combined with capabilities to develop AM materials, and AM machine process parameters. In this vein, one component manufacturer highlighted, "If I have ingenious designs […] they usually only work in combination with a material and process parameters which I also develop." Similarly, an end-product manufacturer shared, "If you qualify and certify materials for AM parts, then it is, of course, core know-how." Thus, manufacturing firms consider the combination of design, material, and process information to be core competencies for AM.

Following the RBV line of argumentation, this reevaluation of core competencies indicates that hierarchical governance is superior for not only AM design but also for manufacturing activities. The central argument for such full internalization of design and manufacturing activities is that the required material and process expertise can only be developed with extensive experience with in-house equipment, foremost with AM machines. Thus, our observation contrasts with the OSCM literature which emphasizes that outsourcing the AM process is a suitable means to specialize and concentrate on core competencies other than AM (e.g., Holmström et al. 2017; Manda et al. 2018; Rogers et al. 2016; Ruffo et al. 2007). In sum, our interviewees strongly indicated the need to interweave digital and physical resources for pursuing AM in-house.

> Prop. 1.1: Digital product specifications of an AM part represent a core competency for a manufacturing firm because value-creating design and rare machine expertise in material and process parameters are combined. Exploiting the full potential of AM encapsulated in digital product specifications, requires mastering activities in the digital and physical domain, thus, internalizing the AM design and manufacturing process.

This rationale applies to Pioneers and Combiners. It is not relevant for manufacturing firms whose core business is not (yet) impacted by AM (Planners) or for firms pursuing tentative strategies for less demanding applications (Waverers).

Intellectual property concerns

General effect

The majority of the manufacturing firms perceived IP protection for AM to be a practical challenge, in line with literature-based reasoning (e.g., Kurpjuweit et al. 2021; Yampolskiy et al. 2014). In particular, manufacturers with established AM governance structures and demanding applications assessed existing IP-protection systems to be insufficient, leaving them exposed to a high risk of copying and counterfeiting. Indeed, one component manufacturer commented, "Sure, you can protect yourself with all kinds of non-disclosure and cooperation agreements […] but how can I ensure that the supplier does not start a spare parts business?" These IP concerns brought forward by the majority of the manufacturing firms are a straightforward TCE example of firms' fear of opportunistic behavior by their outsourcing partners. With perceived uncertainty in this domain, the manufacturing firms are unsure how to secure their IP beyond trust and standard development contracts. As a result, potential opportunism increases the need for firms to monitor transactions closely (Williamson, 2008), which can be avoided by in-house AM.

In contrast, we also encountered the opposite viewpoint among actors from the AM domain and component manufacturers tentatively considering AM make-or-buy decisions. These interviewees argued that IP concerns are exaggerated and emphasized that contractual terms and existing IT security technology can effectively protect IP. As such, blockchain technology has been proposed by these interviewees and by the literature (e.g., Holland et al. 2018; Kurpjuweit et al. 2021; Lacity, 2018) as a way to simplify secure AM outsourcing.

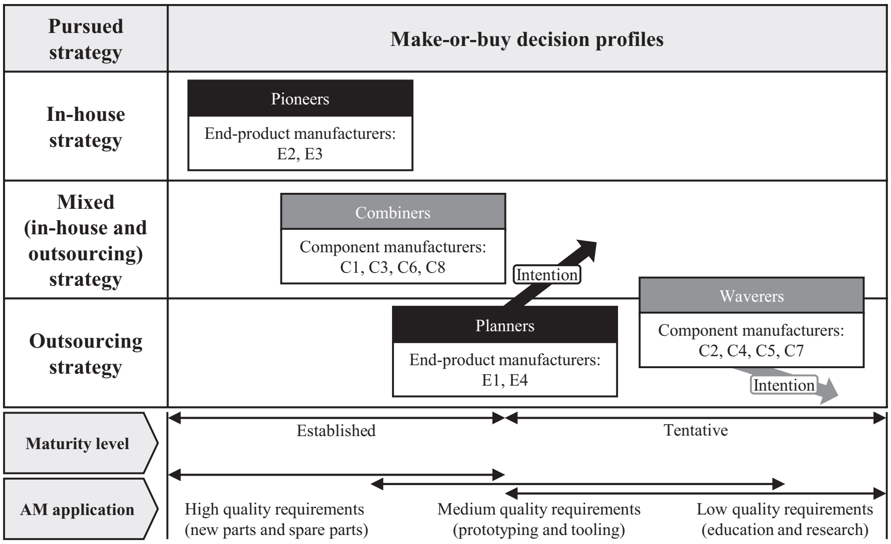

FIGURE 2 AM make-or-buy decision profiles of the manufacturing firms

Contextual modification by digital product specifications

Unambiguous digitally encapsulated design, material, and process specifications can be shared with partners seamlessly, facilitating location-independent manufacturing (e.g., Baumers & Holweg, 2019; Hedenstierna et al. 2019). Previous work expects this advantage to be a cornerstone of outsourcing AM (see Table 1), arguing that the ability to seamlessly transfer specifications lowers transaction costs, following the TCE logic (Berman, 2012). However, we observed that the manufacturing firms perceived the presumed advantage of easily sharing and distributing digital files as a source of increased risk of IP loss and, thus, as a barrier to outsourcing. The fear of copying and counterfeiting appears more pronounced for digitally encapsulated AM parts than for traditionally manufactured "analog" parts.

In line with Massimino et al. (2018), we conjecture that the digital encapsulation of AM itself enhances this fear—that is, it enforces general IP concerns and argues for hierarchical governance from a TCE perspective. For instance, one end-product manufacturer shared, "AM is a digital manufacturing technology. Everything digital is easy to copy." The manufacturing firms explained this rationale of increased IP concerns by arguing that copying traditionally manufactured parts is substantially more time-consuming and costlier (e.g., for required tools and specialized machines) than copying digital AM parts. One tentative explanation is that copyright violations are omnipresent for everyday digital consumer products, such as online music, software, and video games (Appleyard, 2015; Kietzmann et al. 2015; Lan et al. 2020), and firms may be extending this fear to AM.

> Prop. 1.2: Digital product specifications in AM increase manufacturing firms' IP concerns due to the ease of distributing and sharing digitally available information. The resulting fear that AM is an easy target for copying and counterfeiting strongly argues for in-house AM.

Pioneers and Combiners are particularly concerned about losing their digitally specified IP in AM. Planners only express it with respect to their intention of outsourcing AM parts affecting their core business in the future. Waverers have not yet obtained significant IP worth protecting; consequently, they have no concerns in this regard. Finally, the actors from the AM domain do not differentiate between digital encapsulation and "analog" availability of sensitive information and, thus, have limited concerns. One AM platform provider drew a noteworthy comparison, "If I outsource milling jobs, I can also outsource AM jobs. I do not see any difference."

Contextual modification by the emerging stage of AM

From a technological perspective, emerging AM technologies have not yet reached full automation. To date, manual pre- and post-processing and in-depth knowledge of AM machines and materials are necessary to obtain high-quality parts. The manufacturing firms expect increased automation of the AM process with maturity suggesting low human asset specificity, as also predicted by the literature (see Table 1) (e.g., Khajavi et al. 2014; Roca et al. 2019). With that, manufacturing can be unambiguously specified digitally, and the interviewees fear that with properly specified AM material and machine parameters, operating AM machines will become increasingly feasible for non-specialists. Literature-based reasoning positions such potential accessibility of AM for firms outside the industry context as an advantage of outsourcing and an impetus for new business models of actors without manufacturing background like logistics service providers and retailers (e.g., Arbabian & Wagner, 2020; Durach et al. 2017; Holmström & Partanen, 2014). Low market-entry barriers are expected to allow manufacturing firms to outsource to multiple AM service bureaus (Ford & Despeisse, 2016; Holmström et al. 2016; Rogers et al. 2016).

In contrast, the manufacturing firms in our interviews expressed fear of new competitors with limited industry knowledge but expertise in the digital domain (e.g., with extensive engineering skills) entering the market. With that in mind, one component manufacturer highlighted, "You can look at AM parts in an abstract way, and that opens the door for new players." The manufacturing firms feel threatened by competitive pressure while there is uncertainty about which firms will succeed once the AM industry stabilizes, as it has been observed in other nascent markets (Folta, 1998). This rationale has resulted in skepticism and limits trust in young relationships. As one component manufacturer put it, "Customers turn into competitors."

Consequently, we noted the manufacturing firms' fear of working with AM service bureaus or customers that may use obtained knowledge to support their own independent activities. Thus, sharing knowledge is a barrier in the emerging AM industry; in other words, with potential exposure to opportunism, general IP concerns increase and foster hierarchical governance. We observed this rationale for firms with established AM strategies and substantial IP in AM, that is Pioneers and Combiners, and incipiently for Planners.

> Prop. 2.1: The emerging stage of AM increases manufacturing firms' IP concerns due to their fear of actively creating new entrants to the market. Resulting barriers of sharing knowledge and limited trust in young relationships enhance the perceived risk of opportunism, arguing for in-house AM.

Capacity and skill investment

General effect

AM machines require substantial investments, particularly for metal AM. The manufacturing firms pointed out that these financial investments are a burden for SMEs due to their limited financial leeway, as predicted by Strong et al. (2018). In response, AM machine manufacturers emphasized that they offer customized short-term leasing models to overcome this barrier. Once operational, the AM machine needs to be highly utilized in order to run efficiently and we observed that generating sufficient demand is a challenge for the majority of the manufacturing firms. AM service bureaus are in a superior position to pool orders, as suggested by our interviewees and the literature (see Table 1) (e.g., Baumers et al. 2016; Öberg, 2019; Sasson & Johnson, 2016).

However, manufacturing firms disagreed with the claims in the literature that AM requires little labor input (e.g., Chan et al. 2018; Gibson et al. 2015) and that production know-how for industrial AM is relatively easy to acquire (e.g., Ben-Ner & Siemsen, 2017; Chekurov et al. 2018; Fontana et al. 2019). To the contrary, operating an AM machine today requires specialized know-how and a wealth of experience. Thus, investments in AM include not only AM machines but also associated costs for personnel training (i.e., to operate the machines), manual pre- and post-processing, maintenance, and repair. The AM machine manufacturers emphasized in our interviews that starting to operate an AM machine is all about experimenting with the machine, often through a trial-and-error approach, stressing that there is no "plug and play" with these machines. In line with this, an AM industry expert shared with us that it takes about nine to 12 months of adjustments until an AM machine operates reliably.

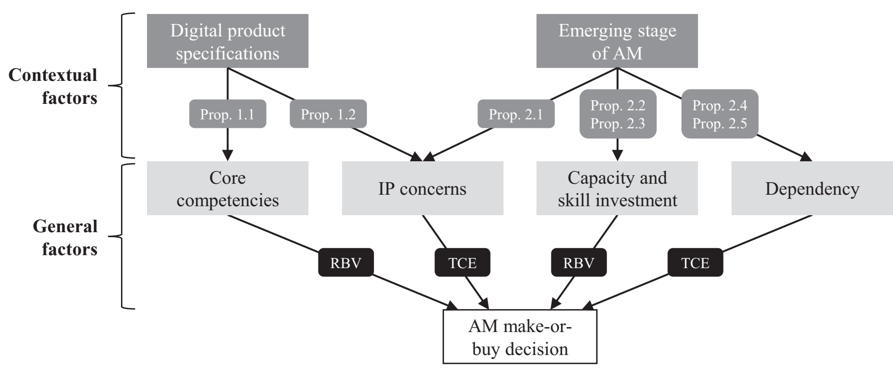

FIGURE 3 Contextual and general factors influencing AM make-or-buy decisions

As a consequence, sufficient demand, capacity investments, and intensive skill and know-how development are necessary to operate an AM machine efficiently. These requirements put specialized providers—namely, AM service bureaus—in a stronger resource position than manufacturers. Öberg (2019) finds that AM service bureaus create such imbalance of resource positions to prevent being outperformed by manufacturing firms. Following Barney (2013), AM service bureaus thus have a competitive advantage over manufacturing firms for AM.

Contextual modification by the emerging stage of AM

The nascent AM market constantly brings technological development that could potentially render existing machines obsolete. Existing literature acknowledges such high technological uncertainty (Conner et al. 2014; Ford & Despeisse, 2016; Mellor et al. 2014). Hence, the manufacturing firms are afraid to invest in specific AM technologies as technological development may outpace the depreciation of the machines. This scenario would either decrease the firms' returns on their AM investments or reduce the utilization of potentially outdated machines. For example, an AM software provider explained, "We have incredibly fast technological development. This means that the machines need to be depreciated in two or three years [or else] they are not state of the art anymore." From a TCE perspective, with respect to technological uncertainty, the high risk of obsolescence is governed efficiently by the market as this governance structure allows manufacturing firms to terminate relationships and flexibly switch to partners with "updated" technological capabilities. In doing so, they avoid being locked in to an obsolete technology (Balakrishnan & Wernerfelt, 1986; Geyskens et al. 2006).

Despite the risk of obsolescence and the general reasoning for a weak resource position, the manufacturing firms often internalize AM. We observed that senior management's high enthusiasm for emerging AM technologies affects the AM implementation process. Often, senior management believes in the potential of AM, as reflected in the firms' willingness to take higher risks for AM machine investments than for investments in traditional manufacturing equipment. In this vein, one end-product manufacturer shared, "We have the support of the board. 100% capacity utilization is not required. At 50%, we already get the 'go' to buy an AM machine." Our interviewees from the AM domain interpret senior management's risk-seeking as over-enthusiasm for AM. They judge that manufacturing firms may invest too quickly in AM machines with inflated expectations and no clear perspective on potential applications. For instance, an AM service bureau commented, "There is extreme hype about AM. In my opinion, it is a bit of a bubble. AM is a manufacturing technology, but it is not a panacea for all technical problems."

Thus, we propose that the high expectations for AM outweigh the reasoning based on the high risk of technological obsolescence and the current weak resource position. We observed multiple such situations among Waverers. This rationale also applies partly to Planners as they indicate a willingness to accept financial risks for their initial in-house AM investments.

> Prop. 2.2: The emerging stage of AM inflates senior managements' expectations for AM. Thereby, it leads manufacturing firms to make risky investments in in-house AM despite a weaker resource position than AM service bureaus and the risk of technology obsolescence.

Possessing in-house AM machines allows manufacturing firms to learn and to gain engineers' acceptance for AM. Hopkinson et al. (2006) point out that firm culture needs to adapt to AM; convincing engineers is perceived important on this path by our interviewees. Furthermore, gaining AM experience early could help firms outpace their competitors. The manufacturing firms in our interviews expect that building internal expertise before the market stabilizes or consolidates may safeguard their positions and become a market-entry barrier as the industry matures. In addition, outsourcing to AM service bureaus complicates or even prevents a later market entry. One component manufacturer emphasized, "As the customer of an AM service bureau, you learn nothing or only very little. And that is why you are not well prepared to buy an AM machine in the future."

Thus, as a central rationale, the manufacturing firms fear that outsourcing prevents internal learning. Moreover, they believe that investing in developing AM production know-how today is a way to prepare so they can create a future first-mover advantage. For instance, one medium-sized component manufacturer explained, "If we deal with AM today, we are well prepared to serve this [...] market tomorrow." This rationale is grounded in uncertainty about the future value of AM. Due to the newness of AM, the manufacturing firms are still scouting to determine if and how AM can generate a competitive advantage in the future. As a result, they respond to the uncertainty with ad hoc trial-and-error learning (Folta, 1998). In a similar vein, Dattée et al. (2018, p. 467) relate such early commitment to "fear of missing the train." Pioneers and Combiners apply this rationale to justify their early market entry. Furthermore, we observed this rationale currently for Planners' intention to combine outsourcing with in-house AM in the future.

> Prop. 2.3: The emerging stage of AM drives manufacturing firms to build their AM production know-how in-house to facilitate learning and fill experience gaps before the market stabilizes. Hence, prospects of first-mover advantages prompt manufacturing firms to strengthen their weak resource positions by investing in equipment and skill development.

Dependency

General effect

Initial outsourcing partners for AM are commonly selected by coincidence or based on their geographical proximity. The latter allows for fast coordination and personal contact, which jointly create trust. Trust is necessary in particular when more demanding AM applications are outsourced and manufacturing firms depend on the quality of parts provided by AM service bureaus. To protect themselves, the manufacturing firms implement supplier-management strategies to cope with dependency. We observed that for demanding applications, the firms carefully select, qualify, and assess AM service bureaus through an in-depth process. For instance, a component manufacturer with an established outsourcing strategy highlighted, “AM service bureaus are audited, selected, [...] and then we train our suppliers. So, we do that for AM just like for traditional manufacturing.”

The rigorous selection and strategic development of AM service bureaus do not align with the literature-based vision of low human asset specificity allowing for flexible, dynamic outsourcing to interchangeable service bureaus (see Table 1) (Holmström et al. 2016; Meyer et al. 2021; Zijm et al. 2019), at least not for demanding applications. Following the TCE logic, it appears that the skills and dedicated human capital invested in AM transactions increase the specificity of those transactions and argue for hierarchical governance (Carney, 1998).

Contextual modification by the emerging stage of AM

Santos and Eisenhardt (2009) identify that industry structures and institutions are lacking in nascent markets, and the same is true for AM currently. Notably, standards for quality control, certification of materials and safety-relevant parts, and a clear-cut legal framework including product liability have not yet emerged. Consequently, manufacturing firms need to establish individual arrangements with every single AM service bureau they depend on, which entails extensive communication efforts and monitoring in each outsourcing relationship (Thomas-Seale et al. 2018). One end-product manufacturer drew the comparison, “Every engineer knows that he can re-draw to DIN or ISO standards for traditional manufacturing technologies like welding. He does not yet have these standards for AM.” An AM material supplier reflected that in his experience, “The manufacturing firms must specify exactly how the AM parts are to be produced [...] otherwise they obtain a different manufacturing outcome every time.” Indeed, with individually provided specifications and measures for quality control, it becomes costly for manufacturing firms to switch to new AM service bureaus. The costs increase the manufacturing firms' dependency and expose them to partners' opportunistic behavior.

With the manufacturing firms locked in, general TCE-reasoning to internalize AM to avoid opportunistic behavior is enhanced (Holcomb & Hitt, 2007; Williamson, 1971). This rationale applies to Pioneers. They refrain from outsourcing due to their inability to fully specify outsourcing in standard contracts and the resulting unilateral dependency. Yet, industry experts expect Pioneers to use their in-house expertise to draw up effective outsourcing contracts once AM reaches a mature stage. For example, one AM industry expert shared, “Once this technology is qualified, approved, and regulated, it is just a normal manufacturing process, and manufacturing firms will go back to their traditional supply chains with one or more key suppliers that know their business.”

> Prop. 2.4: The emerging stage of AM entails that individually provided specifications and measures enhance unilateral dependency and lock-ins for manufacturing firms, arguing for in-house AM.

At the same time, the emerging stage of AM technologies fosters a wide variety of technologies, and materials are developing rapidly. No dominating technologies have emerged as de facto standards yet. It is an immense challenge for manufacturing firms to cover the variety of technologies and materials in-house at this emerging stage. However, AM service bureaus have specialized in technologies and materials. Thus, manufacturing firms may opt for outsourcing in the nascent market to gain knowledge on the multitude of options. For instance, a component manufacturer pointed out, “We have to work with AM service bureaus because there is not just one technology. There is a bouquet of technologies and it is important to know and assess in detail the capabilities of each supplier.” And an AM software provider reflected this view when recommending, "I would enter the market with competent partners that have an idea of the range of the technologies—because there are hundreds of processes and material combinations. It is super confusing." In addition, outsourcing allows the manufacturing firms to remain flexible as to a final technology choice. Folta (1998, p. 1011) suggests that the "option of waiting" enables individuals to make informed choices at a later, more mature stage.

Nevertheless, our interviewees are well aware of their unilateral dependency on the supplier. Dependency is accepted by manufacturing firms with a tentative AM strategy and is outweighed by the benefits of accessing specialized knowledge and of postponing investment decisions in the broad range of emerging AM technologies. Manufacturing firms with an established AM strategy emphasize safeguards and develop close, trust-based, and long-term relationships with AM service bureaus. Eventually, their initiatives aim at creating bilateral dependency with mutual lock-ins (Holcomb & Hitt, 2007). Suppliers for AM are supposed to become so-called "tier 0.5 suppliers," underlining the need for even closer collaboration and faster communication than required for traditional suppliers, as suggested by Delic and Eyers (2020, p. 6) and Giffi et al. (2014, p. 9). Hence, we propose that the emerging stage necessitates and fosters outsourcing even though manufacturing firms are aware of their dependency.

> Prop. 2.5: The emerging stage of AM lets manufacturing firms outsource their activities despite their dependency on suppliers. Benefits of technological flexibility and knowledge acquisition outweigh the risk from dependency.

Waverers and Planners rely on outsourcing partners for a low-complexity entry point for which dependency is of limited concern. Combiners cope with the dependency with trustful, closer, and long-term outsourcing relationships. The rationale does not apply to Pioneers as they have built extensive AM know-how and opted for specific AM technologies early. Thus, the specialized knowledge provided by AM service bureaus is of limited value for them and cannot compensate for their perceived dependency resulting from Prop. 2.4.

CONTRIBUTION TO THEORY

In the following subsection, we embed our results in the extant OSCM literature. Then, we discuss our results from the perspective of TCE and the RBV. Finally, we shed light on the compatibility and tension of TCE and RBV arguments for emerging AM.

Operations and supply chain management literature

Our findings on AM make-or-buy decisions extend the scarce literature in this field. As our foremost contribution, we presented four make-or-buy decision profiles of manufacturing firms for industrial AM and developed an in-depth and context-specific understanding for their rationales. With that, we provide novel rationales and both, supporting and contrary, insights to the existing OSCM literature on AM. Table 3 delineates how the four make-or-buy decision profiles emerge from the developed propositions.

We found rationales for both polar governance structures—namely, for organizing AM in-house and outsourcing. The reevaluation of core competencies (Prop. 1.1), the perceived threat of opportunism for digital (Prop. 1.2), emerging (Prop. 2.1) AM, and commitment to learning early (Prop. 2.3) drive Pioneers and Combiners toward in-house AM design and manufacturing activities. In addition, the inability to fully specify AM outsourcing contracts at the current emerging stage strengthens Pioneers' in-house strategy (Prop. 2.4). Combiners differ from Pioneers in that they accept the challenge in specifying contracts as the overwhelming variety in AM technologies and materials necessitates them to complement their in-house strategy with outsourcing (Prop. 2.5). The two rather tentative profiles, Planners and Waverers, neither have sufficient AM volumes and specific know-how for in-house AM nor does AM affect their core competencies. However, both show evidence that the enthusiasm of senior management for the novel AM technologies is a major driver for in-house AM (Prop. 2.2) leading to potentially disappointing initial AM experiences (Waverers).

The identified rationales go beyond what is currently recognized by the OSCM literature on the AM make-or-buy decision (e.g., Hedenstierna et al. 2019; Ruffo et al. 2007) and the AM implementation process (e.g., Mellor et al. 2014; Thomas-Seale et al. 2018). With that, rather than being a natural consequence of AM implementation, outsourcing becomes an active choice for manufacturing firms. In the current emerging stage of AM, outsourcing relationships are certainly not intended to be flexible and interchangeable, but we observed them to be specific and long-term oriented and to involve investments in dedicated human capital. Our observations give rise to follow-up research in the OSCM literature to formalize the concerns observed across our cases. Such research supports decision makers in making reasoned decisions when it comes to integrating AM in supply chains.

Contextualizing theories for the make-or-buy decision of additive manufacturing

As we navigated within TCE and the RBV, we found arguments consistent with these theories in the domain of industrial AM. By theorizing at the middle range, we can show how the tenor of TCE and RBV argumentation changes based on the digital product specifications and emerging stage of AM that we identified to be specific for the industrial AM context. Thus, we build a context-specific understanding of these theories and contribute to their application for make-or-buy decisions in the digital age, following the call of Stank et al. (2019). Table 4 provides an overview of the chains of argument for both theories developed across the framework we illustrated in Figure 3. The chains span from the general factors to their modification in light of the contextual factors and summarize the effects of the digital and emerging traits of AM.

From a *TCE perspective*, we found the AM make-or-buy decision to be driven by IP concerns and dependency. Both generally argue for in-house AM based on highly specific transactions and the resulting risk of opportunism. In

TABLE 3 Emergence of the four make-or-buy decision profiles

Contextual factors	**Digital product specifications**		**Emerging stage of AM**
General factors	**Core competencies**	**IP concerns**	
Propositions	**Prop. 1.1**	**Prop. 1.2**	**Prop. 2.1**
Pioneers (in-house)	**In-house:** Core competencies in AM; need to master AM design and manufacturing process to generate competitive advantages in AM	**In-house:** Fear of loss of the digitally encapsulated IP; higher risk of copying and counterfeiting than for traditional manufacturing	**In-house:** Increased fear of loss of IP due to unstable relations and unestablished positions in the nascent market
Combiners (mixed)	**In-house:** Core competencies in AM; need to master AM design and manufacturing process to generate competitive advantages in AM	**In-house:** High IP concerns; secure, firm-owned network for IP-sensitive parts; outsourcing only of parts without core know-how	**In-house:** Barriers of sharing knowledge; fear that customers turn into competitors; partners must be carefully selected
Planners (strive for mixed)	**Not applicable:** AM does not affect core competencies; AM is limited to internal applications such as prototypes, tools, and samples	**In-house:** IP concerns based on the digital nature of AM for intention to establish long-term outsourcing of AM for core products in the future	**In-house:** Slight concerns for intended outsourcing; planned tendering process and auditing of partners to reduce risk of IP loss
Waverers (reluctant, tendency toward outsourcing)	**Not applicable:** AM does not affect core competencies; only initial pilots	**Not applicable:** No significant IP in AM to protect	**Not applicable:** No significant IP in AM to protect

particular, our findings indicate a perceived inability to sufficiently protect IP with currently available technology and standard contracts, and a need for rigorous selection and auditing of AM outsourcing partners. This argues for monitoring transactions closely, high administrative efforts, and individual contractual arrangements. By focusing on the specifics of AM, we found that the digital and emerging traits enhance the TCE arguments for in-house AM (see Table 4). The digital traits increase IP concerns based on the perceived ease of copying and counterfeiting digitally encapsulated sensitive information. Likewise, the emerging traits increase IP concerns resulting from the fear of unintentionally creating new competitors in the unstable and fast-moving AM market. Moreover, our results show that the emerging traits increase dependency based on lacking industry guidelines and standards for testing and certification processes. However, technological flexibility and knowledge acquisition appear to necessitate outsourcing despite the high dependency. Thus, the rarity of knowledge and technological variety at the emerging stage force firms into market governance despite high transaction costs. Experienced manufacturing

Capacity and skill investment		Dependency		
Prop. 2.2	**Prop. 2.3**	**Prop. 2.4**	**Prop. 2.5**	**Summary**
Not applicable: Early market entry; sufficient AM applications justify investments in AM capacity and skill development	**In-house:** "Pioneers" of AM; learn today to build engineers' acceptance and experience gaps in AM	**In-house:** Lack of standards for testing and certification; inability to fully specify AM outsourcing contracts	**Not applicable:** Specialized in AM; knowledge provided by AM service bureaus is of little value; cannot outweigh dependency	Develop core competencies in AM with the prospect of first-mover advantages; expected to eventually draw up effective outsourcing contracts for mature AM
Not applicable: Early market entry; sufficient AM applications; AM volumes surpass in-house manufacturing capacities	**In-house:** Foster learning; built experience in AM; integration of AM in the organization; aim to outpace competitors	**Not applicable:** Rigorous selection of partners; cope with dependency with trustful, close, and long-term outsourcing relationships	**Outsourcing:** Variety of AM necessitates outsourcing; aim to take advantage of technological flexibility	Expertise in AM is developed in-house, but the variety in AM technologies and materials requires long-term, trustful outsourcing relationships
In-house: Willingness to accept higher financial risks for initial AM investments than for traditional manufacturing technologies	**In-house:** Awareness that in-house know-how is necessary to evaluate AM and to not miss the chance to position in the AM market	**Not applicable:** Only pilots and internal AM applications; routines with initial outsourcing partners are successively established	**Outsourcing:** Dependency is of limited concern; AM expertise of the partner overcompensates dependency	Start with initial outsourcing as a low-complexity entry but clear vision of strategic outsourcing coupled with in-house know-how development for core products in the future
In-house: Hype of management; owner-initiated investments without extensive prior analysis; disappointing experiences	**Not applicable:** Development of in-house expertise is currently not assessed as feasible	**Not applicable:** Only outsource first pilots to AM service bureaus	**Outsourcing:** Dependency is of limited concern; no permanent outsourcing relationships are established for now	Reluctance to positioning in AM after rushed (partly disappointing) initial experiences based on high enthusiasm of senior management for AM

TABLE 4 Chains of argument for the AM make-or-buy decision

Theory	General factor	Modification by contextual factor	Effect
TCE	*IP concerns*: Manufacturing firms' IP concerns lead to perceived exposure to opportunism, arguing for in-house AM	*Digital traits*: The ease of sharing, reusing, and modifying digital assets becomes a threat, strongly arguing for in-house AM (Prop. 1.2)	The digital and emerging traits increase IP concerns
		Emerging traits: Barriers of sharing knowledge and limited trust in young relationships enhance the fear of opportunism, strongly arguing for in-house AM (Prop. 2.1)	
	Dependency: Rigorous selection and strategic development of outsourcing partners increases the specificity of transactions, arguing for in-house AM	*Emerging traits*: Individual specifications and measures increase unilateral dependency and lock-ins, arguing for in-house AM (Prop. 2.4)	The emerging traits increase dependency
		Emerging traits: Technological flexibility and knowledge acquisition outweigh the risk from dependency, arguing for outsourcing (Prop. 2.5)	The emerging traits force the acceptance of dependency
RBV	*Core competencies*: Design for AM is a core competency and should be conducted in-house; the manufacturing process should be outsourced	*Digital traits*: Interweaving of physical and digital resources requires a full in-house strategy for the design and the AM process (Prop. 1.1)	The digital traits cause a reevaluation of core competencies
	Capacity and skill investment: Manufacturing firms cannot utilize equipment and skills better than the market; their weak resource position favors outsourcing AM	*Emerging traits*: Enthusiasm of senior management and potential first-mover advantages cause manufacturing firms to invest in in-house AM to strengthen their weak resource position (Prop. 2.2/2.3)	The emerging traits encourage capacity and skill investments

firms with established AM strategies accept and counter the dependency by limiting outsourcing to applications without IP concerns and by aiming for close and ideally bilaterally dependent outsourcing relationships.

From a *RBV perspective*, we identified the definition of core competencies in AM and the commitment to capacity and skill investments to form the fundamental arguments for the AM make-or-buy decision. The arguments for both general factors suggest outsourcing the manufacturing process to AM service bureaus. Their ability to specialize in AM technologies and pool orders constitutes a superior resource position. For manufacturing firms, novel design skills emerged as the predominant source for developing competitive advantages in AM. By extracting the specifics of AM, we found that the digital and emerging traits reverse the general arguments and direct them toward in-house AM (see Table 4). The emerging traits trigger firms to reevaluate their core competencies. Following the RBV line of arguments, our results show that firms only feel capable of leveraging AM design skills as a rare, valuable, and imperfectly imitable resource in an interplay with in-house expertise for the physical manufacturing process. Although the importance of digital resources is amplified in AM compared with physical resources (e.g., AM machine and material expertise), both are not decoupled (yet). Whenever AM affects the core business of firms, this coupling explains why firms increase their vertical integration when switching from traditional manufacturing technologies to AM. Besides, the emerging traits have encouraged investments in AM machines to strengthen the

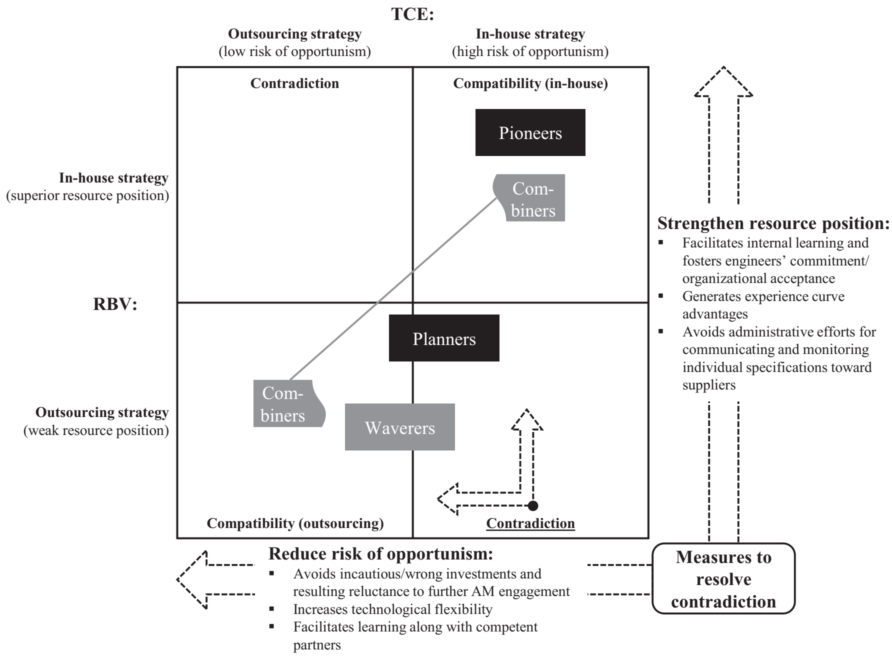

FIGURE 4 Alternative strategies for AM implementation

weak physical resource positions. Firms make substantial and risky investments with the prospect of reaching resource positions that competitors cannot obtain.

Contradicting guidance by theories

Literature-based reasoning suggests that the implementation of AM is a scenario in which TCE and the RBV seem to be complementary. Our study extends this view and provides a more nuanced perspective. As demonstrated in Table 4, TCE and the RBV point on the general level to opposite directions (see *general factors*). As a result, many of the manufacturing firms are in a situation where TCE and the RBV give contradicting guidance on whether to outsource or to internalize AM. The firms fear opportunism by AM service bureaus as they are concerned about IP protection and lock-ins in highly specific transactions. At the same time, the key technology expertise remains with machine manufacturers and specialized service bureaus at the emerging stage. Manufacturing firms find themselves in a relatively weak resource position, see Figure 4.

In such a situation, TCE raises the argument that manufacturing firms should internalize AM due to the risk of opportunism, whereas the RBV suggests outsourcing due to the manufacturing firms' inferior resource position. Conner and Prahalad (1996) and McIvor (2009) have previously discussed the possibility of such a contradiction. From our study, we note that the majority of the manufacturing firms in our sample are currently opting to resolve this dilemma by investing in in-house capacities and capabilities to strengthen their resource positions. Hence, in the AM context (see *contextual factors* in Table 4) manufacturing firms fund in-house capacities and skills to avoid the risk of opportunism. We thus note that TCE arguments aimed at minimizing the risk of opportunism oftentimes outweigh RBV arguments in the case of emerging industrial AM. Only a few experienced manufacturing firms resolve the contradiction by accepting and eventually seeking to reduce the high transaction costs of outsourcing.

MANAGERIAL INSIGHTS

As a direct outcome of our theoretical contribution, this study provides real-world insights for managers confronted with make-or-buy decisions related to industrial AM. We discuss these insights and reflect them in the broader innovation literature.

From the above, we found that strengthening a manufacturing firm's resource position with in-house investments, in light of the high risk of opportunism, is a broadly applied strategy for emerging AM technologies. As depicted in Figure 4, strengthening the AM resource position facilitates internal learning. It fosters engineers' participation as well as organizational and cultural acceptance of AM that have been recognized as crucial factors for implementation success of technologies (McDermott & Stock, 1999; Stock & Tatikonda, 2008). Moreover, early in-house investments put manufacturing firms in a suitable position to avoid falling behind competitors and new entrants from the AM domain. The innovation literature contains multiple examples where incumbents have failed to maintain their competitive positions at the shift of manufacturing paradigms (e.g., Ho & Lee, 2015; Vuori & Huy, 2015) and our results indicate that manufacturing firms in AM fear such a loss of position. They aim to generate experience curve advantages to safeguard superior resource positions in the future as suggested by Lieberman and Montgomery (1988). Furthermore – as a classic TCE argument – strengthening the AM resource position avoids administrative efforts for communicating and monitoring individual specifications toward suppliers.

However, our results demonstrate that managers should carefully consider the benefits of this strategy and balance it against the alternative, namely the reduction of the risk of opportunism by building trustful relationships with partners as illustrated in Figure 4. AM software and platform providers, AM machine manufacturers, and AM industry experts agreed that copying and counterfeiting can be avoided via existing IT security technologies. For instance, one AM industry expert pointed out, “The concerns are seen as greater than they are. After all, solutions are available on the market.” Manufacturing firms should explore these solutions in more detail to reduce IP concerns as suggested by Kurpjuweit et al. (2021) and Holland et al. (2018).

With a reduced risk of opportunism, we propose that, first, outsourcing avoids overly early investments in specific AM technologies. Hype for novel technologies urges firms to join an “innovation race” (Bakker & Budde, 2012, p. 560), and we find an indication for such behavior in AM. An outsourcing strategy, however, protects firms from restricted returns due to a limited number of applications or a wrong technology choice. Thus, it may prevent first-mover disadvantages (Lieberman & Montgomery, 1998) and a reduction of future innovation activities (Ruef & Markard, 2010) as we observed firms whose initial unsuccessful investment let them shy away from AM entirely and potentially miss actual applications. In this vein, one AM industry expert commented, “Several firms, especially the smaller ones with financial constraints, want to get rid of their purchased AM machines because they simply realize, ‘I have no use for it’. [...] it can happen that the machine just stands still or is only used for gimmicks.”

Second, our findings show that outsourcing provides technological flexibility and, thus, allows manufacturing firms to explore and leverage the multitude of technological options of AM (Folta, 1998).

Third, outsourcing brings the opportunity to learn alongside powerful partners. The innovation literature stresses the benefits of open innovation (Chesbrough, 2003). In a similar vein, when manufacturing firms collaborate more to assess the potential of industrial AM, their chances of identifying suitable business cases are likely to increase (Chaudhuri et al. 2019). Several interviewees from the AM domain supported this argument. One AM service bureau, for example, shared the advice, “Do not buy a machine. Develop applications with partners who know the technology. And once you have understood the technology and realized that it makes sense for you, then you can start buying machines.” In a similar vein, Conner et al. (2014) point out that by gaining knowledge, firms can better estimate if AM constitutes a competitive advantage and make informed decisions.

CONCLUDING REMARKS

Additive manufacturing rests on digital traits, which the literature expects to ease outsourcing of the AM process. In contrast, we observed that the current state of the AM industry holds various value-creating governance structures for manufacturing firms, ranging from hierarchy- to market-based structures. To develop a deep understanding of the causal processes involved in manufacturing firms' industrial AM make-or-buy decisions, we used a multiple-case study design. In addition, we gained extensive industrial AM domain knowledge from AM-specific actors.

We identified four AM make-or-buy decision profiles of manufacturing firms characterizing the current variety of governance choices and developed a framework that allows us to explain the rationales of why each of the four profiles emerges. Furthermore, by following a MRT approach, we showed how the empirical context of industrial AM modifies arguments that can be explained following TCE and the RBV. Finally, our study identifies the AM implementation process as a setting in which both theories provide contradicting guidance as to the governance choice. We discussed the advantages and risks of alternative governance structures and raised awareness for an AM market entry with competent partners and cautious implementation of in-house AM.

Limitations and future research

Resulting from our methodological choice, our findings are based on insights shared by individual interviewees. We presented viewpoints from manufacturing firms and actors from the AM domain to ensure a coherent overview but included only a limited number of SMEs. We observed that many manufacturing SMEs have not implemented AM yet, hence our findings cannot entirely reflect their specific perspectives. With the increasing prevalence of

AM, investigating more SMEs will be a valuable next step, enabling the identification of more differentiated rationales. Furthermore, we built our observations on the retrospective views of interviewees and we cannot rule out that they may be overshadowed by a posteriori insights. A longitudinal case study approach would be beneficial in this regard to focus on the dynamics of the make-or-buy decision profiles and the rationales.

Considering our theoretical lens, we decided to focus on the two polar governance structures, market versus hierarchy. Thus, our study sets the ground for investigating hybrid forms (e.g., alliances, joint ventures, and acquisitions) for industrial AM. This creates an opportunity to extend the derived framework of rationales. TCE and the RBV will likely continue to be a suitable theoretical lens, but future work should also consider if other theories can pinpoint additional nuances in manufacturing firms' decision-making behavior.

When selecting the context of our study, we purposefully chose industrial AM with high-quality requirements and extensive approval procedures. Hence, our findings may lack generalizability to the implementation of AM in industries that do not share these characteristics. Elaborating and testing our propositions in different AM contexts, for instance, in the less regulated consumer industry, is a logical next step.

Outlook for emerging digital manufacturing technologies

Albeit from the industrial AM context, we believe that our findings are not limited to AM but are relevant for manufacturing firms implementing technologies with similar characteristics. AM has been coined as a set of inherently digital and emerging manufacturing technologies. The digital traits increase manufacturing firms' IP concerns and drive them to reevaluate their core competencies. The emerging traits, again, increase IP concerns, encourage firms to make risky in-house investments, urge them to learn, and require them to cautiously manage dependency in outsourcing relationships. On an aggregated level, our findings indicate that these rationales may drive firms toward in-house governance for such a setting. The literature suggests that as a nascent market matures, advantages of in-house production are likely to decrease and vertically specialized firms may prevail (Jacobides & Winter, 2005; Malerba et al. 2008; Schilling, 2000).

However, it is not yet clear how digitalization impacts governance decisions in mature digital manufacturing industries. For instance, the more mature and highly digitized semiconductor industry still faces similar IP concerns like the AM industry, including copying and counterfeiting (Gupta et al. 2020). Extensive digital design and data exchange render the digital supply chain more vulnerable than the physical one. A second persisting question is if the digital traits will continue to cause a re-evaluation of core competencies and require vertically integrated firms with interwoven expertise in the digital and physical domain. In the case of AM, Ben-Ner and Siemsen (2017) and Massimino et al. (2018) expect valuable and rare digital design resources to become fully decoupled from the physical manufacturing process. Revisiting the more mature semiconductor industry, again, such a decoupling has initiated the evolution of "fabless" actors with digital capabilities and extensive manufacturing outsourcing practices (Monteverde, 1995). Despite this, a large variety of contractual arrangements characterizes the mature semiconductor industry (Mönch et al. 2018) demonstrating that specialized and integrated firms can purposefully coexist (Kapoor, 2013). For AM, such a decoupling will require technological advances that facilitate a truly robust, automated, and flexible physical production process accepting any designs as an input. These observations from industrial AM may provide a basis for extending knowledge on the impact of digitalization on make-or-buy decisions in general.

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APPENDIX A

Information about the cases and actors from the industrial AM domain

TABLE A1 Information about the cases

Manufacturing firm	Case	Product/service	2020 annual revenue (millions)	Number of employees	Location of the firm	Interview type	Job position of interviewee
End-product manufacturers	E1	Machinery and equipment	$ 1000–5000	10,001–20,000	Germany	Face-to-face[b]	Innovation Manager, Doctoral Candidate[c]
	E2	Industrial conglomerate	> $ 20,000	>100,000	Germany	Face-to-face[b]	Head of AM
	E3	Motor vehicles	n/a	n/a	Switzerland	Phone	Head of Technical Development
	E4	Materials handling equipment	$ 1000–5000	501–5000	Germany	Face-to-face	Director Digital Transformation
Component manufacturers	C1	Basic metal	$ 1000–5000	5001–10,000	Germany	Face-to-face[b]	Head of Operational Excellence
	C2	Motor vehicle components	$ 10–20	51–500[a]	Germany	Face-to-face[b]	Senior Manager
	C3	Rail transportation equipment	$ 5000–20,000	20,001–50,000	Germany	Face-to-face	Vice President Spare Part Services
	C4	Rail transportation equipment	$ 5000–20,000	20,001–50,000	France	Video	Chief Technology Officer
	C5	Machinery and equipment	$ 100–500	501–5000	Germany	Phone	Head Quality Management & Compliance
	C6	Motor vehicle components	$ 5000–20,000	20,001–50,000	Germany	Face-to-face	Head of Additive Technologies
	C7	Machinery and equipment	$ 100–500	501–5000	Germany	Phone	Development and Technical Testing
	C8	Aerospace equipment	$ 20–100	51–500[a]	Germany	Phone	Vice President Business Development

[a]SME.
[b]Two interviewers present.
[c]Two interviewees present.

TABLE A2 Information about the actors from the industrial AM domain

AM-specific actor	Firm	Product/service	2020 annual revenue (millions)	Number of employees	Location of the firm	Interview type	Job position of interviewee
AM service bureaus	S1	Polymer and metal applications	$ 10–20	51–500[a]	Germany	Face-to-face	Key Account Manager
	S2	Metal applications	$ 1–10	1–50[a]	Germany	Face-to-face	Managing Partner
	S3	Polymer and metal applications	$ 20–100	51–500[a]	Germany	Phone	Head of Marketing & Business Development
	S4	Mobile AM micro-factory	n/a	1–50[a]	Norway	Video[b]	AM Expert[c]
AM machine manufacturers	P1	AM machines for metals	$ 20–100	1–50[a]	Germany	Face-to-face[b]	Sales Engineer[c]
	P2	AM machines for polymers	$ 500–1000	501–5000	Germany	Face-to-face	Technical Consultant
	P3	AM machines for metal and polymers	$ 100–500	501–5000	Germany	Face-to-face	Business Development Manager
	P4	AM machines for metals	$ 20–100	51–500	Germany	Phone	Director Business Development
AM material supplier	M1	Specialty chemicals	$ 5000–20,000	20,001–50,000	Germany	Face-to-face	Head of AM
AM software and platform providers	SP1	Software for AM processes	n/a	1–50[a]	Germany	Phone	Managing Director
	SP2	Software for AM design automation	n/a	1–50[a]	Germany	Face-to-face	Managing Director
	SP3	Platform for matching orders and AM service bureaus	$ 1–10	1–50[a]	The Netherlands	Video	Chief Operating Officer
AM industry experts	I1	Established AM firm network	Non-profit organization	1–50	Germany	Face-to-face[b]	AM Expert[c]
	I2	Consulting firm for AM implementation	n/a	1–50[a]	Germany	Phone	Managing Partner

[a]SME.
[b]Two interviewers present.
[c]Internal data provided.

APPENDIX B

Semi-structured interview protocol for manufacturing firms (selection for this study)

1. *Background information*
   a. Interviewee information (name, years in the firm, professional and educational background)
   b. Interviewee's relation to AM (job description, responsibilities, connection to AM)
   c. Firm information (firm name, years in existence, size, number and distribution of firm locations, key products and services)
   d. Traditional supply chain (major suppliers and customers, outsourcing experience)
2. *Firm's state of AM implementation*
   a. Start of AM activities (reasons for AM involvement, timeline, first activities, first applications, partners)
   b. AM status (developed structures and know-how in the organization, collaborations)
   c. Current AM supply chain (AM applications, specific AM suppliers and customers)
   d. Assessment of AM (maturity for firm's AM applications, outlook on expectations for AM in 10 years)
3. *AM make-or-buy decision*
   a. How concrete are your firm's ideas regarding the implementation of AM? How have you/will you implement AM in your organization?
   b. Do you expect a change in your vertical integration?
   c. Which competencies are central for you? Would these competencies remain within your firm in an AM supply chain?
   d. Which new competencies do you expect your firm to build for AM?
   e. Do you see a need for new partners in AM supply chains?
   f. Are the business models of existing partners changing?
4. *Wrap up*
   a. What are the critical milestones for future AM development?
   b. If you could change one existing condition/limitation, what would that be?