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Growing with smart products: Why customization capabilities matter for manufacturing firms

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Abstract

Manufacturing firms that engage in digital transformation develop increasingly smarter versions of their tangible products to reinvigorate growth in shrinking markets. However, they often struggle with translating their investments in digitalization capabilities into actual returns in the form of sales growth. The associated technological advantages often remain unexploited, and digital product innovations frequently fail. Building on the resource-based view of the firm and the demand-side perspective, we theorize that there is a need for complementary capabilities that integrate heterogeneous customer demands, thus, allowing firms to capture more value from smart products. We empirically investigate the mediating role of smart customization capability on the relationship between digitalization capabilities and sales growth. Moreover, we argue that this relationship is further strengthened by integrating information and data across sales and service channels (i.e., channel integration). We test and find support for our hypotheses based on a dataset comprising survey and archival data of 136 smart product manufacturers in Austria, Germany, Switzerland, and the United States. In doing so, we enhance the theoretical understanding of resource and capability configurations needed for digital transformation in general and smart product success in particular. We further update the traditional concept of mass customization by showing how customization with smart products helps manufacturing firms provide personalized solutions at scale.

KEYWORDS

demand-side perspective, digital transformation, mass customization, resource-based view, smart products

1 | INTRODUCTION

Confronted with the commoditization of hardware products, high-tech-driven competitors, and more experience-seeking customers, established manufacturing firms are increasingly leveraging digital technologies (i.e., combinations of information, computing, communication, and connectivity technologies; Bharadwaj et al., 2013) to enhance their business models in a way that creates and captures more value (Verhoef et al., 2021; Vial, 2019). This digital transformation results in new organizational structures, streamlined processes, and changes in products and services (Hanelt et al., 2021; Hess et al., 2020; Svahn et al., 2017). The last result is especially relevant in manufacturing industries, where firms make use of digital technologies to shift from physical to smart product portfolios (Sebastian et al., 2017; Yoo et al., 2012). For this transition, firms need to develop *digitalization capabilities*, which allow them to add digital components to their legacy products and create a default connection between firms, their products, and their environment. When doing so, the resulting smart products are supposed to provide manufacturing firms with new avenues to generate substantial *sales growth* (Ehret & Wirtz, 2017; Meyer et al., 2018; Porter & Heppelmann, 2014).

However, while managers and scholars alike agree on the necessity of investing in internal digitalization capabilities (e.g., Lenka et al., 2017; Russo & Wang, 2019), empirical evidence on their market-level performance implications is scarce, and technology-driven product innovations frequently fail because of a poor product-market fit (Reid & de Brentani, 2010). Consider, for example, the Temial, a smart tea machine that did not fulfill actual customer needs when it was launched in 2019. After less than 2 years, limited customer demand forced the German home appliance manufacturer Vorwerk to take the product off the market. Like other established manufacturers, Vorwerk had trouble identifying smart services that are valuable to its customers (Koster et al., 2021). In line with these observations, Appio et al. (2021) recently called for research examining how smart product manufacturers can "prevent [...] limited value capturing" (p. 15).

Prior literature suggests that customization approaches can potentially overcome this challenge and add to the limited understanding of how firms can leverage the growth potential of smart products (e.g., Beverungen et al., 2019; Kopalle et al., 2020). Consider, for example, original equipment manufacturers (OEMs) in the automotive industry. Firms such as Volkswagen and BMW have recently launched new generations of connected cars, allowing users to not only continuously update and personalize various services via apps but also unlock new hardware features. These developments significantly enhance the value proposition of cars, which evolve from commoditized, stable products into more service-oriented platforms that dynamically and autonomously adjust to changing individual user needs. We argue that firms' ability to tailor smart products to individual customer needs during the usage stage (i.e., *smart customization capability*) positively affects sales growth. We further contend that this relationship can be strengthened by integrating user input at the product level with additional data and information from various customer-facing communication and sales channels.

Practitioner points

- Investing in digitalization capabilities is necessary to succeed with products in the digital age, yet often insufficient to yield sales growth.
- Successful manufacturing firms invest in their smart customization capability to tailor their service offerings to heterogeneous customer needs, thus capturing relatively more value from the market.
- Instead of manufacturing physical products that are designed to meet individual customer needs before purchase, performant manufacturing firms customize smart products in the usage stage.
- Smart products and their digital user interfaces constitute important customer touchpoints that firms need to carefully integrate with existing sales and service channels to leverage the full growth potential of their offerings.

Consider again the example of automotive OEMs, which traditionally use online configurators and portals for prepurchase and a dedicated dealer network to fulfill after-sales service demands. Here, aggregating multi-stop and multi-level contacts is crucial for enabling a seamless customer experience (e.g., information on features, prices, and transactions) across all online and offline channels (Oh et al., 2012; Zander & Zander, 2005). This *channel integration* creates a richer resource base, which is conducive to achieving product-market fit. Therefore, we suggest that the influence of smart customization capability on sales growth is a function of the extent to which firms employ channel integration.

Against this background, our research sets out to investigate the mechanisms through which digitalization capabilities translate into actual returns in the form of sales growth. Following prior innovation research (Guo et al., 2020; Priem et al., 2012), we integrate the resource-based view (RBV) and the demand-side perspective (DSP) of the firm to address this conundrum. The rationale is that in addition to internal capabilities and resources (digitalization capabilities), firms require complementary capabilities that integrate external, customer-related resources (smart customization capability) to achieve their goals (sales growth). Specifically, digitalization capabilities provide the technological foundation for a personalized customer experience with smart products. We thus conceptualize digitalization capabilities as firm-level value-creating capabilities that, when complemented with a value-capturing smart customization capability, enable established firms to achieve better product-market fit and, therefore, increased market-level performance.

We investigate the proposed relationships based on a unique dataset comprising survey and archival data of 136 manufacturing companies offering smart products. Hereby, we follow prior digital transformation literature and concentrate on the diffusion of a particular enabling technology (i.e., smart products; Appio et al., 2021). This focus "is important in tracing how organizations adapt to particular technologies" in a specific context and how this adaptation, in turn, impacts their performance (Hanelt et al., 2021, p. 1174). Indicating that the transition toward smart products can indeed pay off in the form of sales growth, our research makes several contributions to the digital transformation literature in general and research on smart products in particular.

From a broader digital transformation perspective, we shed light on the link between the development of organizational digitalization capabilities and market-level performance (Hanelt et al., 2021; Verhoef et al., 2021). Here, we specifically contribute to the recent theoretical discourse on the importance of resource and capability configurations in mastering digital transformation (e.g., Amit & Han, 2017; Sousa-Zomer et al., 2020; Warner & Wäger, 2019). Distinguishing between different types of capabilities, our results underline the relevance of combining capabilities that create and capture value in successfully embracing digital change. Even though organizational transformation is primarily driven by technological advancements, our research echoes the notion of success in a digitally connected world being deeply rooted in more co-creative firm-customer relationships (Amit & Han, 2017).

Zooming in on the smart products literature, we contribute to prior research that has called for an improved understanding of how the supposedly great market potential of smart products can be unlocked (e.g., Appio et al., 2021; Raff et al., 2020). Our study provides empirical evidence that technological product advancements can exert their influence on firms' market performance via smart customization capability. We further introduce the concept of channel integration as a moderator for this mediated relationship, proving that it creates a richer resource base that makes the achievement of product-market fit more likely.

Furthermore, we contribute to prior mass customization research by highlighting the increasing importance of digital dimensions in addition to hardware in delivering customized experiences. While the current theoretical understanding of mass customization has been dominated by tangible products, hardware, and traditional manufacturing environments (Kaplan & Haenlein, 2006), our research shifts the focus to smart products, software, and digital environments. Here, we contribute to prior literature exploring opportunities emerging from connected products and smart services (e.g., Piller et al., 2010; Salvador et al., 2020).

2 | THEORETICAL BACKGROUND AND HYPOTHESIS DEVELOPMENT

2.1 | Resource-based view and demand-side perspective

According to the RBV, firms create competitive advantage and growth by combining and developing resources that are valuable, rare, inimitable, and non-substitutable (Barney, 1991). Expanding this to firm capabilities, RBV scholars further argue that certain competencies are required to integrate a firm's resources to achieve superior rents (Montgomery & Wernerfelt, 1988; Peteraf, 1993). In our study, digitalization capabilities conform to this definition as they enable firms to merge software and hardware components into smart products, which become deeply integrated into an organization's infrastructure and its digital environment.

However, this perspective is based on the interrelated assumptions that because of (a) homogenous customer demand, (b) firms can gain a competitive advantage by integrating internally available resources in a unique, and (c) independent way (Lavie, 2006; Priem et al., 2012; Zander & Zander, 2005). These assumptions need to be revised against the background of dynamically changing, fragmented, and increasingly complex market environments with blurring boundaries.[1] Given the importance of heterogeneous customer demands and the ability of firms to continuously identify and respond to them on an individual and co-creative basis, we follow recent product innovation management research and integrate the RBV with the DSP (Guo et al., 2020; Priem et al., 2012).

The DSP suggests that market heterogeneity itself is a source of competitive advantage (Priem et al., 2012). The rationale is that firms that are able to (directly) integrate heterogeneous demands of (individual) customers in a unique way will outperform their competitors who lack such a capability. In our case, this ability is argued to be the smart customization capability. We theorize that because of heterogeneous customer needs in the marketplace, digitalization capabilities and the associated RBV

[1]If we solely focused on changing customer demands and the modification of resources as a response to them, the dynamic capabilities (Teece, 2007; Teece et al., 1997) component of the RBV would provide a suitable theoretical perspective (see Kozlenkova et al., 2014).

fall short of delivering an explanation for competitive advantage. Both merely provide a foundation (necessary condition), which needs to be complemented by an additional capability to incorporate external, heterogeneous customer demands in the pursuit of sustainable competitive advantage (sufficient condition).

Being primarily located within the sphere of the firm and executed during the development and production of smart products, we refer to digitalization capabilities as value-creating capabilities, which define the scope and size of the solution space that is subsequently matched with individual customer demands in the customer sphere. Here, we refer to firms' smart customization capability as a value-capturing capability that tailor product features and services to individual customer needs (Salvador et al., 2020). The result is a higher problem-solution fit of smart products, which satisfy individual, heterogeneous customer needs at scale and thus allow firms to achieve superior rents. The resulting product-market fit is argued to be further enhanced by the integration of additional customer insights collected through various communication and sales channels. This information further enriches firms' resource base and provides the opportunity for the identification of latent and expressed customer problems that remain unsolved by existing solutions.

2.2 | Digitalization capabilities

As discussed above, the digitalization of legacy products constitutes a necessary condition to remain competitive in the manufacturing industry. Here, the scholarly debate in the literature on smart products is more focused on product capabilities (e.g., reactivity or adaptability[2]) than on the firm-level capabilities needed for this transition. Yet, two themes emerge in current research (see Lanzolla et al., 2021) that have already been constitutional in the works of Porter and Heppelmann (2014, 2015).

The first theme concerns firms' ability to equip hardware products with smart components such as sensors, software, and digital user interfaces. These components allow firms to generate, process, and display digital data in the form of binary numbers that can be combined with other data sources (Yoo et al., 2010). This digital representation of information, in turn, allows firms to reprogram their products, enabling various functionalities and continuous development in the usage stage (Nambisan et al., 2017; Yoo et al., 2012). Related to this, the second theme concerns firms' ability to connect products with their organizational infrastructure (e.g., cloud computing), third parties (e.g., service providers), and other (smart) products. The transition from stand-alone products to always-connected products is a defining characteristic of value creation in digital environments (Ehret & Wirtz, 2017; Hilbolling et al., 2021; Hoffman & Novak, 2017). As such, this study follows recent innovation research (e.g., Lanzolla et al., 2021; Lenka et al., 2017) on capturing firms' transition from offering purely physical to smart products, thus taking a product-centric perspective on firm-level digitalization capabilities.[3]

2.3 | Digitalization capabilities and smart customization

Based on the above, we explain in this section how digitalization capabilities enable a smarter way of customizing products. These are smarter because traditional mass customization is a merely hardware-focused concept. Mass customization approaches enable customers to co-create an individual product at the time of sale (most often by using a configuration or co-design toolkit) that is then produced on demand in a flexible but still highly automated manufacturing setup (Franke & Piller, 2004; Huang et al., 2008). Contrasting this, smart customization presents a new, complementary perspective on mass customization; one that is fundamentally dependent on the development of more holistic digitalization capabilities (Piller et al., 2010). We refer to smart customization capability as the ability of firms to tailor digital products to individual user needs during the usage stage. Through employing usage data, digital product features can be customized to heterogeneous user behaviors. Increasingly smart products allow for updates, upgrades, and changes throughout the product lifecycle, thereby continuously improving their product-market fit (Zheng et al., 2020). Based on the three dimensions of mass customization presented by Salvador et al. (2009), we briefly outline how digitalization capabilities enable smart customization. These dimensions include (i) solution space development, (ii) choice navigation, and (iii) robust processes.

i. *Solution space development* means that manufacturers must understand on which product attributes customer preferences diverge. Digitalization capabilities enable manufacturers to collect and analyze product usage data to better understand and respond to customer preferences (Decker & Stummer, 2017;

[2]For research on the capabilities of smart products, we refer to the seminal article by Rijsdijk et al. (2007). A more integrated view is provided by Raff et al. (2020).

[3]For a recent review on digitalization capabilities, we refer to Annarelli et al. (2021).

Kopalle et al., 2020; Salvador et al., 2020). These changes can be executed automatically through the product or provided as suggestions or choices to the customer. However, this ability is obviously constrained by the sensors and actuators (hardware) embedded in the smart product. Consequently, digital components developed and produced within the sphere of the firm determine the solution space for personalized services within the sphere of the customer. Therefore, manufacturers have recently begun to embrace the concept of so-called "silent" hardware components (Verganti et al., 2020, p. 221). Long-lasting hardware platforms are often equipped with the latest technology, which remains inactivated until it is demanded by the user and/or complementing software becomes available (see also Porter & Heppelmann, 2015; Raff et al., 2020). For example, Tesla remotely activated a cabin-facing camera for occupants to enable personalized driver settings only 2 years after the initial launch of its Model 3 (Verganti et al., 2020).

ii. *Choice navigation* refers to the capability to help customers identify and decide upon customization options that address their individual needs. In comparison to co-design or configuration toolkits (e.g., Franke & Piller, 2004; von Hippel & Katz, 2002), which characterize conventional mass customization approaches, smart products do not require explicit customer input but enable the detection of latent customer needs by analyzing usage data (Narver et al., 2004). These analytics often run in the back end and require digitalization capabilities that provide the connection of smart products to data storages, cloud-based applications, and data collected by other smart products. Digitalization capabilities increase the autonomy of smart products and also allow them to automatically adapt to their users and their environment (Raff et al., 2020). For example, smart elevators optimize their operations based on product usage in real-time. This even includes the proactive detection of upcoming maintenance needs. Technical problems can be solved individually and in no time through service technicians or over-the-air updates, reducing maintenance costs and downtime (Ren et al., 2019).

iii. *Robust processes* enable fulfillment processes that are simultaneously flexible and efficient. Modularity in products and processes can help manufacturers to fulfill heterogeneous customer needs (Vickery et al., 2016). Modular architectures, enabled by digitalization capabilities, combine reusable core modules (e.g., core technology, product platform, and standard features) and interchangeable modules (e.g., functional components, digital interfaces, and individual service agreements) to offer a variety of customized products while simultaneously exploiting economies of scale and scope (Simpson et al., 2005; Thomas et al., 2014). In turn, designing and deploying a modular architecture makes it possible to produce customized products and simultaneously reduce the variety of components and semi-finished products that must be handled internally (Meyer et al., 2018; Salvador et al., 2020). In smart products, modularity at the hardware level is complemented by modularity through software and digital services. On the one hand, the entire hardware product becomes the standardized platform upon which individual service components provide a customized user experience for customers. On the other hand, the associated software can be used to customize hardware components, for example, by constraining the engine power of vehicles and bundling it to certain software packages (Porter & Heppelmann, 2014).

Building on the arguments above, we propose that digitalization capabilities provide an important technological foundation that leads to the development of smart customization capability and the continuous adjustment of products to individual user needs and behaviors. Hence, we hypothesize:

> **Hypothesis 1.** Digitalization capabilities are positively related to smart customization capability.

2.4 | Smart customization and sales growth

Manufacturing firms usually evaluate their success based on operational performance, focusing on cost- and time-related dimensions. This is rooted in their traditional upstream focus and their "make and sell" business model. When transitioning toward smart products, the conventional focus on value creation in development and production is complemented by a new focus on the customers' usage phase, as "resources are only valuable to the extent that customers value a firm's output" (Schmidt & Keil, 2013, p. 206). As a result, established manufacturers lean toward "product as a service" business models (Amit & Han, 2017), which require a more customer-centric approach when measuring the success of business operations. When smart products develop into value platforms, the most relevant metrics relate to the size of the customer base and its upselling potential. Successful companies grow their customer base and sell personalized software-based features, digital services, and new hardware-based options. This logic can be seen as the foundation of capturing customer value with smart products, which ultimately leads to an increase in revenues, i.e., sales growth.

Manufacturing firms with a superior (mass) customization capability have been shown to outperform competitors by delivering on desired customer benefits in a superior fashion (de Bellis et al., 2019; Um et al., 2017; Wang et al., 2016). Smart customization allows manufacturing firms to continuously collect information about users and their behavior so that customers perceive a greater fit between their needs and the smart products they use (Decker & Stummer, 2017; Salvador et al., 2020). They benefit from a personalized value proposition that increasingly closes the gap between actual needs and product features over time.

Furthermore, delivering smart products to customers without the individual production process of conventional mass-customized products reduces the complexity and challenges for customers during the configuration process (Franke et al., 2009; Salvador et al., 2009). Thus, customers benefit from a cost- and time-efficient standard solution that can be adjusted to individual needs over the entire usage phase. Consider the case of a smartphone: Users personalize a standard piece of hardware by selecting their own apps, their position on different screens, or shortcuts to their favorite apps on the home screen. Since these settings can be transferred to updated versions of the tangible product platform, a personalized experience can be created almost instantaneously.

When customers' explicit and latent needs are responded to in an almost instantaneous and highly personalized way, there is little incentive for customers to become inactive or switch products. The longer customers use their products, the more firms can learn about the customers' needs and adjust their products accordingly (Davenport et al., 2012). Take, for example, the agricultural equipment manufacturer Claas. It actively engages with customers' usage processes: By offering data-driven farming services, it creates direct and continuous interactions, increasing farmers' productivity (i.e., crop yield) and thus enhancing their value-in-use. Since this ability to respond to individual customer needs represents a key condition for superior product performance (Joshi & Sharma, 2004; Yannopoulos et al., 2012), we argue that the more manufacturing firms emphasize smart customization—identifying and addressing the latent needs and benefits of their customers—the better smart products will perform in the market. Hence, we hypothesize:

> **Hypothesis 2.** Smart customization capability is positively related to sales growth.

Taken together, Hypotheses 1 and 2 suggest that:

> **Hypothesis 3.** The relationship between digitalization capabilities and sales growth is mediated by smart customization capability.

2.5 | The moderating role of channel integration

Today, manufacturing firms can track individual customers on numerous online and offline channels and touchpoints at different stages of the customer journey (Lemon & Verhoef, 2016). These customer insights, in the form of data, information, and knowledge, can be used to enhance a firm's resource base and, in turn, improve the foundation for tailored customer services (Cao & Li, 2015; Wetzels, 2021). Consider the example of Claas again, which integrates customer insights from machinery interfaces, customer portals, farm management systems, and dealerships to inform customized service offerings and thus capture value from customers with heterogeneous sets of needs and requirements.

At the same time, manufacturing firms can build on channel integration and not only collect but also share information with customers across different channels (Saghiri et al., 2017). Take, for example, Porsche drivers, who can opt for subscription-based premium lane keeping when configuring their new car in an online configurator, when visiting a local Porsche dealer for service, or by simply using the Porsche Connect app store via the car's entertainment interface. In such situations, information (on products, prices, and transactions), marketing communication, customer support, and order fulfillment should be integrated across all channels to enable a frictionless customer journey (Oh et al., 2012). This is not only relevant from a channel perspective but also when transferring customers from one product generation to another. When customers transition from one car model to another, for example, a seamless experience is linked to a firm's ability to transfer the customer's profile (including preferences, settings, and functions) to the new product generation. Based on the discussion above, we argue that:

> **Hypothesis 4.** Channel integration moderates the relationship between smart customization capability and sales growth such that the relationship is stronger for high levels of channel integration.

Combining Hypotheses 3 and 4, we propose that:

Hypothesis 5. Channel integration moderates the indirect relationship between digitalization capabilities and sales growth via smart customization capability such that the mediated relationship is stronger for high levels of channel integration.

3 | METHODS

3.1 | Data collection and sample

We collected data from different sources to test our hypotheses. First, we distributed an online questionnaire to 3543 product managers from relevant industries (e.g., industrial machinery, electronics, and automotive) that we identified via the business networks LinkedIn and Xing as being responsible for the smart product offerings of their firms. The survey data collection took place between July and November 2019. Each product manager was sent a direct message containing a preview of the study and a personal link to an online questionnaire. Seven days later, a reminder was sent out to managers who had not yet responded. In total, 375 managers completed the survey. After performing a key respondent check and removing incomplete surveys, the sample was reduced to a total of 347 usable survey responses.

We assessed potential nonresponse bias by comparing the demographics of nonrespondents and respondents. The results showed no structural differences between the initial qualified sample and the final sample. We also found no significant differences in the response patterns of early and late respondents regarding the main scales used in this study, providing evidence that nonresponse bias is unlikely to be an issue (Armstrong & Overton, 1977).

Moreover, to minimize the risk of common method bias, our dependent variable was obtained from objective sales data using the Bureau van Dijk's Orbis database. Orbis provides financial information on listed companies and small and medium-sized enterprises in our target countries. We matched the survey responses to company sales records using a one-year time lag (fiscal years 2019 and 2020). After the matching procedure, our final sample consisted of 136 survey responses for which objective sales data were available. Characteristics of the final sample are presented in Table 1.

3.2 | Measures

3.2.1 | Independent variable

In this study, we are interested in *digitalization capabilities*, defined as firm-level technological capabilities that are required for established firms to transition from conventional hardware products to smart products. As no validated scale for measuring this capability at the firm level exists in the literature, we developed a new measurement scale following established scale development procedures (Churchill, 1979; MacKenzie et al., 2011). First, we specified the conceptual domain of the construct and reviewed existing literature on digital transformation and smart products to identify the key properties of the digital capability construct. The analysis of the literature and exploratory interviews with experts from academia and industry led to the specification of the two distinct sub-dimensions, *representation*, and *connectivity*, that together define an established firm's ability to transition from conventional to smart products (Jarvis et al., 2003).

Representation reflects an established firm's ability to integrate smart components into its legacy products to generate, process, and display product and environmental data. *Connectivity* reflects an established firm's ability to connect products with its data storage and processing centers, other connected devices, and complementors through wireless communication networks.

Because the two sub-dimensions can be viewed as defining characteristics, and omitting either of the two would alter the conceptual domain of the construct (Diamantopoulos & Winklhofer, 2001), we refer to representation and connectivity as formative first-order dimensions of the second-order digitalization capability construct. At the first-order level, however, we argue for a reflective measurement approach because the indicators within each dimension should reflect the same underlying sub-construct and be interchangeable to some degree without changing the meaning of the individual sub-constructs (Jarvis et al., 2003).

To develop the scale items, we again turned to the literature and our subject matter experts and developed six reflective indicators for each of the two dimensions. To assess the content validity of the generated items, we constructed a content adequacy matrix (MacKenzie et al., 2011) with items represented in rows and definitions of sub-constructs in columns. We then asked our subject matter experts to rate the extent to which each item belonged to each sub-construct on a 5-point Likert scale (1 = not at all, 5 = completely). A one-way repeated measures ANOVA was then run to assess whether each item's mean rating was significantly different from (and higher for) its preassigned sub-construct. Based on this content validity assessment, two items per dimension were removed. In the final step, a pretest of the survey instrument with 10 product managers was conducted. As a result, we obtained four valid items each for *representation* and *connectivity*. Participants in the

TABLE 1 Sample characteristics ($N = 136$).

Key informant descriptive statistics			
Job title		Characteristics	Avg. (SD)
Head of product management	8.09%	Involvement in innovation[b]	5.59 (1.41)
Head of research and development	5.14%	Involvement in operations[b]	4.70 (1.56)
Head of marketing	5.15%	Job experience[c]	7.84 (8.02)
Product manager	75.00%	Organizational tenure[c]	8.75 (7.63)
Other[a]	6.62%		
Firm descriptive statistics			
Industry affiliation		Firm size (full-time employees)	
Automotive	13.13%	1–50	1.47%
Electrical equipment	17.68%	51–250	16.91%
Electronics	21.21%	251–1.000	26.47%
Industrial machinery	30.81%	1.001–10.000	30.15%
Other[d]	17.17%	10.001–50.000	15.44%
		>50.000	9.56%
Country		Firm age (years since incorporation)	
Austria	11.11%	0–10	1.47%
Germany	7.41%	11–20	3.68%
Switzerland	51.85%	21–50	25.00%
United States	29.63%	51–100	33.82%
		>100	36.03%

[a]For example, innovation or business development manager.
[b]measured on a seven-point Likert scale.
[c]measured in years.
[d]For example, aerospace, commercial machinery, industrial automation, lighting, medical equipment, or transportation.

final survey instrument were asked to respond to the items that together capture a firm's digitalization capabilities by indicating the extent to which they agree to the statements on a seven-point Likert scale (1 = completely disagree; 7 = completely agree).

3.2.2 | Mediator and moderator variables

Smart customization capability (mediator) and *channel integration* (moderator) were also measured using new scales. First, we reviewed the extant literature to specify the domain of the constructs and identify sets of items (five each) that would capture a firm's ability to customize its products' user experience in the usage stage (*smart customization capability*) and a firm's ability to integrate information, communication, and fulfillment across online and offline sales and service channels (*channel integration*). This step was based on existing concepts and measures from the literature on smart products and mass customization (e.g., Huang et al., 2008; Porter & Heppelmann, 2014) and on operations management and retail literature (e.g., Cao & Li, 2015; Oh et al., 2012). Next, our subject matter experts assessed the generated reflective items for face validity, clarity, and comprehensiveness. Based on their feedback, the initial item set for the *smart customization* scale was complemented by two additional aspects that were considered relevant by the experts. The subsequent pretest of the survey instrument confirmed that the developed scales are understandable and manageable from a respondent's point of view. Based on exploratory and confirmatory factor analyses, the final scale for smart customization capability consisted of five items (two items with low loading were removed); likewise, we derived a five-item scale for the channel integration construct. An inventory of measurement items and factor loadings for the questionnaire's main constructs that were operationalized using multi-item scales are provided in Table A1.

3.2.3 | Dependent variable

We used archival data to measure the dependent variable *sales growth* for all companies in our sample. Specifically, we followed extant research (e.g., Morgan & Rego, 2006; Zhang et al., 2022) and calculated the changes in sales as the ratio of a firm's sales in 2020 to its lagged sales in 2019.

3.2.4 | Control variables

Finally, we included a number of control variables that may have an impact on sales growth. These include *firm size* (number of full-time employees) and *firm age* (years since incorporation). While large corporations and older firms have greater access to resources for the innovation process (Chandy & Tellis, 2000) and outperform smaller firms in terms of operational efficiency (Park & Luo, 2001), they often lack the strategic and operational flexibility that helps younger companies to successfully market products in fluid markets (Park & Luo, 2001). In addition, we controlled for the percentage of revenue spent on research and development (R&D), since extant research has shown high *R&D intensity* to be associated with product innovation (Visnjic et al., 2014) and sales growth (Artz et al., 2010). Next, we controlled for *industry effects* by building five dummy variables for *automotive*, *electronics*, *electrical equipment*, *industrial machinery*, and *others* to capture firm goals and environmental dynamism (Kortmann et al., 2014). We also included a dummy variable to control for *customer focus* (i.e., business-to-business [B2B] versus business-to-consumer [B2C]). Moreover, we controlled for a firm's *service focus*, operationalized by the share of service revenue to total revenue, to rule out any effects that servitization strategies may have on our model. Finally, we controlled for country of origin and created a dummy variable that was equal to one for U.S. firms and zero otherwise.

4 | ANALYSIS AND RESULTS

To analyze the relationships in the proposed research model, we employed the partial least squares (PLS) approach to structural equation modeling (SEM) with SmartPLS (Version 4.0.). We adopted PLS-SEM since the structural theory had not been tested in prior research, and its associated measurement instruments were new (Kroh et al., 2018). Hence, this study aimed to predict and explain differences in the target constructs rather than to confirm the proposed theory (Hair et al., 2014; Hair, Sarstedt, & Ringle, 2019; von Delft et al., 2019). Furthermore, PLS-SEM is appropriate for complex models that contain formative second-order constructs and mediation effects (Cepeda-Carrion et al., 2018; Chin, 1998). In contrast to covariance-based SEM, PLS could be used to calculate the reflective-formative main construct of this study (Hair et al., 2017), namely, digitalization capabilities. Finally, PLS-SEM is especially suitable for small sample sizes (Hair, Risher, et al., 2019). We applied a bootstrapping procedure with 4999 subsamples, as recommended by (Henseler et al., 2016), to assess the significance of loadings and paths in the structural model.

4.1 | Measurement model

4.1.1 | Reliability and validity

To test the reliability and validity of the reflective measurement models, we followed recent recommendations by Hair, Risher, et al. (2019) and examined indicator loadings, internal consistency reliability, convergent validity, and discriminant validity. Our analysis supported indicator reliability for all constructs, with all indicators being at or above 0.7. Next, we demonstrated the convergent validity of all constructs, as each construct explained more than 50% of the variance of its items, meaning that the average variance extracted (AVE) values were above 0.5. Third, we assessed the internal consistency using Cronbach's alpha as the lower bound and composite reliability (CR) as the upper bound. All values exceeded the suggested 0.7 threshold. Fourth, we used the heterotrait-monotrait ratio of correlations as proposed by Henseler et al. (2015) to assess discriminant validity. The results support that discriminant validity for all constructs was significantly lower than the conservative cutoff value of 0.85. Since all requirements stipulated by Hair, Risher, et al. (2019) were fulfilled, the reflective measurement models demonstrated adequate reliability and validity. Table 2 summarizes these results.

In contrast to reflective measurement models, formative models do not necessarily covary (Hair et al., 2014). Therefore, the abovementioned tests on internal consistency, such as composite reliability or AVE, could not be applied. Instead, we followed the recent recommendation by Sarstedt et al. (2019) and assessed the formative higher-order construct digitalization capabilities based on multicollinearity, statistical significance, and relevance of the indicator weights. We opted for a disjoint two-stage approach (Becker et al., 2012) to estimate the higher-order construct. In contrast to the repeated indicator approach, which produces smaller bias when estimating the relationship between lower- and higher-order components, two-stage approaches demonstrate a better parameter recovery for the paths pointing between the higher-order construct and other constructs of the model (Sarstedt et al., 2019). Following Becker et al. (2012), we used regression weights (Mode B) and the path weighting

TABLE 2 Correlations, square root of AVE, and statistics of first order measurement scales.

	Constructs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(1)	Representation	0.80[a]															
(2)	Connectivity	0.48***	0.79[a]														
(3)	Digitalization capabilities	0.50***	0.57***	0.79[a]													
(4)	Channel integration	0.33***	0.42***	0.42***	0.85[a]												
(5)	Sales growth	0.00	0.05	0.17*	0.10	na[a]											
(6)	Firm age	0.00	0.12	0.07	0.17*	0.16	na[a]										
(7)	Firm size	0.13*	0.19***	0.11	0.02	−0.09***	0.12**	na[a]									
(8)	R&D intensity	0.00	0.09	0.12	0.18*	−0.02	0.07	−0.05	na[a]								
(9)	Automotive	−0.07	0.03	0.04	−0.02	−0.03	−0.10	−0.07	0.07	na[a]							
(10)	Electronics	0.05	0.03	0.10	0.25***	−0.08	−0.08	−0.05	−0.02	0.12	na[a]						
(11)	Electrical equipment	0.12	0.09	0.08	−0.03	−0.07	−0.12*	−0.09	0.07	0.04	0.34***	na[a]					
(12)	Industrial machinery	0.01	0.08	0.03	−0.02	0.10	- 0.03	0.02	−0.04	0.28***	−0.16*	0.14**	na[a]				
(13)	Other	−0.01	−0.03	−0.02	0.11	−0.08	0.03	−0.01	0.07	−0.15**	−0.02	−0.07	−0.28***	na[a]			
(14)	Customer focus (B2B)	0.07	0.06	0.02	−0.04	0.00	0.13*	0.03	0.02	−0.18*	−0.12	−0.10	0.13	0.03	na[a]		
(15)	Service focus	−0.00	0.06	0.19*	0.18	0.24	0.09	0.08	0.44***	0.06	0.06	−0.15**	0.26***	−0.11*	0.11*	na[a]	
(16)	Country (United States)	0.14*	0.13	0.05	−0.04	0.00	0.01	0.27**	−0.03	−0.02	0.06	0.06	−0.23***	0.08	0.03	0.02	na[a]
	Mean	4.79	4.91	3.98	3.79	0.05	82.13	18.32	17.86	0.19	0.31	0.26	0.45	0.25	0.83	18.49	0.29
	SD	1.42	1.55	2.04	1.62	0.34	51.06	51.49	18.42	0.39	0.46	0.44	0.50	0.43	0.38	20.36	0.46
	AVE	0.64	0.63	0.62	0.73	na	na	na	na	na	na	na	na	na	na	na	na
	CR	0.88	0.87	0.89	0.93	na	na	na	na	na	na	na	na	na	na	na	na
	Cronbach's α	0.81	0.80	0.85	0.91	na	na	na	na	na	na	na	na	na	na	na	na

[a]Value on the diagonal is the square root of AVE (bold). Two-tailed tests are reported.
*indicates significance at the 10% level;
**indicates significance at the 5% level;
***Indicates significance at the 1% level.

scheme to estimate the formative measurement model. To check whether the measurement model was affected by multicollinearity, we calculated the variance inflation factor (VIF). Values of 1.31 for the representation and connectivity indicators were far below the conservative threshold value of 3. Lastly, our assessment demonstrated that both indicators (*connectivity*: 0.69; bootstrapped 95% CI = 0.486, 0.877; *representation*: 0.46; bootstrapped 95% CI = 0.212, 0.675) significantly contributed ($p < 0.01$) to digitalization capabilities.

4.2 | Structural equation model

4.2.1 | Results

Figure 1 and Table 3 present the results of the PLS-SEM analysis. Digitalization capabilities were significantly and positively associated with smart customization capability ($\beta = 0.63$, $p < 0.01$). The results support Hypothesis 1, which proposes that digitalization capabilities foster smart customization. In support of Hypothesis 2, smart customization capability, in turn, significantly fostered sales growth ($\beta = 0.24$, $p < 0.01$). Notably, the direct relationship between digitalization capabilities and sales growth was nonsignificant ($\beta = -0.12$, $p > 0.1$). Following Nitzl et al. (2016), our mediation analysis shows that smart customization fully mediated the relationship between digitalization capabilities and sales growth. The significant indirect effect of digitalization capabilities via smart customization on sales growth ($\beta = 0.15$, $p < 0.01$) supports Hypothesis 3. The results further show that the relationship between smart customization and sales growth was positively moderated by channel integration ($\beta = 0.26$, $p < 0.05$), supporting Hypothesis 4. Figure 2, which plots the relationship at one standard deviation below the mean, at the mean, and at one standard deviation above the mean of the moderating variable (Dawson, 2014), shows a significantly steeper positive slope for high levels of channel integration. Finally, in line with Hypothesis 5, we found that channel integration moderated the indirect relationship between digitalization capabilities and sales growth via smart customization. Following Cheah et al. (2021), we calculated the index of conditional mediation ($\beta = 0.15$; bootstrapped 95% CI = 0.008, 0.249; standard error = 0.07; $t = 2.02$) and tested the conditional indirect effect at the sample mean and at one standard deviation above and below the sample mean of the moderator. Results indicate that the conditional indirect effect was significant at one standard deviation above the mean ($\beta = 0.29$; bootstrapped 95% CI = 0.103, 0.442; standard error = 0.10; $t = 2.81$) and at the mean ($\beta = 0.14$; bootstrapped 95% CI = 0.053, 0.231; standard error = 0.05; $t = 2.61$), but was nonsignificant at one standard deviation below the mean ($\beta = 0.14$; bootstrapped 95% CI = −0.126 to 0.129; standard error = 0.08; $t = -0.05$) of channel integration. The conditional indirect effect of digitalization capabilities through smart customization on sales growth was found to be stronger for high levels of channel integration, thus supporting Hypothesis 5.

4.2.2 | Model fit

To assess model fit, we followed the recommendations of Hair, Risher, et al. (2019) and examined the structural model for critical levels of collinearity. All VIF values were below 3, which indicates that collinearity did not bias the regression results. Second, we evaluated the coefficient of determination (R^2), which measures the variance explained in the endogenous constructs, that is, the in-sample predictive power. The model explained 42% of

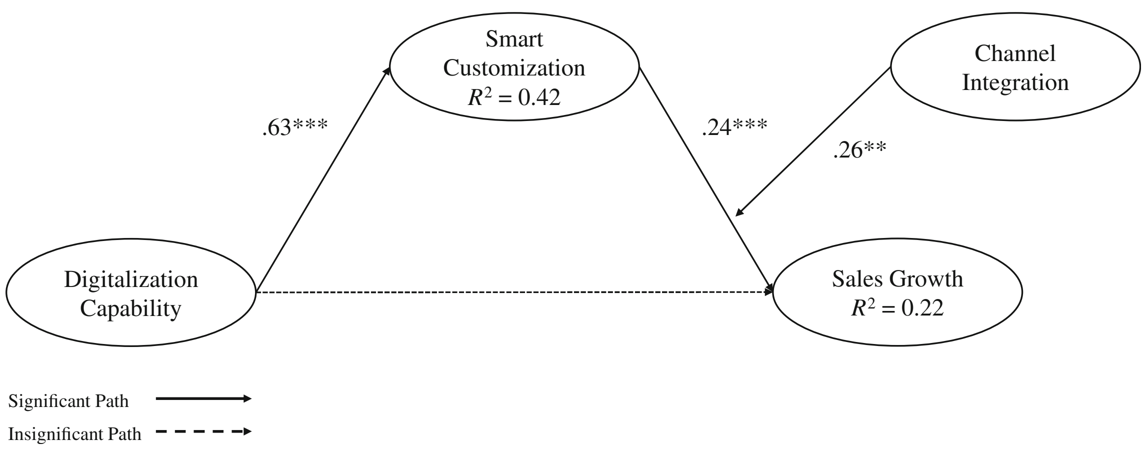

FIGURE 1 Results of structural equation modeling with path coefficients and R^2. *$p \leq 0.10$; **$p \leq 0.05$; ***$p \leq 0.01$. All tests are two-tailed.

TABLE 3 Results of structural equation modeling analysis with β-coefficients.

	Smart customization capability	Sales growth
Direct effects		
Digitalization capabilities	0.63***	−0.12
Smart customization capability	(−)	0.24***
Channel integration	(−)	0.08
Smart customization capability × channel integration	(−)	0.26**
Indirect effects		
Digitalization capabilities	(−)	0.15***
Controls		
Firm age	0.01	0.15
Firm size	−0.01	−0.17***
R&D intensity	−0.02	−0.19**
Automotive	−0.12	−0.12
Electronics	0.09	−0.20
Electrical equipment	0.04	0.08
Industrial machinery	−0.13	0.15
Other	0.04	−0.08
Customer focus (B2B)	−0.06	−0.11
Service focus	0.19**	0.24
Country (United States)	−0.13	0.11

Note: Two-tailed tests are reported: ***indicates significance at the 1% level, **indicates significance at the 5% level, *indicates significance at the 10% level.

the variance in smart customization capability and 22% of the variance in sales growth (see Figure 1), which can be considered satisfactory due to the exploratory nature of this study. The predictive power for the endogenous variables was well in line with comparable studies in the field of innovation management (e.g., Cui & Wu, 2016; Mauerhoefer et al., 2017). Finally, we followed Henseler et al. (2016) and calculated the standardized root mean square residual. The result (0.05) was below the relevant conservative threshold of 0.08 (Hu & Bentler, 1999), which implies an additional argument for an acceptable model fit. The results suggest that our model is well suited to explain the proposed relationships.

4.2.3 | Robustness checks

We performed additional analyses using alternative estimation methods to examine the robustness of our findings. First, we ran ordinary least squares regressions to validate the results of the structural equation model. The results in Models 1–3 (Table A2) largely confirmed the PLS-SEM findings, thus supporting Hypotheses 1, 2, and 4. Second, to complement the interpretation of the interaction term based on coefficients and the simple slopes in Figure 2, we plotted the average marginal effects and associated 95% CIs of smart customization capability at various levels of channel integration in Figure 3. The plot shows that the average marginal effects of smart customization on sales growth were positive and significant and became more positive as channel integration increased. This provides further support for Hypothesis 4.

Third, we performed a Sobel test with bootstrap resampling to test the size and significance of the indirect effect of digitalization capabilities on sales growth through smart customization capability, as proposed in Hypothesis 3 (Hayes, 2009; Shrout & Bolger, 2002). The results indicate that the indirect effect was not zero by a 95% bias-corrected CI based on 5000 bootstrap samples (95% CI = 0.007, 0.118; point estimate of 0.054). Additionally, the paths from digitalization capabilities to smart customization capability (a = 0.617, $p < 0.001$) and smart customization capability to sales growth controlling for digitalization capabilities (b = 0.087, $p = 0.018$) were significant. These results further support the hypothesized indirect effect in Hypothesis 3.

Fourth, we used the *sem* and *nlcom* commands in Stata to estimate the conditional indirect effect of digitalization capabilities on sales growth through smart customization capability at different levels of channel integration. Conditional indirect effects were obtained by multiplying coefficients from the structural equation model with values of the moderator at one standard deviation below the sample mean, at the sample mean, and at one standard deviation above the sample mean. We used a bootstrapping procedure with 5000 replications to obtain the standard errors and the 95% CIs of the estimates. In line with Hypothesis 5, the results show that the indirect effect of digitalization capabilities on sales growth via smart customization capability increased with increasing levels of channel integration. At the mean level of channel integration, the indirect effect was 0.055 (95% CI = 0.014, 0.119; $p = 0.034$). The indirect effect for high levels of channel integration was 0.111 (95% CI = 0.020, 0.241; $p = 0.047$). For low levels of channel integration, and in line with the results obtained from PLS-SEM, the indirect effect was found to be nonsignificant at −0.001 (95% CI = −0.053, 0.033; $p > 0.050$). Overall, these additional tests confirm the results obtained from the PLS-SEM analyses and show that our findings are robust to various specifications.

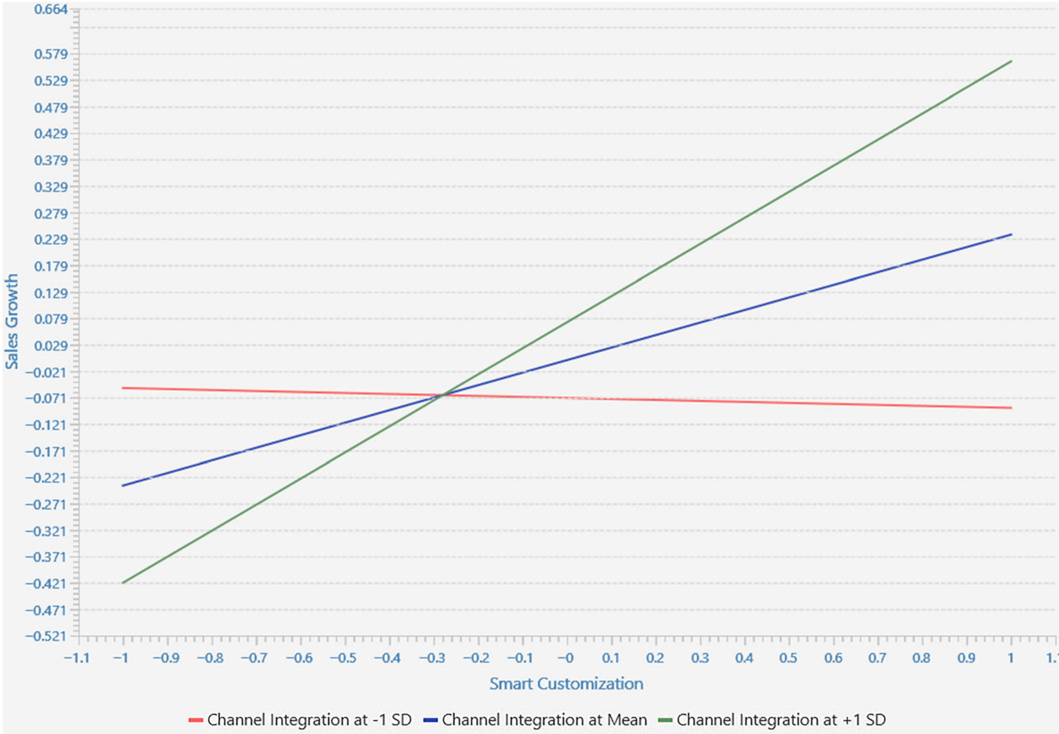

FIGURE 2 Moderating effect of channel integration on the relationship between smart customization capability and sales growth.

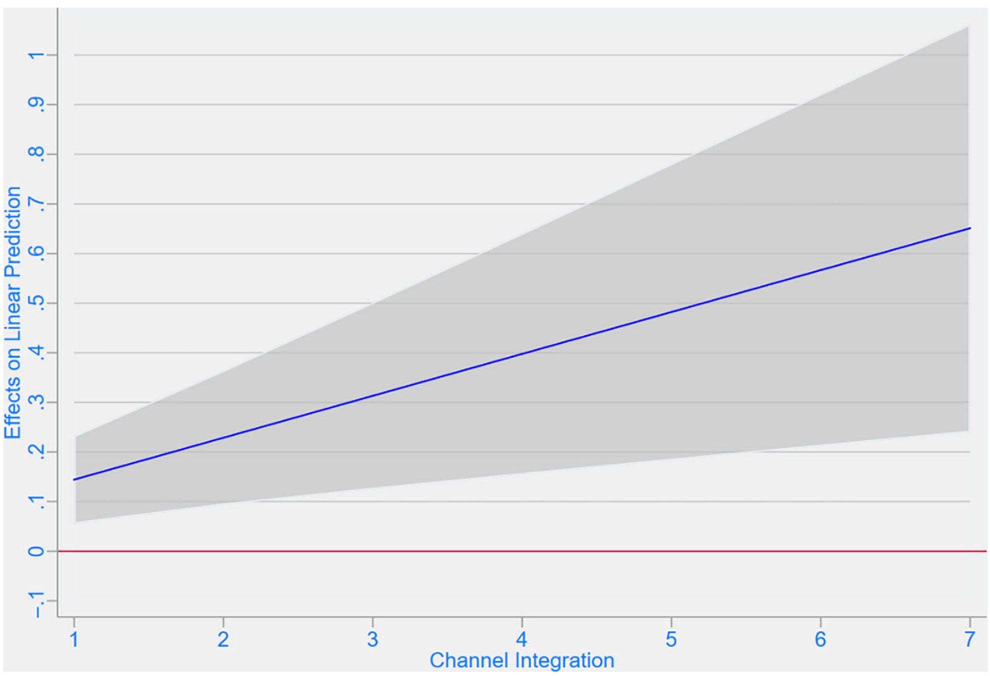

FIGURE 3 Average marginal effects of smart customization on sales growth at different levels of channel integration. This plot is based on Model 3 in Table A2.

5 | DISCUSSION AND IMPLICATIONS

Our work is one of the first empirical studies in the context of smart products in general and the analysis of firm capabilities that enable their successful adoption in particular. Our study shows that digitalization capabilities lay the foundation for smart customization by creating a technological advantage that is subsequently translated into a market-level advantage. Especially if firms additionally invest in the integration of sales and communication channels, superior performance in the form of sales growth can be derived from smart customization approaches. From a theoretical perspective, we integrate the traditional RBV with the DSP to address the widely acknowledged question of how technology-driven innovations can be translated into products that are successful in the marketplace. In the following, we provide an overview of the theoretical and managerial contributions of this study.

5.1 | Theoretical implications

First, we empirically contribute to the current theoretical debate on how capabilities are developed and connected when realizing digital transformation in established firms (e.g., Amit & Han, 2017; Sousa-Zomer et al., 2020; Warner & Wäger, 2019). Our findings provide support for the notion that systems of capabilities, rather than isolated capabilities, drive this transition (see Velu, 2017). Highlighting the importance of heterogeneous market resources as sources of competitive advantage, we build upon and add to recent studies incorporating an integrated perspective on the RBV and DSP (Guo et al., 2020; Priem et al., 2012). Our results indicate that internal resources and capabilities do not directly translate into competitive advantage in digital environments. Instead, complementary capabilities are required, which integrate external, customer-related resources and, thus, allow firms to translate their investments in digitalization capabilities into actual returns. Therefore, we conceptualize smart customization capability as a value-capturing capability, which complements digitalization capabilities as value-creating capabilities in the pursuit of sustainable competitive advantage.

In doing so, we further strengthen the argument that competitive advantage in the digital age is deeply rooted outside a firm's boundaries and primarily related to the ability to embrace customer needs better than their competitors (Amit & Han, 2017; Vial, 2019). Hence, we complement extant research on the role of external partners in today's value networks with a—hitherto often neglected (Amit & Han, 2017)—customer perspective. Our findings highlight the importance of integrated customer resources and firm-customer relationships that help manufacturing firms identify and fulfill (latent) customer needs. Unlocking the full potential of their products thus requires firms to move from a rather inward-oriented strategic posture toward a more outward-oriented one, thereby expanding their activities into the usage phase of the user to offer personalized solutions. This again hinges on investments in digitalization capabilities.

Showing empirically that smart customization capability fully mediates the relationship between digitalization capabilities and sales growth, our research also responds to recent calls on how digital technologies impact firm performance (e.g., Hanelt et al., 2021; Verhoef et al., 2021). While our study could not cover firms' business model dimensions explicitly, the mediating effect of smart customization capability empirically confirms the proposition in the literature that the elements of a business model must be coupled in a coherent way, recognizing their interdependencies or linkages (Baden-Fuller & Haefliger, 2013; Zott & Amit, 2008). An economically sustainable business model demands that the capabilities that a firm obtains to define the value proposition are matched by a corresponding set of activities (and assets) to not only create and deliver but also capture value (Salvador et al., 2020; Wirtz et al., 2016). Our study provides empirical evidence for this conceptual argument and—hopefully—encourages further research investigating these linkages in the context of smart products in more detail.

Second, our study contributes to the emerging literature on smart products by enhancing the understanding of the mechanisms through which manufacturing firms can unlock the market potential of smart products (e.g., Appio et al., 2021; Raff et al., 2020). Our research is among the first to provide empirical evidence for the proposed relationships between digitalization capabilities, smart customization capability, channel integration, and sales growth. While previous research on smart products remains largely conceptual and based on anecdotal evidence, we employ a unique dataset comprising survey and archival data of 136 manufacturing companies offering smart products. Our results underline the relevance of being able to adjust smart products to individual customer needs and thus add to prior studies that explored why digital product innovations often have a poor product-market fit and eventually fail (Reid & de Brentani, 2010).

We show that the value customers perceive depends not only on the product itself and the customized services it enables but also on the interactions and experiences along all customer touchpoints (Lemon & Verhoef, 2016). In this regard, we follow a call made by Mishra et al. (2021) and introduce a new channel integration perspective into the product innovation management literature. We conceptualize the product as the primary touchpoint and link between firms and customers when the latter configure (and reconfigure) their product experience during the entire usage stage. This marks a stark contrast to the conventional retailing context, where digital devices play a facilitating role in online channels but do not constitute a channel themselves. We encourage researchers to examine whether existing channel strategies (e.g., the application of marketing instruments) can be applied to this specific setting. At the same time, our findings also indicate the need for a reconceptualization and revision of the established literature on sales channels for customized products, which have been dominated by studies on online configurators and the interaction processes of customers with these toolkits (e.g., Franke & Piller, 2004; von Hippel & Katz, 2002). When the configurator becomes part of the smart product itself, the conventional division between configuration and usage diminishes. Future research needs to investigate the consequences of this development from a user perspective.

Finally, we contribute by providing an updated conceptualization of the mass customization concept. Table 4 summarizes the main differences between traditional mass customization and customization with smart products, that is, smart customization. We propose a salient role of developing a smart customization capability for success with smart products. Mass customization capability has been conceptualized before as the ambidextrous operational capability that allows firms to offer customized solutions at scale with the efficiency and quality of a (standardized) mass production system (see Kortmann et al., 2014; Patel et al., 2012; Rothaermel & Alexandre, 2008). Such a dual (Daniels et al., 1985) or hybrid (Thornhill & White, 2007) strategic positioning is also required by providers of smart products, but in a different arrangement. Providers of smart products need to combine the efficient and scalable manufacturing of the standardized hardware platform with an efficient and scalable provision of personalized, software-based services at the same time—reversing the conventional logic of many manufacturers to provide customized on-demand manufacturing followed by a standardized after-sales process (if the latter is offered at all). While our empirical design does not allow us to explain this requirement in greater detail, we call for future studies to investigate this ambidextrous position. We suppose that many of the digital transformation challenges in the context of smart products can be related to the need to master these two perspectives at the same time. We call for future research that investigates this strategic challenge as well as the opportunities for new forms of value creation and value capture.

5.2 | Managerial implications

One of the defining characteristics of the current digital transformation of established firms is the digitalization of products. Our study comes with valuable practical implications for this transition and beyond. First, we provide managers in charge of digital transformation with guidance on resource allocation. Specifically, our study highlights that investments in smart product portfolios are necessary to remain competitive in increasingly digitalized market environments, yet insufficient to yield sales growth. Firms may adopt an outward orientation and leverage the ubiquitous availability of customer data to pursue a customization strategy. Our results pinpoint how important it is for established manufacturers to learn from customer experience and continuously optimize product experience (Ebert et al., 2016; Paluch et al., 2020). Over-the-air updates, for example, can be a smart way of instantly adjusting to customer needs without customers being actively involved in the process. The continuous delivery of valuable product features helps alter smart products throughout the product life cycle and thus allows long-lasting co-creative firm-customer relationships.

Second, and related to this, we call for managers to consider whether such service-based customization supplements or rather complements traditional customization approaches. Overall, the solution space for customization has widely opened with smart products. We are not aware of engineering or design approaches that help companies navigate this wide space, for instance, by providing decision templates specifying which features should be customized via traditional mass customization in manufacturing and which should be personalized using smart services during the usage stage (see Table 4). Pioneering companies can create a competitive advantage by utilizing these opportunities in a coherent way. The success of Apple can be seen as a perfect example of such a strategy: the company provides a rather small assortment of physical hardware products to create superior customer value with personalized services and complements during the usage stage.

Third, when manufacturers allow customers to configure their product experience during the usage stage, the product (and its associated interfaces) becomes a focal touchpoint. This new customer-facing sales and service channel adds complexity to the channel infrastructure of the manufacturing firms (Rosenbloom, 2013), not only because it is new but also due to the nature of the resulting interactions, which are more frequent and take place in real-time. Our data indicate that manufacturing firms need to integrate their products with other channels to enable a seamless customer journey. As a foundation, they may start by integrating information on products, prices, and transactions across all customer touchpoints.

5.3 | Limitations and future research

Although our study provides valuable insights, it has certain limitations that offer directions for future

TABLE 4 Comparison of conventional mass customization and smart customization.

	Conventional mass customization	Smart customization
Characteristics		
Domain	Hardware	Hardware, software, and services
Scope	Managing efficient on-demand production to deliver a customized product	Utilizing data from the usage stage to deliver customized services around a (standardized) product
Customer involvement	Episodic at the time of sale (configuration)	Continuously throughout the product lifecycle (utilization of usage data)
Value proposition	Fixed at the time of sale	Evolves throughout the product lifecycle
Focus	Operational efficiency	Operational efficiency and continuous customer value
Capabilities		
Solution space development	Understand the sources of heterogeneities of needs in the customer base and create product architectures (customization options) that allow meeting these requirements efficiently	Develop products that are equipped with sufficient sensors and actuators to automatically adapt to their users and the environment and become the base for the subsequent delivery of customized services (often not yet conceptualized when the product's hardware is designed)
Choice navigation (need identification)	Design and deployment of configuration (co-design) toolkits to support customers to easily find a product offering that fits their needs	Skills to collect and analyze product data to understand the existing and latent needs of a product's user and transfer this data into personalized predictions and prescriptions for each user
Robust processes	Companies make use of modular product architectures, flexible automation processes, and supporting work practices to meet diverging customer needs with high operational efficiency	Companies meet diverging customer needs efficiently through "softwarization" of hardware, interchangeable software components, digital interfaces, and digital services

research. First, respondents of this study were recruited from a sample of managers of smart product firms to which the authors had access via the professional networks Xing and LinkedIn. Although the firms surveyed represent a range of manufacturing industries and smart technologies, they do not represent a random cross-sectional sample. Due to the relatively small sample size and convenience sample, the present study has a somewhat exploratory character. Future research is therefore encouraged to replicate the hypothesized relationships on larger and more representative samples to further validate our findings.

Second, our results do not show a significant direct effect (i.e., a direct association between digitalization capabilities and sales growth), suggesting that there are more potential indirect paths of influence on sales growth that were not part of the formal model in this study and may work in opposite directions. We hence encourage future research to test for additional mediators that may carry the effect of digitalization capabilities on sales growth.

Finally, although this study is among the first to investigate smart customization, the construct only provides an abstract representation of the phenomenon. To better understand the underlying mechanisms, we encourage future research to analyze the distinct roles of data analytics, product and process modularity, and embedded product configuration for smart product-enabled customization (Salvador et al., 2009) and, in turn, sales growth. In this regard, we also encourage future research to empirically study the business model opportunities connected to customization, contributing to the recent debate on monetization strategies in the smart product realm (Raff et al., 2020; Schulz et al., 2021). Related to this, it remains open if and how manufacturers should integrate third-party providers to generate new revenue streams. This is a critical area for future research. Despite these limitations, however, the results of the present study suggest that the construct of smart customization makes an important contribution to understanding the market potential of smart products.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

The authors have read and agreed to the Committee on Publication Ethics (COPE) international standards for authors.

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APPENDIX A

TABLE A1 Construct measurement: Scale items and item loadings.

Construct		Loading
Digitalization capabilities (1 = strongly disagree, 7 = strongly agree)		
Representation: Our products can process information…		
REP1	from various sources (e.g., embedded sensors, microprocessors, operating systems, and/or digital user interfaces).	0.75
REP2	with low human intervention.	0.78
REP3	on a real-time basis.	0.86
REP4	autonomously.	0.82
Connectivity: Our products can connect…		
CON1	through communication networks (e.g., antennas, software, internet protocols).	0.70
CON2	to storing and processing centers (e.g., the cloud).	0.88
CON3	to various services in the cloud (outside the physical product).	0.87
CON4	with other products and machines simultaneously.	0.70
Smart customization capability (1 = strongly disagree, 7 = strongly agree)		
We are able to remotely:		
SCC1	update our products over-the-air (e.g., software updates).	0.74
SCC2	alert and notify the customers when needed.	0.79
SCC3	personalize the user experience (e.g., the user interface).	0.78
SCC4	optimize product performance per individual user.	0.81
SCC5	run predictive diagnostics, service, and repair.	0.81
Channel integration (1 = strongly disagree, 7 = strongly agree)		
In our firm, we integrate…		
CI1	services across all channels.	0.85
CI2	communication across all channels.	0.82
CI3	product/service and pricing information across all channels.	0.85
CI4	databases across all channels.	0.89
CI5	order fulfillment across all channels.	0.85

Note: Respondents were asked to answer the product-related survey items with respect to their firm's product portfolio on average.

TABLE A2 Results of ordinary least squares regressions.

Model	Model 1	Model 2	Model 3
Dependent variable	Smart customization capability	Sales growth	
Controls	b/SE	b/SE	b/SE
Firm age	0.008	0.053*	0.051*
	(0.071)	(0.029)	(0.029)
Firm size	−0.009	−0.062**	−0.063**
	(0.074)	(0.030)	(0.029)
R&D intensity	−0.019	−0.054	−0.065**
	(0.080)	(0.033)	(0.032)
Customer focus (B2B)	−0.061	−0.062	−0.045
	(0.193)	(0.079)	(0.077)
Service focus	0.192**	0.097***	0.081**
	(0.084)	(0.035)	(0.034)
Automotive	0.113	−0.042	−0.039
	(0.191)	(0.079)	(0.077)
Electrical equipment	0.035	0.006	0.018
	(0.174)	(0.071)	(0.070)
Electronics	0.095	−0.070	−0.063
	(0.164)	(0.067)	(0.068)
Industrial machinery	−0.131	0.022	0.044
	(0.164)	(0.067)	(0.066)
Other	0.041	−0.033	−0.023
	(0.168)	(0.069)	(0.068)
Country (United States)	−0.131	0.032	0.026
	(0.164)	(0.067)	(0.065)
Explanatory variables			
Digitalization capabilities	0.628***		
	(0.072)		
Smart customization capability		0.053*	0.059*
		(0.029)	(0.031)
Channel integration			0.015
			(0.033)
Smart customization capability × channel integration			0.085***
			(0.029)
Constant	0.078	0.116	0.050
	(0.214)	(0.087)	(0.088)
N (observations)	136	136	136
F	7.534	1.871	2.307
Model significance	0.000	0.044	0.008
Log likelihood	−155.507	−34.369	−29.682
AIC	337.014	94.739	89.364
R^2	0.424	0.154	0.211

Note: Two-tailed tests are reported.
*indicates significance at the 10% level;
**indicates significance at the 5% level;
***indicates significance at the 1% level.

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