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Leveraging the value from digitalization: a business model exploration of new technology-based firms in vertical farming

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Abstract

Purpose – The purpose of this paper is to investigate how new technology-based firms (NTBFs) overcome established notions of scale and scope through business model innovation, leveraging the value from digitalization.
Design/methodology/approach – The study adopts an exploratory research design, drawing on a novel data set of 50 publicly available interviews with vertical farming (VF) industry leaders and insiders who represent 36 different organizations from North America and Europe.
Findings – The study develops a framework showing how NTBFs leverage the value from digitalization via a paradoxical approach combining both efficiency and novelty value drivers.
Originality/value – The study extends current theorizing on the desirability of a combined business model approach leveraging both efficiency and novelty from digitalization. Furthermore, the study is among the first to investigate the unique and highly technological context of VF.

Keywords Digitalization, New technology-based firms, Business model, Smart manufacture, Vertical farming, Precision agriculture, High-tech SMEs

Paper type Research paper

1. Introduction

> "The idea is that we want to stack these fields close to the point of consumption, eliminate that broken supply chain completely, not fix the silos in between [. . .] but eliminate the whole thing. Truly massively disrupt it. Use technology to enable food production in all these climates that are normally not conducive to such food production and hire locals, reconnect people back to their food supply, and stop this race to the bottom"
>
> Mike Zelkind, CEO 80 Acres Farms

Digitalization, which refers to the transformation of value chains using digital technologies (Buer *et al.*, 2021), is leading a fundamental transformation under the paradigm of Industry 4.0 (Kagermann *et al.*, 2013; Ghobakhloo, 2018; Ortt *et al.*, 2020). Manufacturers employing digital technologies (for example, the Internet of Things (IoT) and artificial intelligence) are expected to derive significant performance improvements, such as increased flexibility, greater customizability of products and services and a reduction in waste (Kagermann *et al.*, 2013; Müller *et al.*, 2018; Montes and Olleros, 2020; Björkdahl, 2020; Büchi *et al.*, 2020).

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However, they face numerous challenges in endeavoring to secure value from digitalization (Buer *et al.*, 2021; Holzmann *et al.*, 2020a; Björkdahl, 2020). In particular, prior research stresses the importance of either pursuing an efficiency or novelty-centered business model design (Visnjic *et al.*, 2017), to avoid the trap of getting "stuck in the middle" (Porter, 1985). To leverage the full potential of digitalization, manufacturers must therefore complement a focus on digital activities with their corresponding value drivers (Amit and Zott, 2001). This is essential for resolving the complex interdependencies between digitalization and the associated business model choices that lead to organizational success (Buer *et al.*, 2021; Baden-Fuller and Haefliger, 2013; Rachinger *et al.*, 2019; Müller, 2019; Chen *et al.*, 2021).

Business models have been conceptualized as firm activity systems (Amit and Zott, 2001; Zott and Amit, 2007; Stabell and Fjeldstad, 1998), with the value chain configuration most commonly associated with manufacturers (Stabell and Fjeldstad, 1998; Porter, 1985). There are principally two strategic choices regarding business model design: efficiency and novelty (Zott and Amit, 2007; Chen *et al.*, 2020). Efficiency and novelty are examples of value drivers that enhance the total value created by the business model (Amit and Zott, 2001; Visnjic *et al.*, 2017). The extant literature highlights the trade-offs present between these value drivers in product-based business models (Visnjic *et al.*, 2017). For example, it is emphasized that firms risk getting "stuck in the middle" if they pursue a business model that is simultaneously focused on efficiency and novelty (Porter, 1985). Firms should therefore choose between "offering a standardized set of products at low cost or targeting differentiated demand with differentiated products" (Fjeldstad and Snow, 2018, p. 34). However, there is growing evidence that, instead of getting stuck in the middle (Porter, 1985; Visnjic *et al.*, 2017; Stabell and Fjeldstad, 1998), new technology-based firms (NTBFs) can successfully adopt a hybrid business model leveraging both efficiency and novelty (Loon and Chik, 2019).

NTBFs are conceptualized as young firms operating in high-tech industries (Colombo and Grilli, 2005). Being "technology based" implies that "the firms rely on a technological advantage as a key element of their initial strategies" (Roure and Keeley, 1990, p. 203). While often being overlooked in favor of a focus on larger equipment manufacturers (Del Giudice *et al.*, 2021), NTBFs can be considered among the most capable of benefiting from digitalization. The smaller size of NTBFs means less complex organizational structures and fewer technological dependencies (Horváth and Szabó, 2019). This supports the ability of NTBFs to innovate their business models through the implementation of new "technologies, processes, and management innovations" (Horváth and Szabó, 2019, p. 129). Nonetheless, it is challenging to leverage the value from digitalization in shifting markets characterized by novel technologies (Baden-Fuller and Haefliger, 2013; Andries and Debackere, 2006). Therefore, while NTBFs are likely to have the ability and potential to make the most of opportunities presented by digitalization, the literature is scarce on how this can be understood in the light of business model innovation (Buer *et al.*, 2021; Montes and Olleros, 2020; Holzmann *et al.*, 2020b; Rask and Günzel-Jensen, 2019; Müller, 2019; Rachinger *et al.*, 2019). Against this background, the study addresses the following research question: *How can NTBFs innovate their business models to leverage the value from digitalization?*

This question is addressed through the indoor vertical farming (VF) industry. VF is a nascent and rapidly growing industry in controlled indoor agriculture, which embodies smart manufacturing by harnessing digitalization (Xydis *et al.*, 2020). External environmental factors are de-coupled by moving production indoors, and precision control is taken of the full range of plant growing conditions. Consequently, indoor VF achieves significant benefits, such as year-round production, high resource efficiency and security of supply (Xydis *et al.*, 2020). This represents a paradigm shift within industrial agriculture, which typically has been characterized by long and complex supply chains that are vulnerable to disturbance. Building on earlier studies exploring business model value drivers (Visnjic *et al.*, 2017; Loon and Chik, 2019; Rosin *et al.*, 2020), this study contends that NTBFs in VF achieve both efficiency and novelty

when leveraging digitalization. VF therefore provides a valuable research context where digitalization is being operationalized by NTBFs pursuing a hybrid business model approach.

2. Theoretical background

The theoretical background begins with a review of the literature on the digitalization of manufacturing value chains, setting the present study in the context of manufacturers undergoing digital transformation. Second, it reviews what is known thus far on how NTBFs leverage digitalization, emphasizing the unique opportunities and challenges associated with developing a hybrid business model that leverages both efficiency and novelty.

2.1 Digitalization of manufacturing value chains

Digitalization represents the mutually reinforcing effects from applying a diverse set of digital technologies, such as IoT, cloud computing and data analytics to transform industry (Ferrás-Hernández *et al.*, 2019). There is a consensus that digitalization has the potential to deliver "more efficient product development, more efficient manufacturing, more sophisticated products and services, and more integrated value chains" (Björkdahl, 2020, p. 19). Furthermore, digitalization of manufacturing operations can result in improved production flexibility, greater output capacity, improved product quality and reduced machine downtime (Büchi *et al.*, 2020). In other words, digitalization is radically changing business models (Chen *et al.*, 2020; Baden-Fuller and Haefliger, 2013; Rachinger *et al.*, 2019; Müller, 2019; Chen *et al.*, 2021; Björkdahl, 2020). However, for business model innovation to be successful, manufacturers must address the increasingly uncertain, complex and dynamic relationships between novel digital technologies and business model trade-offs related to their value chains (Baden-Fuller and Haefliger, 2013; Porter, 1985; Fjeldstad and Snow, 2018; Skinner, 1974; Ferdows and De Meyer, 1990).

The literature tells us that firms belonging to the value chain can either pursue a strategy of cost reduction (efficiency) or differentiation (novelty) (Zott and Amit, 2007; Chen *et al.*, 2020), but crucially not both because this risks getting "stuck in the middle" (Porter, 1985). The value chain activity system configuration typically places the greatest focus on efficiency value drivers to reduce costs (Stabell and Fjeldstad, 1998; Visnjic *et al.*, 2017). Efficiency targets a reduction in transaction costs associated with the flow of components, capacity utilization, proprietary technologies and scale (Zott and Amit, 2007; Porter, 1985; Fjeldstad and Snow, 2018). Novelty relates to new ways of conducting economic exchanges (Zott and Amit, 2007) through differentiation at the level of the product or manufacturing process, or the delivery system (Porter, 1985). As a result, technology development is conceptualized as being undertaken either to enhance efficiency through process improvements or to adapt the product to create novelty (Stabell and Fjeldstad, 1998).

However, diverging views reframe the perceived dichotomy between efficiency and novelty as one of establishing a balance (Skinner, 1974) or cumulative capability development (Ferdows and De Meyer, 1990). For example, focused manufacturing and the plant within a plant concept have proposed ways to address inherent trade-offs (Skinner, 1974). This is achieved through a deliberate focusing of scope that fosters a more balanced, manageable and controllable production system (Skinner, 1974). Others propose that trade-offs can be negated through a sequential and cumulative development of capabilities beginning with quality, then dependability, production flexibility and finally cost efficiency (Ferdows and De Meyer, 1990). More commonly referred to as the sand cone model, this approach has been used to explain the success of manufacturers who seemingly defy traditional managerial approaches that advocate one manufacturing capability at the expense of others (Ferdows and De Meyer, 1990). Advanced manufacturing technologies have been identified as a key enabler behind the ability to simultaneously pursue multiple capabilities (Boyer and Lewis, 2002). Yet prior research nonetheless finds that "plants tend to focus on certain capabilities"

(Boyer and Lewis, 2002, p. 18) and their associated competitive priority for organizational success. Trade-off theory therefore retains its relevance and importance for understanding manufacturing performance (Boyer and Lewis, 2002; Ferdows and De Meyer, 1990; Skinner, 1974). It is therefore pertinent to explore how manufacturers manage efficiency and novelty when innovating their business models to fully leverage the benefits offered by digitalization (Metallo *et al.*, 2018; Horváth and Szabó, 2019; Müller, 2019; Müller *et al.*, 2018; Rachinger *et al.*, 2019). This is especially the case when considering NTBFs that are uniquely positioned to benefit from it (Sabatier *et al.*, 2012; Rask and Günzel-Jensen, 2019; Autio *et al.*, 2018).

2.2 Leveraging digitalization through new technology-based firms

NTBFs are characterized as firms where a new and advanced technological development lies at the core of a business opportunity (Trimi and Berbegal-Mirabent, 2012). NTBFs typically possess few resources, making them particularly vulnerable to the challenges posed by technical and market newness (Andries and Debackere, 2006; Roure and Keeley, 1990). The highly uncertain and dynamic environments in which they operate are a defining feature of NTBFs, differentiating them from non-technological firms as being inherently more risky (Trimi and Berbegal-Mirabent, 2012). This places a greater onus on NTBFs to make "better and faster business decisions regarding operational efficiency and the use of scarce resources" (Trimi and Berbegal-Mirabent, 2012, p. 462). Technology therefore has an important role to play in shaping NTBFs (Autio, 1997) to exploit new business opportunities (Jensen and Clausen, 2017). In particular, the ability of NTBFs to exploit and explore digitalization is critical in order to overcome a lack of resources and adapt the business model to dynamic markets (Del Giudice *et al.*, 2021; Montes and Olleros, 2020; Rosin *et al.*, 2020). However, prior research on digitalization and business model innovation has tended to focus on larger incumbent organizations (Del Giudice *et al.*, 2021), such as established SMEs in traditional industries that are in the early stages of digital transformation (Ghobakhloo and Fathi, 2020; Rachinger *et al.*, 2019; Müller, 2019), rather than on NTBFs who are leading it (Montes and Olleros, 2020; Rosin *et al.*, 2020).

Earlier research provides an explanation for this by suggesting that fully exploiting the potential of digitalization and embedding Industry 4.0 technologies in their manufacturing processes is "out of reach" for manufacturing SMEs (Müller, 2019; Ghobakhloo, 2018). Lack of resources, low production numbers and lack of relevant competence are typical reasons cited for the comparatively lower levels of digitalization in SMEs when compared with larger enterprises (Ghobakhloo, 2018; Müller, 2019; Buer *et al.*, 2021). However, NTBFs diverge from this reasoning. Unlike incumbent manufacturers, NTBFs by virtue of their size have the advantage of "fewer technological dependencies, and fewer barriers to cooperation" than larger firms seeking to exploit novel technologies (Horváth and Szabó, 2019, p. 129). This makes NTBFs more agile in response to changing circumstances than incumbents because they have lower levels of organizational inertia and path dependencies (Spencer and Kirchhoff, 2006; Zott and Amit, 2007). For example, the changing customer–supplier relationships wrought by digitalization requires a shift to a more customer-focused business model capable of being modified in simple ways in response to market demands (Trimi and Berbegal-Mirabent, 2012). Digitalization supports this responsiveness through modularity and quicker adaptation of the product and organizational design of NTBFs (Del Giudice *et al.*, 2021), coupled with faster feedback times from customers (Rosin *et al.*, 2020). Digitalization therefore provides NTBFs with "strategic flexibility . . . to respond to environmental change at the architectural and component levels of the product creation process" (Del Giudice *et al.*, 2021, p. 72). Consequently, NTBFs are "likely to be leading the technological shifts, rather than being forced to respond to them" (Spencer and Kirchhoff, 2006, p. 152).

Indeed, manufacturers that have successfully leveraged new technological developments with novel business model configurations are able to challenge incumbents that have dominated the market for years (Won and Park, 2020). For example, through the adoption of smart

manufacturing technologies, smaller manufacturing firms are able to compete with mass-production models through the ability to flexibly adapt production capacity to meet new market requirements (Büchi *et al.*, 2020; Trimi and Berbegal-Mirabent, 2012). Prior research exploring the effects of digitalization on NTBFs has also shown that digitalization is positively associated with cost savings by streamlining information-intensive processes (Rosin *et al.*, 2020), which support NTBFs in competing on efficiency as well as novelty. However, NTBFs have to cope with the challenge of overcoming the established patterns of value creation and capture in dominant industry logics (Rask and Günzel-Jensen, 2019). What is required is a tradeoff between innovation (novelty) and imitation (efficiency) in business model design in order to earn the legitimacy to exist and operate (Rask and Günzel-Jensen, 2019). Yet prior research shows that attempts to design business models as both efficient and novel may be counterproductive (Zott and Amit, 2007). Developing a better understanding of the dual business model orientation of NTBFs is therefore both of theoretical and practical interest.

2.3 Summary of literature

Despite being recognized as an important element in the transition to Industry 4.0, the ways in which firms across the industrial spectrum leverage digitalization in their business models remains unclear (Buer *et al.*, 2021; Montes and Olleros, 2020; Holzmann *et al.*, 2020b; Rask and Günzel-Jensen, 2019; Müller, 2019; Müller *et al.*, 2018; Rachinger *et al.*, 2019). Achieving a better understanding of how firms leverage digitalization in their business models is a critical question in digital transformation (Del Giudice *et al.*, 2021). This is especially the case for NTBFs that challenge prominent preconceptions of scale and scope related to digitalization and business model innovation (Montes and Olleros, 2020). They are an under-investigated component of an already limited field of research investigating the digitalization of SMEs (Müller, 2019; Müller *et al.*, 2018; Rachinger *et al.*, 2019). The limited work that has been completed thus far has tended to focus on e-business (Loon and Chik, 2019; Rosin *et al.*, 2020; Amit and Zott, 2001) as opposed to NTBFs in manufacturing that must combine physical and digital elements. Hence, exploration of the specific mechanisms by which manufacturing NTBFs leverage the value from digitalization in their business models has the potential to reveal important new insights and challenge the prevailing narrative that firms must choose between efficiency and novelty in the design of their business models.

3. Methodology

3.1 Research approach

An exploratory qualitative research methodology was adopted to investigate how NTBFs in VF leverage the business value from digitalization. Exploratory research is useful in studying contemporary phenomena where limited prior understanding exists (Stebbins, 2001). The study adopts a novel approach to sampling and data collection by drawing on publicly available interviews originating from podcast episodes. Although unconventional, secondary interviews represent one of the numerous and under-valued sources of data at the disposal of researchers (Corbin and Strauss, 1990; Bryman and Bell, 2015; Glaser and Strauss, 1967); the research design utilizing secondary data provides several important advantages including ease and speed of access to the empirical material under study (Glaser and Strauss, 1967). This has enabled the collection of globally diverse insights from industry experts, academia, founders and executive management drawn from a broad range of organizations in the VF industry. Furthermore, usage of pre-existing and naturalistic data that has had minimal to no pre-structuring or filtering by the researcher (Goodwin, 2012) has conferred several advantages, such as reducing the bias from the researcher on the case and from the case on

the researcher (Miles and Huberman, 1994). For example, non-naturalistic data sources, such as newspaper articles, annual reports and company presentations, suffer from the deficiency of having been pre-filtered by an individual with an alternative agenda to that of the researcher (Goodwin, 2012; Glaser and Strauss, 1967). Podcasts, on the other hand, are a relatively unfiltered audio recording open to fresh interpretation. Despite this, it is important to recognize that podcast discussions are nevertheless influenced by both the podcast host and the audience. Uniquely, this very weakness can be considered as strength, with the podcast host occupying the role of a well-informed research assistant heavily engaged in the latest VF industry developments who can stimulate insightful and relevant discussions for analysis. In drawing extensively on secondary data, the study follows earlier studies in manufacturing and technology management that have investigated the innovation of novel digital business models (for example, see Holzmann *et al.*, 2020a; Holzmann *et al.*, 2017; Montes and Olleros, 2020). Similar to previous research, a sole focus on one industry has enabled identification of the most relevant variables of the business model from different patterns emerging from the data (Holzmann *et al.*, 2020a).

3.2 Data selection and collection

Data were selected in accordance with its theoretical utility in answering the research question (Glaser and Strauss, 1967). In order to illuminate the connections between digitalization and business models for NTBFs in VF, different instances of the relationship needed to be revealed (Miles and Huberman, 1994). Investigating different instances of the same phenomena under different conditions, such as in different places and with different people, supports the development of new constructs (Miles and Huberman, 1994). For example, repeating patterns may emerge across the data that can help to signify its importance for the topic of study. It was therefore necessary to strive for variation in the conditions across comparable cases by sampling several different NTBFs as well as supplier organizations in the VF ecosystem. A total of 16 NTBFs categorized as vertical farm *producers* were selected for inclusion in this study. Additionally, the study comprises 21 *suppliers* from the VF producer ecosystem, including technology suppliers, seed suppliers and consultant firms. Appendix provides an overview of the data. The interviews were selected following an extensive online search for podcast episodes on VF published up to and including the 21st of January 2021, containing the key terms: "vertical farm", "indoor agriculture", and "urban agriculture". The primary services used to identify relevant cases included Spotify, iTunes and Poddtoppen. Complementary online searches were conducted to identify relevant cases outside these platforms. Relevance was assessed using the following criteria: (a) VF NTBFs employing digital manufacturing technologies (producers) and (b) ecosystem actors supplying the VF industry (suppliers). The 16 NTBF producers identified through these search processes were established between 2004 and 2018 and were located in the USA. The 21 NTBF ecosystem suppliers identified through these search processes were located in Europe and North America and included representation from the UK, Austria, the USA and Canada. They all support the development of the VF industry but differ in the varying roles they exercise, such as technology supplier, seed supplier and consultant.

For each of the selected producers and suppliers, data were collected from podcast episodes from which they were sampled, and supplementary data obtained from company websites and news articles. Verification of the findings was supported through data source triangulation (Miles and Huberman, 1994) by sampling and analyzing various individuals in the senior leadership teams (for example, founder, CEO, and CFO) at different NTBFs. Moreover, triangulation through data type was established by complementing the podcast transcripts with analysis of supplementary data (Miles and Huberman, 1994). In total, 50 podcast episodes were gathered for the study, recorded between 14/02/2015 and 22/01/2021. The podcast episodes

amounted to a total of 40.5 h and varied in length from 17 min to 101 min, with an average podcast duration of 49 min. These podcasts were downloaded and professionally transcribed. The podcasts covered themes such as how digital manufacturing processes are redefining agriculture and leading to new ways of delivering customer value. They were relevant to this study's research question because they elucidate the digital business model innovation occurring from the digitalization of NTBFs engaged in VF.

3.3 Data analysis

To address the purpose of this study, the data analysis followed a non-linear and abductive process of systematic combining, which shifted between empirical observations and theory to converge on a theoretical model of best fit (Dubois and Gadde, 2002). Systematic combining recognizes the intertwined nature of research activities by framing theoretical development, which begins as articulated preconceptions that evolve, based on new empirical observations or theoretical insights (Dubois and Gadde, 2014, 2002). The 5-step analysis builds on the logic of systematic combining to explain how this study's contribution was brought to fruition.

Step 1: Laying the foundations for an informed engagement with the empirical material of the study, the data analysis began with a literature review of academic publications related to VF. Central themes, such as technology-driven circular business models and digitalization of manufacture, led to the development of a preliminary theoretical framework (Dubois and Gadde, 2014). The preliminary framework guided an initial engagement with the empirical material of the study, thereby enhancing the interpretative potential of the data analysis. An initial research question guiding the first round of data coding was subsequently formulated: *How is the VF paradigm shift in agriculture shaped by the application of digital technologies?*

Step 2: Following the introductory literature review in Step 1, the transcripts were coded. Initial ideas were documented in research memos, and key terms judged relevant to the area of study were recorded. The literature review informed the coding of the data by supporting the identification of how novel digital technologies are related to VF business models. In total, this exercise resulted in 410 codes. These codes were close to the interviewees' own words and were not subject to abstraction or collapse at this stage. Analysis and interpretation of the empirical material from the first round of coding resulted in the identification of new empirical insights not initially explored in the preliminary theoretical framework (Dubois and Gadde, 2002). For example, themes such as the different value chain positioning strategies of high-tech ventures emerged from analysis of the data.

Step 3: To further explore the emergent insights identified in step 2, a secondary review of the literature was conducted (Dubois and Gadde, 2014). Here, themes such as the unique opportunities and challenges of NTBFs competing with incumbent manufacturers were explored. Crucially, indications that NTBFs represented a challenge to the dominant value chain logic of pursuing either efficiency or novelty, and importantly not both, informed a reformulation of the research question: *How can NTBFs innovate their business models to leverage the value from digitalization?* As a result of this shift in study focus, the data were coded for the second time. In total, 308 additional coded segments were created, complementing the 410 codes from stage 2.

Step 4: Having considered their similarities and differences, the first-order codes were condensed into a more manageable twenty-five codes (Gioia *et al.*, 2013). A total of six second-order themes were derived from the condensed listing of data codes in order to

bridge the first-order empirics with theory. The second-order themes relate to ways in which NTBFs leverage value from digitalization and connect with the aggregate dimensions of efficiency and novelty. The generation of themes emerged from a systematic combining approach, moving abductively between theory and empirics (Dubois and Gadde, 2014). For example, the theme "capitalizing on established supply chain inefficiencies" represents the outcome of abductively moving between the case data and a synthesis of the literature on manufacturing business models. A data structure illustrating the connections between first-order concepts, second-order themes and aggregate dimensions is shown in Figure 1.

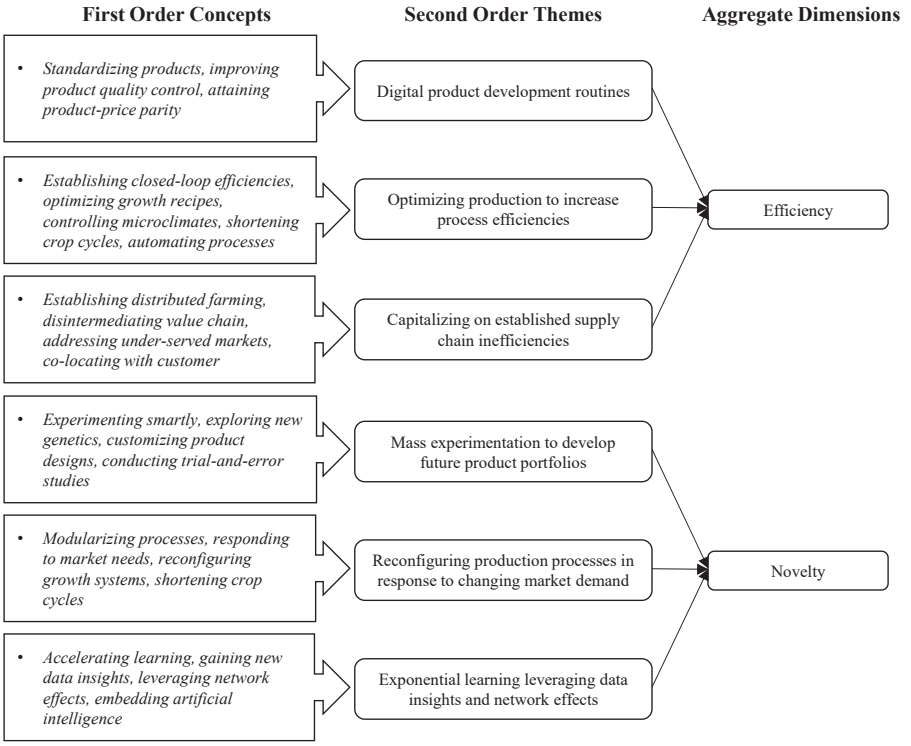

Figure 1.
Data structure

Step 5: The development of a refined theoretical framework showing the relationships between the codes and themes represents the final stage of data analysis, as depicted in Figure 2. Organizing for different types of activities at the product, process and system level, the framework aligns the themes of efficiency and novelty with their corresponding digital activities. Development of the model supported articulation of the connections (as represented by the arrows) between digitalization and the business model value drivers of efficiency and novelty.

4. Findings

The following sections detail the results of the data analysis, which are organized in accordance with the aggregate dimensions of efficiency and novelty.

4.1 Leveraging efficiency from digitalization

Efficiency relates to activities that reduce overall transaction costs through mechanisms such as economies of scale and scope. The analysis demonstrates that the studied NTBFs leverage efficiency through the activities of *digital product development routines, optimizing production to increase process efficiencies* and *capitalizing on established supply chain inefficiencies*.

4.1.1 Digital product development routines. NTBFs leverage efficiency from digitalization via digital product development routines. This refers to digitally enabled activities such as real-time monitoring and precision control of the growing environment to improve quality control and reduce product costs. For example, the CEO of Smallhold commented that "We are capturing about 60,000 data points per day from each of those units, and so if we want to modify the recipe for each variety that you're getting . . . then we can modify that remotely if necessary" (#33). Efficiency is therefore realized by reducing the transaction costs related to the speed and clarity of market feedback when developing products. Furthermore, increased monitoring and control of the growing environment reduces production wastage and ensures that the customer gets "a very precise and standardized product . . . consistent every week" (#35). Digital technologies therefore support VF NTBFs to both quality control and standardize their products. This has a profound effect on the efficiency, with the CEO of Bowery Farming commenting that this has enabled them to deliver better products at a lower price than – or parity with – field-grown produce (#8).

4.1.2 Optimizing production to increase process efficiencies. Production optimization refers to the continuous and incremental process improvements derived from digitally enabled manufacture that minimizes costs and increases productivity. VF NTBFs leverage efficiency from digitalization through micro-climate monitoring and control. For example, the CEO of 80 Acres Farms commented that "we have vision systems and cameras and sensors, all types of sensors in the farm from checking the root zone temperature of the crops to checking the airflow, how many meters per second the air is moving . . . we're checking the microclimates" (#1). This represents a technological leap from conventional field-based agriculture, which enables NTBFs in VF to achieve significantly higher levels of productivity through data-driven insights. Moreover, by moving production indoors, VF producers take control of the climate instead of following traditional farming practices and delegating this responsibility to nature. Not only does this improve product standardization and quality but it also significantly improves the efficiency of resource consumption. For example, the CEO of Crop One Holdings explained that "we use 18,000 gallons of water a year to grow in one of our grow units. To grow the equivalent amount in the field in California, you would need 46 million gallons of water." (#14).

VF producers also leverage efficiency from digitalization by engaging in continuous and incremental process innovation through the automation of manual tasks and control systems that support human decision making. For example, the CSO of Bowery Farming commented that "when you think about all the variables that go into growing plants . . . there's just too many variables to keep track of from a people point of view" (#10). Automation of manual and cognitive tasks reduces the need for human labor in production processes, which in turn reduces operational costs. The CEO of Intelligent Growth Solutions illustrated the significance of digitalization in achieving this by explaining how the use of digital technologies improves control of "an almost infinite number of possible varieties (of variables) . . . layering complexity on complexity on complexity" (#28).

4.1.3 Capitalizing on established supply chain inefficiencies. Capitalizing on established supply chain inefficiencies refers to the ability of VF to leverage efficiency from digitalization to reduce the transaction costs associated with the supply chain. Digitalization supports VFs in achieving supply chain efficiencies through closed-loop manufacturing processes that enable a distributed approach to manufacturing. Distributed manufacturing enables VF producers to locate production at strategically advantageous locations – for instance, at the point of sale or at the point of distribution. The CEO of Green Sense Farms commented that its strategy was to use its business model to disrupt traditional food supply chains "by putting these farms at the point of consumption . . . (like) hospitals, military bases, corporate and college campuses, wherever you're seeing large volumes of meals and then on the distribution side at food processing facilities at grocery store distribution centers, because when they're there . . . we've reduced (the) touch points." (#23). This enables VFs to shorten the supply chain through vertically disintermediation and achieve radically improved efficiencies and control.

4.2 Leveraging novelty from digitalization

Novelty relates to activities that provide new ways of conducting economic exchanges, such as product and process innovations. The analysis shows that VF NTBFs leverage novelty from digitalization through *mass experimentation to develop future product portfolios, reconfiguring production processes in response to changing market demand* and *exponential learning leveraging data insights and network effects.*

4.2.1 Mass experimentation to develop future product portfolios. Mass experimentation refers to the ability of NTBFs in VF to leverage digitalization for novelty via large-scale and systematic trial and error. Unlike conventional agriculture, which is constrained by seasonality and weather and subject to innumerable environmental conditions, a fully controllable indoor growing environment gives vertical farmers laboratory-style growing conditions ideal for product innovation through rapid and large-scale experimentation. As a VF expert commented: "The number of experiments you can run is really high because you can control this particular growing area, and have it with these conditions, and this space has something else, and this space something else." (#18). Data-driven insights from mass experimentation enable VF producers to explore a greater variety of options when innovating new products. A VF expert commented that the large quantities of data create "a really high resolution of feedback . . . (with cycles of testing in the) thousands, tens of thousands even" (#18). Applying machine learning to this data enables the monitoring and control of specific growth parameters that help to differentiate VF produce from field-grown competitors. For example, vertical farmers have developed algorithms that target improvement in product storage attributes, with the CEO of 80 Acres Farms stating that "in fact, that's part of machine learning where we're working on an elliptic algorithm that is tied into your shelf life and your yield" (#1). Novelty is also leveraged at the product level through the ability to customize crops to specific customer requirements. For example, some VFs are exploring the creation of tailored nutrient profiles to satisfy specific customer groups, such as those with medical conditions requiring more or less of certain substances. Future, high-value crops – such as strawberries – are also being explored for integration into the VF production system. The CSO at Plenty summarized its attempts to commercialize future, high-value crops, such as tomatoes and strawberries as an exercise in re-architecting agriculture through new methods of production that have the potential to create new markets. Digitally enabled product innovation routines are therefore central in differentiating VF products from the equivalent grown conventionally.

4.2.2 Reconfiguring production processes in response to changing market demand. Reconfiguring production processes in response to changing market demand relates to the

capacity of vertical farmers to adapt the processes of manufacture in order to, for example, revise output volumes or create new products. Although traditional field-based actors also respond to market needs, NTBFs in VF have much greater responsiveness and flexibility because of their digital, modular and reconfigurable manufacturing processes. Indeed, faster production cycles coupled with an ability to control the growing conditions mean that vertical farmers can be adaptive to new market requirements by quickly adjusting the mix and quantity of different products. The co-founder and CSO of Plenty remarked that "the responsiveness to the market is totally different . . . from start to finish, we can turn a crop . . . in anywhere from two weeks to four weeks. It's a very different profile than say a traditional farm" (#31). Through these new methods of production, VFs can differentiate themselves from the competition. The CSO at Bowery confirmed that "I think one of the things that we truly differentiate ourselves in is in flexibility and the adaptability of our growth systems" (#10).

VF NTBFs also leverage novelty through digitalization using just-in-time manufacture. The co-founder and CSO at Plenty commented on the speed at which vertical farmers can operate: "We have the ability to turn things on and go faster, accelerate, slowdown in response to the markets" (#31). Explaining the benefits from a just-in-time production capability, the CEO of Crop One Holdings stated "if something's not selling, we yank it from production. We know very, very quickly" (#14). This has benefits for not only the VF producer in terms of maximizing sales but also for its retail customers who can mitigate the impact of getting stuck with unsold produce.

4.2.3 Exponential learning leveraging data insights and network effects. NTBFs in VF secure novelty from digitalization through exponential learning, leveraging data insights and network effects. Relative to conventional agricultural practices, NTBFs in VF differentiate themselves through leveraging digital technologies that enable them to learn and scale their operations significantly faster. For example, the co-founder and CEO of Square Roots stated that "instead of shipping food from one part of the world to the other, can you ship climate data from one part of the world to the other? Basically, recreate climates from all around the world, but do that local to the end consumer" (#34). The availability of data is critical to support this organizational learning. The CEO of AeroFarms confirmed this when he stated that "we're collecting, eventually, these tera and tera and terabytes of data, and getting way beyond that soon allows us to grow at such an accelerated rate and learn at such an accelerated rate" (#3). By using this data, NTBFs in VF can develop new insights to support scaling of the business. The chief commercial officer from Bowery commented that "our second farm is 10 times bigger than the first one. The third farm is a hundred times bigger than the first one. We are doing this on an accelerated timeline, but we are with each farm increasing size, increasing capacity, and leveraging the data from the farms before" (#9). This represents a radical departure from conventional farming practices that tend to be more heavily reliant on individual knowledge as opposed to internally developed and decoupled management systems.

4.3 A hybrid approach combining efficiency and novelty to leverage the value from digitalization

Numerous studies have investigated the adoption and implementation of digital technologies on manufacturing performance, yet understanding the mechanisms by which manufacturers can capture the value from digitalization has remained a critical issue (Metallo *et al.*, 2018; Rachinger *et al.*, 2019) By detailing how NTBFs in VF leverage both efficiency and novelty from digitalization, the present study answers calls to investigate the connection between new technologies and novel business model design (Rask and Günzel-Jensen, 2019; Horváth and Szabó, 2019; Loon and Chik, 2019) by addressing the research question: *How can NTBFs*

innovate their business models to leverage the value from digitalization? The framework in Figure 2 shows how NTBFs operating in the VF industry leverage business model value from digitalization through a combined approach of efficiency and novelty.

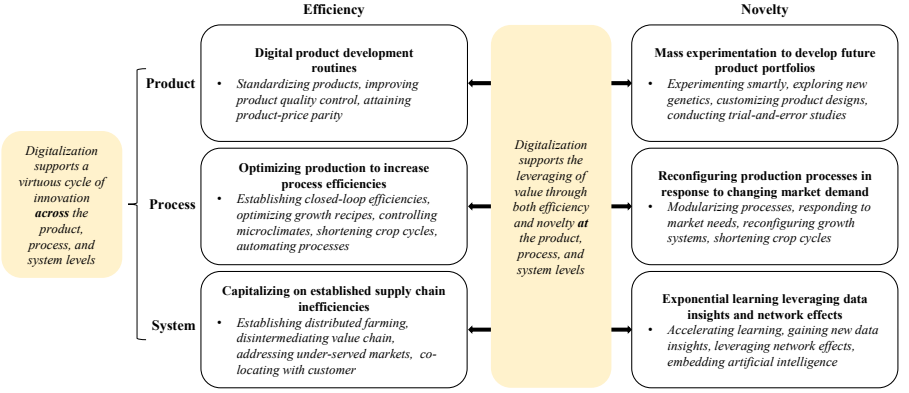

Figure 2.
Leveraging the value from digitalization via a combined approach of efficiency and novelty

In the following section, the role of digitalization in supporting NTBFs in VF to leverage both efficiency and novelty across the product, process and system levels is discussed.

4.3.1 Combining digital value drivers at the product, process and system levels. Contrary to established theorizing, the data indicates that NTBFs in VF can leverage the value from digitalization using a combined approach at the product, process and system levels of the business model. Instead of resulting in a paradoxical trade-off, digitalization makes a hybrid approach between efficiency and novelty possible. This is evident at the product level where the same technologies used in digital product development routines such as precision-control of the growing environment and data-driven insights are used to engage in mass experimentation to innovate products for the future. This is consistent with the conceptualization of VF as a platform for smart experimentation that delivers an end-product for the customer, whilst simultaneously learning how to increase future value. Furthermore, mass customization, the ability manufacture with efficiencies close to mass production but with the ability to customize products to customer requirements, is evident as a mediator between efficiency and novelty value drivers at the product level (Kortmann *et al.*, 2014). Digitalization supports this ambidextrous mediation through greater control of the growing environment driving both efficiency and novelty.

Considered at the process level, there are clear synergistic effects for digitalization between improving the efficiency of production and simultaneously improving responsiveness to market needs. This is principally achieved through a radically shortened production cycle relative to conventional field-grown produce. Shorter production cycles both improve the rates of production and provide new ways of conducting economic exchanges through, for example, faster reconfigurations of product mixes and volumes. This was evident in the way that VFs were able to adjust to the supply chain deficiencies presented by COVID, with the CSO at Plenty stating that "our sales have basically doubled to tripled . . . since the beginning of COVID, and we've ramped things up . . . we have the ability to turn things on and go faster, accelerate, slowdown in response to the markets" (#31).

The system level represents a higher level of abstraction than product and process innovation, addressing changes on the broader firm and industry levels. Combined effects from efficiency and novelty value drivers are also visible here. For example, bringing crop production indoors has allowed VF NTBFs to shift to a distributed mode of farming with radically improved logistical efficiency. The digital technologies supporting this indoor and distributed mode of farming also enable VFs to enhance knowledge accumulation through data-driven insights from enterprise analytics, which enhance organizational learning processes. This is evident in how digital connectivity between the distributed nodes of production enable VFs to leverage their networks and "ship climate data from one part of the world to the other" (#34) and, in so doing, engage in a continuous learning process.

4.3.2 Innovation across the product, process and system levels. In addition to leveraging both efficiency and novelty value drivers, digitalization supports a virtuous cycle of innovation across the product, process and system levels. This is observable in VF where incremental product innovations are intimately connected with digitalized production processes embodied in an indoor and distributed mode of manufacture. Each of these elements is contingent on the other, highlighting the high-tech and uniquely complex context in which NTBFs in VF operate. Innovation across these levels takes the form of a virtuous circle where innovation in one of the levels exerts an impact on the other. For example, organizational learning leveraging data insights from across the distributed nodes of production can feed into new product development efforts and fine-tuning of the production process.

5. Discussion

By drawing on an exploratory investigation of NTBFs in VF, this study is among the first to investigate the connections between digitalization and business model innovation in this novel technological field. Early work investigating NTBFs has highlighted the systemic nature of technological innovation in shaping both business systems and the NTBFs themselves (Autio, 1997). This is true of NTBFs in VF that have identified new market niches through the exploitation of digital technologies. However, the specific ways in which this is achieved are underexplored. In particular, there is a lack of theorizing on the existence of dual business model designs for NTBFs (Loon and Chik, 2019), with earlier research favoring a focus on larger organizations (Ghobakhloo and Fathi, 2020; Rachinger *et al.*, 2019; Müller, 2019; Del Giudice *et al.*, 2021). This study extends the theorizing of previous studies by demonstrating the role of digital technologies in enabling high-tech manufacturing NTBFs to combine the value drivers of novelty and efficiency (Visnjic *et al.*, 2017; Loon and Chik, 2019; Stabell and Fjeldstad, 1998). The study offers important insights for NTBFs in VF, and it addresses calls for "more time-sensitive and contextualized" business model research (Holzmann *et al.*, 2020b, p. 8). The theoretical and managerial contributions are discussed below.

5.1 Theoretical contributions

Firstly, the study develops a framework showing how NTBFs in VF adopt a combined approach to leveraging both efficiency and novelty value drivers from digitalization. Extant research has been unclear on how manufacturers, especially those in shifting markets characterized by novel technologies (Baden-Fuller and Haefliger, 2013), can innovate their business models to leverage the value from digitalization (Metallo *et al.*, 2018; Holzmann *et al.*, 2020a; Müller, 2019; Müller *et al.*, 2018; Rachinger *et al.*, 2019). Through exploration of the digital activities undertaken by NTBFs in VF, this study helps to contextualize the value drivers of efficiency and novelty. Furthermore, prior research has shown that attempts to

design business models to be both efficient and novel may be counterproductive (Zott and Amit, 2007). Through the development of a business model framework detailing specific digital firm activities and their associated value drivers, this study explicitly addresses the underexplored connections within digitalization that are leveraged through multiple sources of value creation (Baden-Fuller and Haefliger, 2013; Berger *et al.*, 2021; Loon and Chik, 2019; Visnjic *et al.*, 2017). In doing so, this study extends previous work exploring digital value drivers in the context of e-businesses (Amit and Zott, 2001; Rosin *et al.*, 2020; Loon and Chik, 2019) and specifically addresses calls for further research on NTBFs within manufacturing (Loon and Chik, 2019).

Secondly, by identifying digital firm activities across different levels of analysis – namely, product, process and system – the framework provides a comprehensive view of how digitalization is used to innovate the business model as a whole (Foss and Saebi, 2018). This provides important insights for NTBFs pursuing a growth strategy, which is best supported by utilizing digitalization to change all the business model elements so that they are complementary and aligned (Fjeldstad and Snow, 2018; Chen *et al.*, 2021). The findings provide empirical support that digital innovation across the different levels of abstraction act in a virtuous cycle, with innovation in one level spurring innovation in the others.

Finally, the present study contributes to the extant literature by offering empirical insights related to the business model innovation of NTBFs. Despite being uniquely positioned to leverage the value from digitalization (Montes and Olleros, 2020; Rask and Günzel-Jensen, 2019), NTBFs are almost exclusively overlooked in research examining the relationship between digitalization and business models (Montes and Olleros, 2020; Holzmann *et al.*, 2020b; Rask and Günzel-Jensen, 2019). The findings from this study provide empirical evidence to strengthen the countervailing insight that NTBFs, despite their comparative lack of firm resources (Buer *et al.*, 2021; Müller, 2019), deviate from the dominant discourse that the digitalization of SMEs lags behind larger enterprises. Contrary to the established view (Buer *et al.*, 2021; Müller, 2019), this study finds that the business model activities of NTBFs are heavily influenced and shaped by digitalization through a combined approach that leverages both efficiency and novelty value drivers. Moreover, unlike larger incumbent manufacturers who may be considering implementation of the first steps of a digital transformation (Ghobakhloo, 2018; Björkdahl, 2020), NTBFs are, relatively speaking, digitally transformed enterprises where each business model element is aligned and complementary in exploiting the value from digitalization (Chen *et al.*, 2021). Therefore, a significant contribution from this research is its exploration of a distinct category of enterprise that does not conform to current orthodoxy. Therefore, the empirical insights from this research challenge the dominant discourse in the literature on scale and scope by showing the unique position occupied by NTBFs.

5.2 Managerial implications

Although the potential benefits of digital manufacturing are clear, there has been limited research on how manufacturers, especially smaller firms, leverage the business value from digitalization. By explicating the interconnections between digitalization, digital firm activities, and the resulting business model value drivers, this study provides insights into how NTBFs can leverage the value from digitalization.

Firstly, NTBF managers should seek to increase their competitiveness by leveraging the value from digitalization in a simultaneous pursuit of both efficiency and novelty. For example, digital product development routines for quality control and standardization can be designed for parallel conduct with digital experimentation of future product portfolios. This combined approach enables NTBFs to leverage the potential of digitalization more fully by creating a greater variety of options and delivering more efficient and flexible responses.

Secondly, managers should consider how to integrate digital activities across the product, process and system levels. By adopting a system perspective of the NTBF business model, managers are better positioned to create a virtuous cycle of digital innovation across the different levels. For example, digital process innovations providing better microclimate control support product standardization and experimentation whilst strengthening the opportunities to capitalize on established supply chain inefficiencies by addressing under-served markets.

5.3 Limitations and further research

The present study adopts an exploratory research design to investigate digital business model innovation by NTBFs in VF. Extensive qualitative data from secondary interviews is analyzed and forms the basis of the study. Despite being a valuable exploratory approach to obtain rich insights from and to gain access to global industry leaders, future research could complement the findings through researcher-led interviews to corroborate the framework.

Future research could explore the performance implications of NTBFs that have digitalized their business models – in particular, the resilience of digital business models under duress. Digital business model resilience is reflected in the capacity of firms to address setbacks through quicker responses and recovery. Although not the focus of this study, preliminary analysis of the data suggests that NTBFs display positive signs of resilience, even to the extent of securing a competitive advantage over established industrial actors when responding to the supply chain disruptions of the COVID-19 pandemic.

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Appendix
Data

#	Company	Location/ Founded	Interviewee	Role	Podcast name	Publication date
1	80 Acres Farms	USA/2015	Mike Zelkind	Co-founder and CEO	Exponential View	2020-11-11
2	AeroFarms	USA/2004	Ed Harwood and Mark Oshima	CSO and CMO	Urban Agriculture	2015-04-25
3	AeroFarms	USA/2004	Ed Harwood	CSO	Vertical Farming Podcast	2021-01-22
4	Agritecture	USA/2014	Henry Gordon-Smith	Founder and MD	Future of Agriculture	2019-03-27
5	Agritecture	USA/2014	Henry Gordon-Smith	Founder and MD	The Modern Acre	2019-03-26
6	Agritecture	USA/2014	Henry Gordon-Smith	Founder and MD	Vertical Farming Podcast	2020-06-10
7	Beta Hatch	USA/2015	Virginia Emery	Founder and CEO	Vertical Farming Podcast	2020-07-21
8	Bowery Farming	USA/2015	Irving Fain	Co-founder and CEO	Future of Agriculture	2018-11-28
9	Bowery Farming	USA/2015	Katie Seawell and Carmela Cugini	CMO and EVP	In Good Hands	2020-06-19
10	Bowery Farming	USA/2015	Henry Sztul	CSO	Vertical Farming Podcast	2020-12-19
11	Bright Agrotech	Canada/2009	Nate Storey	Founder	Future of Agriculture	2016-11-09
12	Clawson Greens	USA/2016	Dave Ridill	Owner and head of operations	Vertical Farming Podcast	2020-06-29
13	Contain	USA/2017	Nicola Kerslake	Founder	Vertical Farming Podcast	2020-07-10
14	Crop One Holdings	USA/2012	Sonia Lo	CEO	Financially Speaking with Mitch Slater	2019-10-14
15	Crop One Holdings	USA/2012	David Vosburg	CFO and SVP strategy	The Modern Acre	2020-04-14
16	Eden Green Technology	USA/2018	Eddy Badrina	CEO	Vertical Farming Podcast	2020-11-20
17	Eden Green Technology	USA/2018	Eddy Badrina	CEO	Sustainability Explored	2020-12-10
18	Farm Urban	UK/2014	Stephen Pankhurst	Lean operations consultant	Vertical Farming Podcast	2020-05-29
19	Farmbox Greens	USA/2012	Dan Albert	Founder	Urban Agriculture	2015-02-14
20	Fork Farms	USA/2012	Alex Tyink	President	Vertical Farming Podcast	2020-08-25
21	Freight Farms	USA/2013	Jon Friedman	COO and co-founder	Vertical Farming Podcast	2020-06-18
22	Gotham Greens	USA/2009	Viray Puri	Co-founder and CEO	Urban Agriculture	2018-03-13
23	Green Sense Farms	USA/2012	Robert Colangelo	Founder and CEO	The Urban Farm Podcast	2016-10-20
24	Green Sense Farms	USA/2012	Robert Colangelo	Founder and CEO	Urban Agriculture	2016-10-18
25	Heilux	USA/2011	Michelle Bonahoom	Interim CEO	Vertical Farming Podcast	2020-09-23
26	Heliponix	USA/2016	Scott Massey	Founder and CEO	Vertical Farming Podcast	2020-08-16
27	Intelligent Growth Solutions	UK/2013	David Farquhar	CEO	The Modern Acre	2019-08-20
28	Intelligent Growth Solutions	UK/2013	David Farquhar	CEO	Vertical Farming Podcast	2020-09-11
29	Intelligent Growth Solutions	UK/2013	David Farquhar	CEO	Vertical Farming Podcast	2020-05-05
30	New Age Provisions	USA/2018	DeMario Vitalis	Founder	Vertical Farming Podcast	2020-12-03
31	Plenty	USA/2013	Nate Storey	Co-founder and CSO	The Modern Acre	2020-09-08
32	Plenty	USA/2013	Nate Storey	Co-founder and CSO	Vertical Farming Podcast	2021-01-08
33	Smallhold	USA/2018	Andrew Carter	Co-founder and CEO	Vertical Farming Podcast	2020-08-03
34	Square Roots	USA/2016	Tobias Peggs	Co-founder and CEO	Vertical Farming Podcast	2020-11-12
35	Stellar Plants	USA/-	Joe Cox	Founder	Middle Tech Podcast	2020-06-15
36	Unfold	USA/2020	John Purcell	President and CEO	Vertical Farming Podcast	2020-12-11
37	Urban Produce	USA/2014	Ed Horton and Danielle Horton	President and CEO, director of marketing	Urban Agriculture	2015-12-01

Table A1.
List of podcast episodes, sorted by company name

(*continued*)

#	Company	Location/ Founded	Interviewee	Role	Podcast name	Publication date
38	Vertical Farm Institute	Austria/2016	Daniel Podmirseg	Founder	Urban Agriculture	2017-12-23
39	Vertical Future	UK/2016	Jamie Burrows	Founder and CEO	The Disruptors Collective	2020-12-01
40	Vertical Harvest	USA/2016	Penny McBride and Nona Yehia	Co-founders and CEO	Urban Agriculture	2015-06-08
41	Vertical Harvest	USA/2016	Nona Yehia	Co-founder and CEO	What's your why?	2019-02-08
42	Vertically Urban	UK/2019	Andrew Littler	CEO	UK Investor Magazine	2020-12-01
43	–	–	–	–	ESG now	2020-06-10
44	–	–	Dickson Despommier	Emeritus professor and podcast host	Urban Agriculture	2017-11-10
45	–	–	Dickson Despommier	Emeritus professor and podcast host	Urban Agriculture	2016-09-02
46	–	–	Herbert Kliegerman and Dino Carter	Co-founder and brand specialist	Agribusiness Academy Podcast	2019-10-14
47	–	–	Jim Pantaleo	Consultant	Future of Agriculture	2020-02-19
48	–	–	Ross and Craig	Podcast hosts	TEAtime	2020-07-04
49	–	–	Walter Isaacson	Podcast host	Trailblazers	2018-07-10
50	–	–	Louisa Burwood-Taylor	AgTech journalist	Vertical Farming Podcast	2020-05-20

Note(s): Abbreviations: CEO (Chief Executive Officer), COO (Chief Operations Officer), CSO (Chief Science Officer), CMO (Chief Marketing Officer), CFO (Chief Financial Officer), SVP (Senior Vice President), MD (Managing Director), EVP (Executive Vice President)

Table A1.

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