

Pathways to Upscaling: Aligning Capabilities with Supply Chain Design in Automotive Manufacturing

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Abstract

Purpose - Taking innovation to scale and accelerating the development of new technologies puts pressure on manufacturers to perform frequent ramp-ups in increasingly volatile markets. Such pressures inevitably bring the role of supply chain right at the centre of the challenge to design supply chains that are ready to upscale. This research aims to explore how manufacturers can design their supply chain and deploy the required capabilities to respond to the upscaling demands.

Design/methodology/approach - Drawing on the Dynamic Capabilities (DCs) theory this study develops a conceptual framework which is validated through multiple case studies. Data was collected and analysed from 14 upscaling projects in automotive manufacturing.

Findings - This study identified specific DCs (e.g. dynamic relational capabilities) that manufacturers deployed in their upscaling projects, explored their micro-foundations, showed how these are coupled with different Supply Chain Designs (SCDs) and how those matches evolve over time. A distinctive finding is the need for automotive manufacturers involved in innovative and technological upscaling projects, to move away from the traditional binary SCD choice (i.e. modular vs. integral) to a less rigid SCD which we called “evolving SCD” and proved to be particularly valuable for companies with limited resources and evolving market positions.

Practical contributions - This research outlines actionable pathways for upscaling and offers guidance on aligning SCD with capabilities. The findings also illustrate how managers can leverage temporal configurational shifts to strategically address evolving priorities from initial market entry concerns like IP protection and capability access, to later-stage challenges around supplier reliability and volume capacity.

Originality - This study introduces the concept of the evolving SCD which is particularly suitable for start-up companies in meeting the upscaling requirements. Our research enriches our understanding on how to manage upscaling projects by offering fresh empirical insights into how manufacturers can successfully upscale by streamlining the SCD with capabilities.

Keywords - automotive, upscaling, supply chain design, dynamic capabilities

Citation

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1. Introduction

“Battery Day” event, Tesla Fremont Factory, California, Tuesday 22 September 2020.

“Making a prototype is relatively easy...the hardest thing is scaling up production... it's insanely difficult...” Elon Musk¹.

Manufacturers in many industries face the same challenges that are faced in the new automotive manufacturing landscape (e.g. autonomous driving, electrification), to develop new technologies and products and perform frequent ramp-ups or upscales² (the two terms used interchangeably in this paper). For example, many Electric Vehicle (EV) start-ups were in a race to establish new supply chains and run Upscaling Projects (UPs) to meet demand (McLain and Eckert, 2023). Established auto manufacturers are also under pressure, not only because of the growing demand for their newly launched models but also due to the need to construct new production plants or repurpose existing ones to expand industrial base capacity and accommodate large-scale manufacturing requirements (Johansson et al., 2025). The race for scale goes well beyond the narrow interests of manufacturers as scale is essential to create a sustainable operational ecosystem (Havlin, 2025).

Previous studies have approached upscaling as an internal challenge focusing on how companies should plan for production ramp-up, what strategies to adopt and what capabilities to invest in (e.g. Kim et al., 2021, Viles et al., 2020). We argue that manufacturers should also focus on designing a supply chain that is specifically tailored for upscaling, including decisions regarding which components and capabilities to keep in-house and which ones to procure from outside. The role of the supply chain in UPs has not been fully explored, with only certain aspects being investigated, such as the role of buyer-supplier relationships and communication in addressing ramp-up related challenges (Gesell et al., 2021) and the sourcing decisions (Meisel and Glock, 2018).

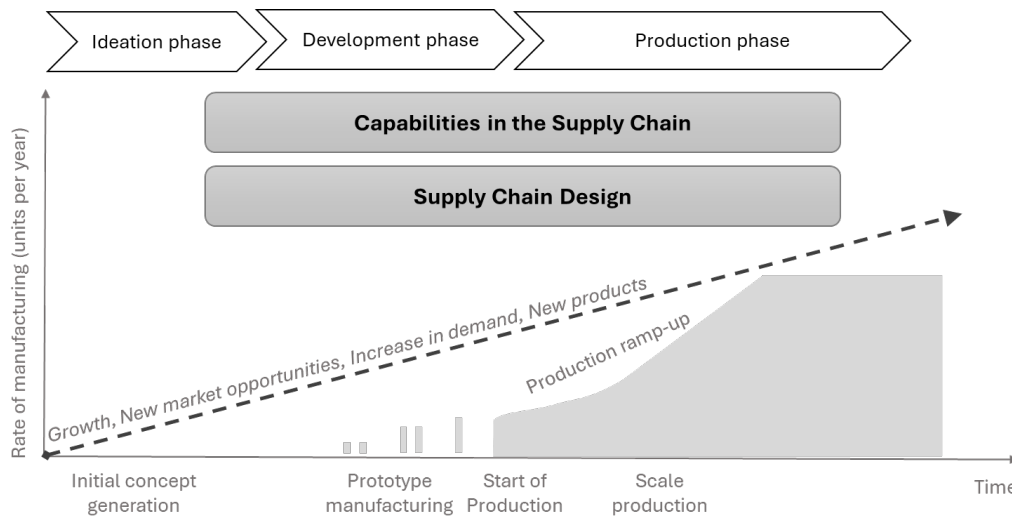
The role of capabilities in upscaling, individually, let alone in relation to Supply Chain Design (SCD) decisions has also been overlooked (Jansen et al., 2023). This is a critical area for entrepreneurs and managers (Aslam et al., 2020) as insufficient investment in necessary capabilities can lead to delays and productivity problems or even trigger a ramp-down which can harm the company financially (Akkermans et al., 2019). In this research, we explore how manufacturers can design their supply chain and deploy the necessary capabilities in response to upscaling demands. Specifically, our research question examines this issue during the period after an automotive manufacturer has generated the idea for a new vehicle and is preparing for (or currently is at) development and production stages in anticipation of upscaling. Accordingly, this study addresses the following research question:

RQ: What supply chain design choices and capabilities do automotive manufacturers deploy to respond to upscaling and why?

¹ Tesla 2020 Battery Day Transcript, Available at: <https://www.rev.com/blog/transcripts/tesla-2020-battery-day-transcript-september-22>

² With roots in the New Product Introduction/Development literature, the upscaling concept developed independently, and it is accepted that “occurs when a new product is introduced into a factory or when a new process or new plant starts up” (Kim et al. 2021) in contrast with capacity expansions which refer to existing products.

Figure 1 graphically illustrates the context of this research, emphasising our focus on capabilities and SCD during the upscaling process. This includes all planning and preparation activities for growth, starting as early as the ideation phase. Upscaling also encompasses the production ramp-up, specifically referring to the phase of increasing volume production. Within this context, we examine specific UPs, which we conceptualise as growth-driven initiatives embedded within ongoing business operations, rather than isolated, standalone projects. These UPs typically involve significant capital investment, such as the construction of new facilities or the development of new supply chains, with the aim of enabling a scalable, sustainable transition from limited to high-volume production and meeting rising market demand.



Source(s): Authors own work

Figure 1. The upscaling context

Our research utilises Dynamic Capabilities (DCs) which is a well-suited theory for capturing the dynamic nature of upscaling in automotive manufacturing, characterised by compressed product lifecycles, constantly changing needs, and high risk (Csiki *et al.*, 2023). To gain a deep understanding of companies' capabilities and SCD in their UPs, we have conducted a multiple case study research program.

This research builds upon and extends the works of Jansen *et al.* (2023) and Fine *et al.* (2005) and makes distinctive contributions in two areas. Firstly, it empirically shows how start-up and established manufacturers match their SCD with their capabilities to meet the upscaling requirements, and shows how these choices evolve over time, contributing to future priorities set out by Jansen *et al.* (2023). Secondly, it elaborates the DC theory by identifying specific DCs in the context of upscaling, particularly exploring their micro-foundations in automotive manufacturing supply chains and by contributing to the ongoing debate about their conceptualisation and the conditions that shape their configuration in dynamic environments (Wilhelm *et al.*, 2022).

Our paper proceeds as follows. First, we establish the theoretical background and we develop our conceptual framework based on prior research and DC theory. Next, we describe our

methodology followed by a within- and cross-case analysis and the discussion of the findings. Then we present a set of propositions and we conclude with the implications of this research.

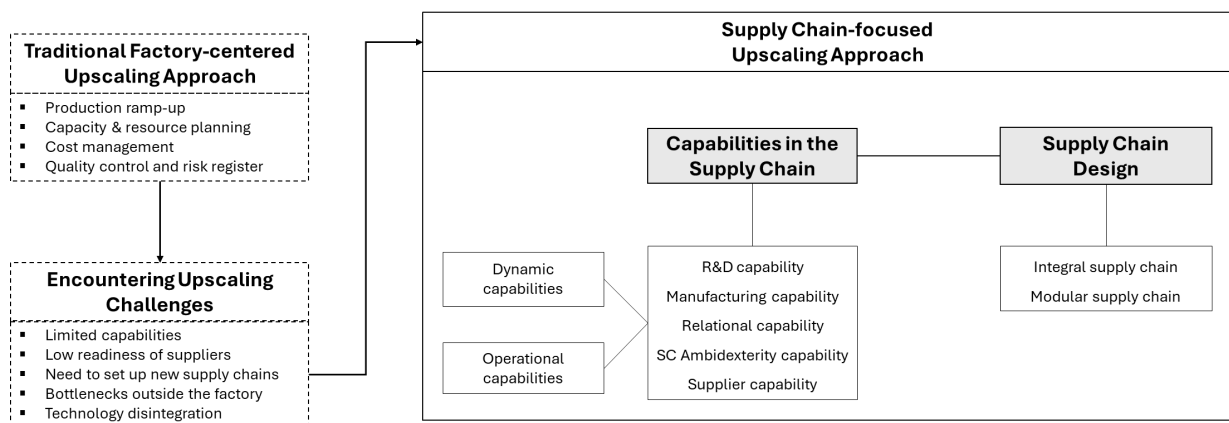
2. Theoretical background and conceptual framework

2.1 Dynamic capabilities as a theoretical lens

Given the dynamic and complex nature of upscaling in automotive manufacturing, this research draws upon DC theory as the most appropriate lens to inform and guide the identification of required capabilities for the upscaling phase (Teece, 2007). By leveraging DC theory, this research can offer valuable insights into how automotive manufacturers can develop the necessary capabilities to successfully navigate the upscaling process. These capabilities comprise sensing (i.e. identification of opportunities), seizing (i.e. construction of procedures and protocols) and reconfiguring (i.e. continuous alignment and realignment of operational practices) capabilities (Teece, 2007) that allow the firm to build and maintain competitive advantage in a rapidly changing environment.

2.2 The conceptual framework

Traditionally, automotive manufacturers and researchers adopt a factory-centered approach in upscaling putting efforts into planning for production ramp-up (e.g. capacity and resource planning, cost management) to ensure the factory can deliver an UP. However, this approach faces significant challenges, including bottlenecks outside the factory, limited capabilities across the supply chain and low supplier readiness especially for start-ups. To address these upscaling challenges, we developed an initial conceptual framework informed by recent industry developments, prior literature, and DC theory. We propose a more holistic, supply chain-focused upscaling approach to support manufacturers in determining the most appropriate SCD including which capabilities should be kept in-house and which should be acquired externally. Through our empirical investigation, we explore how manufacturers can design their supply chain and deploy the necessary capabilities in responding to the upscaling challenges and meeting the UP needs (Figure 2).



Source(s): Authors own work

Figure 2. Conceptual framework

Capabilities in the supply chain. Due to the dynamic and complex nature of upscaling in automotive manufacturing, we reviewed the strategic management literature, particularly DCs, new product development and supply chain management focusing on the capabilities that are relevant to the manufacturing sector. Five capabilities were included in the framework namely: (1) R&D capability, (2) manufacturing capability, (3) relational capability, (4) supply chain ambidexterity capability and (5) supplier capability, primarily because we found these capabilities to be the most critical and prominent product-, production- and supply chain-related capabilities, essential to upscaling. While the broader literature mentions additional capabilities such as knowledge capability, innovation capability, managerial capability (Stei *et al.*, 2024), we found limited empirical evidence linking these directly to the upscaling context. Prior research (e.g. Viles *et al.* 2020) has also shown the link between the selected capabilities and ramp-up performance so this evidence can serve as a good foundation to start the empirical exploration while at the same time being open to capturing other capabilities that might arise.

These capabilities are found internally (product- or process-related) or externally (throughout the supply chain). They can also be categorised as operational (processes and activities that are commonly found in the industry) or dynamic (resting on sensing, seizing and reconfiguring), (Herburger *et al.*, 2024; Teece, 2007). A brief conceptualisation of these capabilities is presented below and summarised in Table 1.

R&D capability: An internal capability that refers to a company's ability to generate new product ideas or expand existing product lines through the exploration and exploitation processes (Lukas and Bell, 2000). Companies can possess either an operational R&D capability, which follows standard processes to generate new products, or a dynamic R&D capability, which involves idiosyncratic and constantly changing processes and activities to generate new products that match or induce market change. Many researchers have focused on dynamic R&D capabilities and their positive impact on a firm's performance and competitive advantage (e.g. Breznik and Lahovnik, 2016). They argue that internal (e.g. organisation culture) and external sources (e.g. customers, suppliers) can inform the dynamic R&D capabilities to sense and seize opportunities, to exploit knowledge, to generate product and process innovation potential, to generate technological innovation and to respond to the changing market conditions.

Manufacturing capability: An internal capability that comprises several elements, including cost, quality, delivery, and flexibility. The operational manufacturing capability involves the ability to achieve cost efficiency through the management of materials, labour and inventory costs (e.g. using Just-In-Time and Total Quality Management) and to enhance the responsiveness of manufacturers (Rama Murthy *et al.*, 2024). It also includes the ability to achieve conformance quality, the ability to deliver on time products to customers, to achieve product/process flexibility in order to respond to changes in product design or volume (Corbett and Claridge, 2002). Dynamic manufacturing capabilities derive from the ability of managers to sense and seize opportunities that can lead to the design of reconfigurable manufacturing systems to adapt operations to

achieve different performance targets such as cost, capacity, process innovation and functionality, depending on the requirements (Csiki *et al.*, 2023; Koren and Shpitalni, 2010).

Relational capability: This external capability is the result of collaborating companies trying to improve their competitive position in the market. The operational relational capability derives from relationships management, supplier involvement, mutual commitment and exchange of information across the supply chain network. Mitrega *et al.* (2017) proposed two types of DCs that facilitate knowledge acquisition, namely collaboration DCs and networking DCs. Both types of external capabilities are focused on relationship management (e.g. selecting suppliers, defining governance structures, developing relational standards such as information sharing) and are considered part of the broader category of relational capabilities in this research. Overall, dynamic relational capabilities stem from the company's ability to sense opportunities throughout the supply chain, seize those opportunities and reconfigure accordingly which can lead to reduced purchasing costs, faster delivery times, increased sales and profits, and enhanced flexibility and innovation (Donada *et al.*, 2016).

Supply Chain (SC) ambidexterity capability: This external capability refers to the ability to balance "mastering the present" with "pre-empting the future" and efficiently manage changing market demands (Stei *et al.*, 2024). It has been identified as a DC that can improve supply chain resilience, adaptability, and overall firm performance (Huang *et al.*, 2014). This capability can be further broken down into supply chain exploitation and exploration, which rely on the DCs of sensing (SC visibility), seizing (SC agility), and reconfiguring (SC flexibility) (Lee and Rha, 2016). More specifically, supply chain ambidexterity capabilities have the potential to build a more resilient supply chain capable of; managing and mitigating risks and disruptions, being adaptive to changes and generating competitive advantage through both exploratory and exploitative innovations (Lee and Rha, 2016; Huang *et al.*, 2014).

Supplier capability: This is an external capability from the perspective of the focal firm and refers to the capabilities that suppliers possess, which can be related to product (e.g. R&D capability), process (e.g. manufacturing capability), or supply chain (e.g. IT-enabled SC capability). Operational supplier capabilities involve simply outsourcing an activity, and while they may provide performance benefits, they are readily available to every other customer/competitor (Azadegan *et al.*, 2008). In contrast, dynamic supplier capabilities emerge when the manufacturer and supplier integrate their capabilities in a mutually, unique, synergetic way (Weigelt, 2013). So, a company's ability to sense and identify suppliers' capabilities, seize opportunities and leverage suppliers' capabilities by forming, for example, alliances and create an exclusive capabilities chain can generate new synergetic value and can be a source of competitive advantage in a rapidly changing environment (Weigelt, 2013).

Table 1. Summary of capabilities in the supply chain

Capability	Type	Definition	Operational Aspect	Dynamic Aspect	Key Outcomes	Key References
R&D Capability	Internal	Ability to generate new product ideas or expand existing product lines	Standardised R&D processes for developing new products	Idiosyncratic, evolving processes that sense and seize opportunities and induce or respond to market change	Product and process innovation, technological innovation, competitive advantage	Lukas and Bell (2000); Breznik and Lahovnik (2016)
Manufacturing Capability	Internal	Ability to manage production in terms of cost, quality, delivery, and flexibility	Cost efficiency, conformance quality, on-time delivery, and flexibility via JIT and TQM	Reconfigurable manufacturing systems enabled by managerial sensing and seizing	Cost reduction, responsiveness, process innovation, operational flexibility	Corbett and Claridge (2002); Koren and Shpitalni (2010); Csiki et al. (2023); Rama Murthy et al. (2024)
Relational Capability	External	Ability to collaborate with supply chain partners to improve competitive position	Relationship management, supplier involvement, governance structures, information sharing	Sensing and seizing opportunities across the supply chain and reconfiguring relationships	Reduced costs, faster delivery, increased sales and profits, flexibility and innovation	Mitrega et al. (2017); Donada et al. (2016)
Supply Chain Ambidexterity Capability	External	Ability to balance exploitation of current SC competencies with exploration of future opportunities	Efficient management of existing SC processes (exploitation)	Sensing (SC visibility), seizing (SC agility), and reconfiguring (SC flexibility) to enable ambidexterity	SC resilience, adaptability, risk mitigation, exploratory and exploitative innovation, competitive advantage	Stei et al. (2024); Huang et al. (2014); Lee and Rha (2016)
Supplier Capability	External	Capabilities possessed by suppliers related to product, process, or supply chain activities	Outsourcing and accessing readily available supplier capabilities	Joint sensing, seizing, and integration of supplier and manufacturer capabilities through collaboration and alliances	Synergetic value creation, exclusive capability chains, sustained competitive advantage	Azadegan et al. (2008); Weigelt (2013)

Source(s): Authors own work

Supply chain design. Fisher (1997) first proposed that the nature of product demand (functional or innovative) has implications for a company's SCD. Subsequently, other researchers (e.g. Fine, 1998; Pashaei and Olhager, 2015) explored the influence of product architecture on supply chain decisions, such as make-or-buy, supplier selection, and contracting, as well as on risk pooling, service levels, delivery, inventory, and information systems. Although research has shown that product characteristics and architecture impact supply chain configuration decisions, a well-matched product and supply chain do not always result in better performance (Selldin and Olhager, 2007). Fine (1998) distinguished between integral and modular supply chains based on two key aspects, the strength of the cross-company links and the barriers to entry.

Integral supply chain: An integral supply chain is one where manufacturers and principal suppliers are in close geographic, organisational, cultural, and electronic proximity, have shared managerial and ownership structures, common business and social culture, and high levels of electronic connectivity (Fine, 1998). This design is characterized by strong cross-company links which makes it difficult for new companies to join the supply chain, given that the manufacturer has complete control over the product (Fine, 2005). Key capabilities are retained in-house and there is a minimal degree of outsourcing, resulting in low dependency levels, and highly synchronized processes. Consequently, close collaboration becomes imperative for the integration of the overall product (Pashaei and Olhager, 2015; Fine, 1998). While an integral supply chain may lack flexibility and requires intensive interactions and efforts across the supply chain, it holds the potential for achieving high performance (Ülkü and Schmidt, 2011).

Modular supply chain: It is characterised by low geographic, organisational, cultural and/or electronic proximity among involved parties and suppliers. Suppliers may be dispersed across a large geographical area, possess autonomous organisational structures, exhibit different cultures, and/or low electronic connectivity (Fine, 1998). The outsourcing level is high, and suppliers hold responsibilities over the final product, presenting opportunities for sharing risks (Pashaei and Olhager, 2015). Also, as Fine (1998) emphasised, in modular supply chains, suppliers of key components are often readily interchangeable, and companies are not heavily investing in supplier relationships and know-how. A growing body of research has shown that modular supply chains can yield cost reductions through economies of scale, increased quality, and provide increased product variety to meet evolving customer needs (Ro et al., 2008). Furthermore, modular supply chains can contribute to increased flexibility and improved responsiveness, allowing manufacturers to leverage superior capabilities of suppliers and anticipate market needs, but they also come with challenges for less established or start-up suppliers (Salvador and Vilenna, 2013).

Nevertheless, this strategic supply chain dichotomy of integral/modular design lacks detailed operationalisation and might be difficult to come across in practice in its “pure form” (van Hoek, 2000). Another important observation is that modular supply chains cannot feature low proximity levels in all dimensions as this would result in a loose, disjointed supply chain so some level of close proximity and integration is expected (Fine, 1998). As Baldwin (2023) emphasised, modularity involves the strategic combination of components in ways that yield most valuable configurations.

In summary, our framework brings together the capabilities that are required in upscaling along with the SCD dimension and through our empirical investigation we try to understand which is the right match, why and how it might evolve over time. In that way, we adopt a “theory as an engine” approach (Pflueger et al., 2024) through which we will contribute to ongoing debates about their conceptualisation, and we will leverage inference (Rouse et al., 2025) as a pathway to understand how automotive manufacturers match capabilities with SCDs in their upscaling projects and why. We bring the capabilities with the SCD dimensions together for the first time in

the context of upscaling and we do our exploration for two types of companies, start-up and established manufacturers, who both face the same challenge - the need to design an appropriate supply chain tailored for upscaling and deploy the right mix of capabilities to respond to the upscaling requirements.

3. Methodology

We chose a qualitative approach to explore how manufacturers can design their supply chain and deploy the right capabilities to respond to the upscaling requirements utilising interviews, observation, and document analysis to gather rich data.

3.1 Case selection

We followed a purposeful three-step sampling process to identify and select the case for this research, i.e. the unit of analysis, which is the UP. First, we focused on a single sector, the automotive manufacturing, to gain in-depth insights (von Gleich *et al.*, 2012) because different industries come with different ramp-up drivers (e.g. product lifecycle, complexity). Then, to identify suitable companies, we screened more than 100 companies with a UK presence that had R&D and manufacturing activities. After screening of companies' websites and additional sources (e.g. LinkedIn), we shortlisted almost 80 companies using three criteria:

- it should involve a new product or process that requires investment decisions (e.g. building a new plant),
- it should be an ongoing project to collect real-time data and gain fresh insights,
- it should be at the development or production stage, allowing for sufficient data collection.

These companies were then contacted to explain the research scope and acquire additional insights before determining their suitability. Eventually, 13 companies were selected. The remaining ones were not included because: (i) 12 companies did not meet the eligibility criteria after having an initial discussion, (ii) 15 companies declined the invitation to participate due to their availability, (iii) 10 companies were unable to share any project specific information/data due to their policy and (iv) several companies did not respond to our invitation within the given timescale. On this basis, sampling bias may have occurred as companies facing greater difficulties, adopting more secretive postures toward advanced technologies, or running unsuccessful projects may have been less willing to participate. Consequently, the sample may overrepresent successful projects and not fully reflect companies with active UPs or failed initiatives. However, we do not anticipate that this impacts the validity of our study as our focus is to understand how manufacturers can improve their SCD and deploy the necessary capabilities in response to upscaling demands through real-life projects.

A holistic case study design was followed, with one UP being selected per company except for one where two UPs were investigated which provided an opportunity for comparisons. The use of multiple case studies provided us with a solid means for exploration and constituted strong evidence of constructs and propositions.

3.2 Data collection

To ensure content validity, we conducted three pilot studies to pre-test the interview guide. The first pilot study was with a manager from a niche vehicle manufacturer, and the second one involved a one-hour meeting with an experienced academic with a long career in the industry, who had served as a director in product design/engineering departments of multi-billion US and UK manufacturing companies. Finally, we conducted an hour-long call with a senior procurement manager of a multibillion German car manufacturer who provided feedback and ascertained the readability of the interview guide. These studies assessed the appropriateness, clarity and accuracy of terms (e.g. readiness, upscaling, how to quantify capabilities) and questions.

The primary data collection process was from May 2018 to July 2019. At least one and up to four informants were interviewed for each UP, depending on the size of the company and the scale of the project. In total, 38 semi-structured interviews were carried out. Most interviews were conducted face-to-face, with only a few exceptions where online interviews were employed. During the interviews, some participants supplemented their statements with internal reports. Interviews were recorded unless participants raised objections generating transcripts to a total of 140,315 words. The interviews were supplemented with ten factory site visits and two secondments within the supply chain departments of two companies. We also collected secondary data from internal company documents, company websites, public databases, and news articles, in two phases: in 2019-2020 right after the interviews to reinforce the interview data and mitigate potential researcher bias and in 2024, to follow up on the progress made for the specific UPs. The utilisation of multiple sources facilitated information triangulation both within and across companies, validating the insights from primary informants.

The collected data was considered sufficient as theoretical insights seemed to reach saturation towards the end of data collection, and no new useful information emerged in relation to the research objectives (Eisenhardt, 1989). To protect anonymity and confidentiality, coding names were assigned to the 14 UPs and the companies running them. Appendix provides information on primary data collection and companies' profile and size (Table A1) and detailed maps for each UP (Table A2). Table 2 below presents an overview of the UPs.

Table 2. Overview of the UPs

UP	Company profile	UP scope	UP stage when data collected	UP background/ challenge
UP_1	A start-up automotive manufacturer of vehicles with sustainable mobility aspirations.	Ramp-up the production of a highly innovative and complex EV which uses a combination of new clean technologies to reach the capacity of 5,000 vehicles/year.	Development	From the project's inception, the company deliberated on the SCD with the goal of aligning it seamlessly with the business model and strategy.

UP_2	A start-up manufacturer and services provider for automotive with focus on sustainable engineering solutions.	Ramp-up the production of an EV to 5,000 vehicles/year.	Development	The project faced significant delays due to low manufacturing and supply chain readiness. Presently, the emphasis is on improving communication and collaboration with suppliers to establish a more stable supply chain.
UP_3	An established, multinational automotive manufacturer of vehicles committed to sustainable mobility.	Ramp-up the production of an EV to 50,000 vehicles/year.	Production steady-state	Customer orders were placed considerably ahead of the vehicle launch prompting a prioritization of production ramp-up. The supply chain and logistics teams were involved very early on to influence sourcing decisions, improve supplier's selection process and reduce logistics costs through improvements in packaging design.
UP_4	Automotive manufacturer	Ramp-up the production of a large EV to 50 vehicles/year.	Development	Despite the company's experience, this new electrification project posed several challenges associated with upscaling. This was primarily due to the use of novel production methods with high voltage electrics and the need to identify new suppliers for electrical and technological parts.
UP_5		Ramp-up the production of a large vehicle to 1,000 vehicles/year.	Development	The project involved the implementation of new tooling and the onboarding of new technology suppliers. It was cross-functionally managed from the outset, led by the engineering team, albeit with some influence from the marketing department.
UP_6	Supplier that manufactures electrical parts for a wide range of applications	Ramp-up the production of a high-power electric part to 100,000 parts/year.	Development	A highly innovative and complex project that requires significant investment decisions including the acquisition of new land, plant expansion, additional tooling, machining upgrades and the integration of automation to meet the targeted production volumes. The key challenges associated with scaling up pertain to production, market dynamics and the supply chain (e.g. reducing costs, identifying suitable partners).
UP_7	Supplier that manufactures engines for a wide range of applications	Ramp-up the production of a high-performance engine to 500 engines/year.	Production steady-state	The R&D, production, engineering, purchasing, supply chain and logistics teams collaborated seamlessly from the inception of the project. The company has invested in internal capabilities to sustain its momentum.
UP_8	Supplier of electrical products for a wide range of applications	Ramp-up the production of an electrical part for energy transmission to 500 parts/year.	Production ramp-up	This project aims to meet the growing demand for intelligent systems in the automotive industry. To facilitate the upscaling process, the company focuses on gathering accurate customer information at the start of the project.
UP_9	Supplier that manufactures	Ramp-up the production of an	SOP	The company is dedicated to upscaling both internally and externally with its suppliers. Efforts are underway to

	engines for a wide range of applications	electrical part to 5,000 parts/year.		ensure that suppliers are well prepared to manage the complexity of the project and are positioned to scale up alongside the company.
UP_10	Supplier that manufactures products/parts for automotive	Ramp-up the production of an innovative part for the automotive to 1,000 parts/year.	Production steady-state	The company gave precedence to incorporating flexibility into its products and processes, with the goal of enabling quick and efficient responses to changes in product design or volume.
UP_11	Supplier that manufactures products/parts for automotive	Ramp-up the production of a precision component to 500,000 parts/year.	Production steady-state	The company invested heavily in new technologies to provide advanced components and increase production capacity. The project, characterized by its complexity, necessitated significant automation, including the use of robots to meet growing demand. Also, new suppliers were enlisted to provide technological expertise and support the project.
UP_12	Supplier that manufactures products for a wide range of applications, committed to circular economy principles and reducing environmental impact	Ramp-up the production of an innovative part for the automotive to 500 parts/year.	Production steady-state	In pursuit of enhanced production efficiency, the company invested in new machinery and implemented in-house improvements. The supply chain for this project is short, reducing transportation mileage, and has been utilized in previous projects.
UP_13	Supplier of parts and systems for automotive	Ramp-up the production of an electrical part to 300 parts/year.	Production steady-state	The company made several investment decisions, including the acquisition of new tools and advanced technology. The primary emphasis was on instilling flexibility and agility into their processes, enabling the company to promptly address any change requests from their customers.
UP_14	Supplier that (re-) manufactures products/parts for automotive	Ramp-up the production of an electronic part to 700 parts/year.	Production ramp-up	From the outset of the project, the company has undertaken significant investment decisions including hiring electronics experts and purchasing new equipment. These efforts are directed towards increasing capacity and growing the customer base.

Source(s): Authors own work

3.3 Data analysis

Thematic analysis was employed to analyse the data, utilising a coding scheme as the basis to identify concepts, relationships and categorise the data (Strauss and Corbin, 1990). The main theme (labelled as aggregate dimension) and the initial second-order themes were obtained from the DC theory and relevant literature while the first-order concepts were derived from the findings. During the coding process, we followed an abductive approach (Dubois and Gadde, 2002) by

iterating between the data and the literature, resulting in the addition of two emerging themes (i.e. risk management capability, evolving supply chain). In total, we analysed 226 quotes from all the UPs and generated 48 first-order concepts, which were grouped into 9 second-order themes. Appendix (Figure A1) provides the data coding structure which visually represents how themes were developed and refined.

As part of the analysis, we developed detailed write-ups, tables and diagrams for each UP, which helped to become intimately acquainted with each case and to identify unique data patterns and the capabilities and SCD of the UPs.

In the cross-case analysis, we searched systematically for cross-case patterns, mapping each case onto the initial conceptual framework, detecting differences and commonalities across the 14 UPs and capturing novel findings. Following upon recommendations from Rockmann and Vough (2023) regarding the storyboarding of the findings, we decided to present our findings in the order of novelty, starting with our most compelling findings.

4. Findings

4.1 Capabilities in the supply chain for upscaling

In this section, we summarise our findings across the 14 cases by reporting the capabilities that manufacturers deployed. The data structure and representative quotes can be found in Table 3.

Relational capability. In most projects, (except UP_12, UP_13, UP_14), manufacturers started to build their relational capabilities early, during the ideation stage, which resulted in suppliers fully understanding the technical requirements. In well-established companies (UP_3, UP_4, UP_9) the decision to involve suppliers early helped to identify cost reduction opportunities from early on and lay a concrete foundation for strong supplier relationships and trust. Those companies reported that having the power, reputation as well as experience working with some of the suppliers facilitated this practice.

The start-ups on the other hand followed new routes to build relational capabilities. In UP_1, they collaborated with new technology companies, which tend to be more open and enthusiastic, rather than using established automotive suppliers which lacked flexibility in adapting to the projects' requirements. In both UP_2 and UP_6, having a vision which is shared with the suppliers was critical, especially for building the relationship, ensuring commitment. Nevertheless, start-up projects (UP_1, UP_2, UP_6) generally required more time and effort to establish relational capabilities, often through a "trial and error" approach, as seen in UP_2 either towards the conclusion of the development stage or the commencement of the production stage.

Dynamic relational capabilities were developed through the establishment of strategic alliances, partnerships and close relationships, which resulted in a unique capabilities chain (UP_2, UP_4, UP_9). These capabilities were enhanced through the implementation of specific standards governing the ongoing evaluation of their preparedness, encompassing aspects such as capacity, deliveries, and reliability, throughout the phases of development and production. In many cases

(e.g. UP_3), suppliers employed a dynamic assessment process, ensuring the prompt identification of any disruptions or risks within the supply chain.

For example, when problems emerged (e.g. delivery delays or capacity issues), the companies reconfigured by either sending a dedicated team to support the supplier in meeting the performance targets or by using recovery strategies (e.g. overtime work, premium transport options). Some operational relational capabilities were also observed in the UP_7, UP_8, UP_10, UP_11 where the companies' focus was to build and/or maintain close collaboration and sometimes longer-term partnerships with critical suppliers and customers. Early supplier involvement was a key practice followed to identify cost reduction opportunities and lay a concrete foundation for strong supplier relationships and trust.

Manufacturing capability. A range of operational manufacturing capabilities was found in all UPs which included investment in production methods (e.g. machining, tooling) to build and improve capacity. Dynamic manufacturing capabilities were also observed in response to the frequent market changes (UP_6, UP_7, UP_10, UP_11, UP_12 and UP_13) with companies building their manufacturing flexibility (e.g. use of mixed-model lines to be able to reconfigure capacity and functionality). This manufacturing flexibility supported the micro-foundational capability to reconfigure and heavily relied on the companies' ability to leverage existing resources and processes. For example, in UP_6 the company built-in the complexity of producing ten different product variants using just one production line for all the variants. Regarding volume flexibility, within UP_10, the company demonstrated the capability to accommodate any customer request. This was facilitated by their machining capabilities across various volume levels (e.g. niche, low, medium and high), enabling them to effectively respond to fluctuations in demand.

Supplier capability. Some operational supplier capabilities were observed in UP_2, UP_4 and UP_5 where the companies had outsourced a big part of their activities, creating a "mix and match" of capabilities to leverage their suppliers' capabilities and benefit from quality improvements.

However, in UP_2, the company did not leverage suppliers' capabilities from the beginning as being a start-up they did not have good knowledge and visibility of their supply chain. For example, their costly production processes increased their operating costs creating many delays. It was only some years later that they managed to leverage suppliers' capabilities and eventually improve performance.

On the other hand, in UP_9, the deployment of supplier capabilities, as early as the beginning of the ideation stage, was part of their competitive strategy. Specifically, the company incorporated supplier capabilities into their product design through the establishment of strategic alliances with select technology start-ups. This strategic move not only enhanced their offerings but also made it more difficult for competitors to replicate their core competencies and capabilities.

R&D capability. Dynamic R&D capabilities were observed in most of the UPs, with companies sensing and exploiting opportunities by combining their core competencies. For example, in UP_4 and UP_5, product engineers worked together with the manufacturing and tooling engineers to ensure that *Design for Manufacturing* principles were adopted early to save production costs.

In UP_6 and UP_7, the engineers included modularity elements in their product designs to build flexibility and to facilitate upscale. More specifically, in UP_7 the engine design was made modular, allowing for customisation to a broad spectrum of applications such as industrial power. All these mechanisms demonstrated how micro-foundations of the dynamic R&D capabilities were premised to generate innovation in a dynamic environment. Other projects (UP_8, UP_10, UP_11 and UP_14) built operational R&D capabilities following more standardised processes when designing new products, through standard operating procedures (SOPs) to ensure quality and safety standards. Those processes were mainly influenced by their customers' requests and standardisation provided them with a stable and reliable framework to build upon while at the same time, being responsive to market demands and allowing for quick pivoting within that framework when necessary.

Risk management capability. This capability emerged as a new theme in UP_1, UP_3 and UP_9 it refers to the ability to manage and mitigate risks, identified as a key success factor for upscaling. For example, in the case of UP_1 and UP_9 operational risk management capabilities were observed in the form of developing a standardised process for conducting risk assessment and analysis for both their business and their supply base. This was instrumental in capturing and enabling access to important information related to the UP as well as allowing teams to respond faster to changes. In UP_3, the dynamic risk management capabilities extended beyond the traditional periodic assessment of suppliers' risk. Instead, they adopted a more dynamic approach involving regular, frequent, and hands-on assessment conducted by a cross-functional team. This approach proved crucial in promptly identifying and addressing supplier performance issues early in the process.

Supply chain ambidexterity capability. Some dynamic supply chain ambidexterity capabilities were observed in UP_2 and UP_3 where companies demonstrated the ability to explore and exploit knowledge and opportunities across their supply chains. Specifically, in UP_2, one of the processes for developing the EV involved specific machining that the company did in-house, but at a very high cost. The company decided to outsource the process to a supplier, with the same machining capability who could do the process quicker and cheaper. Likewise, in UP_3, the company (an established automotive manufacturer) proactively identified its tier-4 suppliers to establish direct communication to expedite the development process. Initially, this initiative faced challenges in implementation, primarily stemming from communication difficulties heightened by intense competition and power imbalances with their tier-4 suppliers, who were very powerful companies in the semiconductor, electronic and computer industries. Over time, the

company successfully adapted by leveraging insights from its strategy and marketing departments, ultimately establishing effective communication channels with its tier-4 suppliers.

4.2 Supply chain design

In this section, we summarise our findings starting with a compelling finding on the evolution of SCDs followed by a description of SCDs across the 14 cases.

Evolving supply chain. The evolving supply chain emerged as a new theme in the case of UP_1 and UP_6 where the configuration of the supply chain evolved during the project lifecycle. For example, the UP_1 witnessed a transition from a modular SCD during the development stage to one with a low modularity degree for the production stage. In the development stage, significant cost components were outsourced, while Intellectual Property (IP) and innovation were retained in-house. The company also maintained close proximity to the supply base to achieve a quick time-to-market. This approach allowed the company to “buy time” for planning in-house investments, subsequently insourcing the supply chain. Ultimately, this enabled the company to retain complete control over product design while also meeting the time-to-volume targets. In the production stage, the company opted for a SCD that exhibited high integrality to address challenges related to suppliers’ insufficient capacity to meet future volume targets.

In contrast, UP_6 employed an integral SCD for the development stage followed by a modular for the production stage. Initially, the company retained activities and technology in-house to safeguard IP and made modest in-house investments to support the low volumes of the development stage. However, the company's ambitious growth plans and the prospect of high production volumes necessitated substantial investments and extensive expansion which raised concerns about the company's ability to innovate and develop new products effectively. Consequently, the company dedicated significant time to designing their supply chain, engaging in meetings and assessments with potential suppliers and partners who share the same vision.

Integral supply chain. This SCD was preferred in the case of UP_10 and UP_12. Outsourcing was kept at low levels (less than 10% in terms of value), with the companies retaining in-house control over core capabilities, full product design, manufacturing and quality. This decision enabled the companies to maintain flexibility in adopting technological innovations and avoid overcommitment to suppliers amid heightened volatility and rapid technological changes. The selection of suppliers was influenced by their location as geographical proximity improved supplier management and minimised the environmental impact.

In UP_10 all tier-1 suppliers (as well as direct customers) were located in the region, with a maximum distance of 100 miles. Similarly, in UP_12 over 90% of tier-1 suppliers and customers were in the same region as the company. Regarding supplier relationships, there was a close collaboration with frequent communication and continuous monitoring of supplier capabilities to prevent delays and production stoppages. Those SCD features exhibited a high degree of integrality and played a pivotal role in facilitating a swift ramp-up of their production processes.

Modular supply chain. The vast majority of cases (i.e. UP_2, UP_3, UP_4, UP_5, UP_7, UP_8, UP_9, UP_11, UP_13, UP_14) presented high outsourcing levels, ranging from 50% to 90% in terms of value, with companies primarily handling sub-assemblies and final assemblies in-house. Additionally, in all those cases, the supply base was strategically dispersed globally, accounting for 50% - 80% (except for UP_13 where suppliers were predominantly local). This dispersion aimed at capitalising on cost reduction opportunities or tapping into expertise from various parts of the world. Both SCD dimensions (outsourcing levels and geographic proximity) featured a high degree of modularity, except for UP_13 which exhibited a low modularity degree in terms of its geographic proximity.

Also, in those cases, suppliers were actively engaged from the ideation phase to gain a comprehensive understanding of the requirements. This practice was evident in UP_9 where the company leveraged the expertise of its supply base to address capability and technological gaps in sub-components. Therefore, the careful selection of suppliers and subsequent continuous assessment and monitoring played a crucial role in the company's ability to fill these gaps. Across UP_2, UP_3, UP_4 and UP_7 assessment tools (e.g. readiness tools) were employed to evaluate suppliers in terms of capabilities, core competencies, current capacities, level of commitment, willingness to grow with the company, interest in diversification, financial stability, quality, accreditations and standards, as well as environmental, safety and quality certifications (e.g. ISO 9001). Furthermore, even if some of those UPs (UP_2, UP_3, UP_4, UP_5, UP_9) exhibited low geographic, organisational and cultural proximity levels, the companies had significantly invested in relationship-specific knowhow and had formed partnerships with suppliers of critical components. In those cases, the relationships exhibited "relationship-specific capital" and therefore did not allow for much interchangeability for alternate suppliers. These partnerships facilitated a quicker response to changes. Similarly, investments in relationships were more resource-intensive in these supply chains, presenting higher degrees of integrality in supplier relationships and integration dimensions. In that way, the dividends paid off, especially when unforeseen, capacity-related, challenges arose during the ramp-up phase. Table 3 below supports our findings with additional, representative quotes for each SCD.

Table 3. Representative quotes for the capabilities and SCD dimensions

Aggregate Dimension	Second-Order Themes	First-Order Concepts	Representative Quotes
Capabilities in the supply chain	R&D capability	New technologies & Newness	<p><i>"It's an electronic car (...) it's got brand new software technologies."</i> (Supply Chain Manager, UP_3)</p> <p><i>"We are doing some world-first really."</i> (Procurement Manager, UP_1)</p> <p><i>"There is nobody in the UK making them, we believe there might be one competitor in the US."</i> (Director, UP_2)</p>
		Collaboration	<p><i>"We get the production engineers involved in an early phase and get them sitting with the engineers to design the part to be"</i></p>

			<i>manufacturable or even get a supplier involved to design.” (Project Manager, UP_4)</i>
	Manufacturing capability	Design for manufacturing	<i>“We not only design for a new model in terms of the aesthetics, we also like to design for manufacture, there is no use in designing something that cannot be manufactured.” (Head of Purchasing, UP_5)</i>
		Modularisation	<i>“The first thing we try to do is understand if it can be modularised (...) and how many people we would need and what the takt time will be.” (Director, UP_2)</i> <i>“Modularity and flexibility are the keys to our product design.” (Head of Production and Logistics, UP_6)</i> <i>“Any workstation should be capable to build all variances ... more expensive ... but you are flexible if something changes.” (Chief Technology Officer, UP_6)</i>
	Relational capability	Identify right supplier	<i>“From the matrix we know who we would need to support us, we get them in ground zero, we say this is what we try to do, do you want to be part? We need to know we’ve got the right supplier.” (Director, UP_2)</i>
		Trust	<i>“The only way we are succeeding is working in partnerships and that takes a lot of trust and finding the right people to work with.” (Director, UP_2)</i>
		Supplier development	<i>“We have people 100% dedicated to managing the development of the suppliers.” (Change Control Manager, UP_3)</i> <i>“We all get to the table with the supplier, understand the project right at the very start and then there are always forward meetings, for very high risks suppliers we do daily or weekly meetings to support them.” (Change Control Manager, UP_3)</i>
		Communication	<i>“When there is a design change from R&D, we will very quickly start communication with the relevant supplier (...) it’s managed quite robustly.” (Change Control Manager, UP_3)</i>
	Supplier capability	Outsourcing	<i>“So rather us doing it, it is cheaper because he has got everything around him, and he can set things quicker than we can (...) what was taken us 3hrs to modify, took him half an hour, it is still a cost but not as big.” (Director, UP_2)</i> <i>“We get suppliers involved early ... it’s their expertise as well we’re trying to get.” (Project Manager, UP_4)</i>
	Risk management capability	Supplier risk assessment	<i>“Understanding the risks and having a very clear management of those is critical for the success of upscaling (...) what we are constantly doing is any issues arising, we are recording them and making sure we drive them through the closure.” (Quality Manager, UP_1)</i> <i>“We have a full risk council for the strategic suppliers, there is a full risk analysis that we complete with them.” (Supply Chain Manager, UP_9)</i> <i>“The risk assessment of the suppliers is dynamic; it’s always continuing changing.” (Supply Chain Manager, UP_3)</i>
	Supply chain ambidexterity capability	Supply chain exploration	<i>“As we are moving now toward more of a technological electronic base, we have seen a lot more suppliers that we did not recognise before, Tier-4 suppliers.” (Supply Chain Manager, UP_3)</i>
Supply Chain Design	Integral supply chain	Close geographical proximity	<i>“We have quite a simple supply chain because we are very highly vertically integrated ourselves.” (General Manager, UP_12)</i>

			<i>"Our supply chain is as close as possible and the reason for that is because of our net carbon footprint, we want to keep road miles down."</i> (General Manager, UP_12)
		Relationships	<i>"We are only working in partnership with a big cost item supplier, we believe is capable of upscaling, although might need some assistance."</i> (Procurement Manager, UP_1) <i>"Communication, talking to suppliers, building relationships are very critical because being with the supplier is like a marriage."</i> (Head of Purchasing, UP_10) <i>"We give suppliers very clear direction, clear timings and clear expectations so there is no ambiguity."</i> (Head of Purchasing, UP_10)
		No risk sharing	<i>"If suppliers haven't got stable manufacturing processes, at the end of the day, we are the ones exposed to that risk."</i> (Production Processes Manager, UP_1)
		No commitment	<i>"The critical components are really the new technologies and we do not want to commit to suppliers because technologies rapidly change."</i> (Chief Engineer and Founder, UP_1)
	Modular supply chain	Global supply chain	<i>"We have gone to a really global supply base, for many reasons. We look for low cost (...) for expertise (...) "</i> (Continuous Improvement Manager, UP_9)
		Risk sharing	<i>"Providing the supplier competence, not only produce a part but also doing sub-assemblies, save yourself money and it's shared risk."</i> (Director, UP_2)
		Early supplier involvement	<i>"We involve suppliers in the design really early ... we are experts in designing engines but not experts in making other parts (...) so we use the supply base, it cuts cost, complexity, reduces risks and quality issues."</i> (Continuous Improvement Manager, UP_9)
		Commitment	<i>"We get the supply chain involved as early as we can so they can see what the intention is, the market space, the level of investment (...) there is joint thinking."</i> (Director, UP_2) <i>"To convince your partner to commit to your plan and invest you need to share the same vision of the future."</i> (Chief Technology Officer, UP_6)
		Relationships	<i>"We treat the supplier as a partner (...) you have got to trust your supplier that is not going to increase the price once you have gone over the initial demand, so that's a critical relationship."</i> (Director, UP_2)
	Evolving supply chain	Design Change: Modular → Integral	<i>"We're outsourcing one of the biggest cost items at the moment, but it will come in-house eventually because the supplier is not capable of doing our future volumes."</i> (Procurement Manager, UP_1) <i>"We are aiming toward our supply chain within the UK (...) at the moment it is not the case."</i> (Production Processes Manager, UP_1) <i>"Suppliers is not something we have worked on very much (...) but those relationships will have to change and we will become more dominant."</i> (Procurement Manager, UP_1)
		Design Change: Integral → Modular	<i>"Design a supply chain differently for different phases (...) because suppliers fall away, technology changes, new materials come, new machines come, all this 3D printing for example for small volumes."</i> (Chief Technology Officer, UP_6) <i>"With the volumes we work today, we are completely dependent on some suppliers (...) but we need to find new ones (...) relationships will change, and we will finally have our supply chain people (...) but these relationships really grow with the volume."</i> (Chief Technology Officer, UP_6)

Source(s): Authors own work

4.3 Matching SCD with capabilities and UP performance

The cross-case findings indicate a variety of different, distinctive combinations when it comes to how start-up companies design their supply chain and deploy capabilities to support their UPs. Specifically, in UP_1 and UP_6 an evolving supply chain had been designed to support upscaling in five and three years, respectively, and both companies had initially deployed only dynamic internal capabilities and were working towards the development of relational capabilities for the scaling up at the production stage.

In UP_2 and UP_13 a modular supply chain had been designed to support upscaling in nine and two years, respectively with dynamic and operational capabilities in the supply chain being used in UP_2, unlike UP_13 where the modular SCD was solely matched with dynamic internal capabilities which proved sufficient to enable the company to treat most of their suppliers as interchangeable and retain their flexibility.

On the other hand, the results from the projects run by established companies (UP_3, UP_4, UP_5, UP_7, UP_8, UP_9, UP_11, UP_14) were more consistent in the use of a modular supply chain to support their UPs deploying a mix and match of internal, external, dynamic and operational capabilities. Their UPs were either anticipated or accomplished more swiftly, typically ranging from one to three years, in contrast to start-ups that required anywhere from two to nine years. In two instances, UP_10 and UP_12, a modular supply chain was designed and matched predominantly with internal capabilities. In these instances, the upscaling was completed within four months and three years, respectively. Table 4 below compiles data on each UP performance, as presented above, in terms of time- and volume-related factors. While acknowledging that UP performance can also be assessed along other dimensions (e.g. quality or cost), we consider these temporal dimensions to be both relevant and critical, given the time-sensitive nature of automotive manufacturing, particularly in the context of upscaling and given the unavailability or confidentiality of such data.

Table 4. UPs performance and outcomes

UPs	Time-to-market (years)	Time-to-volume (years)	UP duration (years)	Volumes (units/year)	Comments/ Outcomes
UP_1	3 (A)*	2 (E)**	5 (E)	5,000 (E)	Project on track when data was collected. Rapid growth, further ramping up underway.
UP_2	3 (missed) new target: 5 (A)	2 (missed) new target: 4 (A)	5 (missed) new target: 9 (A)	5,000 (A)	Not initially successful. Missed the initial target due to manufacturing and SC low readiness but new target met.
UP_3	1.9 (A)	0.1 (A)	2 (A)	50,000 (A)	Project completed successfully, currently preparing for a new lineup.
UP_4	2 (A)	1 (A)	3 (A)	50 (A)	Successful
UP_5	1.67 (A)	0.33 (A)	2 (A)	1,000 (A)	Successful
UP_6	1.5 (A) + 0.5 (E)	1 (E)	3 (E)	100,000 (E)	Project on track when data was collected.

UP_7	0.5 (A)	0.5 (A)	1 (A)	500 (A)	Successful
UP_8	1 (A)	0.17 (A)	1.17 (A)	25,000 (A)	Successful
UP_9	1.75 (A)	0.25 (E)	2 (E)	5,000 (E)	Project on track when data was collected.
UP_10	0.25 (A)	0.05 (A)	0.3 (A)	50,000 (A)	Successful
UP_11	3 (A)	0.5 (A)	3.5 (A)	500,000 (A)	Successful
UP_12	2.5 (A)	0.5 (A)	3 (A)	500 (A)	Successful
UP_13	1.5 (A)	0.5 (A)	2 (A)	300 (A)	Successful
UP_14	0.67 (A)	0.33 (A)	1 (A)	700 (A)	Successful
* Achieved (A)					
** Expected (E)					

Source(s): Authors own work

5. Discussion

Revised framework and propositions

Figure 3 synthesises our findings into a revised framework and a set of propositions that illustrates how manufacturers design their supply chain and deploy the right capabilities to respond to the requirements of their UP.

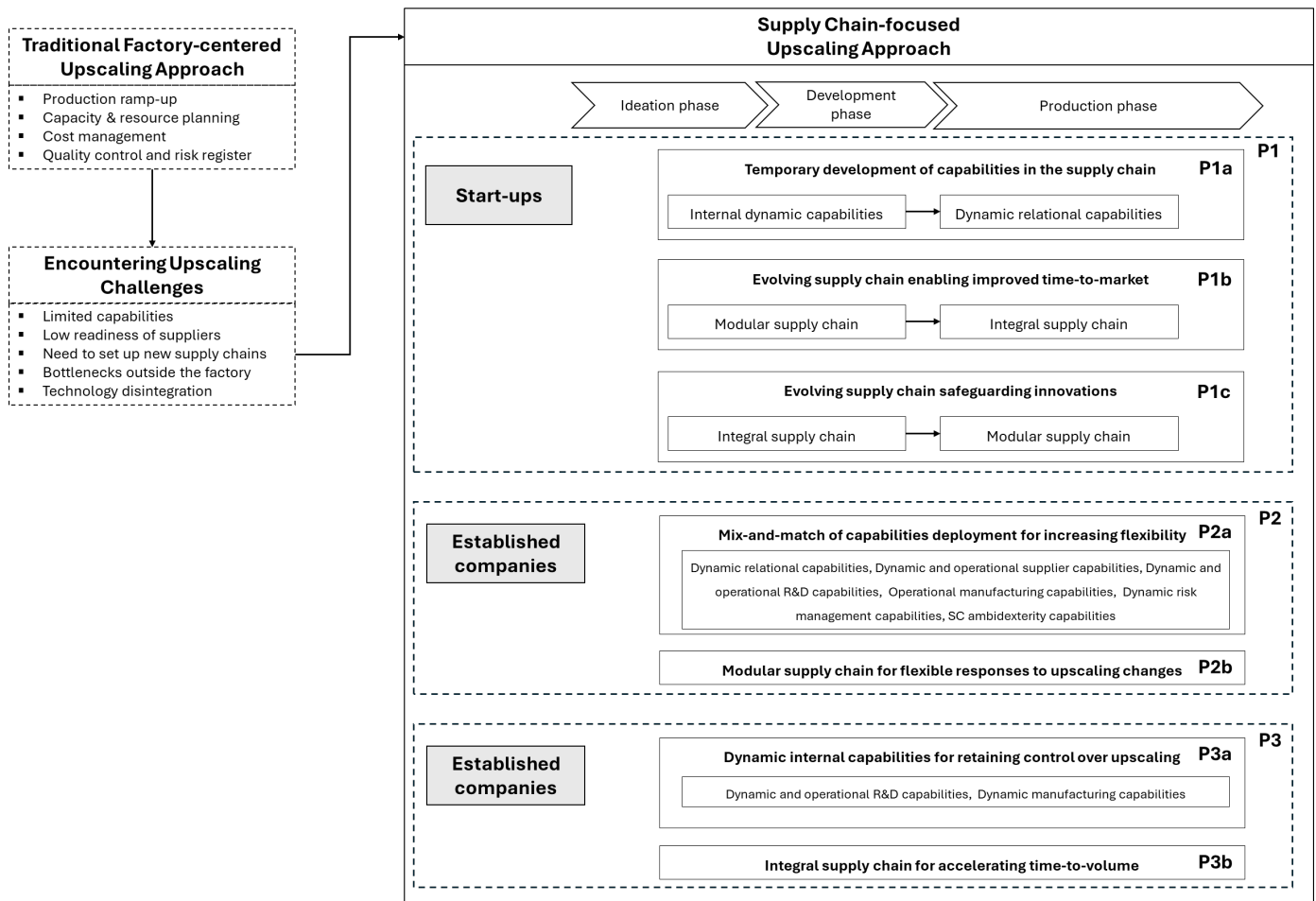


Figure 3. Revised framework, Source(s): Authors own work

During the cross-case analysis of start-ups (UP_1, UP_2, UP_6, UP_13) one of the first observations was the wide range of capabilities being used, and their deployment at different stages of the upscaling and supply chain development strategies being used. A common view amongst them was that even if they recognised the importance of building relationships early with suppliers, they found it particularly challenging because of their infancy in the market which came with limited buying power, credibility and risks to their IP. Those insights challenge established knowledge on the innovation potential stemming from relational capital for start-ups, in particular (Onofrei *et al.*, 2020) and deepen our understanding of why they struggle to leverage relational capital in supply chains. More focused prior research on start-ups highlights their additional infancy-related challenges such as gaps in skills and their legitimacy in the market (Jansen *et al.*, 2023) and we extend this knowledge by showing how the adoption of different SCD strategies can enable them to overcome these challenges.

In UP_1, an evolving SCD was adopted, with a modular SCD during the development phase and an integral SCD during the production phase. The modular SCD was strongly exhibited at the outsourcing level of the SCD which, in line with established research on modularity (Ro *et al.*, 2008; Fine *et al.*, 2005), provided quick access to suppliers' capabilities, reducing costs and improving time-to-market. This allowed the company to prepare for upscaling internally (e.g. by purchasing machining, hiring more engineers) before adopting an integral SCD, with low outsourcing levels, which was necessary as suppliers lacked both capacity and commitment (Pashaei and Olhager, 2015). The goal in UP_1 was to produce 5,000 units/year within five years.

Similarly, in UP_6, an evolving SCD was used but vice versa, with an integral supply chain during the development phase, to protect the product design until the company could identify suppliers who were willing to work and upscale with them and change to a modular SCD for the production phase, achieving an annual production of 100,000 units within three years, which would have been unattainable without leveraging the capabilities of suppliers. Internal investments on such a scale would have posed a significant constraint on the company's potential and ability to diversify, which is in line with prior research (Salvador and Vilenna, 2013). That is why the company put much effort into increasing the degrees of integrality for the supplier relationships and integration as well as supplier commitment and trust dimensions of the SCD, during the production phase, to ensure that suppliers would not fail them as were critical to their operations. However, in UP_2 and UP_13, both run by start-ups, the exclusive adoption of a modular SCD did not alleviate the upscaling challenges in relation to time and/or production volume targets and they both faced delays due to the need for redesigning work and developing a strategy to work with large suppliers. While that challenges previous research (Salvador and Vilenna, 2013) on the benefits of a modular SCD, we bring evidence on the need for a more tailored approach for start-ups.

All in all, a combination of internal factors, stemming from the firms' early-stage maturity and upscaling requirements, and external industry dynamics, including intensified market competition, mounting cost pressures, and heightened supply risks, necessitated a temporal evolution in both

capability deployment and SCD. These factors contribute to a volatile operating environment that challenges the rigidity of traditional modular or integral designs and calls for more adaptive and responsive supply chain configurations that can evolve over time.

Therefore, the evolving SCD proved to be an effective and dynamic strategy for the start-ups UP_1 and UP_6 in overcoming upscaling challenges, such as building dynamic relational capabilities and safeguarding IP. It facilitated time-efficient adaptation to upscaling. However, it is widely recognised that there are hidden costs associated with changes (Larsen et al., 2013), especially when transitioning from one SCD to another within a single project. For start-ups encountering numerous new challenges, these costs appear to be offset by the benefits of the evolving SCD, a scenario that might not be the same for established companies. Thus, the first proposition is formulated as follows:

P1: *Start-up manufacturers undergo significant temporal evolution in both capability deployment and supply chain design, driven by challenges inherent to their organisational infancy and dynamic industry conditions.*

P1a: *To address infancy-related challenges, start-ups should strategically sequence their capability development - prioritizing dynamic internal capabilities (particularly R&D) during early upscaling phases (ideation and development), then shifting focus to dynamic relational capabilities as they transition toward production and scaling in rapidly evolving industries.*

P1b: *Start-ups can design an evolving supply chain that strategically transitions from modular design in early upscaling phases to integral design during production, enabling rapid access to supplier capabilities and improved time-to-market performance.*

P1c: *Start-ups can design an evolving supply chain that strategically transitions from integral design in early upscaling phases to modular design during production, safeguarding internal innovations until a scalable supply chain foundation is established.*

The second observation refers to established companies in UP_3, UP_4, UP_7, UP_5, UP_8, UP_9, and UP_14 who adopted a modular supply chain with high outsourcing levels and with a mix and match of capabilities that allowed them to reduce design complexities, increase product volume and variety, and respond flexibly to changes. This approach required careful supplier selection, and prior research has shown that supplier selection decisions and their integration can impact a project's performance (Petersen et al., 2005). Moreover, research on modular designs (Baldwin, 2023) has emphasised this “mix and match” approach enabling the flexible configuration of components to maximise value within a specific context.

Additionally, even if modular supply chains tend to feature interchangeable suppliers for critical components (Fine, 1998), we observed that in some projects (UP_3, UP_4, UP_5 and UP_9) their internal, R&D and/or manufacturing capabilities were not sufficient and the companies had invested significantly in deploying dynamic relational capabilities, exhibiting relationship-specific capital and not allowing for much interchangeability for alternate suppliers (Onofrei et al., 2020). The deployment of those dynamic relational capabilities led to increased responsiveness, reduced

purchasing costs, and improved supplier performance (Onofrei et al., 2020). Collaborating closely with suppliers and involving them in projects from the early stages helped improve quality by leveraging suppliers' expertise (Salvador and Vilenna, 2013; Saeed et al., 2019). However, if companies cannot access the right capabilities or find suppliers who can meet their desired capacity targets, upscaling can be at risk. Thus, it is proposed:

P2: *Established manufacturers mix and match capabilities within modular supply chains as a strategic response to increasing volatility during upscaling, seeking to enhance efficiency and flexibility in dynamic industry conditions.*

P2a: *To navigate upscaling complexities and increase flexibility, established manufacturers adopt a mix-and-match approach to capability deployment, with particular emphasis on developing dynamic external capabilities, specifically relational and supplier capabilities, that enable them to configure unique capability chains tailored to their upscaling requirements.*

P2b: *Established manufacturers can design modular supply chains featuring strategically dispersed supply bases that deliver cost reduction opportunities, enhanced access to expertise, and rapid, flexible responses to upscaling changes - contingent upon investing in relationship-specific knowledge and forming strategic partnerships with critical component suppliers.*

The third observation relates to projects that used an integral SCD (UP_10, UP_12), which were led by established companies that had developed all their capabilities in-house. These companies managed to achieve fast upscaling within a short period of four months to three years, compared to other cases that required one to nine years. By keeping outsourcing to a minimum, they maintained full control over the design, manufacturing and quality of their products and that is in line with previous research (Ülkü and Schmidt, 2011; Fine, 1998). Their dynamic manufacturing capabilities, which relied on reconfigurable production systems and lean practices, allowed them to respond faster to production ramp-up and achieve cost-efficiencies. The benefits of reconfigurable systems and the potential for faster ramp-up have also been supported by prior research (e.g. Koren and Shpitalni, 2010).

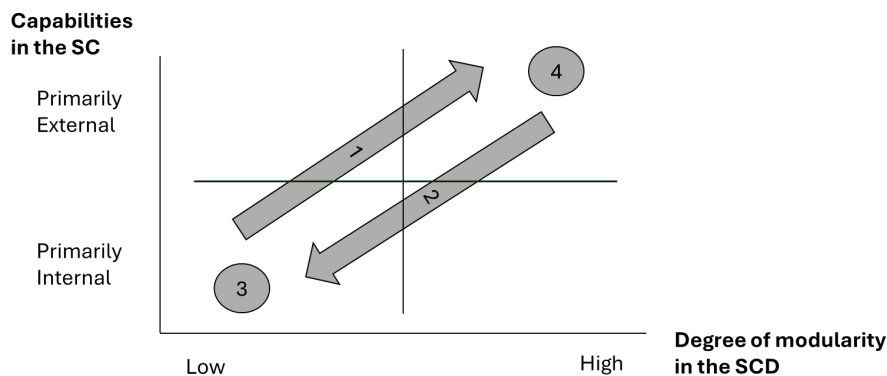
While previous research (Parente and Geleilate, 2016) explored the interplay between process clockspeed, structure and supply chain integration in the development of new products in the automotive industry, we added a new lens that demonstrated which capabilities are well matched with integral SCDs in the upscaling context. We observed that companies in UP_10 and UP_12 focused on building product and process flexibility in-house, enabling them to quickly respond to changes in design and/or volume. The integral SCD, combined with working with local suppliers, helped them reduce costs and monitor and assess the capabilities and performance of their suppliers to avoid delays and production stoppages. Hence, it is proposed:

P3: *Established manufacturers strategically deploy dynamic internal capabilities within integral supply chains to retain in-house control over upscaling processes and to enable rapid production ramp-up.*

P3a: To maintain control over their core competencies, established manufacturers deploy dynamic R&D and manufacturing capabilities, fostering in-house innovation while enhancing manufacturing flexibility throughout the upscaling process.

P3b: Established manufacturers that design integral supply chains, characterised by minimal outsourcing, reduced supplier dependency, and tight control over product design, manufacturing, and quality, are better positioned to accelerate their time-to-volume during upscaling.

Figure 4 below summarises the four successful pathways to upscaling that this research identified and highlights the most important benefits that each pathway can offer to start-ups or established companies. While those outcomes focus on the primary performance outcomes of time and volume, the intervention was also assessed across additional dimensions, including quality and cost considerations, as part of a holistic assessment; however, confidentiality requirements preclude the disclosure of those results.



Start-up companies: Pathway 1 to safeguard internal innovations at the early phases or Pathway 2 for a quick time-to-market at the development phase.

Established companies: Pathway 3 for a quick time-to-volume at the production phase or Pathway 4 for flexibility throughout all phases.

Figure 4. Successful pathways to upscaling, **Source(s):** Authors own work

Finally, drawing on insights from our 14 UPs, we summarise key transition points where manufacturers shift their SCD configuration:

- Concept-to-Development transition: Initial SCD decisions (20-40% defined)
- Development-to-Production preparation: Intermediate SCD refinement (40-70% defined)
- Production ramp-up and steady-state phase: Near-final SCD configuration (70-100% defined)

Guided by the Agile-Stage-Gate principles (Cooper and Sommer, 2016), we propose tracking the progressive definition of SCD from initial configurations through iterative refinements to fully optimised states. Key measurable dimensions include in-house versus external component sourcing, strategic supplier composition, vertical integration levels, and relational governance intensity, captured through quarterly snapshots of procurement data, supplier assessments, and engineering specifications.

6. Implications for theory

This study contributes to the DC theory by identifying specific DCs in a new context (i.e. UPs in automotive manufacturing) and extends our understanding of how their micro-foundations are premised in a high environmental dynamism environment (Csiki *et al.*, 2023; Aslam *et al.*, 2020). Additionally, we provide empirical evidence to the ongoing debate about their conceptualisation by showing how DCs can be deployed within and across the company boundaries despite reservations on their usefulness. For example, we show how start-ups with limited resources in a highly dynamic environment deploy DCs from a problem-solving stance, bringing evidence on the conditions that shape DCs configuration. By applying a dynamics perspective, we emphasise the importance of increasing flexibility across the supply chain to adapt to changes such as design or volume changes. Our research highlights the usefulness of the DC theory in guiding strategic decision-making, especially in the emerging sector that faces rapid technological changes, innovations, and time pressures.

7. Implications for practice

Our study holds some valuable lessons for practice. A first observation is around the need for entrepreneurs, and managers to think about their supply chain beyond the traditional view of achieving cost and quality improvements but as a vehicle for growth. Possibly, for Silicon Valley Unicorn type of start-ups developing or accessing capabilities in the supply chain might be less of a concern, but for the great majority of newly established firms that scale up, year after year, having an appreciation of their SCD can make a difference for the successful commercialisation of new products and ultimately for their survival and growth. Our research shows that successful upscaling largely depends on the supply chain and procurement teams' ability to actively manage the supply base. This responsibility is especially challenging for start-up companies, which must identify suitable suppliers between prototype and small batch (1000off<1000off) and full-scale production (10000off and more). Our findings provide actionable pathways for upscaling and offer guidance on how to adopt different SCDs with the right match of capabilities that will allow managers to strategically address evolving priorities from initial market entry concerns like IP protection and capability access, to later-stage challenges around supplier reliability and volume capacity. At a broader level, beyond the managerial and firm levels, our findings support societal objectives, such as industrial resilience, by revealing gaps and capabilities across firms and providing evidence that can inform industrial strategies and policy interventions.

8. Conclusion

8.1 Contributions

There are several contributions to knowledge stemming from our research. Firstly, our research offers fresh empirical insights into the often-overlooked topic of how to scale up the production of new technologies in the automotive manufacturing supply chain. We build upon and advance existing studies that have shed some light on capabilities and SCDs during new product

developments (e.g. Jansen *et al.*, 2023; Saeed *et al.*, 2019; Ülkü and Schmidt, 2011), but not in isolation from each other as of today. Our primary and novel contribution lies in the underexplored start-up supply chain literature, where we demonstrate that SCD choices are not static but exhibit significant temporal evolution. We reveal the concept of "evolving supply chain design" and we advance understanding of start-up supply chain strategy by demonstrating that temporal shifts in SCD correspond to evolving strategic priorities. This dynamic approach adds new knowledge to the body of literature that largely looks at consistent SCDs among established manufacturers by suggesting that temporal flexibility in SCD may be particularly valuable for companies with limited resources and evolving market positions.

Secondly, our research highlights the importance of considering SCD in the early stages of upscaling and during strategic decision-making, especially in dynamic and emerging sectors, where a substantial number of companies are start-ups and Small-Medium Enterprises (SMEs). Previous studies have suggested that, for SMEs, the supply chain can serve as a means to address deficiencies in areas where they should excel, such as new product design (Branzei and Vertinsky, 2006). Notably, empirical research exploring the supply chain implications during the mid-launch/early commercialisation stage for a product has been limited. Our research shows how manufacturers can combine SCDs of high or low degree of modularity with their core competencies and capabilities during an UP to support the transition to production at scale and ultimately, meet the rising market demand. This includes building strategic SCD, relationship-specific capital and safeguarding their IP. In this context, our work also elaborates on the concept of UPs and deepens our understanding of supply chain development under scaling pressures. We distinguish UPs from conventional one-off projects by positioning them as growth-driven, transitional initiatives embedded within ongoing business operations and unlike traditional projects, UPs' goal is not simply to deliver a predefined output, but to enable a scalable, sustainable transition from limited to high-volume production.

Finally, our research contributes to the wider literature on industry architecture, organisational capabilities, and design evolution by advancing understanding of how capabilities shape strategic choices related to SCD and providing an in-depth, empirically grounded analysis of their role in upscaling. By explicitly linking capability configurations to decisions about organisational boundaries and coordination mechanisms (through SCDs), we extend existing work on capability architecture in complex industry environments. In doing so, we complement and advance prior conceptualisations of industry architecture (Brusoni *et al.*, 2009) by demonstrating how SCD decisions actively reconfigure organisational architectures over time. Furthermore, our findings build on Baldwin's (2023) work on the co-evolution of modular architectures by showing how SCD decisions function as a key mechanism through which such co-evolution occurs. Overall, our study establishes SCD as a central driver of organisational boundary formation and coordination in contemporary supply chains, with particular focus on upscaling.

8.2 Limitations and future research

While our research provides valuable insights, it is essential to acknowledge its limitations and identify opportunities for further validation and extension in other settings. Our study focused solely on capabilities and SCD in automotive manufacturing, but there are other critical factors (e.g. contextual factors) involved in the upscaling challenge. While our findings may be transferable to industries characterised by complex, multi-tier supply chains (e.g. aerospace, defence industries), future research could test and refine our proposed framework across industries and geographies and explore the interplay between various factors (e.g. regulatory environment, uncertainty levels, risk profiles, strategic directions) as well as the differences in how established and start-up companies approach upscaling. For instance, established companies may face challenges with displacement and contractual commitments to suppliers, whereas start-ups may represent a higher risk to suppliers due to differing dynamics.

Furthermore, the evolving SCD concept is a central contribution of our study, but this was not fully operationalised, as this was beyond our scope. Therefore, developing a comprehensive, validated measurement instrument represents an important avenue for future research. Such work could establish standardised scales, identify transition triggers, create practitioner diagnostic tools, and conduct large-scale studies to test the generalisability of the evolution patterns observed in our cases.

Additionally, the identified pathways mainly reflect mechanisms associated with successful upscaling and this focus may underrepresent alternative trajectories, including failed or stalled pathways, which could involve different constraints, trade-offs or contextual dynamics that remain unexplored. Another potentially interesting area for future research involves exploring the impact of various combinations of SCDs and capabilities on closed-loop supply chain configurations. For example, an interesting research question to answer would be “how manufacturing companies could address circular economy challenges such as collection, refurbishing, repurposing, remanufacturing by adopting specific SCDs?”.

Finally, our research is positioned in periods of growth, but the automotive manufacturing sector, as well as many other sectors, also experience periods of recession, particularly in today’s extremely volatile environment. EVs for example, come with lower demand data reliability (as they are new products) and it seems that the sector’s enthusiasm around EVs is waning as sales growth for the models slows and the EV supply chain shows signs of contraction even before it is fully built out. Further research could investigate how companies can manage downscale dynamics in this sector, and more specifically the SCD and capability implications of handling volume fluctuations with the use of system dynamic techniques or simulation methodologies.

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Pathways to upscaling: aligning capabilities with supply chain design in automotive manufacturing

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