On the strategic use of product modularity for market entry

Arrieta, J.P.; Fontana, R.; Brusoni, S.

DOI
10.1093/icc/dtac053
Publication date
2023
Document Version
Final published version
Published in
Industrial and Corporate Change

Industrial and Corporate Change, 2023, **32**, 155–180
DOI: https://doi.org/10.1093/icc/dtac053
Advance access publication date: 8 December 2022
Original Article

On the strategic use of product modularity for market entry

Jose Pablo Arrieta [1,*], Roberto Fontana [2,3] and Stefano Brusoni [4]

[1]Amsterdam Business School, University of Amsterdam, Plantage Muidergracht 12, Amsterdam, Noord-Holland 1018 TV, The Netherlands. e-mail: j.p.arrieta@uva.nl, [2]Department of Economics and Management, University of Pavia, Via San Felice 5, Milan, Pavia 27100, Italy. e-mail: roberto.fontana@unipv.it, [3]ICRIOS-Bocconi University, Via Roentgen 1, Via Sarfatti 25, Milan 20136, Italy. e-mail: roberto.fontana@unipv.it and [4]Department of Management Technology and Economics, ETH Zurich, Weinbergstrasse 56/58, Zürich 8092, Switzerland. e-mail: sbrusoni@ethz.ch

*Main author for correspondence.

Abstract

We model the conditions under which firms should enter the market with modular products that support multiple standards instead of an integral product that supports a single standard. Product modularity enables firms to broaden their portfolios and increase their chances of investing in the "right" technologies early in a technology cycle. Entry with integral products instead occurs later in the cycle. We test the model's predictions on a sample of the Local Area Network industry entrants during the 1990s.

JEL classification: O330, L150, M110

1. Introduction

Baldwin and Clark's *Design Rules: Volume 1* introduced the idea of looking at modularity as a "real option" phenomenon (Dixit *et al.*, 1994; Trigeorgis, 1996), in which the development of modules and the architecture that connects them are viewed as investment options firms create during the design process (Baldwin and Clark, 2000). Since then, modularity has been used to understand value creation and capture from intellectual property, such as open source and user innovation (Baldwin and Clark, 2006; Baldwin *et al.*, 2006; MacCormack *et al.*, 2006; Baldwin and Von Hippel, 2011; Henkel *et al.*, 2013; Lakhani *et al.*, 2013; Baldwin and Henkel, 2015) and to understand the hidden structures behind complex forms of industrial organization, such as transaction networks, platforms, and ecosystems (Baldwin, 2008, 2012; Baldwin and Woodard, 2009; Luo *et al.*, 2012; Baldwin *et al.*, 2014). Following this progression, *Design Rules: Volume 2* focuses on the role of open-source communities, standard-based platform systems, and system integrators in bringing new ideas to market (Baldwin, 2022).

This article builds upon and extends the initial discussion about the creation of real options, focusing on entry and exit decisions during a technology cycle. While this article is not about ecosystems, entry and exit decisions impact the composition and structure of ecosystems. More specifically, we explain how firms can use product modularity to enter markets in the presence of competing open standards (Ulrich, 1994; Baldwin and Clark, 2000; Wiegmann *et al.*, 2017). We rely on prior work on market entry decisions under conditions of high uncertainty (Folta and O'Brien, 2004). Previous work on firm entry focused on the uncertainty, irreversibility, and timing of market entry decisions to explain post-entry performance (Folta *et al.*, 2006). This article extends this line of reasoning by exploring how product architecture (i.e., modular or integral) affects market entry and firm performance. The presence of competing standards presents a strategic opportunity for firms, but it also complicates their market entry decision (Suarez, 2004). In the presence of multiple standards, a firm can err by waiting too long to enter the market. It can also err by entering early with the "wrong" standard (i.e., one that does not become dominant) (Suarez and Utterback, 1995; Garud *et al.*, 1997). This article explains how product modularity can help articulate market entry decisions.

We study an unconventional use of standards by focusing on market entrants who license open standards (Fontana, 2008)[1]; standards are "open" in the sense that (i) they are not owned by any one firm and (ii) they cannot be changed single-handedly by any one firm (see Chen and Forman, 2006; West, 2007; Waguespack and Fleming, 2009). The firms use standards and product modularity to help them introduce new products to the market and survive, but not necessarily to make one specific standard dominant. This use is analogous to the idea of multihoming, in which an architectural innovation (product modularity in this case) enables firms to focus and improve their main performance dimension while keeping uncertainty at bay by entering the market with a broader portfolio (Bakos and Halaburda, 2020). As such, we argue that our study can serve to bridge the two volumes of design rules while keeping product modularity as the crucial element for understanding innovation (Baldwin and Clark, 2000; Baldwin, 2022).

Modularity is a well-known strategy for organizing the development of new products (Baldwin and Clark, 2000; Garud *et al.*, 2009). Scholars have explored in depth how modularity can enable firms to solve problems effectively (Schilling, 2000; Brusoni and Prencipe, 2001; Fang *et al.*, 2010) and introduce a broader portfolio of products to market (Ulrich, 1994; Huang and Kusiak, 1998; Fisher *et al.*, 1999). They have also outlined the inherent limits to the use of modularity as an organizational strategy at times of high technological uncertainty (Brusoni *et al.*, 2001; Chesbrough and Kusunoki, 2001; Schilling and Steensma, 2001; Brusoni and Prencipe, 2006; Fang and Kim, 2018). Less is known about how "modularity operators" (e.g., splitting, substituting, and augmenting) are used to adapt a firm's market entry strategy to the market's uncertainty (Baldwin and Clark, 2000: 245). It is known that firms should match their product portfolio breadth and resource allocation to the level of uncertainty in the environment (Garud *et al.*, 1997; Klingebiel and Rammer, 2014; Klingebiel and Joseph, 2016). However, how modularity operators can be used during product design to adapt a firm's market entry strategy through risk diversification has not yet been explored (see Fixson and Park (2008) and Cabigiosu *et al.* (2013) for the closer cases).

In this article, we develop a real options model to identify the boundary conditions under which product modularity can help firms during market entry. Our formal model builds on the idea that early in a technology cycle, there is uncertainty about which standard will become dominant. This uncertainty makes plausible the existence of substantial early-mover advantages (Folta *et al.*, 2006). Yet, uncertainty also increases the odds of introducing the "wrong" standard and hence the chances of incurring switching costs (Farrell and Klemperer, 2007; Eggers, 2014; Abolfathi, 2021; Abolfathi *et al.*, 2022). Early in a technology cycle, a firm that introduces a broad product portfolio can benefit from this uncertainty. We test the model's predictions with data from a sample of firms and products from the Local Area Network (LAN) industry, a context in which modularity played a pivotal role in enabling firms to cope with uncertainty about which standard would emerge as dominant. The LAN industry experienced a full technology cycle during the 1990s when it moved from an era of ferment, in which multiple standards battled for dominance, to an era of incremental change, in which a single winning standard was in place (Fontana, 2008). Our data allow us to identify the firm's market entry strategy and the time of market entry of each firm active in the industry during the period of interest. Differences in the strategy and timing of market entry allow us to test our predictions concerning firms' entry, product introductions, and survival.

1 In data communications, standards are developed at different levels of the network: local (i.e., intra-network) level (as it was the case with Ethernet, Fast Ethernet, etc.); wide (i.e., extra-network) level (e.g., Synchronous Optical Network (SONET)); global (i.e., Internet) level (e.g., the Internet protocol suite (TCP/IP)). These standards are developed by the Internet Engineering Task Force, the International Organization for Standardization, or the Institute of Electrical and Electronic Engineers.

2. Background literature

In this article, we propose that firms can use product modularity as a tool to diversify and reduce the risks associated with entry into markets where a winning standard has yet to emerge. This section introduces the relevant streams of literature and explains how we build on them in our study.

2.1 Market entry

Market entry is a key strategic move for firms, particularly in fast-changing environments (Kalish and Lilien, 1986; Lilien and Yoon, 1990; Baron, 1995; Sundali *et al.*, 1995). In turn, market entry is strongly influenced by uncertainty (Dixit, 1989; Dixit *et al.*, 1994; Maskin, 1999). O'Brien *et al.* (2003: 515) show "that high uncertainty in the target industry dissuades entry." However, later studies showed that "the effect of uncertainty in entry is not monotonic" (Folta and O'Brien, 2004). They argue that one needs to consider three crucial factors that affect the uncertainty of market entry decisions: the irreversibility of the decision, the potential for growth, and the potential early-mover advantage. Folta *et al.* (2006) found that irreversibility can strongly defer entry in uncertain environments. Additionally, they found that the potential for growth and early-mover advantage complicates the investment decision; the firm needs to estimate potential externalities because early entry can promote market growth. The studies by Folta and colleagues allow us to estimate whether market entry is viable for a firm and when an early entry is preferable.

Market tenure has been shown to be a critical aspect of timing a firm's entry decision. Mitchell's (1991: 85) pioneering study showed how incumbents could afford to delay entry to a "new technical subfield," but newcomers should enter as early as possible. However, for incumbents, this delay can be problematic as "incumbent firms [can] experience great difficulty making the transition between successive technological trajectories," which limits their survival (Dowell and Swaminathan, 2006: 1165). These findings have been broadly replicated and provide an important reference for the timing of market entry (Schilling, 2002; Bayus and Agarwal, 2007; Chen *et al.*, 2012).

Although uncertainty can deter entry, firms can develop innovation strategies to outperform the competition. Klingebiel and Joseph (2016) present two ways in which firms can adapt to the market's uncertainty: to enter early and hedge their bets by introducing multiple products or to delay entry so they can enter with "appropriate" products. They find that firms make timing and portfolio breadth decisions jointly; in parallel to deciding when to enter the market, the firm also decides the breadth of the product portfolio products with which to enter. According to Klingebiel and Joseph (2016), a broad entry strategy is best when a firm enters the market early as it increases the chances of entering with the "right" product. Conversely, if the firm decides to enter late, it benefits from choosing only the few products that the market expects to succeed, a narrower product line.

The development of "vanilla boxes" presents a middle path (Swaminathan and Tayur, 1998). During periods of high uncertainty, firms can start to design products that can potentially serve multiple markets and "defer the stage after which the products assume their unique identities" (Lee and Tang, 1997: 40). In designing vanilla boxes, firms can choose to invest in a specific product type without needing to define the exact characteristics of the product (Swaminathan and Tayur, 1998). In so doing, firms can delay entry while still exploring a broader set of product lines.

Garud *et al.* (1997) provide a conceptual foundation for why firms may benefit from jointly making timing and portfolio breadth decisions. Garud and colleagues discuss entry timing in the context of technology cycles (Anderson and Tushman, 1990). They explain that early in the technology cycle, omission errors (i.e., failure to introduce the future dominant technology to the market) are costlier than commission errors (i.e., investment in a technology that fails to dominate the market in the future). In contrast, late in the technology cycle, introducing the "wrong" technologies to the market should be more costly than failing to introduce any technology.

In our study, we build on Klingebiel and Joseph's (2016) findings and the conceptual foundation from Garud *et al.* (1997) to develop a formal model that identifies the conditions under which a firm should enter the market with a product that supports one standard or a product that supports multiple standards.[2] We then show how product architecture—specifically product modularity—can significantly reduce costs when introducing products that support multiple standards to the market.

2.2 Product modularity

Modularity is a foundational concept of organization science (Simon, 1962; Henderson and Clark, 1990; Sanchez and Mahoney, 1996; Baldwin and Clark, 2000). "Modularity is a general set of design principles for managing the complexity of … interdependent systems" (Ethiraj and Levinthal, 2004: 161). It involves "breaking up a complex system into discrete pieces—which can then communicate with one another only through standardized interfaces within a standardized architecture" (Langlois, 2002: 19).

Our study explores one specific type of modularity: product modularity. Ulrich (1994) introduced the concept of product modularity to define how a product can be separated into distinct modules that communicate via well-defined interfaces. The relevance of product modularity was then broadly expanded by the work of Baldwin and Clark (2000). We study product modularity as an attribute of product design—not an attribute of the structure of the organization that designs it, nor the potential mirroring between the two (Cabigiosu and Camuffo, 2012; MacCormack *et al.*, 2012; Furlan *et al.*, 2014; Colfer and Baldwin, 2016).

In so doing, we study the use of product modularity for market entry decisions as a tool for "splitting" a product and creating "substitutes"[3] to broaden the conditions under which the firm will benefit from the uncertainty in the environment (Baldwin and Clark, 2000: 243). That is, to create products that diversify the firm's risk by marketing products that support multiple competing standards. Similar to how Cabigiosu *et al.* (2013) look at modularity in the auto industry or how Fixson and Park (2008) look at the opposite trend, "product integrality" in the bicycle industry; that is as "operators" firms can employ to adapt their product design and position their firm in dynamic markets.

Product modularity allows firms to broaden their product portfolio for market entry. By employing product modularity, firms can afford to introduce multiple modular variations of the same product, each targeting different market niches (Klingebiel and Joseph, 2016). This increased breadth enables firms to gain early-mover advantages, a benefit that delaying entry by developing vanilla boxes and waiting until uncertainty settles down does not (Swaminathan and Tayur, 1998). Additionally, as Christensen *et al.* (1998: 207) point out, in industries characterized by rapid change, "firms that target new market segments with an architectural innovation will tend to be more successful than those that target existing markets or innovate in component technology." We leverage this insight to identify and discuss the conditions under which the use of product modularity, a form of architectural innovation, can be beneficial for a new market entrant.

Developing a modular product that supports one single standard is more costly than developing an integral one with the same capabilities; it requires the additional design of well-defined interfaces between modules. However, once the interface has been designed, the costs of creating a second or third module to support a second or third standard are lower than the costs of creating new integral products that support the other standards. Therefore, by reducing the costs of introducing products that support multiple standards, product modularity allows firms to diversify their market entry risk, increase their chances of gaining early-mover advantages, and prevent switching costs.

2.3 Standardization

One context in which alternative technologies compete is that of a market undergoing standardization. "Standardization aims to resolve situations where involved actors prefer a common

2 In contrast to prior studies, we focus on the portfolio of supported standards and not features or products.

3 In this article, the "substitutes" refer to modules that support different standards (e.g., Fast Ethernet or ATM). Therefore, they do not "allow a designer to swap one module of the system for a better version of the same module" (Baldwin and Clark, 2000: 262). The modules that communicate with the distinct LAN standards are not seen as better or worse at the time they are designed but as different routes the technology could take.

solution to a problem but have not yet agreed which option to choose" (Wiegmann *et al.*, 2017: 1371). The topic has been the focus of many studies (Farrell and Saloner, 1985; Geels, 2002) and has been effectively employed to articulate its effects on the development of technologies and markets (Tassey, 2000; Garud *et al.*, 2002; Schilling, 2002; Gao, 2014). Of crucial importance in this literature are integrated strategic actions (i.e., market and nonmarket actions) made by firms during the standardization process (Baron, 1995; Oberholzer-Gee and Yao, 2018). Wiegmann *et al.* (2017) present a typology of three modes in which standardization can occur: committees, markets, and governments. In this article, we focus on how standardization happens in markets. Within the market-based standardization, we study an unconventional use of standards: firms that do not create the standards employ product modularity to choose when and with which standards to enter a market undergoing standardization.

The process of standardization sometimes involves transitioning from old technology to a new and improved one. From this viewpoint, it is associated with the eras that define a technology cycle (Anderson and Tushman, 1990; Tushman and Murmann, 2002). The cycle starts when an old technology that has been stable for some time progressively fails to resolve new "technological bottlenecks" (Rosenberg, 1969). Following this, a new set of technologies emerges that changes what people regard as possible—the so-called "era of ferment," as defined by Anderson and Tushman (1990). During this era, multiple alternative designs and technologies were created as firms found different ways of solving technical problems and bringing new products to market. Wiegmann *et al.* (2017) conceptualize these different technologies as multiple standards battling for dominance—in their definition a standardization process. At some point, the battle for dominance ends, and a dominant design appears—i.e., a winning standard (Suarez, 2004; Murmann and Frenken, 2006; Fontana, 2008). The emergence of the winning standard ushers in a new era—the "era of incremental change"—and finalizes the standardization process. By this time, a single technology can be claimed as both the "dominant design" and the "winning standard" in the terminologies of the two literature streams.[4]

A firm that enters a market undergoing standardization must confront both the risk of entering "too late" and also the risk of entering with the "wrong" standard (i.e., one that will eventually fail to dominate the market). However, a firm that enters early with products based on the "right" standard will benefit from early-mover advantages (Folta *et al.*, 2006), network effects (Schilling, 2002; Farrell and Klemperer, 2007), and preventing switching costs (Farrell and Shapiro, 1988; Abolfathi, *et al.*, 2021, 2022). Crucially, early on, it is impossible to predict which standard will dominate.

A way for firms to diversify their risks is to design products that support multiple standards (Klingebiel and Joseph, 2016). However, entering the market with products based on multiple standards is costly. As Ulrich (1994) explains, a way of reducing these costs is through product modularity. Firms that employ product modularity will incur lower development costs when introducing a product that supports multiple standards and reuses specific modules. As a result, they will have the option to invest in products that support a broader set of standards and diversify their risk, which will increase their chances of having invested in the right standard (Garud *et al.*, 1997). This increased chance benefits the firm in two ways: first, by preventing switching costs, such as the need to design new products for the winning standard (as their products already support it), or designing bridging products between their prior supported standards and the winning standard; second, by gaining early-mover advantages, such as an increased experience in building products for the winning standard, and market share in the winning submarket. Given that "once a dominant design emerges, future technological progress consists of incremental improvements" (Anderson and Tushman, 1990: 613), then the benefits can help fuel the firm's performance in the latter part of the technology cycle.

We note from the prior review that product modularity could benefit firms during market entry. In the next section, we present a real options model to outline the conditions under which using product modularity to introduce products based on multiple standards to a market is the best option for a firm. We show how, in general, the condition depends on the interplay among early-mover advantage, switching costs, and development costs.

4 For simplicity, we call it "winning standard" in the article.

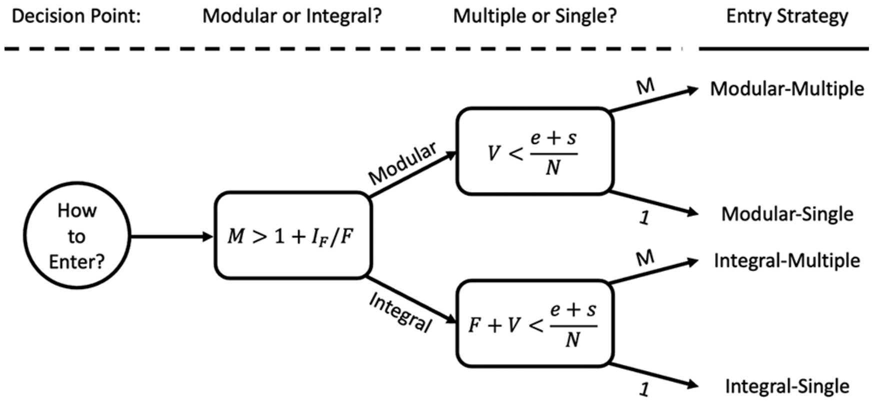

Figure 1. Simplified decision tree for choosing a market entry strategy

3. Model

Real options analysis is a common tool for studying market entry decisions (Dixit *et al.*, 1994; Trigeorgis, 1996). A key benefit of real options analysis is leveraging uncertainty by breaking market entry decisions into a set of options: for example, when exactly to enter (Folta and O'Brien, 2004), how broadly to enter (McGrath *et al.*, 2004), what capabilities to build (Kogut and Kulatilaka, 2001), when to vary one's resource allocation (Klingebiel and Adner, 2015), or when to exit the market (O'Brien and Folta, 2009), among other (see Li *et al.*, (2007) and Trigeorgis and Reuer (2017) for reviews).

In this section, we study the use of "modularity operators" to create real options that help firms diversify their risk (Baldwin and Clark, 2000: 245). We build the model from the assumption that the firm has already decided to enter a particular target market with a specific standard (Adner and Levinthal, 2004).[5] The "modularity operators" serve as simple design rules managers can employ while deciding how to enter a highly volatile and uncertain market (Bingham and Eisenhardt, 2011): (i) the splitting (or not) of the firm's product and (ii) the design of multiple substitute modules. The design of multiple substitute modules creates real options (i.e., "rights but not obligations") that a firm that chose to build a modular architecture (i.e., to split their product) can choose to invest in. We then build hypotheses from these market entry options and explore their strategic use during a full technology cycle (Anderson and Tushman, 1990). Furthermore, we explore the choice of a firm that chose not to split (i.e., to design an integral product) to 'augment' their design in order to support multiple standards.

The use of the "splitting," "substituting," and "augmenting" operators leads us to a model with four branches, as shown in Figure 1, each a distinct market entry strategy. Our model aims to define the conditions under which each one of these market entry strategies can be optimal. Figure 1 presents the decision tree used in our real options analysis and the simplified conditions to check for traversing the tree ("up" if met, "down" if not).

3.1 Definitions

This section focuses on the design choices available to a single firm when entering a market where multiple standards compete for dominance and the real options they create. As products differ in their architecture and the number of standards they support, we need to specify what constitutes a product, what constitutes a portfolio, and when if ever they can be equated. Figure 2 provides

5 The model was built for the era of ferment. Yet, our hypotheses generalize to firms entering at any point in the technology cycle. Although the emergence of the winning standard dominates the core uncertainty inherent in the business decisions and outcomes, the tensions described in the model continue to operate throughout the technology cycle. Thus, we can generalize the model to the era of incremental change as there is little reason to imagine that entering the market with products that support multiple standards would benefit the firm after the winning standard emerged. Similarly, developing a modular product that supports a single standard is more costly than developing an integral product.

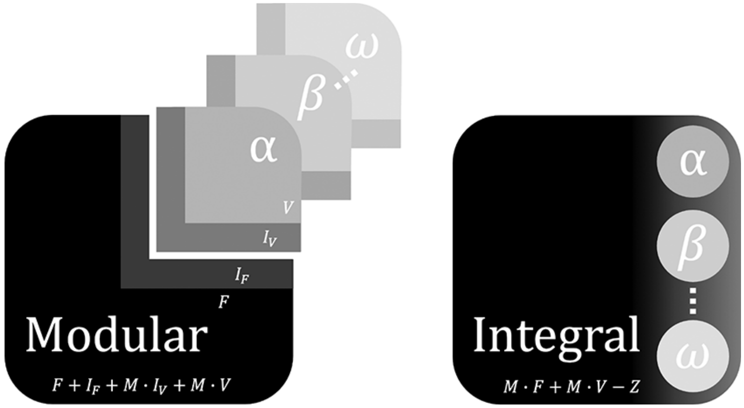

Figure 2. Visualization of the two product architectures[6]

a depiction of two different products.[7] On the left, we see a modular product. This is composed of two modules: a black box called a chassis on the bottom left and a set of M overlaid standard-specific modules on the upper right; one for each standard supported. On the right, we have an integral product. This is depicted as a single black box with ports for the multiple standards on the right.

Products that support multiple standards are active in separate submarkets. A modular product architecture allowed firms to market their product (chassis plus M standard-specific modules) as a multi-standard product portfolio. Each combination could cater to each specific submarket, and in some cases (as further discussed in Section 4.2.), customers could mix and match multiple standards within the same product. In contrast, a firm that developed an integral product that supported the same M standards would have one multi-standard product that competes in the adjacent M submarkets.

We argue that products acted as portfolios as they cater to multiple adjacent submarkets with different requirements. A firm with a broader portfolio—one whose product supported more standards—competes for a varied set of customer pools. A firm with a narrow portfolio—one that supports a single standard—caters to just one portion of the market. Given that the whole market is undergoing a technology cycle, the fate of the different submarkets is dependent on which standard will dominate and become the winning standard. When this comes to pass, all firms will need to transition their product offerings to the winning standard and winnow down any other offering.

To build the model, we assume that there exists a universe of standards ($\mathbb{U} \in \{\alpha, \beta, \ldots, \omega\}$) composed of N different standards competing in the market, i.e., the cardinality of the set ($N = |\mathbb{U}| > 1$). We assume that firms are uncertain about which standard will become the winning standard. Thus, introducing multiple standards to the market can be a potential benefit. The model will determine the potential benefits ($B(\mathcal{M}, A)$) for the firm to introduce a subset $\mathcal{M}$ of the standards ($\mathcal{M} \subseteq \mathbb{U}$), as well as the type of product architecture the firm should develop ($A \in \{Integral, Modular\}$). The potential benefits depend on (i) $E(\mathcal{M})$, the early-mover advantage that the firm can gain if it enters the market early with a product based on the future winning standard; (ii) $S(\mathcal{M})$, the switching costs for the firm if it did not choose the winning standard; and (iii) $D(\mathcal{M}, A)$, the development costs of introducing a product that supports a set $\mathcal{M}$ of standards

6 For simplicity, in Figure 2, the modular product is shown as having a chassis that fits one standard-specific module. This is not always the case, many products had chassis that would fit multiple standard-specific products and these modules could be for different communication standards. See Section 4.2. for examples of modular products.

7 For products that employ a modular architecture, it was most common for products to present a "chassis" on which a standard-specific module (e.g., ATM) could be mounted and exchanged for another standard-specific module when needed (e.g., Fast Ethernet). However, products existed that could hold multiple standard-specific modules at the same time by having a larger chassis. Integral products could support a single standard and thus would have a single port or support multiple standards, which could lead to the presence of multiple ports as shown in Figure 2.

with a product architecture A. It follows that the potential benefits of choosing a specific market entry strategy are given by the following equation:

$$B(\mathcal{M},A) \equiv E(\mathcal{M}) - S(\mathcal{M}) - D(\mathcal{M},A) \tag{1}$$

The first product that a firm introduces to the market determines what we call the firm's market entry strategy. This strategy is defined by whether the product supports a single standard or multiple standards and whether the product was developed under an integral or a modular product architecture.[8] Thus, four market entry strategies are possible, as shown in Figure 1. Our model aims to define the conditions under which each one of these market entry strategies can be optimal. We rely upon certain assumptions to derive these conditions, which we describe later.

3.2. Naïve portfolio diversification assumption

We assume that the potential benefits of a firm's market entry strategy depend only on the number of standards introduced and not the specific standards introduced.[9] We refer to this simplification as the naïve diversification assumption (DeMiguel *et al.*, 2009). This assumption simplifies our notation as the only aspect important is the number of standards: $M = |\mathcal{M}| \leq N$. We can thus redefine the potential benefits from Equation (1) in terms of the number of standards supported:

$$B(\mathcal{M},A) = B(M,A) \equiv E(M) - S(M) - D(M,A) \tag{2}$$

Furthermore, since the firm is certain that one out of the N standards will eventually dominate the market, a firm whose product supports all standards is certain it bet on the winning one.

$$p(\mathbb{U}) = \sum_{i=1}^{N} p(\mathbb{U}_i) = 1 \tag{3}$$

But under the naïve diversification assumption, any standard, i, has the same probability of dominating the market $(p(i) = p(1) = 1/N \forall i \in \mathbb{U})$. Similarly, if a firm introduces just M out of the N standards, then it lacks certainty about the prospects of its portfolio. However, we can define the probability of having invested in the winning standard as follows:

$$p(\mathcal{M}) = \sum_{i=1}^{M} p(\mathcal{M}_i) = p(M) = M \cdot p(1) = \frac{M}{N} \tag{4}$$

3.3 Early-mover advantage and switching costs

We employ Equation (4) to derive the potential benefits of alternative market entry strategies, $B(M,A)$. The first step involves the definition of switching costs, $S(M)$, and early-mover advantages, $E(M)$, for a firm that decides to introduce products based upon M standards to the market. We start with the early-mover advantage. To do this, we assume that the early-mover advantage a firm can expect to capture totals an amount e. A firm that introduces products that support M standards has a less than unity probability of capturing the first-mover advantage, e:

$$E(M) = e \cdot p(M) = \frac{e \cdot M}{N} \tag{5}$$

Through a similar logic, a firm that enters with M standards will have a $(1 - p(M))$ probability of missing out on the winning standard. If that is the case, it will expect to undergo switching costs for a total amount of s. Therefore, we can estimate the prevented potential switching costs as follows:

$$S(M) = s \cdot (1 - p(M)) = s \cdot \left(1 - \frac{M}{N}\right) \tag{6}$$

8 Technically speaking, a firm could enter with any number of standards, not one or multiple. Yet, as we will see later, the conditions shown in the model lead to these two corner cases.

9 This assumption has validity during the era of ferment, as at that time, it is uncertain which standard would dominate. A firm could act strategically and benefit from the equifinality present at the time (Arrieta and Shrestha, 2022). Yet, they risk the chance of choosing the wrong standard. Therefore, in this model, we build on the naïve diversification assumption. However, the assumption loses validity in the era of incremental change as then a winning standard exists.

3.4 Development costs

We further assume that each firm adopts either an integral or a modular product architecture for market entry: $A \in \{Integral, \ Modular\}$. A firm that employs an integral product architecture develops products with an integrated structure that cannot be further broken down. In contrast, a firm that employs product modularity splits its products into different modules so that modules of the same functionality or type are interchangeable. Both types of architecture, in principle, allow firms to introduce products that support multiple standards to the market. A firm that chooses a modular product architecture and splits its product will benefit from being able to reuse previously designed modules and building substitutes that function with each specific standard. In contrast, a firm that chooses an integral architecture will need to augment its product and essentially create M products to cater to the different standards. Herein lies the advantage of product modularity: firms that use it can reduce development costs when introducing products that support multiple standards.

3.4.1 Modular products

Our model considers modular products as split into two modules and containing one interface that controls how the two types of modules interact.[10] This product architecture is depicted on the left side of Figure 2. In black, we show what we call the "fixed module." To develop the fixed module, the firm incurs a fixed development cost, F, once, but the module can be reused M times: once for every standard supported by their product. The second module must be designed anew for each standard the firm wishes to introduce to the market. We call this module the "standard-specific module," this module is shown as the "detached" part in Figure 2. The firm needs then to design M "standard-specific" modules that communicate with a unique standard and serve as substitutes for each other (e.g., the overlaid modules in Figure 2).

To design the standard-specific modules, the firm incurs a "variable" development cost $V(i)$ for each standard ($i \in \mathcal{M}$) it introduces to the market. Finally, the firm needs to develop an interface to connect the two modules. The interface has a fixed development cost $I_F(i)$ and a variable cost $I_V(i)$, which is needed to account for the changes needed to connect each of the standards to the interface. Both interfaces are shown in lighter shades of gray in Figure 2.

For simplicity, we assume that the costs of developing each standard ($V(i)$) and adapting it to the interface ($I_V(i)$) are the same for each specific standard,[11] so that

$$V(i) = V \, and \, I_V(i) = I_V \, \forall \, i \in \mathrm{U} \tag{7}$$

The total cost of developing a modular product that supports M standards is thus

$$D(M, modular) = F + I_F + M \cdot I_V + M \cdot V \tag{8}$$

3.4.2 Integral products

Our model considers integral products as composed of a "black box" that supports multiple standards (as shown on the right of Figure 2). We will assume that the costs of developing one integral product and one modular product differ only in the costs of developing the interface between the modules of the modular product (i.e., $D(1, Modular) = D(1, Integral) + I_F + I_V$).[12] This assumption allows us to compare the development costs of the different product architectures.

10 The intuition here is that by separating its products into two components (one component whose development is under its control and another that deals with the uncertainty of the standard battle), a firm can exploit its core competencies to differentiate its products while allowing market dynamics to select the winning standard.

11 This assumption of "equality of development costs" can be justified through a counterfactual. If the contrary were true, and some standards were much more expensive to develop but achieved the same benefits, firms would choose to develop other, less costly standards. We use this assumption for simplicity's sake, but detailed knowledge can make the comparisons possible without the need for this assumption. However, engineers might often know the differences in development costs and factor them in.

12 This assumption of "equality of cost across standards" is equivalent to saying that development costs differ only in the cost of designing the interface. It can be motivated by the empirical observation that designing the interface is a lengthy process that requires significant discussion and deliberation.

However, this assumption holds only when the integral product supports one standard. Organizations learn as they perform similar tasks multiple times (Argote and Epple, 1990) and as a firm augments its product to support different standards, the fixed costs of developing a product that supports M standards will decrease. We can bundle these savings into a single value Z that encapsulates all learning efficiencies. Therefore, the cost of developing an integral product that supports multiple standards can be written as follows:

$$D(M, Integral) = M \cdot F + M \cdot V - Z \tag{9}$$

3.5 Modular or integral entry?

We can now determine the conditions under which a modular product architecture will be more beneficial for the firm. For simplicity, in the model, product architecture, A, neither affects the early-mover advantage the firm gains nor the switching costs prevented. We can focus on the development costs alone to estimate when each architecture benefits the firm the most. Additionally, modular products require developing an interface over and above the cost of developing a single product, then the benefits of product modularity can emerge only when $M > 1$. Therefore, to estimate when product modularity leads to higher potential benefits, we need to check when the costs of developing a modular product are lower than the costs of developing an integral product. Namely,

$$D(M, Modular) < D(M, Integral) \tag{10}$$

which can be rewritten as follows:

$$F + I_F + M \cdot I_V + M \cdot V < M \cdot F + M \cdot V - Z \tag{11}$$

and simplified into

$$M > 1 + \frac{I_F + I_V}{F - I_V} + \frac{Z}{F - I_V} \tag{12}$$

The right-hand side of the inequality presents two different aspects that increase the minimum number of standards supported for making a modular architecture less costly than an integral one. The first is the cost of the interface: $I_F + I_V$. If developing the interface is much more costly than developing the fixed module, F, then the inequality will only hold when M is large. The number of standards introduced will need to be even higher if the variable costs of designing the interface, I_V, approach the costs of developing the fixed module, F. Under these conditions, the right-hand side of the inequality would tend toward infinity. However, the inequality should hold provided that the interface costs are not too high. The second is the savings due to learning accrued by a firm that employs an integral architecture, the higher the savings when compared to the cost of the fixed module, the higher the number of standards the modular product will need to support in order for Inequality (12) to hold.

We developed the model to account for market entry decisions of firms during the era of ferment of a technology cycle, as the naïve diversification assumption can be expected to hold during this time. During the era of incremental change, instead, a dominant design (i.e., winning standard) has already emerged and a firm should introduce at most $M = 1$ standards, a condition that can never hold under Inequality (12). We thus hypothesize that:

Hypothesis 1a: Firms should enter the market more frequently with modular products *during the era of ferment in the technology cycle than during the era of incremental change.*

Hypothesis 1b: Firms should enter the market more frequently with integral products *during the era of incremental change in the technology cycle than during the era of ferment.*

3.6 Multiple- or single-standard support?

We can now determine the potential benefits of introducing products that support multiple standards to the market. We start with firms that choose to employ that split their product and thus follow a modular product architecture (i.e., firms taking the "upper" path in the decision tree in Figure 1). As Inequality (12) shows, product modularity can reduce the costs of development under a broad set of conditions. As mentioned later, we detail the conditions under which introducing a modular product that supports multiple standards provides a higher benefit than introducing a modular product that supports a single standard. Namely,

$$B(M, Modular) > B(1, Modular) \tag{13}$$

from Equations (5), (6), and (8), we can rewrite this as follows:

$$E(M) - S(M) - D(M, Modular) > E(1) - S(1) - D(1, Modular) \tag{14}$$

this inequality can be rewritten as follows:

$$\frac{eM}{N} - s\left(1 - \frac{M}{N}\right) - (F + I_F + M \cdot I_V + M \cdot V) > \frac{e}{N} - s\left(1 - \frac{1}{N}\right) - (F + I_F + I_V + V) \tag{15}$$

and simplified to[13]

$$V + I_V < \frac{e+s}{N} \tag{16}$$

Therefore, if the full costs of supporting a new standard (i.e., $V + I_V$) are lower than the gained early-mover advantages and prevented switching costs ($(e+s)/N$), then it will be beneficial for the firm to introduce a product supporting multiple standards. If the conditions are not met, the firm should introduce products that support a single standard. Note that Inequality (16) does not provide a threshold for the number of standards to introduce to the market. The lower boundary for that decision is set in Inequality (12), but the upper bound is left open. Thus, when Inequality (16) holds, the firm should create products that support all standards: $M = N$.

The prior conditions present just the upper paths of the decision tree, as shown in Figure 1. We now turn to the bottom two paths by finding the conditions under which integral firms benefit from developing products that support multiple standards. Namely,

$$B(M, Integral) > B(1, Integral) \tag{17}$$

this inequality can be rewritten as follows:

$$\frac{eM}{N} - s\left(1 - \frac{M}{N}\right) - (M \cdot F + M \cdot V - Z) > \frac{e}{N} - s\left(1 - \frac{1}{N}\right) - (F + V) \tag{18}$$

and simplified to

$$F + V - \frac{Z}{M-1} < \frac{e+s}{N} \tag{19}$$

In contrast to the design of modular products (Inequality (16)), the exact number of standards developed, M, does not disappear for the case of integral products (Inequality (19)). The more savings due to learning (Z), the more easily the firm will manage to decide in favor of developing integral products that support multiple standards. Note that the savings function should be convex for the savings due to learning to outperform the linearly decreasing denominator ($M-1$), an uncommon behavior according to Argote and Epple (1990).

Furthermore, Inequalities (16) and (19) can only hold during the era of ferment because after the winning standard emerges, the potential early-mover advantage erodes ($e=0$), and it should

13 One can calculate the conditions required for a firm to benefit from introducing M modular standards to the market instead of a single integral standard. The change leads to a more complex inequality: $M > 1 + (I_F + I_V)/((e+s)/N - V - I_V)$. This inequality is much harder to estimate, and thus, it is more plausible that the firm would instead follow Inequality (16) when choosing its market entry strategy.

be clear which standard is dominating. Thus, no switching costs will be incurred ($s = 0$). As such, $V + I_V > 0$. We hypothesize that:

> *Hypothesis 2a: Firms should enter the market with products that support* multiple standards *more often during the era of ferment in the technology cycle than during the era of incremental change.*

> *Hypothesis 2b: Firms should enter the market with products that support a* single standard *more often during the era of incremental change in the technology cycle than during the era of ferment.*

Jointly, Hypotheses 1 and 2 predict that more firms should enter the market with *modular products that support multiple standards* during the era of ferment than during the era of incremental change. In contrast, firms should enter the market more often with *integral products that support a single standard* during the era of incremental change than during the era of ferment. As such, our model serves as an application of "a general rule" from *Design Rules: Volume 1*. Namely, "an interconnected design process [i.e., integral architecture] will deliver one option—to take the output of the process or leave it. In contrast, a modular design process creates many options" (Baldwin and Clark, 2000: 234). However, in our model there is a key difference; the technology cycle—an industry-level dynamic—drives the firm-level decision to create "many options" and enter the market with a modular product.

3.7 Temporal dynamics

The model is written without accounting for the effects of time. Yet, it is only during the era of ferment that there is uncertainty about which of the standards will dominate the market and thus that the naïve diversification assumption holds. Clear losers and potential winners appear as the transition to the era of incremental change approaches, and thus the probabilities of each standard winning the battle should vary with time. Therefore, one would expect firms to introduce a single standard when close to the emergence of the dominant design. However, other values used in the model can also change, and these can affect how firms choose to split their product architectures, create substitutes, and augment their product features. For example, both sides of Inequality (12) change during a technology cycle. On the right-hand side, the costs of creating an interface between modules can decrease as the required knowledge becomes easier to codify or imitate from the competition. Similarly, during the era of ferment, new standards will be developed, enabling the left-hand side to reach higher values as the universe of standards grows. Thus, the benefits of creating a modular architecture could increase, while the costs of creating the interface decrease.

Both conditions make it plausible for firms to continue introducing modular products to the market even when the winning standard is close to emerging, and firms might know of clear losers in the battle for dominance: i.e., the temporal dynamics of the model are ambiguous. There are aspects that encourage the introduction of modular products that support multiple standards and aspects that discourage this action. To pinpoint the specific temporal dynamics, we would need much more complex models. We step away from this complexity and focus on studying how a "stable" era of ferment (i.e., one where development costs, switching costs, and early-mover advantages do not change) affects market entry. Assuming a stable era might not work for all industries, but if the era is short enough, as in the case of the LAN industry in the 1990s, the results should hold.

4. Empirical exercise

The real options model serves as a formal and rigorous framework whose validity needs to be tested in an empirical exercise. These options are open during the full technology cycle. However, it is only during the era of ferment that there is strong uncertainty about which of the N standards will dominate the market. This section presents an industry context in which we will empirically test the real options model. We then extend the model's predictions and present broader implications for the different ways in which product modularity can help firms after market entry (e.g., performance), in addition to those inferred from the literature and formalized in our real options model (e.g., entry strategy).

4.1 Context

The context analyzed is the LAN equipment manufacturing industry during a time of intense technological development: the decade spanning 1990–1999.[14] During this decade, the key problem firms tried to solve was network congestion. Firms followed two complementary paths to achieve this aim, and product modularity helped in both.

On the one hand, a few firms engaged in developing high-speed standards. At the beginning of the 1990s, several high-speed standards (Fiber Distributed Data Interface [FDDI], Fast Ethernet, Asynchronous Transfer Mode [ATM], and 100VG-AnyLAN) were "battling" to become the main successor to Ethernet, the most widely adopted standard at the time. In the LAN environment, standards were "open," and users could freely mix and match the equipment manufactured by different firms but still support the same standards. However, modules would only operate with the chassis from the same manufacturer. By commercializing modular equipment, firms could coordinate the migration of their installed user base from one generation of equipment to the next. Modularity also responded to an explicit strategy of "exploring" the product design space. A modular design allowed manufacturers to add new features and improve upon the existing design quickly as they could reuse designs enabling the improvement of the products and thus a more efficient way of decreasing network congestion. After a period of uncertainty, the battle ended in 1994 when Fast Ethernet became the *de facto* standard (Fontana, 2008).[15] Hence, we can identify a point at which a single standard won the "battle."

The second solution path led to changes and improvements in the hardware design of existing equipment. Modularity played an important role in facilitating these changes. The physical design of modular equipment revolved around a chassis (i.e., the fixed module) with several slots that housed the modules responsible for connectivity under a specific standard (i.e., the standard-specific modules). Modularity became part of the manufacturers' strategy to manage uncertainty and transform it into market opportunities. Standards were substituted simply by sliding the standard-specific module into the slot provided on the product chassis (i.e., the fixed module). In addition, modularity enabled manufacturers to introduce multiple standards to the market, thereby confronting existing uncertainty on which standard would finally prevail. From the manufacturers' viewpoint, modularity enabled firms to master technical change by focusing on the parts of the product design in which they could excel and leveraging uncertainty by creating products that support more standards. Such ease of adaptation benefited both buyers and manufacturers, who were not required to commit to any of the standards competing for supremacy until 1994—when Fast Ethernet emerged as the winning standard and both needed to transition away from the losing standards.

From the earlier narrative, we can highlight some crucial aspects of testing our hypotheses. First, before 1994, when Fast Ethernet ultimately came to dominate, multiple standards battled for market domination as firms were confronted with high uncertainty and frequently used modular product designs. Second, the *de facto* standardization of Fast Ethernet in 1994 represented a "watershed" in the LAN industry, reorienting firms' efforts toward developing product design rather than the proliferation of alternative solutions that had characterized the previous phase. We can thus identify two phases: (i) an early phase in the industry, before 1994 (i.e., the era of ferment), characterized by high early-mover advantage and switching costs; (ii) a late phase, from

14 LANs constitute the infrastructure that enables computers, other types of end-stations, or peripherals to be linked to form a network connecting different users within a relatively small area, such as a university campus or different buildings on a company site. The functioning of LANs can be described as follows. A computer wanting to transmit some information breaks the data into packets. The packets are sent to the LAN through adapter cards, which physically connect the computer to the channel. Once sent to the channel, packets travel first either to a hub or to a switch. In early LANs, packets normally travel to a hub, i.e., a device that sends the packets it receives to *all* users connected to a specific LAN segment so that each user can "see" every packet. Switches are more sophisticated because they can select and create a private connection between the sender and the receiver.

15 Fontana (2008) provides a detailed account of the events that led to the dominance of Fast Ethernet.

1994 onward (i.e., the era of incremental change), in which new entrants could no longer gain early-mover advantages, and the need to switch was nonexistent.

4.2 Products

During the decade of study companies introduced products that followed many different designs. Yet, the key distinction between the products was the presence of a modularly separated chassis. A chassis was an enclosure in which other modules could be slipped in and out when needed. We call "modular" those products which have a chassis that could be separated from the other modules. In contrast, integral products were composed of only one block. As mentioned later, we present a representative array of the various forms in which products came to market.

4.2.1 Variety of modular products

The OmniSwitch 5 produced by Xylan Corp followed a quite common modular architecture. This modular product employed a chassis with a 5 slots backplane. To work, one needed to include one module for power and management and up to four standard-specific modules. Available standard-specific modules could support up to five standards: Ethernet, Fast Ethernet, FDDI, Token Ring, and ATM. The fully configured equipment could support a total of 48 Ethernet, 32 Fast Ethernet, 8 FDDI, 24 Token Ring, and 16 ATM ports or any combination of them.

A typical customer could buy a chassis, a power and management module, and three Fast Ethernet modules on day one. Later, they could buy an ATM module and add it to the fifth and last slot in the chassis. Later still, they could replace a Fast Ethernet module with an FDDI one. At this point, the OmniSwitch would be connecting systems that worked on three different standards. Yet, from the start the product supported all these different standards, it was the choice of this hypothetical customer to buy only one at the start.

Not every modular product included a chassis that could accommodate multiple standard-specific modules. Some could accommodate only one at a time. For example, the NetVantage NV7500 introduced in 1995 supported Fast Ethernet, FDDI, and ATM. However, as the system could have just one standard-specific module at a time, the company advertised the product as providing "a choice of interface option cards [that] allow plug-and-play migration" to the different standards, migration being the key action on the user side (product introduction Ad at Network World, 1995: 53).

Other products supported only one LAN standard but had chassis that could accommodate multiple standard-specific modules at the same time. These systems generally had a higher capacity, such as the Cisco StrataCom BPX a system released in 1996, that supported only ATM but had 30 times the capacity of the OmniSwitch. This product had a chassis that could hold 15 different modules simultaneously (one power and management module and up to 14 ATM modules).

4.2.2 Variety of integral products

The IBM 8272-108 LANStreamer Switch was a common integral product. The product was significantly smaller than the OmniSwitch although their capacity was equivalent. However, in addition to the standards available to the OmniSwitch, the LANStreamer also supported the 100Vg-AnyLAN standard. The downside of the LANStreamer was that it could connect at most eight different systems together due to its more limited number of ports. Integral products were more homogeneous. Even when they would support multiple standards, the customer could not customize anything in the product offering itself. All was included in the initial purchase, and customers could not extend the product's capacity or interconnectivity.

4.2.3 Alignment with the model

Our model follows the options open to a company as it decides how to enter the market. As such, the model accounts for the design costs the firm will need to incur prior to market entry. For simplicity, we focus on the major decision points during the design. For example, having a chassis or not (i.e., being modular or integral) is a big design decision, whereas having a deeper or shallower chassis is a minor decision as all key interdependencies and interfaces had to be defined when the chassis was designed.

Modular products varied broadly. But the splitting of the products into a fixed module and a set of substitute modules for the different LAN standards holds well. The fixed module includes the chassis that houses all the interconnections between modules, the backplane which makes all the networking possible between all the systems connected to the product, and the power supply that ensures the product works under adequate conditions. The standard-specific module is then composed of one part, which includes all the ports for connectivity with other networking systems and a port that connects to the fixed module which manages the communications.

We bundle together all products that have a chassis and label them modular. We then contrast modular products to products without a chassis (i.e., integral). From the viewpoint of the company, both the integral product and the set of modules that comprise a modular product could be considered equivalent (one could design one or the other to solve the same problem, e.g., Figure 1). We employ this equivalence in our model and empirical exercise to compare the performance of firms after entering the high-speed LAN market.

4.3 Data

We employ a data set from the LAN industry during the 1990s to test the model's predictions. The year 1999 is a good "cutoff point" for the data because that year, a reasonable mix of products still supported all the different standards. The data set includes 1071 LAN products manufactured by the 85 firms that introduced at least one high-speed standard during the study period, 677 of which supported high-speed standards.[16] Information on the products was collected from *Network World*, a specialized publication targeted at network professionals. Trade journals (*Network World* in particular) give extensive coverage of new product introductions by reporting product characteristics, prices, manufacturers, and introduction dates. When possible, dates were double-checked against press communications and manufacturers' product announcements. The independent variables we use for the empirical analysis are *Modular*, a dichotomous variable equal to 1 if the firm entered the market with a modular product architecture or 0 if the firm entered the market with an integral product. *Multiple standards*, equal to 1 if the firm's first product introduced to the market supported more than one standard, 0 if not. *Before1994*, equal to 1 if the firm entered the market before 1994, the year Fast Ethernet became the *de facto* standard. If the firm entered from 1994 onward, the value is 0. *Years active*, encoded the difference between the year the firm entered the market and the year it was acquired or went bankrupt.

The dependent variables we use in the econometric exercise are *Survived*, equal to 1 if the firm survived until 2006 and 0 if it failed or was acquired before that date, and *Number of products*, the count of products yearly introduced by each firm.[17] Additionally, we have a set of firm-level control variables. *New entrant*, equal to 1 if the firm entered as a start-up to the market (e.g., it was not a spin-off nor an incumbent). *Year founded*, encoded when the company was founded (e.g., 1990 is coded as 90),[18] *US Headquarter*, equal 1 if the headquarter was in the United States. *LAN Experience*, encoded the number of products introduced by the firm to the market before its first high-speed product. Table 1 reports the descriptive statistics and zero-order correlations among the variables.

4.4 Modularity and market entry

Figure 3 (filled line) shows the number of firms that entered the LAN market each year during the decade of study. The dashed line shows the yearly number of high-speed LAN products introduced to the market by all the firms in the industry. The vertical line separates the era of ferment (to the left) from the era of incremental change (to the right). Clearly, market entry grows around the time the dominant standard emerges peaks 1 year after and declines sharply afterward. The number of new products also follows a similar pattern of growth with an acceleration in 1994 and a peak 1 year after the peak in the number of entrants.

16 Prior studies employing the same data set are Fontana and Nesta (2009) and Fontana (2007).

17 Table 1 shows the sum of products introduced by a firm during the period of study, but the yearly introductions are used in the regressions of Table 4.

18 For firms founded before 1960, we store 60 to avoid having a strongly right-hand skewed variable. 1960 is a good cutoff, as only a few firms entered before that year.

Table 1. Descriptive statistics and zero-order correlations

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Number of Products	1.									
2. Survived	0.202	1.								
	(0.063)									
3. Years Active	0.419	0.854	1.							
	(0.000)	(0.000)								
4. Multiple Standards	0.088	−0.171	−0.091	1.						
	(0.425)	(0.118)	(0.406)							
5. Before 1994	0.276	−0.218	−0.047	0.368	1.					
	(0.010)	(0.045)	(0.671)	(0.001)						
6. Modular	0.207	−0.107	0.039	0.342	0.525	1.				
	(0.057)	(0.329)	(0.722)	(0.001)	(0.000)					
7. New Entrant	0.034	−0.055	−0.012	−0.108	−0.052	0.083	1.			
	(0.760)	(0.616)	(0.913)	(0.324)	(0.640)	(0.449)				
8. Year Founded	−0.148	−0.126	−0.146	−0.047	−0.045	−0.159	0.174	1.		
	(0.176)	(0.249)	(0.183)	(0.672)	(0.684)	(0.146)	(0.111)			
9. US Headquarter	0.196	−0.226	−0.161	0.158	0.288	0.033	−0.064	−0.208	1.	
	(0.073)	(0.038)	(0.141)	(0.149)	(0.007)	(0.761)	(0.561)	(0.056)		
10. LAN Experience	−0.136	0.046	−0.018	0.016	−0.227	−0.089	0.282	−0.438	−0.073	1.
	(0.215)	(0.677)	(0.869)	(0.888)	(0.036)	(0.417)	(0.009)	(0.000)	(0.507)	
Mean	5.776	30	7.082	41	32	43	40	81.57	60	9.682
SD	8.414	of 85	4.512	of 85	of 85	of 85	of 85	8.22	of 85	4.604

Note: *P*-value of correlations is shown in parentheses.

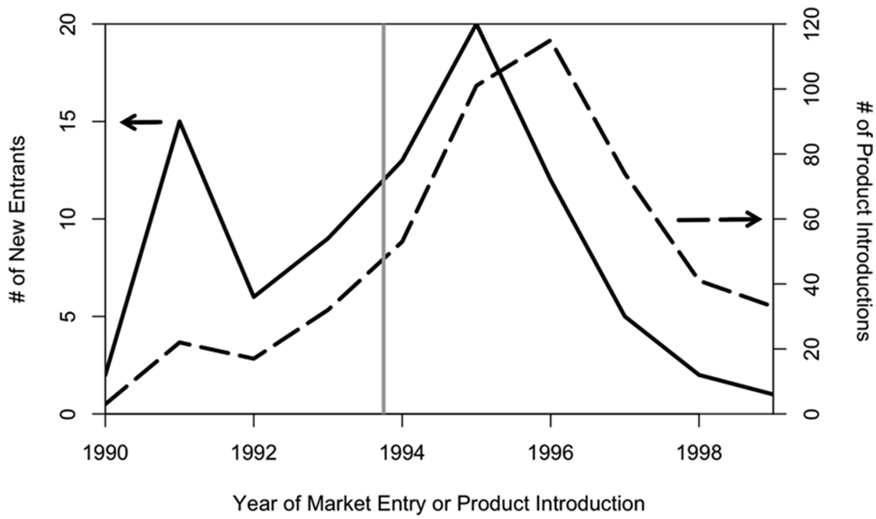

Figure 3. Market entry and product introductions during the 1990s

Table 2. Number of entrants categorized by the product architecture used at entry

	Integral	Modular	Total
Ferment: before 1994	5	27	32
Era of incremental change: from 1994	37	16	53
Total	42	43	85

Table 3. Number of entrants categorized by the number of standards supported

	Single standard	Multiple standards	Total
Era of ferment: before 1994	9	23	32
Era of incremental change: from 1994	35	18	53
Total	44	41	85

Figures 4 and 5 show the proportion of products introduced under each market entry strategy or product type. There are four strategies or types: modular products that support multiple standards, modular products that support a single standard, integral products that support multiple standards, and integral products that support a single standard. The four types are color coded with an increased brightness level (e.g., modular-multiple is the darkest, integral-single the lightest). Figure 4 presents a clear trend as the firms that entered the market with modular product architectures were much more prevalent early in the technology cycle (before 1994, to the left of the gray vertical line). In contrast, integral products (e.g., the two lighter shades) become the most common entry strategy during the era of incremental change.

Figure 5 provides a similar pattern but looks at product introductions instead. Again, modular products that support multiple standards are the most common early in the decade. In contrast, later the modal product entry type is an integral product architecture that supports a single standard. However, Figure 5 shows, even late in the technology cycle, many products introduced supported multiple standards (around a third in 1998) or employed a modular product architecture (about a fourth in 1998). Note that these practices were uncommon as market entry strategies, as Figure 4 shows. Still, it appears incumbents benefited from a broader and more diverse set of products after entry.

This visual analysis provides initial support for the predictions of our model. Quantitative support is found by looking at the descriptive statistics presented in Tables 2 and 3. Table 2 reports

Table 4. Estimating the post-entry performance of firms in the LAN industry

	Number of products introduced y_{it}		
	(1)	(2)	(3)
Before 1994	0.535***		−0.161
	(0.339, 0.731)		(−0.648, 0.326)
Modular		0.415***	−0.104
		(0.220, 0.611)	(−0.412, 0.204)
Before 1994 × Modular			0.842**
		(0.282, 1.402)	
New Entrant	0.472***	0.438***	0.404***
	(0.262, 0.682)	(0.225, 0.652)	(0.191, 0.616)
Year Founded	−0.039***	−0.035***	−0.035***
	(−0.051, −0.027)	(−0.047, −0.023)	(−0.047, −0.023)
US Headquarter	0.339*	0.551***	0.319*
	(0.080, 0.598)	(0.304, 0.798)	(0.051, 0.587)
LAN Experience	−0.070***	−0.077***	−0.073***
	(−0.094, −0.045)	(−0.102, −0.051)	(−0.098, −0.048)
Intercept	2.507***	2.094***	2.277***
	(1.407, 3.606)	(0.941, 3.248)	(1.114, 3.441)
Year dummies	Yes	Yes	Yes
Company dummies	Yes	Yes	Yes
Log-likelihood	−1041.8	−1047.4	−1036.0

Note: 95% confidence intervals are shown in parentheses.
*$P < 0.05$,
**$P < 0.01$,
***$P < 0.001$.

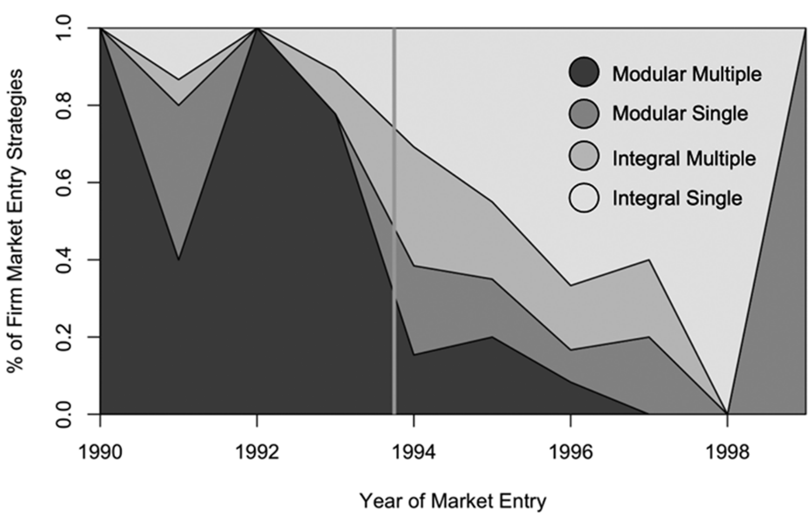

Figure 4. Firm entry by market entry strategies

the number of firms that entered the market with modular products during each technology cycle era. We find that during the era of ferment (i.e., before 1994), more than 80% of firms employed product modularity as their market entry strategy. In contrast, more than two-thirds of firms entered the market with integral products during the era of incremental change (i.e., from 1994) ($\chi^2 = 21.3$, $p < 0.001$). These results support Hypotheses 1a and 1b.

Table 3 reports the number of firms that entered the market with products that supported either single or multiple standards during each era of the technology cycle. During the era of ferment, over two-thirds of the firms entered with products that supported multiple rather than a single

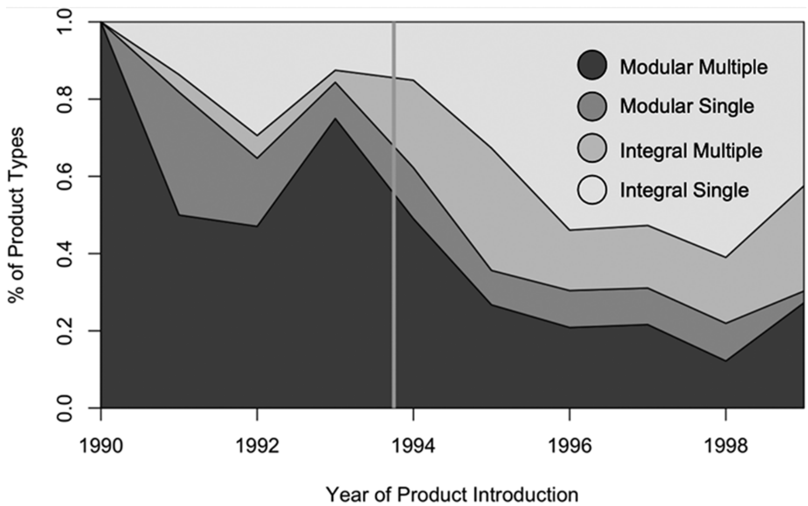

Figure 5. Trends in product-type introductions

standard. The opposite is true during the era of incremental change. At that time, two-thirds of the firms entered the market with products that supported a single standard ($\chi^2 = 10.0,\ p < 0.002$). These results support Hypotheses 2a and 2b.

4.5 Modularity and firm performance

We have presented empirical evidence concerning modularity and market entry strategy for the firms in our sample. Our findings suggest that product modularity was particularly suitable as an entry strategy in the era of ferment. Although important and consistent with our model's prediction, the prior evidence is mainly descriptive and considers only the effect of modularity on motivating the firms' market entry. However, *what about the consequences of modularity firms' post-entry performance?* For modularity to be strategically important, we would also expect firms that chose modular entry to perform better than others who chose to follow another strategy.

In this section, we explicitly tackle this question and investigate the consequences of a firm choosing a specific entry strategy. Indeed, in Section 4.1, we identified several empirical advantages of modularity, ranging from greater mastery of technical change and quicker exploration of the product design space when searching for new solutions. These advantages indicate that firms that employed a modular strategy at entry during the era of ferment should fare better than those that employed integral architectures. As mentioned later, we explore these ideas by employing the frequency of product introductions and firm post-entry survival as proxies for the performance of the firm's market entry strategy. Both metrics have been used in prior studies (Stavins, 1995; Lerner, 1997; Christensen *et al.*, 1998; Greenstein and Wade, 1998; Sorenson, 2000; Lee, 2008).

In our estimations of product introductions, we employ a pooled Poisson regression with year and firm fixed effects and report the results in Table 4.[19] In Model (1), we find that firms that entered the market in the era of ferment (i.e., before 1994) introduced a higher number of products (y_{it}) than those that entered from 1994 onward. Model (2) looks instead at the effect of product modularity during market entry on the number of products introduced by the firm during the study period. Again, the results suggest that modular entry was associated with an increase in the number of product introductions. Model (3) presents the interaction of the

19 The specific model estimated is as follows:

$$E[y_{it}|X_t] = exp[\beta_0 + \beta_1 \cdot Modular_i + \beta_2 \cdot Before1994_i + \beta_3 \cdot Modular_i \cdot Before1994_i + \delta_t]$$

Table 5. Estimating the post-entry performance of firms in the LAN industry

	Hazard rate of exit		
	(4)	(5)	(6)
Before 1994	0.419		1.593**
	(−0.155, 0.994)		(0.489, 2.697)
Modular		0.257	0.471
		(−0.301, 0.816)	(−0.318, 1.259)
Before 1994 × Modular			−1.669*
		(−3.011, −0.326)	
New Entrant	−0.127	−0.147	−0.076
	(−0.702, 0.449)	(−0.735, 0.442)	(−0.699, 0.546)
Year Founded	0.041	0.040	0.038
	(−0.005, 0.087)	(−0.005, 0.085)	(−0.009, 0.086)
US Headquarter	0.666	0.782*	0.717*
	(−0.024, 1.356)	(0.119, 1.445)	(0.007, 1.426)
LAN Experience	0.049	0.044	0.064
	(−0.025, 0.123)	(−0.031, 0.120)	(−0.012, 0.140)
Log-likelihood	−216.19	−216.80	−213.57
Number of firm exits	55	55	55
R^2	0.102	0.089	0.156
Wald test	8.330 (df = 5)	7.290 (df = 5)	15.680* (df = 7)

Note: 95% confidence intervals are shown in parentheses.
$^{*}P < 0.05$,
$^{**}P < 0.01$,
$^{***}P < 0.001$.

previous two variables. Crucially, the main effects were not significant; they were both driven by their interaction.

These results support the idea that product modularity was beneficial to firms, but only during the era of ferment. If we focus on the interaction, we find that on average a firm that entered the market with a modular product before 1994 introduced 1.0 more products per year. In contrast, firms that followed the other three market entry strategies introduced 0.40 products per year.[20] Thus, product modularity allowed early entrants to introduce over twice as many products to the market as firms that entered the market later or those that entered before 1994 but with integral products.

In Table 5, we perform a Cox proportional hazard rate model to estimate the exit rate. The reference category comprises the firms that enter the market after 1994 with integral products. From Models (4) and (5), we find that the timing of entry and the chosen product architecture have no significant effects on the hazard rate of entry. Model (6) shows that the interaction does have two significant effects. Firms that enter the market before 1994 have a higher hazard rate of exit. But if the firm entered with a modular architecture, the effect is counteracted. Jointly, the two significant betas explain that the highest hazard rate of exit was estimated for the group of firms that entered the market before 1994 with an integral product. This result directly aligns with our model predictions. The evidence that early entry with modular products (i.e., the interaction term) leads to a lower hazard of exit aligns with the expectations of our real options model and is consistent with the results of Model (3) on the number of product introductions.[21]

We find that firms employed product modularity predominantly during the era of ferment and relatively less during the era of incremental innovation, which supports Hypotheses 1a and 1b. We also find that more firms introduced products that supported multiple standards during the era of ferment and relatively less during the era of incremental change, supporting Hypotheses 2a

20 The range of the average number of product introductions by firms that entered the market after 1994 (independent of the product architecture) or before 1994 with an integral product is very similar—the lowest being 0.3997 and the highest 0.4025—as the coefficients of the main effects are low.

21 The controls do not influence the insights we draw from the regressions. Even though the control variables have significant coefficients, we find the same results if we remove the controls.

and 2b. Finally, we find that the firms that enter the market using product modularity during the era of ferment outperform other firms by introducing more products and surviving longer. In the next section, we discuss these results and the implications of the proposed real options model.

5. Discussion

Pioneered by the landmark studies by Baldwin and Clark (2000), research on modularity has focused on its benefits for organizational problem-solving (Ethiraj and Levinthal, 2004; Brusoni, 2005; Brusoni *et al.*, 2007; Fang and Kim, 2018) and creating broader and more adaptable product portfolios (Ulrich, 1994; Huang and Kusiak, 1998; Fisher *et al.*, 1999). This article contributes by showing firms can use modularity operators during product design to manage uncertainty through risk diversification. Although not a paper on platforms or complementors, the role of standards has analogies to how Baldwin and Clark's *Design Rules* have been used to understand innovation since its original publication (Baldwin, 2008, 2012; Baldwin and Woodard, 2009; Luo *et al.*, 2012; Baldwin *et al.*, 2014). The firms we study employed multiple standards to leverage risk and give themselves time to focus on the vital task of decreasing network congestion. We observe how a whole industry evolved and adapted around the "standard battles" in which only a few companies were directly involved. As such, this article can serve as a bridge between the two volumes of design rules (Baldwin and Clark, 2000; Baldwin, 2022) and highlight the crucial role of product modularity in managing uncertainty for industrial change.

In this article, we have introduced a real options model to explain how firms can use product modularity to enter markets in the presence of technological uncertainty and competing standards. We then tested the model on a sample of firms in the LAN industry during the 1990s. We proposed that by splitting a product and creating standard-specific substitutes, a firm can bet on multiple standards that may allow firms to gain early-mover advantages and prevent switching costs despite the higher cost of designing a larger number of modules. We tested these claims in the empirical analysis. We found that the firms indeed employ product modularity and introduce products that support a broader set of standards during times of rapid change. We also found that the firms that used modularity outperformed firms that employed other entry strategies by introducing more products and achieving a lower hazard rate of exit.

These results complement and extend prior works on modularity and market entry in four ways. First, Folta and colleagues have shown how market entry is a highly strategic decision, especially in uncertain environments. Similarly, prior studies have highlighted that the decisions to enter the market early, with multiple product features, or late, with a limited feature range, should be taken jointly (Klingebiel and Joseph, 2016). We validate and extend their findings by showing how firms can design their product architecture strategically and reduce their exploration costs during the era of ferment.

Second, product modularity allows firms to reduce their switching costs over the technology cycle. Although we do not account for switching costs empirically, a firm that introduced several modular products to the market will only need to develop a single new standard-specific module rather than an entirely new integral product. Based on these lower switching costs, we can argue that product modularity is a way of diversifying their risk while being active in the market. This finding complements prior studies that modeled firms as using nonmarket strategies (e.g., deferring market entry by building vanilla boxes) to delay the choice of the final product design (Lee and Tang, 1997; Swaminathan and Tayur, 1998).

Third, our model extends prior work on the use of product modularity during the era of ferment—the most turbulent phase of the technology cycle. Indeed, Brusoni *et al.* (2007) predicted that a firm would benefit from making their products less modular in turbulent times, as turbulence requires the constant updating of designs. However, their simulation model assumes that any given product's technical features drive competitive dynamics. In our setting, standards played a pivotal role in explaining performance and survival. The firms could openly adopt the standards. Yet, the vast majority of firms did not develop the standards (West, 2007). The availability of open standards adds an extra layer of complexity to our model's entry decision (Chen and Forman, 2006; Waguespack and Fleming, 2009); hence, the different results. The use of product modularity that we put forth manages the market's turbulence by leading the firm to invest in multiple competing standards. Thus, our model puts forth a new way in which modularity can be valuable during market entry.

Finally, our study directly relates to relevant developments in innovation management in the past decades. For example, the use of standards by the firms in our study parallels the practice of multihoming by software developers (Bakos and Halaburda, 2020). Multihoming started in the early times of the Internet and has been continuously employed to relaunch products on different platforms and arbitrage over market uncertainties ever since. Similarly, our study revolves around the creation of exponentially growing infrastructures. These infrastructures might not be the norm, but they are common. At the moment, multiple such infrastructures are being built in sustainability (e.g., carbon capture and storage, incorporation of renewable energy, and electric cars into the grid) and finance (e.g., blockchains or nonfungible tokens). From this angle, the use of product modularity as a way of introducing products that support multiple standards seems a recurrent real option for innovative firms.

Our study has limitations. As the industry had just 85 firms active, we are not able to create more definite analyses for market entry. We pair these analyzes with Figures 2 and 3 to provide a visual signal of how major the change in product strategy was during the period of study. Future work can focus on replicating the implications of our model and the findings of the empirical exercise. Furthermore, we only model the benefits of modularity-in-use (Henkel *et al.*, 2013); we claim that "modularity-in-design" was less common during the technology cycle. If not, Hypothesis 2 would not have held; future studies could explore this important disambiguation.

Similarly, our empirical results on entry hold independent of whether the entrant firm is a start-up or an incumbent. Yet, there is a long tradition of studies that show market tenure to have an important effect on market entry (Mitchell, 1991; Bayus and Agarwal, 2007; Chen *et al.*, 2012; Gao, 2014; Shermon and Mooen, 2022) and that, in contrast to our results, market entry happens markedly before the winning standard emerges (Agarwal and Bayus, 2002). We attribute these discrepancies to the exponential growth the LAN industry underwent in the 1990s. The number of hosts connected to the Internet during the decade expanded by three orders of magnitude (for reference, it expanded by just one order of magnitude in the two decades since). As the industry grew, the experience of incumbents might have been thwarted by new ideas. In an exponentially growing market, it is plausible to imagine that demand outpaced supply enabling new entrants to find a niche even after the winning standard emerged. Finally, in the industry we studied, the standards employed by the firms were open. Firms did not need to incur the costs of developing the standards from scratch and could freely choose the ones they wished to introduce to the market. However, in many industries, standards are not open (Suarez, 2004). When this is the case, our model's propositions would still hold, but the costs of developing standards anew would increase significantly. The LAN industry was, therefore, a perfect setting for studying the model's implications and exploring the strategic use of product modularity.

References

Abolfathi, N., A. Fosfuri and S. Santamaria (2022), 'Out of the trap: conversion funnel business model, customer switching costs, and industry profitability,' *Strategic Management Journal*, **43**(9), 1872–1896.

Abolfathi, N., S. Santamaria and C. Williams (2021), 'How does firm scope depend on customer switching costs? Evidence from mobile telecommunications markets,' *Management Science*, **68**(1), 316–332.

Adner, R. and D. A. Levinthal (2004), 'What is not a real option: considering boundaries for the application of real options to business strategy,' *The Academy of Management Review*, **29**(1), 74–85.

Agarwal, R. and B. L. Bayus (2002), 'The market evolution and sales takeoff of product innovations,' *Management Science*, **48**(8), 1024–1041.

Anderson, P. and M. L. Tushman (1990), 'Technological discontinuities and dominant designs: a cyclical model of technological change,' *Administrative Science Quarterly*, **35**(4), 604–633.

Argote, L. and D. Epple (1990), 'Learning curves in manufacturing,' *Science*, **247**(4945), 920–924.

Arrieta, J. P. and Y. R. Shrestha (2022), 'On the strategic value of equifinal choice,' *Journal of Organization Design*, **11**(2), 37–45.

Bakos, Y. and H. Halaburda (2020), 'Platform competition with multihoming on both sides: subsidize or not?' *Management Science*, **66**(12), 5599–5607.

Baldwin, C. Y. (2008), 'Where do transactions come from? Modularity, transactions, and the boundaries of firms,' *Industrial and Corporate Change*, **17**(1), 155–195.
Baldwin, C. Y. (2012), 'Organization design for business ecosystems,' *Journal of Organization Design*, **1**(1), 20–23.
Baldwin, C. Y. (2022), 'Design Rules Volume 2: How Technology Shapes Organizations,' Available at SSRN: 3889755.
Baldwin, C. Y. and K. B. Clark (2000), *Design Rules: The Power of Modularity*, Vol. 1. MIT Press: Cambridge, MA.
Baldwin, C. Y. and K. B. Clark (2006), 'The architecture of participation: does code architecture mitigate free riding in the open source development model?' *Management Science*, **52**(7), 1116–1127.
Baldwin, C. Y. and J. Henkel (2015), 'Modularity and intellectual property protection,' *Strategic Management Journal*, **36**(11), 1637–1655.
Baldwin, C., C. Hienerth and E. Von Hippel (2006), 'How user innovations become commercial products: a theoretical investigation and case study,' *Research Policy*, **35**(9), 1291–1313.
Baldwin, C., A. MacCormack and J. Rusnak (2014), 'Hidden structure: using network methods to map system architecture,' *Research Policy*, **43**(8), 1381–1397.
Baldwin, C. Y. and E. Von Hippel (2011), 'Modeling a paradigm shift: from producer innovation to user and open collaborative innovation,' *Organization Science*, **22**(6), 1399–1417.
Baldwin, C. Y. and C. J. Woodard (2009), 'The architecture of platforms: a unified view,' *Platforms, Markets and Innovation*, **32**, 19–44.
Baron, D. P. (1995), 'Integrated strategy: market and nonmarket components,' *California Management Review*, **37**(2), 47–65.
Bayus, B. L. and R. Agarwal (2007), 'The role of pre-entry experience, entry timing, and product technology strategies in explaining firm survival,' *Management Science*, **53**(12), 1887–1902.
Bingham, C. B. and K. M. Eisenhardt (2011), 'Rational heuristics: the "simple rules" that strategists learn from process experience,' *Strategic Management Journal*, **32**(13), 1437–1464.
Brusoni, S. (2005), 'The limits to specialization: problem solving and coordination in "modular networks",' *Organization Studies*, **26**(12), 1885–1907.
Brusoni, S., L. Marengo, A. Prencipe and M. Valente (2007), 'The value and costs of modularity: a problem-solving perspective,' *European Management Review*, **4**(2), 121–132.
Brusoni, S. and A. Prencipe (2001), 'Unpacking the black box of modularity: technologies, products and organizations,' *Industrial and Corporate Change*, **10**(1), 179–205.
Brusoni, S. and A. Prencipe (2006), 'Making design rules: a multidomain perspective,' *Organization Science*, **17**(2), 179–189.
Brusoni, S., A. Prencipe and K. Pavitt (2001), 'Knowledge specialization, organizational coupling, and the boundaries of the firm: why do firms know more than they make?' *Administrative Science Quarterly*, **46**(4), 597–621.
Cabigiosu, A. and A. Camuffo (2012), 'Beyond the "mirroring" hypothesis: product modularity and interorganizational relations in the air conditioning industry,' *Organization Science*, **23**(3), 686–703.
Cabigiosu, A., F. Zirpoli and A. Camuffo (2013), 'Modularity, interfaces definition and the integration of external sources of innovation in the automotive industry,' *Research Policy*, **42**(3), 662–675.
Chen, P. Y. and C. Forman (2006), 'Can vendors influence switching costs and compatibility in an environment with open standards?' *MIS Quarterly*, **30**, 541–562.
Chen, P. L., C. Williams and R. Agarwal (2012), 'Growing pains: pre-entry experience and the challenge of transition to incumbency,' *Strategic Management Journal*, **33**(3), 252–276.
Chesbrough, H. and K. Kusunoki (2001), 'The modularity trap: innovation, technology phase shifts, and the resulting limits of virtual organizations,' *Managing Industrial Knowledge*, **6**, 202–230.
Christensen, C. M., F. F. Suárez and J. M. Utterback (1998), 'Strategies for survival in fast-changing industries,' *Management Science*, **44**(12, Part 2), S207–S220.
Colfer, L. J. and C. Y. Baldwin (2016), 'The mirroring hypothesis: theory, evidence, and exceptions,' *Industrial and Corporate Change*, **25**(5), 709–738.
DeMiguel, V., L. Garlappi and R. Uppal (2009), 'Optimal versus naive diversification: how inefficient is the 1/N portfolio strategy?' *The Review of Financial Studies*, **22**(5), 1915–1953.
Dixit, A. (1989), 'Entry and exit decisions under uncertainty,' *Journal of Political Economy*, **97**(3), 620–638.
Dixit, A. K. and Pindyck R. S (1994), *Investment under Uncertainty*. Princeton University Press.
Dowell, G. and A. Swaminathan (2006), 'Entry timing, exploration, and firm survival in the early US bicycle industry,' *Strategic Management Journal*, **27**(12), 1159–1182.
Eggers, J. P. (2014), 'Competing technologies and industry evolution: the benefits of making mistakes in the flat panel display industry,' *Strategic Management Journal*, **35**(2), 159–178.

Ethiraj, S. K. and D. A. Levinthal (2004), 'Modularity and innovation in complex systems,' *Management Science*, **50**(2), 159–173.

Fang, C. and J. H. Kim (2018), 'The power and limits of modularity: a replication and reconciliation,' *Strategic Management Journal*, **39**(9), 2547–2565.

Fang, C., J. Lee and M. A. Schilling (2010), 'Balancing exploration and exploitation through structural design: the isolation of subgroups and organizational learning,' *Organization Science*, **21**(3), 625–642.

Farrell, J. and P. Klemperer (2007), 'Coordination and lock-in: competition with switching costs and network effects,' in M. Armstrong, and R. H. Porter (eds), *Handbook of Industrial Organization*, Vol. **3** North Holland: Amsterdam, the Netherlands, pp. 1967–2072.

Farrell, J. and G. Saloner (1985), 'Standardization, compatibility, and innovation,' *The RAND Journal of Economics*, **16**(1), 70–83.

Farrell, J. and C. Shapiro (1988), 'Dynamic competition with switching costs,' *The RAND Journal of Economics*, **19**(1), 123–137.

Fisher, M., K. Ramdas and K. Ulrich (1999), 'Component sharing in the management of product variety: a study of automotive braking systems,' *Management Science*, **45**(3), 297–315.

Fixson, S. K. and J. K. Park (2008), 'The power of integrality: Linkages between product architecture, innovation, and industry structure,' *Research Policy*, **37**(8), 1296–1316.

Folta, T. B., D. R. Johnson and J. P. O'Brien (2006), 'Uncertainty, irreversibility, and the likelihood of entry: an empirical assessment of the option to defer,' *Journal of Economic Behavior & Organization*, **61**(3), 432–452.

Folta, T. B. and J. P. O'Brien (2004), 'Entry in the presence of dueling options,' *Strategic Management Journal*, **25**(2), 121–138.

Fontana, R. (2007), 'Technical change, prices and communications technology: insights from the Local Area Networking industry,' *Technological Forecasting and Social Change*, **74**(3), 313–330.

Fontana, R. (2008), 'Competing technologies and market dominance: standard "battles" in the Local Area Networking industry,' *Industrial and Corporate Change*, **17**(6), 1205–1238.

Fontana, R. and L. Nesta (2009), 'Product innovation and survival in a high-tech industry,' *Review of Industrial Organization*, **34**(4), 287–306.

Furlan, A., A. Cabigiosu and A. Camuffo (2014), 'When the mirror gets misted up: modularity and technological change,' *Strategic Management Journal*, **35**(6), 789–807.

Gao, X. (2014), 'A latecomer's strategy to promote a technology standard: the case of Datang and TD-SCDMA,' *Research Policy*, **43**(3), 597–607.

Garud, R., S. Jain and A. Kumaraswamy (2002), 'Institutional entrepreneurship in the sponsorship of common technological standards: the case of Sun Microsystems and Java,' *Academy of Management Journal*, **45**(1), 196–214.

Garud, R., A. Kumaraswamy and R. Langlois (eds) (2009), *Managing in the Modular Age: Architectures, Networks, and Organizations*. John Wiley & Sons: Malden, MA.

Garud, R., P. R. Nayyar and Z. Shapira (1997), 'Technological choices and the inevitability of errors,' in R. Garud, P. R. Nayyar, and Z. B. Shapira (eds), *Technological Innovation: Oversights and Foresights*. Cambridge University Press: Cambridge, UK, pp. 20–40.

Geels, F. W. (2002), 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study,' *Research Policy*, **31**(8–9), 1257–1274.

Greenstein, S. M. and J. B. Wade (1998), 'The product life cycle in the commercial mainframe computer market, 1968-1982,' *The RAND Journal of Economics*, **29**(4), 772–789.

Henderson, R. M. and K. B. Clark (1990), 'Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms,' *Administrative Science Quarterly*, **35**(1), 9–30.

Henkel, J., C. Y. Baldwin and W. Shih (2013), 'IP modularity: profiting from innovation by aligning product architecture with intellectual property,' *California Management Review*, **55**(4), 65–82.

Huang, C. C. and A. Kusiak (1998), 'Modularity in design of products and systems,' *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, **28**(1), 66–77.

Kalish, S. and G. L. Lilien (1986), 'A market entry timing model for new technologies,' *Management Science*, **32**(2), 194–205.

Klingebiel, R. and R. Adner (2015), 'Real options logic revisited: the performance effects of alternative resource allocation regimes,' *Academy of Management Journal*, **58**(1), 221–241.

Klingebiel, R. and J. Joseph (2016), 'Entry timing and innovation strategy in feature phones,' *Strategic Management Journal*, **37**(6), 1002–1020.

Klingebiel, R. and C. Rammer (2014), 'Resource allocation strategy for innovation portfolio management,' *Strategic Management Journal*, **35**(2), 246–268.

Kogut, B. and N. Kulatilaka (2001), 'Capabilities as real options,' *Organization Science*, **12**(6), 744–758.

Lakhani, K. R., K. J. Boudreau, P. R. Loh, L. Backstrom, C. Y. Baldwin, E. Lonstein and E. C. Guinan (2013), 'Prize-based contests can provide solutions to computational biology problems,' *Nature Biotechnology*, **31**(2), 108–111.

Langlois, R. N. (2002), 'Modularity in technology and organization,' *Journal of Economic Behavior & Organization*, **49**(1), 19–37.

Lee, G. K. (2008), 'Relevance of organizational capabilities and its dynamics: what to learn from entrants' product portfolios about the determinants of entry timing,' *Strategic Management Journal*, **29**(12), 1257–1280.

Lee, H. L. and C. S. Tang (1997), 'Modelling the costs and benefits of delayed product differentiation,' *Management Science*, **43**(1), 40–53.

Lerner, J. (1997), 'An empirical exploration of a technology race,' *The RAND Journal of Economics*, **28**(2), 228–247.

Li, Y., B. E. James, R. Madhavan and J. T. Mahoney (2007), *Real Options: Taking Stock and Looking Ahead*. Emerald Group Publishing Limited: Bingley, UK.

Lilien, G. L. and E. Yoon (1990), 'The timing of competitive market entry: an exploratory study of new industrial products,' *Management Science*, **36**(5), 568–585.

Luo, J., C. Y. Baldwin, D. E. Whitney and C. L. Magee (2012), 'The architecture of transaction networks: a comparative analysis of hierarchy in two sectors,' *Industrial and Corporate Change*, **21**(6), 1307–1335.

MacCormack, A., C. Y. Baldwin and J. Rusnak (2012), 'Exploring the duality between product and organizational architectures: a test of the "mirroring" hypothesis,' *Research Policy*, **41**(8), 1309–1324.

MacCormack, A., J. Rusnak and C. Y. Baldwin (2006), 'Exploring the structure of complex software designs: an empirical study of open source and proprietary code,' *Management Science*, **52**(7), 1015–1030.

Maskin, E. S. (1999), 'Uncertainty and entry deterrence,' *Economic Theory*, **14**(2), 429–437.

McGrath, R. G., W. J. Ferrier and A. L. Mendelow (2004), 'Real options as engines of choice and heterogeneity,' *Academy of Management Review*, **29**(1), 86–101.

Mitchell, W. (1991), 'Dual clocks: entry order influences on incumbent and newcomer market share and survival when specialized assets retain their value,' *Strategic Management Journal*, **12**(2), 85–100.

Murmann, J. P. and K. Frenken (2006), 'Toward a systematic framework for research on dominant designs, technological innovations, and industrial change,' *Research Policy*, **35**(7), 925–952.

Network World. (1995), 'The Newsweekly of Enterprise Network Computing', 12(3).

Oberholzer-Gee, F. and D. A. Yao (2018), 'Integrated strategy: residual market and exchange imperfections as the foundation of sustainable competitive advantage,' *Strategy Science*, 3(2), 463–480.

O'Brien, J. and T. B. Folta (2009), 'Sunk costs, uncertainty and market exit: a real options perspective,' *Industrial and Corporate Change*, **18**(5), 807–833.

O'Brien, J. P., T. B. Folta and D. R. Johnson (2003), 'A real options perspective on entrepreneurial entry in the face of uncertainty,' *Managerial and Decision Economics*, **24**(8), 515–533.

Rosenberg, N. (1969), 'The direction of technological change: inducement mechanisms and focusing devices,' *Economic Development and Cultural Change*, **18**(1, Part 1), 1–24.

Sanchez, R. and J. T. Mahoney (1996), 'Modularity, flexibility, and knowledge management in product and organization design,' *Strategic Management Journal*, **17**(S2), 63–76.

Schilling, M. A. (2000), 'Toward a general modular systems theory and its application to interfirm product modularity,' *The Academy of Management Review*, **25**(2), 312–334.

Schilling, M. A. (2002), 'Technology success and failure in winner-take-all markets: the impact of learning orientation, timing, and network externalities,' *Academy of Management Journal*, **45**(2), 387–398.

Schilling, M. A. and H. K. Steensma (2001), 'The use of modular organizational forms: an industry-level analysis,' *Academy of Management Journal*, **44**(6), 1149–1168.

Shermon, A. and M. Moeen (2022), 'Zooming in or zooming out: entrants' product portfolios in the nascent drone industry,' *Strategic Management Journal*, **43**(11), 2217–2252.

Simon, H. A. (1962), 'The architecture of complexity,' *Proceedings of the American Philosophical Society*, **106**(6), 467–482.

Sorenson, O. (2000), 'Letting the market work for you: an evolutionary perspective on product strategy,' *Strategic Management Journal*, **21**(5), 577–592.

Stavins, J. (1995), 'Model entry and exit in a differentiated-product industry: the personal computer market,' *The Review of Economics and Statistics*, **77**(4), 571–584.

Suarez, F. (2004), 'Battles for technological dominance: an integrative framework,' *Research Policy*, **33**(2), 271–286.

Suarez, F. F. and J. M. Utterback (1995), 'Dominant designs and the survival of firms,' *Strategic Management Journal*, **16**(6), 415–430.

Sundali, J. A., A. Rapoport and D. A. Seale (1995), 'Coordination in market entry games with symmetric players,' *Organizational Behavior and Human Decision Processes*, **64**(2), 203–218.

Swaminathan, J. M. and S. R. Tayur (1998), ‘Managing broader product lines through delayed differentiation using vanilla boxes,’ *Management Science*, **44**(12, Part 2), S161–S172.

Tassey, G. (2000), ‘Standardization in technology-based markets,’ *Research Policy*, **29**(4–5), 587–602.

Trigeorgis, L. (1996), *Real Options: Managerial Flexibility and Strategy in Resource Allocation*. MIT Press: Cambridge, MA.

Trigeorgis, L. and J. J. Reuer (2017), ‘Real options theory in strategic management,’ *Strategic Management Journal*, **38**(1), 42–63.

Tushman, M. and J. P. Murmann (2002), ‘Dominant designs, technology cycles, and organizational outcomes,’ in R. Garud, A. Kumaraswamy, and R. N. Langlois (eds), *Managing in the Modular Age: Architectures, Networks, and Organizations*. Blackwell Publishing: Malden, USA pp. 316–348.

Ulrich, K. (1994), ‘Fundamentals of product modularity,’ in S. Dasu, and C. Eastman (eds), *Management of Design: Engineering and Management Perspectives*. Springer Dordrecht: New York, pp. 219–231.

Waguespack, D. M. and L. Fleming (2009), ‘Scanning the commons? Evidence on the benefits to startups participating in open standards development,’ *Management Science*, **55**(2), 210–223.

West, J. (2007), ‘The economic realities of open standards: black, white, and many shades of gray,’ in S. Greenstein and V. Stango (eds), *Standards and Public Policy*. Cambridge University Press: Cambridge, UK, pp. 87–122.

Wiegmann, P. M., H. J. de Vries and K. Blind (2017), ‘Multi-mode standardisation: a critical review and a research agenda,’ *Research Policy*, **46**(8), 1370–1386.