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Introduction

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The power of modularity today: 20 years of "Design Rules"

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Abstract

In 2000, Carliss Baldwin and Kim Clark published "Design Rules: The Power of Modularity," a book that introduced new ways of understanding and explaining the architecture of complex systems This Special Issue of *Industrial and Corporate Change* celebrates this seminal work, the research it has inspired, and the insights that these collective efforts have generated. In this introductory essay, we review the impact of "Design Rules" across numerous fields, including organization theory, competitive strategy, industry structure, and innovation management. We offer perspectives on key themes that emerge from contributions in this issue, including the alignment between organizational and technical designs ("mirroring"), the dynamics of industry evolution, and the role that individuals play in shaping and responding to system designs. We close by highlighting opportunities to apply the theory in Design Rules to *new* phenomena and puzzles that have emerged in the past 20 years.

JEL classification: L14, L22, O32

1. An intellectual journey

It is now more than 20 years since Carliss Y. Baldwin and Kim Clark (2000) published their landmark book, "Design Rules – The Power of Modularity." In that time, the book has had a profound impact on organization theory, competitive strategy, and innovation research, as well as on technical studies of system architecture and performance. The theory of modular design and industrial evolution, as presented by the authors, has been used to analyze and explain a multitude of different phenomena, ranging from the structure of organizations, the design of technical artifacts, competition within and across industry boundaries, to the ability to create and capture economic value through innovation.

Organizational studies have drawn extensively on the concepts presented in "Design Rules" in a variety of ways. Modularity theory helps to explain the internal structure of organizations (Sanchez and Mahoney, 1996; Brusoni and Prencipe, 2001; Langlois, 2002; Karim, 2006; MacCormack *et al.*, 2006, 2012; Puranam, 2018) as well as why and how the boundaries of the firm have been drawn (Brusoni *et al.*, 2001; Jacobides and Billinger, 2006; Baldwin, 2008). Against this backdrop, scholars have explored various aspects of the "mirroring hypothesis" (Henderson and Clark, 1990; Sanchez and Mahoney, 1996; MacCormack *et al.*, 2012; Colfer and Baldwin, 2016; Tee, 2019; Windrum *et al.*, 2019), which conjectures that the "organizational ties within a project, firm, or group of firms (e.g., communication, collocation, employment) will correspond to the technical dependencies in the work being performed" (Colfer and Baldwin, 2016). At a more granular level, empiricists have fruitfully applied the tool of design structure matrices, highlighted in the book, to study organizational and technical designs and to understand the degree of alignment between them (Browning, 2001; Sosa *et al.*, 2004; Eppinger and Browning, 2012; Sosa *et al.*, 2013; Baldwin *et al.*, 2014).

In the field of strategy research, scholars have employed the concept of modularity to explain the design of different business models (Aversa *et al.*, 2015), the competitive dynamics of industries (Garud and Kumaraswamy, 1993), choices of product variety (Matutes and Regibeau, 1988; Garud and Kumaraswamy, 1995), and the development of organizational capabilities (Jacobides, 2006). At a higher level of analysis, the theory of modularity has informed research on industry structure, in particular on the vertical integration and disintegration of industries (Jacobides, 2005; Fixson and Park, 2008; Luo *et al.*, 2012; Kapoor, 2013), the division of labor between firms (Schilling, 2000; Sturgeon, 2002), as well as the nature of business ecosystems and strategies for platform competition (Gawer and Cusumano, 2002; Iansiti and Levien, 2004; Baldwin, 2012; Waltl *et al.*, 2012; Parker *et al.*, 2016; Jacobides *et al.*, 2018; Cusumano *et al.*, 2019).

With respect to the study of innovation, "Design Rules" built upon earlier contributions on the design of complex systems, developing a more comprehensive framework on which future work was based. Beginning with the decomposition and development of technical systems (Simon, 1962; Parnas, 1972; Arthur, 2009), scholars have shown how modularity facilitates innovation (Langloi and Robertson, 1992; Baldwin and Clark, 2006; Baldwin *et al.*, 2014) and user innovation, in particular, (Von Hippel and Finkelstein, 1979; Baldwin and Von Hippel, 2011) but can also invite competitive imitation (Pil and Cohen, 2006; Ethiraj *et al.*, 2008). Others have shown how the concept of modularity can be used strategically in new product and process development (Ulrich and Eppinger, 1994; Ulrich, 1995; Krishnan and Ulrich, 2001; MacCormack *et al.*, 2001; Tee, 2019; Windrum *et al.*, 2019), knowledge management (Carlile, 2004), and the process of technological search (Fleming, 2001). Finally, research has explored the subtle interplay between modularity and intellectual property, investigating the impact of design on a firm's ability to capture value from innovation (Jacobides *et al.*, 2006; Quan and Chesbrough, 2010; Henkel *et al.*, 2013; Baldwin and Henkel, 2015).

Today, more than 20 years after the book was first published, the sequel, "Design Rules: Volume 2: How Technology Shapes Organizations" is nearing completion, with the manuscript published as a series of working papers by Carliss Y. Baldwin. Hence, this represents the perfect time to take stock of developments in the field, gathering contributions motivated by the original work, and that use its theoretical and empirical underpinnings to bring new insights and evidence to bear on related topics.

Carliss Y. Baldwin's contribution to this collection, "Design Rules: Past and Future", opens the Special Issue. The article offers a fascinating look at the making of "Design Rules" as well as its sequel. It traces the authors' intellectual journey from a puzzling empirical observation in the computer industry—the unlikely success of Sun Microsystems, Inc., with its modular and open architecture—to its end point: a sophisticated way to understand and explain the architecture of complex systems, developed through the lens of an in-depth historical analysis of the computer industry. This "theory of modularity" is founded upon two basic insights. First, modular designs create "options" for both designers and users. Second, modular designs can evolve, as designers search for, evaluate, and select new and improved modules, integrated within a coherent overall architectural framework.

Baldwin's essay reflects on the main contributions of the original book and evaluates its shortcomings, viewed through the lens of 20 years of subsequent research in the field. Some of the limitations relate to the difficulty of measuring fundamental constructs that underpin modularity theory—including dependencies between design elements and the distribution of potential values that a particular design may generate. Others relate to a disconnect between the mechanisms through which designs are shown to evolve (i.e., via modular "operators") and the more holistic way that humans perceive changes in a complex system (and with it, potential complementarities). Perhaps, the most fundamental insight, however, relates to the notion of "mirroring"—the congruence that exists between organizational and technical designs. Design Rules 1 *assumed* the concept of mirroring as fait accompli, yet subsequent work has shown that "mirrors are sometimes broken." Indeed, her subsequent work in this area explores how and why these dynamics occur.

Ultimately, Baldwin sets out to address these shortcomings, while at the same time, integrating insights that emerge from a new set of organizational puzzles and surprises, found once more in the computer industry: Ecosystems, platforms, and open-source communities. In combination, these considerations form the agenda for the long-awaited sequel—Design Rules 2—with the explicit goal of explaining "how technology shapes organizations." The articles collected in this Special Issue complement this goal by exploring related questions using a variety of lenses and perspectives.

While each of the papers in this collection contributes insights across multiple domains of analysis, we find it useful to organize them into three groups, based upon their central contributions, as well as how the contributions relate to *other papers* in the issue. Of course, in doing this, we do not mean to limit the scope of any paper. Writing about modularity, it turns out, is not a modular endeavor.

The first set of papers look at the relationship between modularity and organizational design and specifically at the "mirroring hypothesis." This set includes contributions by Ron Sanchez, Peter Galvin, and Norbert Bach ("How Design Rules Emerge and Evolve: A Co-evolutionary Architectural Perspective on Firm and Industry Organization"), Christina Fang and Ji-hyun Kim ("Is Modularity Robust to Misfits? A Formal Test"), and Marc Alochet, John Paul MacDuffie, and Christophe Midler ("Mirroring in Production? Early Evidence from the Scale-up of Battery Electric Vehicles")—though we note the latter also explores implications for industry architecture overall, highlighting the links between modularity and organization at the level of the firm and at the level of a sector.

The second set of papers explores how modularity drives industry evolution and competitive dynamics. Contributions include "Platform Competition and Complementor Responses: Insights from Combining Design Rules with the Comparative Adjustment, Opportunity and Transaction Cost Framework" by Nicholas J. Argyres, Jackson A. Nickerson, and Hakan Ozalp; "Exploring the Structure of Internal Combustion Engine and Battery Electric Vehicles: Implications for the Architecture of the Automotive Industry" by Peter J. Murmann and Benedikt A. Schuler; and "On the Strategic Use of Product Modularity for Market Entry" by Jose Arrieta, Roberto Fontana, and Stefano Brusoni.

The final set of papers have as a common theme the role of individuals in modular systems and how these individuals can both shape, and are influenced by, the design of the system. This set comprises Robin Cowan and Nicholas Jonard: "Modular Organizations and Informal Structures: Modularity, Performance and the Alignment of Organizational Networks"; Stephan Billinger, Stefano Benincasa, Oliver Baumann, Tobias Kretschmer, and Terry Schumacher: "Learning to Search Collaboratively: How Dyads Overcome Complexity and Misaligned Incentives in Imperfect Modular Decompositions"; Sabine Brunswicker and Satyam Mukherjee: "The Microstructure of Modularity in Design: A Design Motif View"; and Richard Langlois, "Modularity, Identity, and the Constitutional Diagonal."

Below, we offer an overview of each area in this Special Issue and the articles contained in each.

2. Exploring organizational and technical designs: the mirroring hypothesis

The idea of "mirroring"—that organizational ties correspond to technical dependencies—has a long history in the literature, both prior to Design Rules 1 and as a consequence of its publication. This alignment (or lack thereof) can be examined at two levels of analysis: the first being *intrafirm*, as a firm makes choices in how to organize its business units based on the arrangement of its component technologies and the interactions between them, and the second being *interfirm*, as a firm makes choices about its boundaries (i.e., levels of horizontal or vertical integration) as well as the broader industry structure. Three contributions in this special collection of papers focus on this topic.

Sanchez, Galvin, and Bach present a co-evolutionary architectural perspective on firm and industry organization. Their model of a firm's strategic (product and organizational) architecture decision process highlights that firms' choices of architectures are influenced by both *firm-level* and *industry-level* considerations. In this model, firms are likely to evaluate and choose among alternative characteristics of (product and organizational) architectures and supporting design rules; they specifically focus on two sets of characteristics: system properties of architectures (i.e., open versus closed) and modular properties of architectures (i.e., modular or non-modular). Their model delves into the firm and industry factors that likely influence a firm's choice of architecture and how this choice co-evolves with the market preferences a firm serves and the industry dynamics the firm faces (or believes it will face in the future)—what they refer to as the evolution of competitive and cooperative interactions among firms in an industry. The authors suggest that firms will adopt design rules to align their architectures to these external dynamics and that these architecture decisions will be influenced by the potential to capture value through gains from specialization and gains from trade, as well as from both ex-ante and ex-post transaction costs implied by their architecture decisions. This paper reinforces several important ideas. In particular, it highlights that Colfer and Baldwin (2016), when speaking of the mirroring hypothesis, did "not impose a direction of causality," and, thus, both the mirroring hypothesis and reverse mirroring hypothesis are, in fact, expected. Product designs and organization designs interact to reflect one another. The mirror runs both ways.

Achieving mirroring is not easy for an organization designer since the true nature of the underlying task (dependency) structure is not always apparent (as Baldwin concludes in her introductory essay). One might create misfits by over or under-modularizing, either leaving too many cross-module dependencies or creating inefficiently large modules. In "Is Modularity Robust to Misfits? A Formal Test", Christina Fang and Ji-Hyun Kim devise a succession of computational experiments to understand the consequences of different *departures* from mirroring crossed with different search strategies for better designs. The authors discover that most misfits turn out to be either neutral, when organizations allow modules (units) to search locally without organizational level coordination, or even performance-enhancing, when the units carry out near-global search while coordinating and evaluating the alternatives at the organizational level. Tying together insights from prior work, this paper neatly crystallizes two ideas: first, while misfits are unambiguously bad for execution, they need not be for search; and second, the scope of search and evaluation are complements.

In "Mirroring in Production? Early Evidence from the Scale-up of Battery Electric Vehicles," the authors Marc Alochet, John Paul MacDuffie, and Christophe Midler examine the mirroring hypothesis in the context of a shift in automobile manufacturing. The mirroring hypothesis posits that modularity in design will be mirrored by modularity in production. The authors note that because battery electric vehicles (BEV) are in some ways more modular than internal combustion engine vehicles (ICEV), we might anticipate that as a company shifts to producing these technologies, we will see increasingly modular production systems—for example, relying more heavily on external battery and electric drive train suppliers for more of the new BEV components. However, drawing on data from both incumbent and *de novo* BEV automakers, they find that these firms have continued being quite vertically integrated. In fact, they often make BEVs on the same assembly lines as internal combustion vehicles. Furthermore, after securing battery cells from suppliers, the vast majority of them internalize the rest of battery pack and e-motor production. The authors point out that this may be, in part, because the production systems for automobile manufacturing are already quite modular and automakers are leveraging this expertise—plus their existing facilities and workforce—to internally manage the transition from ICEVs to BEVs. Automakers also value the power and control they gain by keeping more of the process in house as well as the opportunity to learn a new technology during its scale-up phase. Intriguingly, Murmann and Schuler (below) also study mirroring in the electric vehicle industry but adopt a complementary focus on modularity in design, as opposed to modularity in production. Both papers use data on firm-level choices to speculate about the long-run impact on industry architecture, particularly as mobility technology and services beyond electrification are implemented.

3. Linking modularity to industry evolution and competitive dynamics

In Design Rules 1, Baldwin and Clark give a fascinating account of the introduction of IBM's System/360 and its consequences. Customers appreciated its modular architecture for the multitude of configuration options that it offered, but so did competitors: The system invited module-level competition, which in turn eventually led to a radical change in industry structure: from vertical silos to horizontal layers. Here again, "mirroring" was at work, hence at least one of the contributions in this section (by Murmann and Schuler) could also fit into the first set of papers described above. However, the contributions we choose here have strong similarities on another dimension: they analyze how modularity relates to industry evolution and competitive dynamics, across a diverse set of industries, including the video game, electric vehicle, and local area network industry.

In "Platform Competition and Complementor Responses: Insights from Combining Design Rules with the Comparative Adjustment, Opportunity and Transaction Cost Framework," Nicholas J. Argyres, Jackson A. Nickerson, and Hakan Ozalp connect the discussion about modularity with the bourgeoning field of digital platforms This is important, as the original work on modularity focused on the computer industry (and microelectronics more generally) *before* the rise of Internet technologies. In particular, the authors focus on the dynamics of system-level innovation, rather than component-level innovation. The authors develop a framework that integrates design rules and transaction costs considerations to analyze the interaction between the strategic decisions of platform owners and those of their complementors. The video game industry offers the context for their analysis. They show that while (changes in) design rules offer opportunities for innovation and competition, the specific strategic options that are pursued (and by whom) depend on the interplay between design rules on the one side and transaction and opportunity costs on the other.

Murmann and Schuler compare the technological structure of ICEVs and BEVs and derive implications for the architecture of the industry. Using data from large incumbent automobile companies and start-ups, they create technical descriptions of the power trains and derive and compare the design structure matrices of ICEVs and BEVs. While they find, as expected, the power train of BEVs to be structurally simpler than that of ICEVs, the DSM difference matrix surprisingly shows that BEVs generally introduce more direct dependencies than they remove, making them less modular overall—to the surprise of the authors themselves. The authors go on to discuss how these changes will affect BEV industry architecture and value capture. They conclude that, while BEVs remain more integral than commonly expected, suggesting that predictions of radical change of the automobile industry architecture may be misplaced, integrality should not be equated with stability in terms of value capture. OEMs could lose an important element of their architectural advantage, at least in the short term. However, as the underlying production structure still favors integrality, OEMs are likely to muster the new skills required, investing in skills pertaining to new bottlenecks—a trend that we already observe. Murmann and Schuler's paper shows that a careful analysis using DSMs can help dispel popular and broadly held misconceptions (about levels and types of modularity) and illustrates the benefits of linking the analysis of modularity of production to the level of the sector (or overall ecosystem), with implications for both value creation and value capture.

Finally in this section, in their article "On the Strategic Use of Product Modularity for Market Entry," Jose Arrieta, Roberto Fontana, and Stefano Brusoni study the link between modularity and industry dynamics, but in the opposite direction. They ask how firms entering an emerging market can employ modularity to overcome the inherent challenges of strong and unpredictable industry dynamics. In short, how do expected industry dynamics determine the optimal product architecture? The authors model a market in which several open technical standards vie to become the dominant standard and ask: Is a modular or an integral architecture preferable? And how many of the competing standards should it support? They find that a modular architecture supporting several standards is preferable in the early era of "ferment" of the new industry, since it enables firms to broaden their portfolios and increase their chances of investing in the "right" technologies. In contrast, entry with integral, single-standard products is optimal later in the industry life cycle. They test the model's predictions on a sample of local area network industry entrants during the 1990s, finding them broadly supported. In this market, various benefits of modularity are seen: The cost advantage when building multi-standard products; the flexibility it offers users in choosing the preferred standard(s); and the option value it creates for the seller when, after product launch, other new standards are introduced.

4. Investigating the role of individuals in modular systems

Technological systems, organizational structures, and the potential "mirroring" between these designs do not emerge by themselves but are the result of human cognition and design decisions. As Carliss Y. Baldwin points out in her retrospective for this collection, an important shortcoming of the Design Structure Matrix methodology is the effort required to compile a list of all relevant decisions or tasks and the dependencies between them. Modular designs, like any other artifact, are limited by the bounded rationality of their creators and their tools. Further, Baldwin acknowledges that "humans approach complex systems more holistically and conceive of changes 'in groups,' not as a series of incremental 'moves."' These more "behavioral" aspects of modularity are arguably an under-researched field with great opportunities for future research. For instance, how do the complementarities we perceive cause us to bundle changes together (or not) and what are the consequences? The final four papers in this Special Issue address this "human side" of modularity.

In Robin Cowan and Nicolas Jonard's "Modular Organizations and Informal Structures: Modularity, Performance and the Alignment of Organizational Networks," the authors integrate research on modular product designs and workflows with psychological work on emotional contagion and the effects of stress in small groups. Using a series of models, they show that when both the formal organizational structure and the informal communication network within the firm is organized around a modular workflow, there is greater risk of the occurrence of low-performing groups of employees who experience (and amplify among themselves) high stress. In a non-modular workflow, on the other hand, or one in which the informal organization structure is non-modular, an individual experiencing high stress is more likely to have that stress dissipated through their contact with others who are both less likely to be experiencing high stress and less likely to be connected to each other. This unusual and interesting finding, about the potential disadvantages of loosely coupled organizations, will hopefully stimulate further work on the psychological effects of modularity when used as a design choice in organizational processes.

In "Learning to Search Collaboratively: How Dyads Overcome Complexity and Misaligned Incentives in Imperfect Modular Decompositions," the authors (Stephan Billinger, Stefano Benincasa, Oliver Baumann, Tobias Kretschmer, and Terry Schumacher) explore the search behavior of agents as they interact in the absence of a formal hierarchy. The analysis builds on the findings of a laboratory experiment. Within a 2×2 factorial design, the authors study the role of different types of incentives and different levels of interdependencies in shaping search and performance in dyads. Overall, dyads always learn how to search collaboratively, despite misaligned incentives and less-than-modular structures. The results of this experiment are interesting, as they advance the discussion about top-down vs. bottom-up coordination in the modularity literature. First, the authors make explicit the role that incentives play in explaining behavior. Second, the findings reveal that—even in the absence of a fully developed modular architecture—collaboration may still emerge as a solution without the need to resort to formal hierarchies.

Reversing the traditional emphasis on modularity as a designed property resulting from top-down decisions, Sabine Brunswicker and Satyam Mukherjee, in "The Microstructure of Modularity in Design: A Design Motif View," instead examine the emergence of (non-)modularity at the system level through the decentralized decision-making of actors trying to solve problems in their local task environments. The authors describe the frequency distribution of five different possible interaction patterns (i.e., microstructures) that can arise among triads of actors using data about the design structure of Nova, a complex open-source software cloud computing system. The data comes from the behaviors of actors in creating dependencies between code segments. The methodology the authors employ to detect microstructures is computationally intensive and novel to organization science. It yields insights on the high frequency of "common resource" microstructures and the low frequency of "cyclical loops," as well as the difference between cyclical and sequential loops. The connection the authors draw between interdependence microstructures and causal graphs is a promising theoretical development that may be generative for future work.

In "Modularity, Identity and the Constitutional Diagonal," Richard Langlois applies the framework of modular systems, articulated in Design Rules 1, to a new arena: the design of social institutions. In particular, Langlois' invites us to consider how individuals or groups can experience intangible (negative) externalities, or "moralisms," when expressing their Identity. Langlois shows that, in situations where asserting one's Identity generates negative externalities for others, individuals tend to modularize into Identity groups, to minimize these costs. One way to reduce potential conflicts between groups is to impose rules of behavior (a "constitution" of sorts) to govern their interactions. However, inherent incompatibilities between identities often dictate there is no stable, socially optimal, outcome. In such cases, good outcomes are only achieved via the increased standardization of identities (thereby reducing the costs of externalities). Langlois illustrates his conjectures by applying them to the problems facing modern social networks, like Facebook, with respect to managing content on its platforms. Langlois' paper shows how broadly the concepts and frameworks in Design Rules can be applied. Modular systems are all around us. This paper generates unique insights into the ways that conflicts can (and cannot) be managed, with respect to the expression of "Identity" in the social systems within which we are embedded. The topic is of utmost importance, given the increasingly fragmented and political world we all must navigate. The paper elegantly walks us through these concepts and illuminates the challenges ahead.

5. From DR1's impact to DR2's promise

Taken together, the papers included in this issue not only celebrate the accomplishments and impact of DR1 but also open-up *new avenues of research* in the broad field of modularity. First, many of the foundational principles advanced in DR1 built on examples and phenomena cataloged well before the emergence of the modern digital platforms that are rapidly reshaping whole ecosystems, as well as our understanding of the dynamics of competition and innovation (Argyres *et al.*, 2023). Hence, the discussion of complementarities in product and industrial architectures needs to be revisited in the light of new phenomena that make network externalities a cornerstone of the analysis of strategy and industrial evolution. In this vein, the contributions on how design rules initially evolve (Sanchez *et al.*, 2023) and how firms leverage modularity as a way to de-risk new technologies (Arrieta *et al.*, 2023) are important illustrations of this potential for future research. Similarly, alongside digital technologies, new energy technologies are emerging that fundamentally change the architectures of traditional industries, such as the automotive sector (Alochet *et al.*, 2023; Murmann *et al.*, 2023). A deep understanding of the principles from DR1 can shed new light on firm and sector dynamics but will also drive a better understanding of organizational and sectoral dynamics, which in turn can help us refine our understanding of what drives modularity and what determines its impact.

As the papers in this volume (including Brunswickr and Mukherjee, 2023) suggest, organizational design has become a critical part of the DR1 legacy and the area where further research is needed to advance our knowledge. With new technologies such as artificial intelligence enabling new organizational forms, we need to rethink foundational issues such the interplay between formal and informal structures (Cowan and Jonard, 2023) and the emergence of new mechanisms of decision, inclusion and, possibly, conflict—even at a societal level (Langlois, 2023). In this endeavor, new research methods can complement established qualitative and quantitative methods, thereby shedding light on topics such as the micro-foundations of search and decision-making processes across diverse environments (e.g., in the laboratory and with computational experiments; Billinger *et al.*, 2023; Fang and Kim, 2023).

In short, design rules and modularity remain a productive and progressive line of research that is still enabling the scientific community to ask important questions in response to the emergence of new phenomena. Yet, as we consider this legacy, which has invigorated research across a huge number of fields, DR2 now beckons (Baldwin, 2023). Given the eagerly anticipated publication of this second volume (hopefully, in the months after the Special Issue), we look forward to another catalyst for research that scholars will refer to with excitement and appreciation in the decades to come. In sum, the promise of research on the power of modularity has grown increasingly stronger over the past 20 years. This issue celebrates this historical legacy, as well as the important work that is still to come.

References

Alochet, M., J. P. McDuffie and C. Midler (2023), 'Mirroring in production?: Early evidence from the scale-up of electric vehicles (BEV),' *Industrial and Corporate Change*, **32**(1).

Argyres, N. J., J. A. Nickerson and H. Ozalp (2023), 'Comparative adjustment, opportunity and transaction costs, and the Design Rules of dynamic-platform competition,' *Industrial and Corporate Change*, **32**(1).

Arrieta, J. P., R. Fontana and S. Brusoni (2023), 'On the strategic use of product modularity for market entry,' *Industrial and Corporate Change*, **32**(1).

Arthur, W. B. (2009), *The Nature of Technology: What It Is and How It Evolves*. Simon and Schuster: New York, NY.

Aversa, P., S. Haefliger, A. Rossi and C. Baden-Fuller (2015), 'From business model to business modelling: modularity and manipulation,' *Advances in Strategic Management*, **33**(1), 151–185.

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. (2023), 'Design Rules: Past and Future,' *Industrial and Corporate Change*, **32**(1).

Baldwin, C. Y. and K. B. Clark (2000), *Design Rules, Volume 1: The Power of Modularity*. 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. Y., 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.

Billinger, S., S. Benincasa, O. Baumann, T. Kretschmer and T. Schumacher (2023), 'How incentives and modularity shape search in rugged landscapes: an experimental study,' *Industrial and Corporate Change*, **32**(1).

Browning, T. R. (2001), 'Applying the design structure matrix to system decomposition and integration problems: a review and new directions,' *IEEE Transactions on Engineering Management*, **48**(3), 292–306.

Brunswickr, S. and S. Mukherjee (2023), 'The microstructure of modularity of open system architectures: a network motif perspective,' *Industrial and Corporate Change*, **32**(1).

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., 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.

Carlile, P. R. (2004), 'Transferring, translating, and transforming: an integrative framework for managing knowledge across boundaries,' *Organization Science*, **15**(5), 555–568.

Colfer, L. J. and C. Y. Baldwin (2016), 'The mirroring hypothesis: theory, evidence, and exceptions,' *Industrial and Corporate Change*, **25**(5), 709–738.

Cowan, R. and N. Jonard (2023), 'Modular organizations and informal structures: modularity, performance and the alignment of organizational networks,' *Industrial and Corporate Change*, **32**(1).

Cusumano, M. A., A. Gawer and D. B. Yoffie (2019), *The Business of Platforms: Strategy in the Age of Digital Competition, Innovation, and Power*. Harper Business: New York, NY.

Eppinger, S. D. and T. R. Browning (2012), *Design Structure Matrix Methods and Applications*. MIT Press: Cambridge, MA.

Ethiraj, S. K., D. Levinthal and R. Roy (2008), 'The dual role of modularity: innovation and imitation,' *Management Science*, **54**(5), 939–955.

Fang, C. and J. Kim (2023), 'Is modularity robust to misfits? A formal test of the mirroring process,' *Industrial and Corporate Change*, **32**(1).

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.

Fleming, L. (2001), 'Recombinant uncertainty in technological search,' *Management Science*, **47**(1), 117–132.

Garud, R. and A. Kumaraswamy (1993), 'Changing competitive dynamics in network industries: an exploration of sun microsystems' open systems strategy,' *Strategic Management Journal*, **14**(5), 351–369.

Garud, R. and A. Kumaraswamy (1995), 'Technological and organizational designs for realizing economies of substitution,' *Strategic Management Journal*, **16**(S1), 93–109.

Gawer, A. and M. Cusumano (2002), *Platform Leadership*. Harvard Business School Press: Boston, MA.

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.

Iansiti, M. and R. Levien (2004), *The Keystone Advantage: What the New Dynamics of Business Ecosystems Mean for Innovation, and Sustainability*. Harvard Business Press: Boston, MA.

Jacobides, M. G. (2005), 'Industry change through vertical disintegration: how and why markets emerged in mortgage banking,' *Academy of Management Journal*, **48**(3), 465–498.

Jacobides, M. G. (2006), 'The architecture and design of organizational capabilities,' *Industrial and Corporate Change*, **15**(1), 151–171.

Jacobides, M. G. and S. Billinger (2006), 'Designing the boundaries of the firm: from "make, buy, or ally" to the dynamic benefits of vertical architecture,' *Organization Science*, **17**(2), 249–261.

Jacobides, M. G., C. Cennamo and A. Gawer (2018), 'Towards a theory of ecosystems,' *Strategic Management Journal*, **39**(8), 2255–2276.

Jacobides, M. G., T. Knudsen and M. Augier (2006), 'Benefiting from innovation: value creation, value appropriation and the role of industry architectures,' *Research Policy*, **35**(8), 1200–1221.

Kapoor, R. (2013), 'Persistence of integration in the face of specialization: how firms navigated the winds of disintegration and shaped the architecture of the semiconductor industry,' *Organization Science*, **24**(4), 1195–1213.

Karim, S. (2006), 'Modularity in organizational structure: the reconfiguration of internally developed and acquired business units,' *Strategic Management Journal*, **27**(9), 799–823.

Krishnan, V. and K. T. Ulrich (2001), 'Product development decisions: a review of the literature,' *Management Science*, **47**(1), 1–21.

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

Langlois, R. N. (2023), 'Modularity, identity, and the constitutional diagonal,' *Industrial and Corporate Change*, **32**(1).

Langlois, R. N. and P. L. Robertson (1992), 'Networks and innovation in a modular system: lessons from the microcomputer and stereo component industries,' *Research Policy*, **21**(4), 297–313.

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.

MacCormack, A., R. Verganti and M. Iansiti (2001), 'Developing products on "Internet time": the anatomy of a flexible development process,' *Management Science*, **47**(1), 133–150.

Matutes, C. and P. Regibeau (1988), 'Mix and match": product compatibility without network externalities,' *RAND Journal of Economics*, **19**(2), 221–234.

Murmann, J. P., B. A. Schuler and B. A. Schuler (2023), 'Exploring the structure of internal combustion engine and battery electric vehicles: implications for the architecture of the automotive industry,' *Industrial and Corporate Change*, **32**(1).

Parker, G., M. V. Alstyne and S. P. Choudary (2016), *Platform Revolution: How Networked Markets are Transforming the Economy and How to Make Them Work for You*. W.W. Norton & Co: New York, NY.

Parnas, D. L. (1972), 'On the criteria to be used in decomposing systems into modules,' *Communications of the ACM*, **15**(12), 1053–1058.

Pil, F. K. and S. K. Cohen (2006), 'Modularity: implications for imitation, innovation, and sustained competitive advantage,' *Academy of Management Review*, **31**(4), 995–1011.

Puranam, P. (2018), *The Microstructure of Organizations*. Oxford University Press: Oxford, UK.

Quan, X. and H. Chesbrough (2010), 'Hierarchical segmentation of R&D process and intellectual property protection: evidence from multinational R&D laboratories in China,' *IEEE Transactions in Engineering Management*, **57**(1), 9–21.

Sanchez, R., P. Galvin and N. Bac (2023), 'How Design Rules emerge and evolve: a co-evolutionary architectural perspective on firm and industry,' *Industrial and Corporate Change*, **32**(1).

Sanchez, R. and J. T. Mahoney (1996), 'Modularity, flexibility, and knowledge management in product and organizational 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,' *Academy of Management Review*, **25**(2), 312–334.

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

Sosa, M., S. Eppinger and C. Rowles (2004), 'The misalignment of product architecture and organizational structure in complex product development,' *Management Science*, **50**(12), 1674–1689.

Sosa, M., J. Mihm and T. R. Browning (2013), 'Linking cyclicality and product quality,' *Manufacturing & Service Operations Management*, **15**(3), 473–491.

Sturgeon, T. J. (2002), 'Modular production networks: a new American model of industrial organization,' *Industrial and Corporate Change*, **11**(3), 451–496.

Tee, R. (2019), 'Benefiting from modularity within and across firm boundaries,' *Industrial and Corporate Change*, **28**(5), 1011–1028.

Ulrich, K. (1995), 'The role of product architecture in the manufacturing firm,' *Research Policy*, **24**(3), 419–440.

Ulrich, K. T. and S. D. Eppinger (1994), *Product Architecture, Methodologies for Product Design and Development*. McGraw-Hill: New York, NY.

Von Hippel, E. and S. N. Finkelstein (1979), 'Analysis of innovation in automated clinical chemistry analyzers,' *Science & Public Policy*, **6**(1), 24–37.

Waltl, J., J. Henkel and C. Y. Baldwin (2012), 'IP modularity in software ecosystems: how SugarCRM's IP and business model shape its product architecture,' *in International Conference of Software Business*. Springer: Berlin, Germany, pp. 94–106.

Windrum, P., M. Haynes and P. Thompson (2019), "'Breaking the mirror": interface innovation and market capture by Japanese professional camera firms, 1955–1974,' *Industrial and Corporate Change*, **28**(5), 1029–1056.