

# Design Rules, Volume 2: How Technology Shapes Organizations

Chapter 4 The Mirroring Hypothesis: Linkages Inside and  
Across Transaction Free Zones

Carliss Y. Baldwin

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Carliss Y. Baldwin  
Harvard Business School

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## **Design Rules, Volume 2: How Technology Shapes Organizations**

### **Chapter 4 The Mirroring Hypothesis: Linkages Inside and Across Transaction Free Zones**

**By Carliss Y. Baldwin**

**Note to Readers:** This is a draft of Chapter 4 of *Design Rules, Volume 2: How Technology Shapes Organizations*. It builds on prior chapters, but I believe it is possible to read this chapter on a stand-alone basis. The chapter may be cited as:

Baldwin, C. Y. (2020) “The Mirroring Hypothesis: Inside and Across Transaction Free Zones,” Harvard Business School Working Paper (August 2020).

I would be most grateful for your comments on any aspect of this chapter! Thank you in advance, Carliss.

#### **Abstract**

A technology is a specific way to achieve a material goal. It describes a feasible path—a recipe—by which a group of people can arrive at a goal that none could achieve individually. Technical recipes thus require linkages between and among the various contributors to the technical process.

The purpose of this chapter is to look at the relationship between the steps in a given technical recipe and organizational linkages between and among people implementing the recipe. I begin by introducing two concepts: (1) technical dependencies which are properties of the technical architecture; and (2) organizational ties which are properties of the organizational architecture. The idea that organizational ties ought to correspond to technical dependencies is known as the *mirroring hypothesis*. This chapter defines the mirroring hypothesis and describes its origins. It then investigates the theory behind the hypothesis and identifies a set of “predictable exceptions” where the hypothesis does not hold. Finally it considers the evidence for and against mirroring in the economy at large.

#### **Introduction<sup>1</sup>**

A technology is a specific way to achieve a material goal. It describes a feasible path—a recipe—by which a group of people can arrive at a goal that none could achieve

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<sup>1</sup> This chapter is based on my paper “The Mirroring Hypothesis: Theory, Evidence and Exceptions,” co-authored with Lyra Colfer. (Colfer and Baldwin, 2016.)

individually. The technical recipe can be distilled into a specific set of tasks (actions) and transfers of material, energy, and information between the tasks. Particular tasks can then be allocated to different actors (and machines) according to their capabilities and the specifications of the technical recipe.

For example, the physics of iron working requires a hot fire and simultaneous hammering of semi-molten metal. The technical recipe translates these requirements into tasks and transfers that can be performed by human beings in conjunction with specific tools (bellows, anvil, hammer, tongs). A smith using traditional equipment cannot simultaneously operate the forge and the bellows. Thus the technical recipe requires at least two people each performing a different set of tasks in a synchronized fashion.

Technical recipes generally require linkages between and among the various contributors to the technical process. These linkages are what distinguish organized effort directed at a particular goal from random encounters and interactions. The synchronized transfers that take place in a traditional smithy, a modern assembly line, or a research laboratory and the transactions that take place in established markets or in a supply chain have a quality that is different from a casual conversation struck up with a friend. Structured interactions *respond to the needs of the underlying technology* and allow an organization to define its purpose and reach its goals.<sup>2</sup>

The purpose of this chapter is to look at the relationship between the steps in a given technical recipe and organizational linkages between and among people implementing the recipe. I begin by introducing two concepts: (1) technical dependencies which are properties of the technical recipe; and (2) organizational ties which are properties of the organizational architecture. The idea that organizational ties ought to correspond to technical dependencies is known as the *mirroring hypothesis*. This chapter defines the mirroring hypothesis and describes its origins. It then investigates the theory behind the hypothesis and identifies a set of “predictable exceptions” where the hypothesis does not hold. Finally it considers the evidence for and against mirroring in the economy at large.

## 4.1 Technical Dependencies

In the technological theory of economic systems proposed in Chapters 2 and 3, the fundamental units of analysis are tasks and transfers. A task changes the material world by transforming inputs (material, energy and information) into outputs. Transfers specify how material, energy and information must move from one task to another to achieve a technological goal.

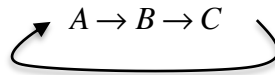
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<sup>2</sup> Puranam, Alexy and Reitzig (2014); Puranam (2018).

Let me define the *technical architecture* of a system as an abstract description of “what depends on what” as determined by the underlying technical recipe.<sup>3</sup> Technical dependency exists when there are required transfers of material, energy and/or information between tasks. Specifically, Task B *depends on* A if there are transfers of material, energy or information from A to B.<sup>4</sup> One-way dependency is also called *hierarchical dependency*. Indirect hierarchical dependency arises when Task C depends on B which in turn depends on A:

$$A \rightarrow B \rightarrow C .$$

Tasks A and B are *interdependent* if B depends on A and A depends on B directly or indirectly. Interdependent tasks cause *cyclic dependency*, that is cycles in the flow of material, energy or information. Indirect cyclical dependency arises when C depends on B, B depends on A, and A depends on C:



Large, indirect cycles are characteristic of many complex technical systems.<sup>5</sup>

Technical dependency through transfers implies *economic complementarity* between the tasks. The value of the whole is greater than the sum of the parts, which is the fundamental definition of complementarity in economics.<sup>6</sup> The output of all tasks is more valuable than the output of any subset.

In a large system, technical dependencies through transfers create a complex network of propagating cause and effect.<sup>7</sup> Such networks we have seen can be mapped via a Design Structure Matrix (DSM). By definition, high levels of technical interdependency exist within modules; few or no dependencies exist across modules. Hierarchical dependencies exist between early and later tasks in a recipe, and between the design rules and the modules of a modular system.

Problem solving in these systems consists of tracing paths of cause and effect through the task network and tweaking inputs or decisions at each step to make the ensemble perform better. Improvement of such systems occurs through a combination of

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<sup>3</sup> Colfer and Baldwin (2016); Baldwin (2018).

<sup>4</sup> Pahl and Beitz (1990); Ulrich and Eppinger (1994); Kusiak (1999); Puranam (2018).

<sup>5</sup> McCord and Eppinger (1993); Baldwin and Clark (2000) Ch. 4.

<sup>6</sup> Milgrom and Roberts (1990; 1995); Jacobides, Cennamo and Gawer (2018).

<sup>7</sup> Pearl (2009); Pearl and Mackenzie (2018).

informed search, conjecture, and trial-and-error in a very complex space of potential actions.<sup>8</sup>

## 4.2 Organizational Ties

The technical architecture of a task network does not specify who will perform the tasks and transfers nor how they will coordinate their work. The *organizational architecture* is a scheme by which the tasks in the technical architecture are assigned to people or teams plus the organizational ties between and among those people.<sup>9</sup> And just as the entire task network is not contained within a single organization, an organizational architecture does not end at the organization's boundaries. Transactions and transfers to and from external parties are also part of a firm's organizational architecture.

*Organizational ties are linkages between task performers that facilitate transfers and permit adaptation to contingencies within and across transaction free zones.* Since transfers and adaptation are necessary to achieve the goal, a good placement of organizational ties is essential to the success of the overall effort.

There are in turn several types of organizational ties.

If the transfers are of material goods or energy, it may be necessary for the participants (and their equipment) to be in in the same place. A smith at his forge is not helped by a bellows minder down the street. *Collocation* is an organizational tie that links the smith and bellows minder in ways that address the material requirements of the technology.

To facilitate transfers of information, the actors need ways to communicate. Collocation helps here, but it is not the whole story. Two smiths similarly trained but speaking different languages could probably get a job done, but there would be inefficiencies in the process until they worked out a set of codes and gestures. Effective *communication links* are thus a second organizational tie between individuals. Traditionally, collocation and communication went hand in hand, but modern technology makes possible instantaneous communication at a distance.

Effective joint action by humans also demands that they be motivated to act in ways that brings the process closer to its goal. Recall that many transfers within a transaction free zone cannot be easily defined, counted or measured. There are, by definition, opportunities to shirk and free-ride on the efforts of others. Thus it is helpful

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<sup>8</sup> Eppinger et al. (1994); Baldwin and Clark (2000); Nickerson and Zenger (2004). Actions that change the network correspond to an application of the "do" operator in Judea Pearl's theory of causal inference. When the actions taken change the outcomes (for better or worse), a causal link between the actions and the phenomenon has been provisionally established. Pearl (2009).

<sup>9</sup> Tasks may be allocated to machines, but, in this chapter, I shall treat machines as resources under human control, not independent agents.

to the technological process if the actors want to go beyond minimal performance of their tasks in order to help one another. *Social ties between actors can foster cooperation.* These ties include employment by the same firm, as well as feelings of sympathy created by face-to-face interaction, a common background, previous acquaintance, and/or dedication to the same cause or goal.

Lastly, no complex process or technology is ever completely pre-determined in its execution. Problems and questions will arise and decisions must be made on behalf of all. Decision-making in turn has two parts: (1) setting policy and direction, for example, deciding what to make in what quantities or sequence; and (2) settling conflicts and controlling opportunism among actors in a timely and effective way. *Recognition of the same decision-maker or dispute resolution process* is a fourth type of organizational tie that serves the needs of technology.

Just as the architecture of a technical system affects the location and cost of transactions, so too does technology largely determine where and how much collocation, communication, cooperation and consistent decision-making will be needed inside and across transaction free zones. In organizations subject to unified governance, creating appropriate organizational ties is the responsibility of head of the organization and her delegates. Their tools are divisional and firm boundaries, reporting relationships, job assignments, location assignments, budgets, incentives, and evaluation processes.

Markets, ecosystems, commons organizations and open collaborative projects are subject to distributed governance. Thus there is no central authority capable of mandating collocation, communication, cooperation and decision-making. Organizational ties in these settings tend to arise in two ways. First, they can arise through *ad hoc* processes of voluntary association and joint consultation.<sup>10</sup> Second, a central authority may set rules that solve common conflicts in advance. Rulemakers include the governing boards of organized marketplaces, the sponsors of platforms with ecosystems, the leaders of commons organizations, and founders and leaders of open collaborative projects. Membership in organizations with distributed governance is voluntary, but following the rules is often the price of admission.<sup>11</sup>

### 4.3 Where Will Organizational Ties Exist? The Mirroring Hypothesis

In Chapter 2, we considered the question: where will (or should) transactions be located in a task network? We can ask the same question about organizational ties. Some organizational ties operate across an entire enterprise. For example, all employees of a company are linked through their common employment relation. Other organizational

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<sup>10</sup> Raymond (2001).

<sup>11</sup> On rule-making in traditional markets, see for example Milgrom, North and Weingast (1990) and Greif (2006). On platform sponsors as regulators, see Boudreau and Hagiu (2009); on rule-making in commons organizations, see Ostrom (1990) and Carlisle and Grubey (2017); on the founder's role as rule-maker in open source projects, see Raymond (2001) and O'Mahony and Ferraro (2007).

ties are local, for example, a worker may be physically close to some co-workers, and have communication links with some and not with others.

The *mirroring hypothesis* states that the organizational ties in a project, firm or group of firms will (or should) correspond to the technical dependencies in the work being performed. Thus the technical architecture and the organizational architecture will “mirror” one another in the sense that the network structure of one will correspond to the structure of the other.

Inset Box 4-1 provides a visualization of mirroring based on design structure matrices (DSMs).

**Inset Box 4-1 Visualizing the Mirroring Hypothesis**

To visualize what it means to be mirrored, we can split the DSM of a task network into two subsidiary DSMs, one showing technical dependencies, the other showing organizational ties.

The *technical DSM* shows the network of dependencies among the technical components or tasks. For example, Figure 4-1 depicts a technical system with three tasks arranged along the main diagonal.<sup>12</sup> The technical recipe indicates that Task 2 depends on Task 1 and vice versa. The cyclic dependency between Task 1 and Task 2 is recognized by placing an ‘x’s’ on both sides of the main diagonal. The heavy lines in the figure group the tasks according to their dependencies.

**Figure 4-1 A Technical DSM**

|   | 1 | 2 | 3 |
|---|---|---|---|
| 1 | * | x |   |
| 2 | x | * |   |
| 3 |   |   | * |

The *organizational DSM* is constructed by first associating a person or team with each task (or job) and labeling each cell on the main diagonal accordingly. For example, for the system depicted in Figure 4-1, suppose Alice is given Task 1, Bob is given Task 2, and Carol is given Task 3.

In a separate 3x3 matrix with similar rows and columns, we place the uppercase letters A, B and C along the main diagonal as shown in Figure 4-2. These assignments indicate which agents have primary responsibility and knowledge about each task.

<sup>12</sup> The cells on the main diagonal may represent groups of individual tasks that have been aggregated into jobs or roles.



**Figure 4-2 An Organizational DSM** (corresponding to the previous technical DSM)

|   | 1  | 2  | 3 |
|---|----|----|---|
| 1 | A  | ab |   |
| 2 | ab | B  |   |
| 3 |    |    | C |

The mirroring hypothesis predicts that, given the technical dependencies between their tasks, Bob and Alice will share one or more explicit organizational ties that enable them to coordinate their actions. We denote the (presumptive) presence of an organizational tie between Alice and Bob, by placing the notation “ab” in Row 1, Column 2 and Row 2, Column 1. By comparison, Carol shares no technical dependencies with Alice or Bob, thus the mirroring hypothesis predicts no organizational ties for her.

More generally, the mirroring hypothesis predicts that the technical DSM and organizational DSM will have entries in the same cells. The structure of one will correspond to the structure of the other, as can be seen by overlaying Figure 4-2 on Figure 4-1.

#### 4.4 Mirroring as an Economical Approach to Problem Solving

The mirroring of technical dependencies and organizational ties can be explained as an approach to organizational problem-solving that conserves scarce cognitive resources. People charged with building or maintaining technical systems are inevitably faced with interdependencies that create problems and conflicts in real time. They must arrive at solutions that take account of their knowledge of underlying technical constraints. This process is generally more efficient if those involved can communicate with one another and cooperate to solve problems. Communication channels, collocation, plus common employment and social relationships are organizational ties that support communication and cooperation between individuals.<sup>13</sup>

At the same time, organizational ties are costly to create and place demands on individuals. Everyone cannot communicate with everyone else, nor be collocated, nor feel a social bond. Thus it is economical to have organizational ties where they are most needed, that is, at points where problems requiring coordination and cooperation are most

<sup>13</sup> Nickerson and Zenger (2004) make a similar argument. They note that solving complex problems with many interdependencies requires knowledge sharing (communication) among agents, but such exchanges are subject to opportunistic hazards. Markets have a low capacity for remedying these hazards, they argue, thus complex problems are best addressed within hierarchies, which (in their view) may be authoritarian or consensual.

likely to arise. As a result, we might expect to see a very close relationship between a network graph of technical dependencies within a complex system and a graph of various organizational ties. In other words, organization ties will (or should) be numerous and dense between people working *within* modules of a technical architecture and fewer and weaker between people working in different modules. To the extent that module boundaries correspond to firm boundaries, the mirroring hypothesis holds that organization ties will (or should) be numerous and dense within firms and fewer and weaker across firms.

Aligning organizational ties with technical dependencies does not have to be a conscious choice by any one person or group. Such alignment can arise through an evolutionary process of decentralized problem solving.<sup>14</sup> That is, the people charged with managing a complex technical system will create and/or eliminate technical dependencies and organizational ties where and when needs arise. If needs persist, the association between technical dependencies and organizational ties will also persist.

The mirroring hypothesis has a complex origins in organization theory, engineering design, and management strategy. Inset Box 4-2 describes its history.

#### **Inset Box 4-2 History of the Mirroring Hypothesis**

Different versions of the mirroring hypothesis were derived independently by James Thompson and Melvyn Conway at approximately the same time.

Thompson, an organization theorist, argued that, given bounded rationality, actors performing technologically interdependent tasks should be collocated and communicate more with each other than with actors outside their group.<sup>15</sup> Furthermore, when interdependence overtaxes communication channels, the organization should let those with the greatest interdependency form a group, and then cluster the smaller groups into “an overarching second-order group.”<sup>16</sup>

This method of clustering implicitly forms a hierarchy. Thompson went on to say that “if we assume that the probability of conflict among [actors] or groups is directly proportional to their degree of interdependence,” then this hierarchical structure can serve as a device for the resolution of conflicts.<sup>17</sup> Thus actors performing interdependent tasks should have the organizational ties of collocation, communication linkage, and a common dispute-resolution mechanism. This is the mirroring hypothesis, with causal effects running from technical dependencies to organizational ties.

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<sup>14</sup> Alchian (1972); Nelson and Winter (1982); Sosa, Eppinger and Rowles (2004).

<sup>15</sup> Thompson (1967).

<sup>16</sup> *Ibid.* p. 59.

<sup>17</sup> *ibid.* p. 60.

Conway was a practicing engineer, who spoke from his firsthand experience designing software systems.<sup>18</sup> Before the design process can start, he noted, there must be a provisional partitioning of the system into subsystems and components. On the basis of that preliminary idea, task groups are formed and activities delegated to those groups. Within the task groups there will be many communication links, while across groups there will be few or none at all.

Conway argued that, in order to have a dependency between two components of the larger system, the designers of those components must have previously negotiated and agreed upon an interface specification, because technical components generally do not work together by pure chance. Thus the presence of a working technical dependency is evidence of prior communication and cooperation, that is, organizational ties, between the designers. Conversely, if there is no communication and cooperation between designers there can be no effective dependencies between their components (although there may be latent dependencies that cause the system to break down).

In other words, the existence of organizational ties can affect the placement of technical dependencies. This conjecture became known as Conway's Law: "organizations which design systems ... are constrained to produce designs which are copies of [their] communication structures."<sup>19</sup> This is also the mirroring hypothesis, but with causal effects running from organizational ties to technical dependencies.

Rebecca Henderson and Kim Clark were the first to use the term "mirroring" to describe this relationship between the technical and organizational structure: "We have assumed that organizations are boundedly rational, and, hence that their knowledge and information structure come to mirror the internal structure of the product they are designing."<sup>20</sup> Drawing on their field work, they went on to suggest that strict mirroring was not optimal because it leaves firms vulnerable to unforeseen architectural innovation by competitors: "architectural knowledge embedded in [organization structure] becomes inert and hard to change."<sup>21</sup>

The mirroring hypothesis entered the strategy literature via seminal works by Richard Langlois and Paul Robertson (1992) and Ron Sanchez and Joseph Mahony (1996). The key insight in these papers was that the absence of technical dependencies might determine or predict the absence of organizational ties, *hence the location of firm boundaries*. Thus technical systems made up of many discrete modules can be implemented by separate firms, while systems with many interdependencies require unified governance (and hierarchical authority) as in a single firm.

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<sup>18</sup> Conway (1968).

<sup>19</sup> *ibid.* p. 31.

<sup>20</sup> Henderson and Clark (1990), p. 27.

<sup>21</sup> *Ibid.*

What are the alternatives to mirroring? By definition, unmirrored systems are those where organizational ties are present without technical dependencies or technical dependencies are present without organizational ties. (Note: It is easy for latent technical dependencies to exist in the absence of organizational ties, but these generally are a threat to the functioning of the system.)

It is quite common to have communication, collocation, and social linkages without technical dependencies. Transaction free zones serve social as well as productive purposes and humans are constantly mixing and gathering. Social ties unrelated to technical dependency are thus to be expected. However, social ties require maintenance and too much attention to a social network can detract from productivity. Still, it would not be surprising to see more ties between actors within and across transaction free zones than were strictly required to manage the technical system.

A single corporation, proprietorship or partnership can also own and manage technically unrelated businesses. Separate transaction free zones may be *strong economic complements*: each may have no value, except in the presence of the other. In that case, transaction cost economics and property rights theory both recommend that the units should be placed in a single corporation under unified governance.

In summary, the mirroring hypothesis can be viewed as a set of predictions derived from a theory of economical problem solving within a task network. The theory posits that organizational ties create linkages between people in the form of collocation, communication, a common employer and a common dispute resolution process. Such ties facilitate cooperation and joint problem solving by individuals and groups. Dependencies in the underlying technology are a likely cause of problems in any technical system. Thus organizational ties are most necessary in places in the task network where technical dependencies are numerous. It follows that organizational ties will be dense where technical dependencies are dense, and sparse where dependencies are sparse. The result is a mirroring of technical and organizational architectures.

The theory summarized above gives rise to five specific predictions that apply in different settings. The settings are: (1) buyer-supplier relations; (2) industry dynamics; (3) organizational ties within corporations; (4) management of knowledge, alliances and consortia; and (5) open collaborative projects.

At the same time, a careful examination of costs and benefits leads to several predictable exceptions where the hypothesis will be only partially satisfied or contradicted. These “predictable exceptions” can arise in any of the five settings listed above. The next two sections describe both the specific predictions and the predictable exceptions.

## 4.5 Specific Predictions Consistent with the Mirroring Hypothesis

### I. Buyer-Supplier Relations

If the mirroring hypothesis holds, the boundaries of firms are likely to coincide with the boundaries of technical modules. This prediction arises from the fact that it is easier (cheaper) to create organizational ties within firms than across firms. Conversely, as we saw in Chapter 2, it is easier (cheaper) to locate transactions at module boundaries (thin crossing points) than module interiors.

For buyer-supplier relations, the prediction implies that *components with a high degree of technical interdependency with other components in the product design will be insourced, while those with a low degree of interdependency will be outsourced*. In addition, “mirrored” sourcing relations will be viewed as satisfactory, while “unmirrored” relations are more likely to be viewed as unsatisfactory.

### II. Industry Dynamics

When the technology of an industry changes, firms must change their internal processes and external relations. If a modular technology supersedes a more integrated technology, firms making modules can gain a foothold and the industry will become more fragmented. Conversely, if an integrated technology replaces a modular technology, vertically integrated firms are likely displace specialist firms, and the industry will become more concentrated. Reversing the direction of causality, mergers among firms encourage the adoption of integrated technologies, while divestiture and breakups reward the adoption of modular technologies.

Thus, if the mirroring hypothesis holds, *when the technical architecture of an industry changes, firm boundaries will change to reflect the new pattern of technical dependencies. Symmetrically, when firm boundaries change (for example via mergers), the pattern of technical dependencies will change to reflect the new boundaries*.

### III. Organizational Ties within Corporations

The theory of economical problem solving posits that organizational ties within corporations, specifically collocation and communication linkages, are expensive to create and maintain. For the sake of efficiency, such ties should be placed where they are most needed. Technical cause-and-effect relationships (dependencies) are an important source of problems in any large technical system. Therefore, a high degree of collocation and high-bandwidth communication channels are needed in those parts of the task network where dependencies are dense and complex.

Thus, if the mirroring hypothesis holds, *within a single corporation, organizational ties, such as communication and collocation are most likely to exist where technical dependencies exist*. In addition, corporate units whose organizational ties are

aligned with the structure of their technology will perform well, while those that are not well-aligned will perform poorly.

#### *IV. Management of Knowledge, Alliances and Consortia*

Transfers of knowledge require communication linkages whose bandwidth corresponds to the complexity of the knowledge. Thus the theory of economical problem solving suggests that knowledge will flow easily within transaction free zones where transfers are uncensored and unpriced. At the same time, conflicts of interest between firms as to the equality of contributions make it difficult and costly for two or more firms to share single transaction free zone.

Thus, if the mirroring hypothesis holds, *knowledge transfers will take place within firms, but not across firms*. Attempts to share knowledge across firm boundaries or to build common knowledge among a group of firms will be risky and prone to failure.

However, we know from the arguments presented in Chapters 2, that with effort, firms can share complex knowledge for purposes of enabling transactions. In Chapter 3, we saw that a group of autonomous firms can create a shared transaction free zone for the purpose of creating common industry standards. In both cases, the knowledge transfers and shared effort come at a cost. The firms involved must build long-lasting, robust communication linkages and trust in the joint relationship.

The mechanisms that enable flows of knowledge and cooperation across firms are formal and relational contracts. Hence in cases involving knowledge management, alliances, and consortia, the theory of efficient problem solving predicts that exceptions to mirroring (1) arise only in cases where benefits to all parties are perceived to be high; and (2) are buttressed by significant and long-lasting formal and relational contracts.

#### *V. Open Collaborative Projects*

Open collaborative projects are informal organizations of individuals with common interests who come together to pursue a joint enterprise.<sup>22</sup> Digital technology and the Internet have made the creation of these projects relatively easy. Some collaborations are purely social, however, in some cases, members use technologies they know to create an artifact or provide a service they would otherwise have to buy.

Participants in open collaborative projects have few classic organizational ties. They are usually geographically dispersed, not employed by the same firm, have few social ties (except through the project itself). Commitments are transient and contributions are voluntary. Disputes are dealt with via negotiation, consensus or

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<sup>22</sup> Baldwin and von Hippel (2011). The most famous open collaborative projects create “open source” software, however, some create other digital artifacts (eg. Wikipedia), or physical artifacts (eg. prosthetic hands) while others produce services such as advice and community events.

“forking.”<sup>23</sup> However, via the Internet, participants in open collaborative projects generally have high-bandwidth communication linkages in the form of central repositories, chat, email, bulletin boards, etc.

Given the lack of many classic organizational ties, if the mirroring hypothesis holds, *contributors to open collaborative projects will create modular systems with a high division of labor and high levels of information hiding.*

The italicized sentences above summarize the main testable predictions consistent with the mirroring hypothesis. However, the broader theory of efficient problem solving provides room for exceptions. The central theory views both technology and organizational structure as the result of a balancing of costs and benefits. *When the benefits of non-mirroring are high*, we would expect to see examples of non-mirrored organizations that succeed as well as mirrored organizations that perform poorly. “Predictable exceptions” to the mirroring hypothesis are discussed in the next section.

#### **4.6 When Mirroring Does Not Hold: “Predictable Exceptions” to the Mirroring Hypothesis**

Cases where the benefits of non-mirroring are likely to outweigh the costs can be grouped under five headings:

- Partial mirroring: Firms know more than they make.
- Digital technology provides substitutes for organizational ties.
- Formal and relational contracts make possible transactions at thick crossing points and shared transaction free zones.
- Strict mirroring may “trap” firms within obsolete technical and organizational architectures.
- Tight-knit teams with many organizational ties may create modular products and processes.

The exceptions are discussed in sub-sections below.

##### *Partial Mirroring: Firms Know More than They Make*

In Chapter 2, I argued that information hiding is a key benefit of modular technical systems. People working in one part of the system can focus on tasks related to their module and do not need to know very much about what goes on in other modules. This partitioning of knowledge reduces complexity and the amount of knowledge needed by any one person or group. Following this logic, a simple version of the mirroring

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<sup>23</sup> “Forking” is the practice of splitting the software codebase into two or more branches which may proceed independently or merged together at a later date. Raymond (2001)

hypothesis would predict that knowledge, like tasks, should be divided in accordance with the modular structure of the underlying technical system.

This view has been challenged by a stream of work on system integration initiated by Stefano Brusoni, Andrea Prencipe and Keith Pavitt.<sup>24</sup> Observing the design and construction of complex technical systems involving many firms, they found that whereas the systems were modular (and mirrored) for most participants in the project, the *systems integrator* had to coordinate the entire network of component suppliers. To fulfill this role, systems integrators needed capabilities that spanned a wide range of technical fields. Thus their knowledge extended well beyond what was directly relevant to the tasks they performed inhouse. Such firms perform “know more than they make”<sup>25</sup>

Partial mirroring is effective because, in complex systems with changing technologies, tasks and decisions are often more interdependent than system designers realize. Until a system is well-understood, latent dependencies will be present that can greatly compromise system performance and may cause a new system to fail. Partial mirroring views the technology across firm boundaries, and thus may resolve these latent dependencies in an efficient, timely way.

These observations lead us to expect to see “partially mirrored” organizations whose knowledge boundaries are drawn more broadly than their task boundaries.

### *Digital Technology*

Today, the very nature of organizational ties may be changing because of the influence of digital technology. The decreasing cost of computers and advent of the Internet gave rise to a variety of online and open source communities based on open boundaries, self selection of tasks, and free sharing of information. Members of these communities are not collocated and not employed by the same firm, hence lack those organizational ties. They do not work within a managerial hierarchy nor do they have formal task assignments.

However, the groups generally have many high-bandwidth communication channels, including bulletin boards, chat rooms, instant messaging, and email, that simply did not exist before the Internet. Should we consider organizational ties to be dense in these communities, by virtue of their dense communication linkages? Or are these communities sparsely connected by virtue of geographic distance, lack of face-to-face interactions, and the absence of a managerial hierarchy?

If instantaneous high-bandwidth communication linkages are a substitute for collocation and a common employer, then we would expect to see more exceptions to the

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<sup>24</sup> Brusoni, Prencipe and Pavitt (2001).

<sup>25</sup> Ibid. p. 597.



mirroring hypothesis in firms and projects supported by digital technology than traditional firms.

### *Formal and Relational Contracts*

In Chapter 2 we saw that it is possible to locate transactions at thick crossing points in the task network although transactions costs, both mundane and opportunistic will be higher in such places. Chapter 3 further showed that it is possible to create transaction free zones under distributed governance. Commons organizations, standards-setting organizations and open collaborative projects are all examples of such organizations. As legal persons, corporations can also enter into alliances, joint ventures and consortia with other firms. In these organizations, information, material and energy can be transferred freely among participating members without measurement or (direct) compensation.

Transactions at thick crossing points and intercorporate transaction free zones are sustained by formal and relational contracts. Formal contracts attempt to categorize the responsibilities of all parties in some detail, so that no side will be surprised or disappointed after the fact. However, when transfers are complex and uncertain, it is impossible to foresee, much less enumerate, all contingencies.<sup>26</sup>

Relational contracts take a different approach. Here value is assumed to reside in a continuing cooperative relationship. The parties will “settle up” imbalances after the fact in ways that are fair to all rather than risk losing the benefits of the relationship.<sup>27</sup>

Formal and relational contracts depend on an initial degree of trust between participants. However, repeated interaction and problem solving also allow the parties to learn about each other, both as individuals and as representatives of their respective organizations. If the individuals and organizations show themselves to be trustworthy, their mutual trust will grow over time. Disputes will be easier to resolve and the ongoing costs of maintaining the relationship will decline as a result.<sup>28</sup>

The relationship will then become a stable pattern in the task network.<sup>29</sup> In this fashion, transactions at thick crossing points as well as alliances, joint ventures and consortia can be sustained to the benefit of all parties. Their benefits can be large, thus we should not be surprised by these exceptions to strict mirroring. However, we also expect them to rest on a solid foundation of formal and relational contracts and trust.

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<sup>26</sup> Hart (1995).

<sup>27</sup> Baker, Gibbons, Murphy (2002); Gibbons and Henderson (2012).

<sup>28</sup> Macneil (1978, 1987); Mayer and Argyres (2007); Baldwin and Henkel (2014).

<sup>29</sup> Aoki (2001) calls such patterns institutions: “equilibria in a set of linked games with self-confirming beliefs.”

### *A Mirroring “Trap”*

Seeking knowledge outside the boundaries of the existing task network is likely to be advantageous in industries subject to rapid technical change. In such cases, strict mirroring of organization ties and task dependencies may prevent a firm from seeing opportunities to change its boundaries and/or restructure its technology. Thus, while mirroring conserves scarce cognitive resources, strict mirroring can be a trap. In technologically dynamic industries, firms must scan new technologies and organizational arrangements to identify opportunities to change technical dependencies and organizational ties to create a better match between technology and organization structure.<sup>30</sup>

For example, in the photolithographic alignment equipment industry, Rebecca Henderson and Kim Clark described how successive waves of new entrants introduced new product and process architectures to the industry. Relying on only organizational ties required by their own technical architecture, engineers and managers at the incumbent firm could not see the value inherent in the innovations arising outside the firm’s boundaries.<sup>31</sup>

Thus we expect to see strictly mirrored firms perform poorly in the face of new technologies arising outside their boundaries.

### *Modular Technical Systems Created by Tight-knit Teams*

Modular technical systems do not arise naturally within firms. Transaction free zones within corporations support low-cost communication linkages, collocation, and dispute resolution processes. These organizational ties makes possible high levels of technical integration within the zone. Such ties are the antithesis of the strict rules and information hiding that define truly modular systems.

Nevertheless, the natural tendency to integrate technical systems with a firm can be over-ridden by managers when the rewards of a modular system are perceived to be high. Managers may envision a modular technical system with design rules and thin crossing points between modules and set out to make the vision real. This is in fact how IBM System/360 was created: a tight-knit team within IBM saw the value inherent in a broad, modular product line that allowed hardware and software upgrades at the user’s discretion. The task force specified the basic architecture of that system, and IBM then

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<sup>30</sup> Jacobides et al., 2006; Baldwin (2018).

<sup>31</sup> Henderson and Clark (1990). Later, the ability to take in knowledge from outside a firm’s boundaries came to be known as “absorptive capacity.” Cohen and Levinthal (1990).

invested heavily to create a full line of compatible new products.<sup>32</sup> The result was the first modular computer system and a template for all future computer systems.<sup>33</sup>

Corporations and other organizations can make the creation of a modular technical architecture an organizational priority. Thus we would expect to see cases where tight-knit teams operating within transaction free zones design and implement modular technical systems.

In summary, the theory of an economic system based on tasks, transfers and transaction free zones suggests that creating a correspondence between technical dependencies and organizational ties is an economical way to solve problems arising in complex technical systems. Such “mirroring” places organizational ties where they are most needed. However, a deep dive into the theory reveals that there are times when mirroring is not the most desirable way to implement a given technical recipe or to respond to technical change. Because of these “predictable exceptions,” the extent of mirroring in the economy is an empirical question. The final sections of the paper discuss the results of an empirical investigation of mirroring across a range of firms and industries.

## **4.6 Empirical Evidence**

In a paper published in 2016, Lyra Colfer and I reviewed 142 empirical studies, most of which appeared between 2000 and 2015. The sample included studies from the five settings listed above:

- buyer-supplier relations;
- industry dynamics;
- organizational ties within corporations;
- knowledge management, alliances and consortia; and
- open collaborative projects.

The studies were widely distributed across industries and over time, but they were not a random sample of the economy. Information-based industries were overrepresented, while continuous flow, extractive and service industries were underrepresented in the sample. Thirty nine studies involved software: half of these (19) described open collaborative projects. Autos (19) and semiconductors (15) had the next highest number of studies followed by computers (12) and aircraft & defense (11).<sup>34</sup>

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<sup>32</sup> Baldwin and Clark (2000) Ch. 7.

<sup>33</sup> Bell and Newell (1971); Hennessy and Patterson (1990); Ferguson and Morris (1993).

<sup>34</sup> A complete listing of studies, and a breakdown by industry and year can be found in Colfer and Baldwin (2016).

In each study in the sample, the authors had carefully observed both technical dependencies and organizational ties and assessed their correspondence in a rigorous quantitative or qualitative fashion. *Descriptive studies* looked simply at the correlation between technical dependencies and organizational ties, without making any prediction about performance. *Normative studies* sought to evaluate the success and/or failure of mirrored and unmirrored systems.

We formally tested the mirroring hypothesis using the specific predictions derived from it in each setting (see above). We established definitions of full, partial and no support for each specific prediction, evaluated each case study, and assigned it to one of the three categories.

Descriptive studies were deemed supportive if they indicated high correlation between technical dependencies and organizational ties and unsupportive if they indicated no correlation. They were considered partially supportive if they found mixed results.

Normative studies were considered supportive if they showed that mirrored organizations performed well *or* that unmirrored organizations performed poorly. They were considered unsupportive if they showed that a mirrored organization performed poorly *or* an unmirrored organization performed well. They were considered partially supportive if a partially mirrored organization performed well.

Once the studies were categorized, we looked more carefully at the partially supportive and non-supportive studies.

Among the partially supportive studies, we looked to see if the firms in question drew their knowledge boundaries more broadly than their task boundaries and thus “knew more than they made.”

Among the unsupportive studies, we first sought to explain the particular benefits and costs of mirroring in each case. We then grouped the studies according to their similarity. The “predictable exceptions” described above were sufficient to explain all non-supportive cases.

## 4.7 Findings

Table 4-1 presents a summary of our findings. The Appendix to this chapter expands on this summary.

The results show that mirroring is a common pattern in the economy. In studies of buyer-supplier relations, industry dynamics, and organizational ties within corporations, more than 80% of the studies provided full or partial support for the hypothesis. Thus the mirroring hypothesis predicts both the location and performance of transactions *and* organizational ties within companies.

**Table 4-1 Summary of Empirical Results**

|  |           | <b>Full Support</b>   | <b>Partial Support</b> | <b>Non-support (Exceptions)</b> | <b>Total</b> |
|--|-----------|---|------------------------|---------------------------------|--------------|
| Buyer-Supplier Relations   |           | 30  | 13                     | 9                               | 52           |
| Industry Dynamics  |           | 9   | 0                      | 1                               | 10           |
| Organizational Ties within Corporations  |           | 24  | 5                      | 7                               | 36           |
| Management of Knowledge, Alliances and Consortia   |           | 3   | 13                     | 6                               | 22           |
| Open Collaborative Projects  |           | 9   | 3                      | 10                              | 22           |
| <b>Total</b>   |           | <b>75</b>   | <b>34</b>              | <b>33</b>                       | <b>142</b>   |
| Buyer-Supplier Relations   |           | 58%   | 25%                    | 17%                             | 100%         |
| Industry Dynamics  |           | 90%   | 0%                     | 10%                             | 100%         |
| Organizational Ties within Corporations  |           | 67%   | 14%                    | 19%                             | 100%         |
| Management of Knowledge, Alliances and Consortia   |           | 14%   | 59%                    | 27%                             | 100%         |
| Open Collaborative Projects  |           | 41%   | 14%                    | 45%                             | 100%         |
| <b>Total</b>   |           | <b>53%</b>  | <b>24%</b>             | <b>23%</b>                      | <b>100%</b>  |
| <b>Partial Mirroring</b>   |           |   |                        |                                 |              |
| Knowledge boundaries often exceed task boundaries: firms may choose to “know more than they make.”   | 26        | Buyer-Supplier Relations 13<br>Management of Knowledge 13   |                        |                                 |              |
| <b>"Predictable Exceptions"</b>  |           |   |                        |                                 |              |
| High-bandwidth communication made possible by digital technology reduces the need for collocation and a common employer.   | 13        | Buyer-Supplier Relations 2<br>Organizational Ties within Corporations 1<br>Open Collaborative Projects 10 |                        |                                 |              |
| Transactions at thick crossing points and collaboration across firms are possible in the task network, when buttressed by formal and relational contracts.   | 11        | Buyer-Supplier Relations 5<br>Management of Knowledge 6   |                        |                                 |              |
| When the underlying technology is dynamic (technical recipes are changing), mirroring may create a “trap” in which the firm is unable to respond to a new technological architecture originating outside its boundaries. | 5         | Buyer-Supplier Relations 2<br>Industry Dynamics 1<br>Organizational Ties within Corporations 2            |                        |                                 |              |
| A team with many, close organizational ties may create a modular system.   | 4         | Organizational Ties within Corporations 4   |                        |                                 |              |
| <b>Total</b>   | <b>33</b> |   |                        |                                 |              |

However, further investigation of the results shows that the boundaries of firms are quite permeable with respect to knowledge. In total, we found 26 cases of partial mirroring where the knowledge boundaries of firms exceeded the boundaries of their direct tasks. In such cases, firms “know more than they make.” This was a common pattern in buyer-supplier relations (13 cases) and in the management of knowledge, alliances and consortia (13 cases). The pattern of partial mirroring was universally correlated with good performance.

In contrast, in open collaborative projects, only 55% of the studies fully or partially supported the hypothesis, while 45% did not. All of the non-supportive cases made intense use of digital technology. Indeed across the entire sample, thirteen non-supportive cases involved software developed using high-bandwidth communication linkages over the Internet. *High-bandwidth communication apparently can serve as a substitute for both collocation of software developers and hierarchical management of software projects.*

The next-most-common “predictable exception” was the placement of transactions at thick crossing points in the task network (5 cases) and the creation of intercorporate transaction free zones (6 cases). Consistent with the theories presented in Chapters 2 and 3, *these organization structures were always accompanied by formal and relational contracts.*

There were five cases of a mirroring “trap,” where strict mirroring appears to have been detrimental in the presence of dynamic technological change. These cases lend further support to the observation that firms may benefit by drawing their knowledge boundaries more broadly than their task boundaries.

Last but not least, there were four instances where collocated teams within a corporation created highly modular technical architectures.

#### **4.8 Conclusion—How Technology Shapes Organizations**

This chapter has attempted to explain how the complex work specified by technical recipes gets done both within and across firms in the task network. For this purpose, I split the network of tasks and transfers introduced in Chapter 2 into two subsidiary networks: (1) a network of technical dependencies reflecting cause-and-effect relations within the technical recipe; and (2) a network of organizational ties linking the people performing the work. Organizational ties include collocation, communication channels, employment by the same company, and a common means of dispute resolution.

The mirroring hypothesis predicts that there will (or should) be a correspondence between the cause-and-effect relations in a technical architecture and the organizational ties among those responsible for implementing it. Organizational ties are designed to facilitate communication and joint problem-solving. Thus an economic approach to problem solving in a task network would place organizational ties where technical problems are most likely to arise.

Lyra Colfer and I used data from 142 empirical studies to test the mirroring hypothesis. The studies were drawn from five different settings: buyer-supplier relations; industry dynamics; organizational ties within corporations; the management of knowledge, alliances and consortia; and open collaborative projects.

Our analysis showed that mirroring is a common, but by-no-means universal pattern in the economy today. It is prevalent in traditional firms, and less common in open collaborative projects that make intense use of digital technologies. Partial mirroring—drawing knowledge boundaries more broadly than task boundaries—is also a common pattern. The strategy of “knowing more than you make” generally performs well in cases where the underlying technologies are changing rapidly.

In conclusion, technology shapes organizations by generating technical problems in different parts of a technical system. Human skills and attention are needed to solve technical problems in a timely and efficient way. The mirroring of technical dependencies and organizational ties is one way to address the problem of managing complex technical systems while conserving scarce cognitive resources.

Mirroring has benefits, thus not surprisingly, it is a prevalent pattern in the economy at large. But it also has costs, especially when the underlying technologies are dynamic. Digital technologies also give rise to new methods of coordination based on high bandwidth communication but not collocation or managerial hierarchies.

In the next chapter, I turn from the microstructure of technical dependencies and organizational ties to the macrostructure of the economic system. I define a new layer of organization for large technical systems: the business ecosystem. I argue that, as organizations, business ecosystems are shaped by economic complementarities that are strong enough to reward some amount of coordination across firms, but not so strong as to require hierarchical management within the boundaries of a single corporation.

## Chapter 4 Appendix—Detailed Breakdown of Predictions and Results

### I. Buyer-Supplier Relations

| N= 52   | Full Support | Partial Support | Non-support (Exceptions) | Total |
|---|--------------|-----------------|--------------------------|-------|
| a) Components with a high degree of technical interdependency with the buyer’s system are insourced; those with a low degree of interdependency are outsourced. (Descriptive) | 13           | 1               | 3                        | 17    |
| b) Mirrored sourcing relationships perform well; non-mirrored relationships perform poorly. (Normative)   | 17           | 12              | 6                        | 35    |
|   | 30           | 13              | 9                        | 52    |

#### Classification of Exceptions

|                                 |          |
|---------------------------------|----------|
| Formal and Relational Contracts | 5        |
| Mirroring trap                  | 2        |
| Digital technology              | 2        |
|                                 | <u>9</u> |

### II. Industry Dynamics

| N= 10   | Full Support | Partial Support | Non-support (Exceptions) | Total |
|---|--------------|-----------------|--------------------------|-------|
| a) When the technical architecture of an industry changes, firm boundaries change to reflect the new pattern of technical dependencies. Symmetrically, when firm boundaries change, the pattern of technical dependencies changes to reflect the new boundaries | 9            |                 | 1                        | 10    |

#### Classification of Exceptions

|                |   |
|----------------|---|
| Mirroring trap | 1 |
|----------------|---|



**Chapter 4 Appendix—Continued****III. Organizational Ties within Corporations****N=36**

a) Within a single corporation (subject to unified governance), organizational ties, such as communication and collocation, are most likely to be found where technical dependencies exist. (Descriptive)

| Full Support | Partial Support | Non-support (Exceptions) |
|--------------|-----------------|--------------------------|
|--------------|-----------------|--------------------------|

|    |   |   |
|----|---|---|
| 12 | 3 | 1 |
|----|---|---|

b) Mirroring provides performance benefits; lack of mirroring is detrimental. (Normative)

|    |   |   |
|----|---|---|
| 12 | 2 | 6 |
|----|---|---|

|    |   |   |
|----|---|---|
| 24 | 5 | 7 |
|----|---|---|

**Classification of Exceptions**Collocated teams create modular systems **4**Mirroring trap **2**Digital technology **1****7****IV. Management of Knowledge, Alliances and Consortia****N=22**

a) Knowledge flows more easily within a transaction free zone, e.g. inside a corporation. (Descriptive)

| Full Support | Partial Support | Non-support (Exceptions) |
|--------------|-----------------|--------------------------|
|--------------|-----------------|--------------------------|

|   |   |   |
|---|---|---|
| 2 | 8 | 0 |
|---|---|---|

b) It is difficult (and costly) for two or more firms to share a transaction free zone. (Normative)

|   |   |   |
|---|---|---|
| 1 | 5 | 6 |
|---|---|---|

|   |    |   |
|---|----|---|
| 3 | 13 | 6 |
|---|----|---|

**Classification of Exceptions**Formal and relational contracts **6****V. Open Collaborative Projects****N=22**

a) Distributed actors will create modular systems with a high division of labor and high levels of information hiding. (Descriptive)

| Full Support | Partial Support | Non-support (Exceptions) |
|--------------|-----------------|--------------------------|
|--------------|-----------------|--------------------------|

|   |   |    |
|---|---|----|
| 5 | 3 | 10 |
|---|---|----|

b) Pairing small teams with well-defined modules results in good performance; the converse results in poor performance. (Normative)

|   |   |   |
|---|---|---|
| 4 | 0 | 0 |
|---|---|---|

|   |   |    |
|---|---|----|
| 9 | 3 | 10 |
|---|---|----|

**Classification of Exceptions**Digital technology **10**

## Chapter 4 References

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