

A Problem-solving Approach to Organizational Design*

Luis Garicano and Yanhui Wu

September 2015

Abstract

This paper develops a problem-based approach to analyze key issues in organizational design, and thus provides a microeconomic foundation for the knowledge-based theory of the firm. Central in the analysis is the argument that organizations emerge to integrate dispersed knowledge that is used to solve problems in production. A production process can be decomposed into a series of problems (tasks). Knowledge, after being acquired, can be used many times without diminishing returns. A hierarchy – in which workers specializing in a narrow set of knowledge refer to unsolved problems to managers with more advanced knowledge – intensifies the use of knowledge, which in turn encourages the acquisition of knowledge for the entire team. We show how the optimal design of hierarchies and the distribution of knowledge among team members are determined by the relationship (notably complementarity or substitutability) of problems, the efficiency of communicating knowledge, and a firm's product choice. Finally, we argue that organizational process and structure that facilitates the communication and acquisition of knowledge within firms are the core of organizational capital, which generates rent and sustains organizational growth.

Key Words: problem-solving, knowledge, codifiable knowledge, communication, organizational architecture

JEL Classifications: D2, D8, L2, M5

*This paper is a technical and enriched version of "Knowledge, Communication, and Organizational Capabilities" (Garicano and Wu 2012).

1 Introduction

As Hayek (1945) pointed out, the knowledge required to solve economic problems is usually fragmented among different individuals. Organizations exist, to a large extent, to coordinate and integrate distributed information and narrowly specialized knowledge to achieve efficient economic outcomes. The purpose of this article is to investigate how the attributes of problems that must be solved or of the tasks that must be performed determine the knowledge distribution, organizational process and structure inside the firm. We show that organizational processes, in particular communication, function as a mechanism to integrate knowledge and coordinate talents and thus complement the limitations to human ability in performing complex tasks. Moreover we discuss how organization structure is designed to cope with human limitations in decision making.

The heart of this task-based approach is that the complexity of tasks and the relationship between tasks play a crucial role in determining organizational knowledge, span of control and the scale of organization. The complexity of tasks, owing to production technology and operating environment faced by a firm, determines the extent of human limitation and characterizes the economic activities: whether they are difficult or easy, innovative or routine, exploring or exploiting. The relationship between tasks, particularly the complementarity among them, governs the efficient distribution of knowledge among separate individual workers and organizational hierarchies. The interplay between the intra-task attribute and the inter-task attribute jointly shapes the level and structure of organizational knowledge.

Scattered knowledge must be integrated and agents with different knowledge must be coordinated for the production process to succeed. Even without conflicts of interests, coordination can be very costly and integration can fail. We pay particular attention to communication as a channel to achieve efficient coordination and integration. Given the complexity of tasks, effective communication can avoid additional cost of knowledge acquisition, attain higher output using the same reservoir of knowledge and reduce decision bias. The prominent role of communication in production is due to the fact that communication allows for knowledge leverage and thus sustains economies of scale. The extent of knowledge leverage depends on the nature of knowledge, codifiable or tacit, and on the technology of communication. What we emphasize is not only the level of communication, but also the process of communication, which changes the relation between the knowledge inputs that are required to perform tasks. This is an important aspect of organization research that calls for further exploration. We investigate an application in decision making, in which organizational architecture determines the mode of communication, the relation between decision makers and the level of organizational errors.

The task-based approach to organization is closely related to a strand of knowledge-based theory of the firm, in which the firm is conceptualized as a nexus of knowledge (Nelson and Winter 1982, Kogut and Zander 1992, Conner and Prahalad 1996 and Grant 1996 among many others). As in Grant (1996), we emphasize that organizational process works as an

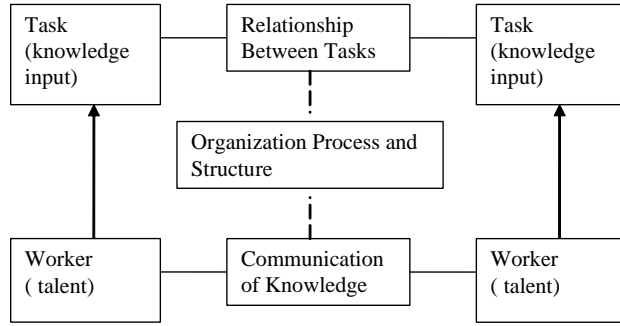


Figure 1: A Task Oriented Analysis of Knowledge and Organization

institution for integrating knowledge that resides in individual human capital. The most distinctive feature of our analysis derives from the basic observation that organization is task oriented. The characteristics of tasks and their relations are the key driving force that shapes the process, structure and knowledge of organization. Moreover, a detailed and specific analysis of the characteristics of tasks and their relations allows us to address the issue of knowledge acquisition without the danger of obscuring the function of organizational process. In our view, knowledge acquisition and knowledge integration are two interacting factors in organizational knowledge and should be jointly determined. Figure 1 outlines the task-based approach to knowledge and organization. The analysis throughout the paper aims to fill in the task-oriented organization processes that determine the organization structure.

The task-based approach unpacks organizational capabilities into task-specific ability. Conceptually, this approach complements the resource-based theory of the firm (Wernerfelt 1984, Barney 1991) and the dynamic capabilities theory (Teece 1982, Teece et al 1997). Empirically the large heterogeneity in tasks across industries, firms within the same industry, divisions in the same firm and even different activities within the same division, allows us to examine the heterogeneity in organizational practices, which in turn identifies the significance of organizational process and the source of organizational capabilities. We believe an integration of the task-based approach into the dynamic capabilities theory will yield more empirically relevant explanations for organization capital, organization rent and organization growth without the tendency of fragmentation.

As we take the view that tasks are performed by embodied knowledge (human capital) and that “All learning takes place inside individual human heads” (Simon 1991), our theory has far reaching implications for human resource management or talent strategy. The theory sheds light on some heterogeneity in managerial practices. In particular, a task based approach explains some managerial practices in Japanese firms long regarded as “special” . For instance, why do Japanese firms emphasize more on knowledge sharing, middle-up-down management and process improvement than their Western counterparts? The theory also

challenges some conventional wisdom in talent strategy on hiring of star employees and on empowerment of human capital. Throughout the paper, we will apply the analysis to a wide range of issues regarding human resource management.

2 Task, Knowledge and Talent

In this section, we conceptualize the function of an organization as performing a specific task, which can be selecting a project, marketing a new product, conducting a certain R&D activity or hiring an employee. In this sense, an organization is a task performing unit or a team that is endowed with a production function. In later sections, we will integrate these units in various ways according to the relation between tasks.

We focus on knowledge-based production, although more general implications can be drawn from the analysis. A knowledge-based production process is one where knowledge is the main input in production. Throughout this paper, knowledge is referred to as know-how and expertise to solve specific problems. Organizational knowledge is thus referred to as the knowledge that an organization acquires to perform well defined tasks.¹ Knowledge can be general, such as understanding of a broad subject or narrow, such as specialized expertise. Some knowledge is explicit, codifiable and easily transmittable. However a large class of knowledge is difficult to codify and transfer to another person. This knowledge is tacit (Polanyi 1966) and requires human experimentation and experience to utilize. Organizational knowledge is often embodied in human capital. So talent is the knowledge acquired by workers to perform tasks.

Going hand-in-hand with the knowledge-based production is uncertainty, which comes from production technology and market environment. Uncertainty is partly a result of limitations to human ability. Limited access to information, unawareness of situations, making judgement errors and misunderstanding between people are all human nature. We admit all these forms of bounded rationality by modelling the production process as stochastic and imposing costs of resolving uncertainty. Following Garicano (2000), we define a random variable Z as the knowledge content of a task, which also indicates the problem that the worker will confront when performing the task. Let $\Omega \subset \mathbb{R}^+$ be the set of all possible problems and $A \subset \Omega$ be the set of problems that a worker is able to solve, referred to as "knowledge set". When production starts, the knowledge content $Z \in \Omega$ is drawn from an a priori known distribution F , referred to as "knowledge distribution" of a task. The problem is solved and the task is completed if the realized knowledge content is within the worker's knowledge set, namely, $Z \in A$. Alternatively, we can interpret Z as the correctness of actions during the process of performing the task. Z being outside the knowledge set leads to errors and the production process 'gets stuck.'

¹Only in occasional cases and with explicit explanation, knowledge is referred to as the information of personnel ability and awareness of organizational process.

The knowledge distribution defines the complexity of a task. One may measure the complexity of tasks using first order stochastic dominance and second order stochastic dominance. An effective alternative is to use certain statistical moments to characterize the complexity of a task. For instance, the mean captures the average knowledge content of the task. A higher mean requires more knowledge and implies more difficulty. The variance captures the predictability of a task. A larger variance implies that the task is more unpredictable. The third moment (or the skewness) captures the innovativeness feature of the task. A highly positively skewed distribution has a thick right tail, meaning a high probability that a tricky problem is encountered. The moments distinguish routine tasks such as assembling, book-keeping and a number of standardized administrative jobs from complex tasks such as R&D, fashion design and many other creative activities.

A convenient distribution to characterize the complexity of task is the exponential distribution, $F_Z(z) = 1 - e^{-\lambda z}$ with $z \geq 0$ and $\lambda \geq 0$ as the single shape parameter λ captures the "composite" simplicity of the task— a higher λ is a simpler task, a smaller λ is a more complex task.²

The central role that workers play in this single task production is to acquire knowledge to solve problems. Talent is thus defined as the knowledge set that a person attains. A more talented worker is simply one who acquires more knowledge, which allows him to solve more problems and complete the task with higher probability. The optimal level of knowledge or talent is determined by a comparison between the marginal value of additional knowledge and the marginal cost of acquiring this additional knowledge.

We give a simple example to illustrate the main ideas. Suppose that the cost of acquiring a knowledge set A (learning all the problems in A) is proportional to its size, i.e. the ‘number’ of problems in it (formally, its Lebesgue measure) $\mu(A)$. For example, $\mu(A) = z$ if $A = [0, z]$. The cost (for any worker) of acquiring knowledge set A is $a \cdot \mu(A)$, where a is a constant. The expected output x of a worker is $E(x) = \int_A dF(Z)$. For a continuous and nonatomic F , a worker in autarchy confronting such a production function and knowledge distribution of a task maximizes the expected net output y :

$$E[y] = \Pr(Z \leq z) - az = \int_0^z f(\varphi)d\varphi - az.$$

The optimality condition is simply

$$f(z^*) = a, \tag{1}$$

which equates the marginal value of acquiring knowledge to the marginal cost: he learns those

²When the interest is to distinguish the impact of different moments, one can explore more general extreme value distributions, in particular Fréchet distribution (extreme value Type II) and Weibull distribution (extreme value Type III), which are widely used in engineering and economic analysis of innovation and diffusion.

problems which are ‘common enough’ to justify investing in them.³ The worker’s optimal knowledge level is z^* and his knowledge set is $[0, z^*]$. The optimal level of knowledge also stands for the worker’s talent. If Z is exponentially distributed, the first order condition $\lambda e^{-\lambda z-1} = a$ determines a unique optimal z .⁴ It can be shown that the sign of $\frac{dz}{d\lambda}$ depends on $2 - \ln \frac{\lambda}{a}$. So when the task is very complex ($\ln \frac{\lambda}{a} < 2$), the knowledge acquired increases in λ , implying that less complex task encourages more knowledge acquisition and attracts more talented workers. This is because the marginal gain from attempting an already very tricky problem is low and the worker is not willing to acquire a large amount of knowledge. An increase in complexity (a decrease in λ) depresses his incentives of acquiring knowledge. When the task is easy ($\ln \frac{\lambda}{a} > 2$), the optimal knowledge acquired is high. Although further complexity gives rise to more difficulty, it also brings about more opportunities to solve the problem (a smaller λ leads to a thicker tail in the exponential distribution), resulting in a even higher knowledge level.

The above analysis illuminates the first point of this article: organizational knowledge is task-oriented. The complexity of task determines the optimal level of knowledge acquisition and talent, possibly in a non-monotone manner.

3 Relations between Tasks and Matching of Talents

If production processes involved a sole task and a single worker, coordination would be unnecessary and organization would not matter. In modern business, however, most productive activities demand conducting a series of interdependent tasks, simultaneously and/or sequentially. Organization emerges to integrate disperse knowledge associated with various tasks and coordinate talent embodied in different workers. The coordination role of organization raises our second point: the relation between tasks that an organization needs to perform determines the allocation of knowledge among members of the organization.

Complementarities and substitutability are two most notable relations between tasks. Complementarities forge balanced distributed knowledge and homogeneity in talent while substitutability leads to unbalance in the allocation of knowledge and the heterogeneity in talent. This contrasting result was noticed in the early team theory literature (Marschak and Radner 1972) and in recent economic analysis of corporate culture (Cremer 1993) and trade and specialization patterns between countries (e.g. Grossman and Maggi 2000). Systematic pursuit of the theme in the context of organizational structure and talent strategy is still lacking although complementarities among managerial practices are widely discussed.

³Throughout this paper, we assume the regularity conditions for existence of optimum are satisfied. If the density function $f(Z)$ is nonincreasing, the second order condition is always satisfied and the solution is unique.

⁴The second order condition is always satisfied. In order to to guarantee an interior solution, the parameters λ and a need to satisfy $\ln \frac{\lambda}{a} > 1$.

3.1 Complementarities and Homogeneity

The importance of complementarities in modern business has been well recognized in the economics literature (Milgrom and Roberts 1990, 1995, Holmstrom 1999, and Roberts 2004). The general principle is that factors that are complements to each other should be sorted and bundled together. Kremer (1993) describes a vivid story about this mechanism: the malfunction of the O-rings, one of the thousands of components in the space shuttle Challenger, and probably the cheapest, caused its explosion. Following his analysis of the O-ring production, we demonstrate that strong complementarities of similar tasks will lead to homogenous team through the acquisition of similar knowledge levels.

Suppose that a job consists of n tasks to be performed or problems to be solved. The knowledge content of the job can be described by a random vector $Z = (Z_1, Z_2, \dots, Z_n)'$, in which each component follows a well defined distribution function as in Section 2 and the distributions across tasks are independent. The tasks are complements in the sense that all the tasks need to be correctly performed in order to complete the job and realize its market value. We also assume that each worker acquires his or her knowledge independently with the same linear cost function. Consider a case where the value of each task symmetrically enters the value of the job. A resource manager who matches workers to tasks is to solve

$$\max_{z_i} y(z) = n \prod_{i=1}^n F_i(z_i) - a \sum_{i=1}^n (z_i).$$

That is, production only takes place if each of the problems is solved, which, if knowledge acquired by workers 1, 2, ..., n is z_1, z_2, \dots, z_n , happens with probability $F(z_1) * F(z_2) * \dots * F(z_n)$. The first order condition for this maximization problem is

$$n \cdot f_i(z_i) \prod_{j \neq i}^n F_j(z_j) = a \text{ for all } i. \quad (2)$$

Under regular optimality conditions, the optimal level of knowledge for a worker on task i depends on the other team members' knowledge. Compared to (1), there is an additional term $n \prod_{j \neq i}^n F_j(z_j)$, reflecting a typical trade-off in team work: on the one hand, a worker's contribution is amplified through the team size n ; on the other hand, his probability of success is reduced as other team members may fail. Only if $n \prod_{j \neq i}^n F_j(z_j) > 1$, the worker assigned to i will acquire more knowledge than when he works alone. This implies that if the production changes from individual production to a complementary process, the worker who originally performs task i should be trained to acquire more knowledge or replaced with a more talented one. If $n \prod_{j \neq i}^n F_j(z_j) < 1$, a worker should acquire less knowledge when in a team than alone- being in a team reduces the marginal value of his talent. Thus if others are very knowledgeable he should become more so; if others are less knowledgeable he should become less so as well. This tendency towards homogeneity is implied by the positive cross derivative $\frac{\partial^2 y}{\partial z_i \partial z_j} > 0$. In particular, if all the tasks feature the same knowledge distribution,

then

$$\frac{f(z_i)F(z_j)}{f(z_j)F(z_i)} = 1 \text{ for all } i, j \leq n.$$

For a downward sloping $f(z)$, the solution needs to satisfy $z_i = z_j$ for all i, j , which means all the workers acquire the same level of knowledge or equally talented.⁵ If the complexity differs across tasks, the allocation of knowledge and talent allocation should be balanced or homogenized to exploit the complementarities.

3.2 Substitutability and Heterogeneity

When an organization is formed to perform a job that consists of tasks that are substitutes, the allocation of knowledge and talent to perform these tasks substantially differ from when tasks are complements. The substitutability of tasks is less well recognized in management. After all, if tasks are substitutable, why are they bundled together as a job? But bundling substitutable tasks is not uncommon for creative activities. For instance, high-tech companies often employ scientists to try various alternatives and develop different products even when only one will be marketed.

If tasks are strongly substitutable, then production will take place whenever any one of these tasks succeeds. Using the same setup as in Section 3.1, the expected output becomes:

$$E[x] = 1 - \prod_{i=1}^n \Pr(Z_i > z_i) = 1 - \prod_{i=1}^n (1 - F_i(z_i)).$$

A resource manager confronted with such a production function is to:

$$\max_{z_i} y(z) = [1 - \prod_{i=1}^n (1 - F_i(z_i))] - a \sum_{i=1}^n z_i$$

The first order conditions associated with each i type of problem require that:

$$f_i(z_i) \prod_{j \neq i} [1 - F_j(z_j)] = a. \tag{3}$$

First of all, notice that $\frac{\partial^2 y}{\partial z_i \partial z_j} < 0$, which implies negative sorting. There is a tendency towards heterogeneity: more talented workers are matched with less talented workers, and all the talent is assigned to the most promising task. More precisely, the composition of talents in a team depends on a hazard function for each task $h_i(z_i) \equiv f_i(z_i) \prod_{j \neq i} (1 - F_j(z_j))$, which is the probability that the job is completed by the knowledge in the i component

⁵ Knowledge and talent across complementary tasks may not be comparable as different tasks may require different knowledge and talent. But if the tasks do not differ substantially in nature, for example subtasks on an assembling line or research on similar projects, it is not far from reasonable to compress knowledge and talent to a single dimension.

given that none of the other components are known. The optimality condition for an interior solution can be rewritten as

$$\frac{h_i(z_i)}{h_j(z_j)} = 1 \quad \forall i \neq j$$

At the optimum, the ratio of hazard rates must be equal to the ratio of marginal costs. The marginal benefit of acquiring some more knowledge about i is the conditional probability given that the confronted problem is not in the area that is already known (it will be in the next dz_i). This must be equalized across problems up to a constant given by the cost ratio at the optimum.

If the knowledge distribution for each task is $F_i(z_i) = 1 - e^{-\lambda_i z_i}$ for $z \in [0, \bar{z}]$,⁶ all the knowledge and talent will be only devoted to the least complex and most predictable task (the one with largest λ) due to the memoriless property and thus constant hazard rate of the exponential distribution.⁷ This extreme example illuminates that substitutability of tasks forges heterogeneity in the team composition.

3.3 Managerial Implications

The above two cases characterize two typical production process: the O-ring production represents complementarities and the creative production represents substitutability. The distinct relations between tasks yield contrasting managerial implications, in particular for talent strategy.

1. Japanese Managerial Practices. Japanese firms often have different managerial practices than their Western counterparts (see Womak, Jones and Roos, 1990). For example, Japanese firms emphasize multi-skill employees, knowledge sharing and process improvement. From our point of view, these "distinct" features are actually not specific to Japanese firms. They stem from the complementarities in the lean manufacturing in which the Japanese firms have developed their comparative advantages. A key aspect of lean manufacturing is no tolerance for defects— in Toyota a worker who detects any defect may stop the whole production line. Thus any task or any component of a task is crucial for success. When failure occurs, the whole system needs to be overhauled. The gain from improving one single task on its own, no matter how significant, is small. Therefore innovations tend to take the form of process improvement as improvement in one task needs to be complemented by improvements in other tasks. As we have shown, complementarities in tasks lead to homogeneity of talent; thus the use of on-the-job training, multi-skill employees and knowledge sharing as tools to harmonize the talent of employees.

2. Explorers and Exploiters. Explorer and exploiter firms (March, 1991) have different structure of tasks. Exploring is characterized by substitutabilities: if we are exploring for

⁶We assume that the distribution is truncated from above to avoid the counter intuitive result that knowledge goes to infinity.

⁷Interior solutions can be obtained if the cost function is not linear. But the basic result that more knowledge is acquired for the less complex task remains.

a new idea, we succeed as long as any one team comes up with a successful idea. Thus in the production process of creative activities, rather than seeking to create homogeneous teams and spreading the talent around, firms should seek to create a star team that concentrates all of the talent. This kind of talent strategy is often applied in R&D divisions in companies, in which high talents (e.g. well-known scientists) are concentrated on the most promising tasks while junior researchers (e.g. post-docs) independently working on similar tasks to try their chance of success. When a bottleneck is encountered, talents should be diverted to alternative ways to approach the job. It is in exploration process of this kind where superstars can realize their value. Examples are R&D, movie-making, fashion design and many other creative activities that share this features— they rely on a team in which only a few stars dominate and teams of less skilled employees are used to support them.

Exploitation tasks, on the other hand, are characterized by complementarities. Successfully exploiting a new idea is all about responsiveness, efficiency, and flexibility. Competitive advantage in exploitation is attained by delivering on time, by responding to customer needs and by doing this at a low cost. Thus exploitation requires that each individual undertakes his or her task successfully. As our analysis has shown, this implies that exploitation requires balanced assignment of talent to tasks. If the allocation of talent is unbalanced, the top talent is wasted. All workers must be of equal quality. This underlies the warning of the danger of hiring superstar employees (Groysberg et al 2004, Huselid et al 2005). The value of a A player can be discounted substantially in a B position and in a B team when the task conducted by each member is complementary. For example, an effective problem solving team in investment banks or consulting firms needs to selectively choose members with relatively homogenous talent.

3. Sequential Production. When a series of tasks are performed sequentially, it is of great importance to allocate talent in the right sequence. In a complementary production process, highest talent should be involved in the latter stages of production as getting things right is more valuable at these stages. On the contrary, most talented workers are hired to try the job at the very beginning if the sequential tasks are substitutable. Thus an innovative enterprise starts with a few highly talented entrepreneurs.

4. Talent Strategy. The relation between tasks determines the relative level of knowledge and talent in each task. Given a fixed distribution of talents, there exists an optimal allocation rule to match the talents to tasks. When knowledge is acquirable and talent is variable, the distribution of organizational knowledge needs to take the complexity of each task into account. In the O-ring production, more knowledge and talent should be allocated to the more complex tasks but the match of talents and tasks is governed by the relative complexity of tasks. When tasks are substitutes, it is the relative hazard rate and thus higher moments than variance of the knowledge distribution of a task that determines the allocation of knowledge and talent. When tasks are not very complex in the sense that the probability of encountering tricky problems is not high, talent needs to be allocated to various tasks and

more talent will be assigned to the trickier problem as the (conditional) marginal probability of completing the task is high. This may be true for mild innovative process. When innovation is drastic, tasks are usually fairly complex and the probability of encountering difficult problems is quite high, allocating too much talent to the harder tasks is not worthwhile.

In reality, many production activities are a hybrid of complementarities and substitutabilities. For example, a new generation of E-products requires both innovations in function and design, which are complementary in creating added value of the product; but with regard to either the functional aspect or the design aspect, different ideas and inventions compete with each other and the best one will beat all the others. Or consider the combination of basic and applied knowledge in production. Usually basic knowledge is complementary to a variety of applied knowledge. But the specific applied knowledge developed may substitute other applied knowledge. In these hybrid cases, the pattern of organizational knowledge can be fairly complex. But our governing principle remains: it should be governed by the complexity of the main task and the relation between tasks.

4 Communication as an Integrating Mechanism: The Role of Managers

In the previous section, knowledge and talent are allocated by a resource manager who knows the ability of workers and the attributes of tasks. Each task was done by one worker, and an organization is essentially a team executing multiple tasks, in which there is no specific mechanism to integrate knowledge and coordinate talents. While highlighting the role of the attributes of tasks in shaping organizational knowledge, this simplification limits rich organizational structure, which may allow for more efficient division of labour and knowledge leverage. In this section, we investigate how communication between workers functions as a knowledge integrating mechanism and how organizational structure and talent allocation are affected by the presence of communication.

Communication changes the relation between knowledge residing in different workers and restructures organizational knowledge in a substantial manner. Starting from the technological aspects of knowledge: codifiable or tacit, we analyze how the corresponding communication structures turn the technical process into an organizational process. Vertical communication of tacit knowledge allows to leverage talent and employ hierarchies of knowledge. On the other hand, horizontal communication of codified knowledge allows for the division of labour and knowledge specialization. Finally, we investigate the case in which communication an organization can design codes to facilitate communication.

We maintain the general setup in Section 2, and focus on how a team of workers can rely on communication to undertake together one task. The knowledge distribution of a job is characterized by a well behaved distribution function $F_Z(z)$ with $z \in \mathbb{R}^+ = [0, \infty)$ and its density function $f(z)$ over a set Ω . The knowledge acquired by worker i is characterized as

a subset $A_i \subset \mathbb{R}^+$. In principle, a worker's knowledge set can be a union of subsets that may be disjoint. To avoid this complication, we normalize the density function $f(Z)$ to be nonincreasing so that easier knowledge will be acquired first at optimum. This ordering has an intuitive economic interpretation: easier questions (requiring less knowledge) are more frequently encountered and harder questions are less common.

4.1 Tacit Knowledge and Vertical Communication

When knowledge is tacit, it is hard to formalize, express, store and transfer in some form of code. In order to solve a problem, workers need to discuss, clarify and check the information encompassed in the problem to be solved, irrespective of whether they know the answer or not. Usually this communication is between workers and managers and thus vertical. The process involves person to person and often face to face conversations and joint work. The communication cost is mainly the opportunity cost of time that otherwise can be devoted to production. Certain types of technological progress such as e-mail and video conferences may reduce communication cost. It is also possible that the cost diminishes through frequent and repeated interactions. In this subsection, we adapt a simplified model from a general treatment of the issue in Garicano (2000) to demonstrate the main mechanism.

Consider a simple organization with $n + 1$ team members to carry out production that involves problem solving as before. There are two organizational alternatives: a one-layer structure in which all members devote their time to production and a two-layer structure with n production workers and 1 manager who can help the workers to solve problems. Suppose the workers perform the same task independently. The one-layer organization acquires knowledge to

$$\max R_1(n) = \sum_{i=1}^{n+1} [F(A_i) - a\mu(A_i)]. \quad (4)$$

By the assumption of identical and independent distribution and the linear cost function, the optimal condition is reduced to the first order condition: $f(z_i) = a$. The team size can be pinned down elsewhere, as there are no organizational constraints to team size when workers work on their own, for example through market competition (e.g. free entry).

In a two-layer organization, there is a manager who may acquire more knowledge and spend time helping production workers who cannot deal with their own problem due to the limitation of their knowledge. However, help incurs communication costs: it takes time for a worker to propose a question and for a manager to figure out a solution. For simplicity, we assume that a request from a worker incurs a fixed helping cost h , which is proportional to the production time of the worker and borne only by the receiver for notational simplicity. Then the organization's target is to

$$\max R_2(n) = \sum_{i=1}^n [F(A_i \cup A_m) - a\mu(A_i)] + t_m^p F(A_i \cup A_m) - a\mu(A_m) \quad (5)$$

Subject to

$$1) \ t_m^p + t_m^h \leq 1; \quad 2) \ t_m^h = \sum_{i=1}^n h[1 - F(A_i)].$$

Here A_m is the manager's knowledge set and A_i is each worker's knowledge set. By the downward sloping assumption of $f(z)$, $A_i = [0, z_w]$ and $A_m = [0, z_m]$, where z_w and z_m are the knowledge level acquired by each worker and the manager respectively. As a result, $A_i \cup A_m = [0, z_m]$.⁸ t_m^p is the manager's time devoted to production and t_m^h to helping workers.

Compared to (4), the two-layer organization allows for a division of labor and maybe more knowledge acquisition. The manager plays a key role in this process: she is able to leverage her knowledge – it will be worthwhile to learn unusual problems, since she can use it to answer questions from an entire team. But this advantage comes with two costs. One is the cost of acquiring additional knowledge. The other is that helping others competes away her time for production. The communication cost can be seen from the constraints. The first constraint says that the overall time for the manager is limited to a normalized unit. Since time is always valuable, this constraint will bind at optimum. The second constraint is essentially an identity that equates the communication time from both sides of the communicators (time answering questions must be equal to time asking questions)

It can be shown that $t_m^p = 0$ and $t_m^h = 1$. That is the manager completely specializes in problem solving. This is because if it pays to spend the first fraction of time leveraging time to help some workers then it is rewarded to spend all other units of time in helping and not producing. Formally, the value of extra time Δt_m on production is $\Delta t_m F(z_m)$, while the value of time helping workers is $\frac{\Delta t_m}{h} \frac{F(z_m) - F(z_w)}{1 - F(z_w)}$, and both are linear in Δt_m . Then the objective function is reduced to

$$\begin{aligned} \max R_2(z_m, z_w, n) &= nF(z_m) - anz_w - az_m \\ &\text{subject to} \\ 1 &= [1 - F(z_w)]hn. \end{aligned}$$

The solution is pinned down by the conditions:

⁸Here we assume that the manager needs to know the worker's knowledge in order to solve the problem. The analysis applies to the case in which the knowledge sets of the manager and workers are not overlapping.

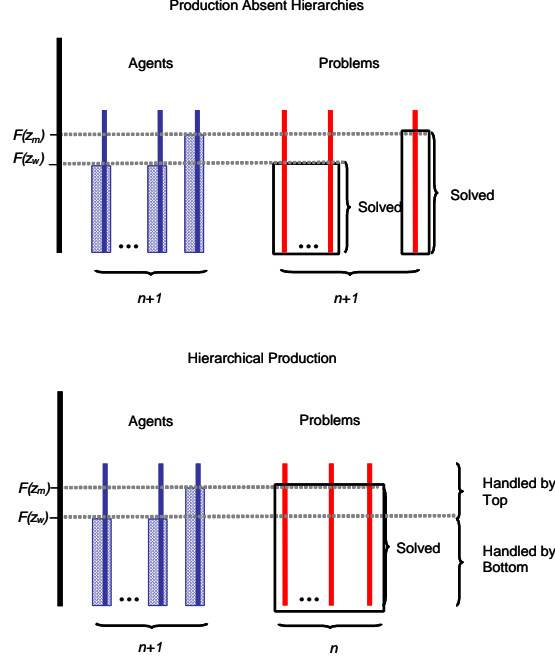


Figure 2: *The benefit of hierarchy is that it allows the manager to leverage his knowledge in problem solving ($F(z_m)$) by combining it with the time of less knowledgeable workers, so that the team solves more problems; the cost is that the number of problems tackled is lower than in autarchy ($n+1 > n$), since 1 unit of time (the manager's time endowment) is spent in communication.*

$$nf(z_m) = a; \quad (6)$$

$$F(z_m) = a \left[\frac{1 - F(z_w)}{f(z_w)} + z_w \right]; \quad (7)$$

$$1 = nh[1 - F(z_w)] \quad (8)$$

From (6), the optimal knowledge level in the two-layer organization is higher than in the one-layer organization: the marginal value of manager knowledge is larger, as it is spread over n workers. This is exactly the effect of knowledge leverage which allows for specialization and a higher knowledge level. Second, given that $f(z_m)$ is decreasing in z_m , a more knowledgeable manager attains a larger span of control. third, it can be shown from the second condition (7) that $\frac{dz_m}{dz_w} > 0$, which implies that the manager's talent is complementary to the worker's talent. Interestingly but intuitively, the number of workers increase in the knowledge they acquire since a more knowledgeable worker asks fewer questions and gives more time to other workers. A comparison of the hierarchical production and the production absent of hierarchy is illustrated in Figure 2.

A full model without restrictions on the number of layers is developed in Garicano (2000).

In this model, a knowledge hierarchy efficiently integrates tacit knowledge. Members in the organization specialize either in production or in solving problems and only one class specializes in production (referred to as production workers). Those who specialize in problem solving are managers allocated at the higher level of the hierarchy. Production workers learn to solve the most common problems; managers or problem solvers learn the exceptions. The higher is a member in the hierarchy, the more unusual the problems she is able to solve. Moreover the organization has a pyramidal structure, each layer possessing a smaller size than the previous one.

The complexity of task affects the allocation of knowledge and talent through the optimal level of overall knowledge acquisition and then division of labor. A more complex task requires more overall knowledge. When knowledge is tacit and communication takes time, more complex tasks reduce the span of control for the manager or widens the worker's knowledge. It also increases the number of layers of the organization required to solve a given proportion of problems.

4.2 Codified Knowledge and Horizontal Communication

When knowledge is codifiable, it is easy to explicitly express and record in the form of hard data, scientific formulae, coded procedures. It is possible to transfer codified knowledge without distortion, which results in horizontal communication across people performing different tasks. In this case, communication can be impersonal and takes the form of market transactions of knowledge. What prevents communication from flowing outside the organization is the production process and the transaction costs. For example, when production consists of a series of interdependent tasks, the value of knowledge for each task is hard to separate and price in the market. Therefore, the benefit of communication is the possibility of specialization and the saving of the cost of knowledge acquisition while the communication cost is related to knowledge coding and transferring. The following simple model, inspired by Becker and Murphy (1992), illustrates the main idea.

We use similar setup as in the previous subsection except that now the hierarchical structure is replaced by a horizontal chain. The resource manager must choose the size of the team $n \geq 1$ and to allocate knowledge sets A_i to each team member:

$$\max_{\{A_i\}, n \geq 1} \Pr(Z \subseteq \cup_i A_i) n - \sum_{i=1}^n a \cdot \mu(A_i) - H(n). \quad (9)$$

The first term is the expected output per unit time when the knowledge content of the task lies in the team's overall knowledge set and thus the problem is solved, times the number of units of time available. The second term is the total cost of acquiring relevant knowledge. Each worker acquires his or her knowledge independently and has the same linear cost function of the Lebesgue measure of the knowledge set, $\mu(A_i)$. The last term is the overall horizontal communication cost, a function of the number of communicators. With the assumption that

$f(z)$ decreases in z , at optimum $\Pr(Z \subseteq \cup_i A_i) = F(z_n)$, $\mu(A_i) = z_i - z_{i-1}$, with $i \geq 1$ and $z_0 = 0$. Then the optimization problem (9) reduces to

$$\max_{z_n, n \geq 1} nF(z_n) - az_n - H(n).$$

This reformulation clearly shows the benefits when communication is present: the possibility of division of labor and the saving of knowledge acquisition cost. The team members divide their labor to specialize on a non-overlapping subset of the knowledge and integrates them into overall organization knowledge through communication. Therefore the cost of acquiring each piece of knowledge is paid once but the knowledge is used n times. This echoes the fundamental economic rationale pointed out by Rosen (1983): knowledge implies a fixed cost independent of its utilization and thus it always pays to let workers learn a narrower set of tasks and use it more intensely. How narrow the specialization should be and how intensity the knowledge should be used crucially depend on the communication cost.

If the cost function $H(n)$ is linear in n , which implies that communication does not cause any information jam, the optimal team size is either 0 or N , an exogenous upper bound of the number of individuals. Useful knowledge (i.e. as long as $f(\cdot) > 0$) is either never used or used as many times as possible. In other words, either the team does not exist or, in the words of Adam Smith, “the division of labor is limited by the extent of the market”.

However, as Becker and Murphy (1992) have argued, coordination costs are in fact what limits the division of labor. If communication costs increase in a convex way with team size, then we have an interior team size. Suppose, for instance, that $H(n)$ is quadratic: $\frac{cn^2}{2}$. Under some mild restrictions on $F(\cdot)$, a unique pair of solutions (z_n, n) is determined by

$$f(z_n) = \frac{a}{n}, F(z_n) = cn.$$

The knowledge distribution of the task and the efficiency of knowledge acquisition and communication jointly determine the optimal overall amount of knowledge and the size of the team, which governs the degree of labor division. An advance in knowledge acquisition or/and a decrease in communication cost due to improvements in information technology or common understanding of knowledge will induce finer division of labour and an expansion of team size.⁹

Note that the organization knowledge z_n and the team size n increase in each other. This reinforcement effect is due to the implicit complementarities between each member’s knowledge: the presence of other member’s knowledge increases the probability of solving the problem or saves the cost of knowledge acquisition. In general, greater complementarities, which can be reflected by z_n in this simple example, tend to increase specialization. This is the reason that greater division of labor and specialization are observed in more developed

⁹These intuitions can be readily seen if we assume that z_n is exponentially distributed: $F(z_n) = 1 - e^{-\lambda z_n}$, in which case we solve $n = \frac{\lambda + \sqrt{\lambda^2 - 4ac\lambda}}{2c\lambda}$.

economies, as emphasized by Becker and Murphy (1992). They also derive some empirical implications of the importance of coordination costs in specialization. In small towns or rural areas, specialization is indeed limited by the extent of the market— i.e. it must indeed be the case that each specialist has some monopoly power in his or her own area of expertise. In large metropolitan areas in which many doctors or lawyers have the same skills, however, it must be that coordination costs are the answer to the limitation of team size given these duplications.

4.3 Product Choice and Organizational Structure

Wu (2015) extend the above model to incorporate an important strategy variable: a firm’s product choice. In particular, a firm that is endowed with the technologies of acquiring and integrating knowledge as before makes three choices: 1) the vertical position of a product that correlates its market value positively with the complexity of problems in production; 2) the hierarchical structure that specifies the extent of knowledge leverage measured by the span of control, i.e., the subordinates-to-supervisor ratio; and 3) the levels of knowledge acquired by all workers. The essential insight is that the alignment between product position and hierarchical structure resolves the conflict between value creation through selecting superior products, on the one hand, and production efficiency through leveraging knowledge, on the other hand. For instance, a high-end product creates more unit-value for a firm, but workers have a high probability to encounter unknown problems and must frequently interact with managers. For a manager with time constraints, frequent interactions with one worker imply fewer interactions with other workers. Thus, the scope of knowledge integration is reduced and the extent of leveraging superior knowledge is limited. Conversely, a low-end product generates less market value but allows a firm to easily sustain a high level of knowledge leverage and to achieve production efficiency. To simultaneously attain a high-end product position and a high level of knowledge leverage, a firm must acquire substantial knowledge for its employees and maintain a balanced distribution of knowledge across hierarchical layers.

The model establishes a mechanism that ties together a firm’s knowledge input, organizational structure, and product selection to achieve superior performance. A firm’s ability to acquire knowledge and its efficiency in integrating knowledge are two key drivers. A firm’s ability to acquire knowledge can be viewed as a capability that enables workers to overcome their cognitive limitations during the process of problem-solving. Thus, better training and mentoring of workers, the adoption of advanced information-extraction technology, and the use of new learning methods all improve a firm’s ability to acquire knowledge. Such improvements increase a firm’s profitability by simultaneously expanding its span of control and upgrading its product as the consequence of an even increase in the knowledge level of all workers. A firm’s ability to integrate knowledge depends on the codifiability of knowledge, which distinguishes whether knowledge is explicit or tacit and governs the cost to communicate knowledge. The model predicts that firms that primarily use coded knowledge in

production, such as engineering and accounting firms, tend to employ a hierarchy with a large span of control, matched to an unbalanced distribution of knowledge across layers, whereas firms whose production relies more on tacit knowledge, such as consulting and law firms, tend to employ a hierarchy with a narrow span of control, matched to a balanced distribution of knowledge across layers. Furthermore, improvements in communicating knowledge – either coded or tacit – lead a firm to expand its span of control, but may induce it to upgrade or downgrade its product, depending on whether knowledge in the production of a superior product becomes more or less codifiable. These results can be applied to study the effects of advances in information and communication technology on skill-biased organizational change and product innovation.

4.4 Codifiable Knowledge: Optimal Code and Organization Structure

We have discussed two examples in which knowledge is either completely tacit or fully codifiable. In reality, knowledge possesses both dimensions of properties: knowledge is partially codifiable. In this situation, codes, which are a shared technical language between workers, form an important part of the communication infrastructure of firms and organizations (Arrow 1974). Miscoded knowledge may lead to ambiguity, confusion, misunderstanding and inefficiency in communication and production. An optimal design of codes needs to trade off between specialization and commonality. On the one hand, a narrow specialized code facilitates communication within a particular function that performs a task, but limits communication between functions that perform various tasks and thus makes coordination between tasks more costly. On the other hand, a broad common code improves coordination across tasks at the expense of less precise and more costly communication within task. In this subsection, we use a simplified variant of Cremer, Garicano and Prat (2007) to explore the effects of the attributes of tasks and the synergies between tasks on the design of codes and the interplay of optimal codes and organizational structure.

4.4.1 A Simple Model of Code

A team of two workers, worker 1 and worker 2 are employed to perform a task. As in the case of tacit knowledge and vertical communication, if worker 1 is not able to perform the task or solve the problem associated with the task, he can ask for help from worker 2. However this kind of vertical communication is limited by two forms of bounded rationality. First, both workers have a limited ability to learn codes which allow for the identification of exact problems. Second, they have a limited ability to solve problems that involve incomplete information. An example would be a team that is composed of a salesman and an engineer to serve clients, who have problems with products or services. The salesman can classify problems raised by clients but not perfectly. The engineer and the salesman have to rely on a previously specified and agreed code to transmit coarsely information. In order to make the intuition more transparent, we carry on this example to interpret the following model and

use salesman for worker 1 and engineer for worker 2. The basic implications apply to many other tasks and occupations.

As in the previous sections, we assume that the knowledge content of task z is drawn from a distribution function F_z with the probability density function f_z on a set Ω . That is clients approach salesmen with a problem that demands a solution z with probability $f_z > 0$ from Z . The salesman, after reviewing the problem, sends a code to the engineer. Formally, a code C is a partition $\{\Omega_1, \Omega_2, \dots, \Omega_K\}$ of the set Ω , where the subscript of the Ω s represents a word k that gives the information that the problem z belongs to the subset Ω_k . The breath of word k is n_k , the number of of events that Ω_k contains when Ω is finite or the 'size' (the Lebesgue measure) of Ω_k when Ω is a continuum. A code $C_t = \{\Omega, \emptyset\}$ represents extremely coarse information and implies the knowledge is tacit and not codifiable. A code with a very large K or a very small k represents precise information and the knowledge is codifiable.

For simplicity, we normalize the firm's profit from solving a client's problem to 1 and its target is just to minimize the expected communication cost between the salesman and the engineer, defined as $D(C; F) = \sum_{k=1}^K p_k d(n_k)$, where p_k is the frequency of a word k being sent. The per unit communication cost, which can be regarded as "diagnosis cost" of the problem, depends on the precision of the information (the breath of word) sent by the salesman. It is natural to assume that the cost is increasing in the breath of k as less precise information brings about more costly communication. This simple specification leads to some intuitive results: a code should use precise words for frequent events and vaguer words for more unusual ones; a more unequal distribution of events increases the value of the creation of a specialized code, since the precision of the words can be more tightly linked to the characteristics of the environment.

The following two-word-code example illustrates the main ideas. Suppose that a salesman deals with consumers's problems $z \in [0, 1]$ drawn from a distributions with cumulative distribution function

$$F(z) = (1 - b)z + bz^2,$$

and density

$$f(z) = (1 - b) + 2bz,$$

with $b \in [-1, 1]$ being a measure of the evenness of the distribution. At $b = 0$, the distribution is uniform and the distribution becomes more uneven when b deviates more from 0. We also assume that codes can have at most two words, $K = 2$, and that the diagnosis cost is linear in the breath of word. The optimal code problem is to

$$\min_z D(C, F) = F(z)z + (1 - F(z))(1 - z)$$

This optimization yields a unique cutoff \hat{z} that splits the set Ω into two words: $\Omega_1 = [0, \hat{z})$ and $\Omega_2 = [\hat{z}, 1]$. At $b = 0$, $\hat{z} = \frac{1}{2}$. Since each problem is equally likely to occur, there is

no need to use codes with different precision. When $b \neq 0$, $\hat{z} = \frac{1}{6b} \left(3b - 2 + \sqrt{(3b^2 + 4)} \right)$. Obviously $f'(z) > 0$ and $\hat{z} > \frac{1}{2}$ if $b > 0$, and $f'(z) < 0$ and $\hat{z} < \frac{1}{2}$. This delivers the result that more precise code is used to deal with more frequent problems. It can be shown that \hat{z} deviates further from $\frac{1}{2}$ when $|b|$ deviates more from 0, which implies that a more specialized code is adopted when the distribution of problems is more unequal. For future reference, define the optimal cost at $b \neq 0$ as

$$D^*(b^2) = \frac{8 + 36b^2 - (4 + 3b^2)^{\frac{3}{2}}}{54b^2}. \quad (10)$$

4.4.2 Integration and Separation

We have illustrated that optimal codes are designed to facilitate vertical communication between workers that perform the same tasks within the same organization unit. In many situations, communication is horizontal and takes place between people that perform different tasks in different working units. Then tailoring codes to the needs of particular agents in an organization unit may be costly as it limits the set of agents among whom the codes are useful. The design of optimal codes needs to take into account the possible synergies across tasks and organization units. Two organizational units that face similar tasks will not find a common code too costly and they should be integrated through the same code.

We extend the simple two-word-code model discussed above to allow two service or functional units A and B . Each of them is composed of one salesman and one engineer. We focus on two possible organizational forms as shown in Figure 3 (Panel A and Panel B): (1) Separation (the two units use different codes); (2) Integration (the two units share the same code). To generate a need for coordination, there must be a potential synergy among the two services, which we model as follows. Customers arrive randomly, and there may be excessive load in one service and excessive capacity in the other. If that happens, the two services benefit from diverting some business from the overburdened service to the other. Formally, suppose that salesmen from services A and B deal with consumers from two different distributions F_A and F_B ,

$$F_i(z) = (1 - b_i)z + b_i z^2, \quad i = A, B$$

with $b_A = b$ and $b_B = -b$ and $b \in [-1, 1]$. Let z_i^* be the cutoff between words of each service, with (by symmetry) $z_B^* = 1 - z_A^*$, and $D_i^*(b)$ the expected diagnosis cost in either service as in (10).

Each engineer has the ability to attend to the needs of at most one client. Salesmen bring

sales leads randomly to each engineer. The arrival process is as follows:

$$y = \begin{cases} 0 & \text{with probability } p, \\ 1 & \text{with probability } (1 - 2p), \\ 2 & \text{with probability } p, \end{cases}$$

where p belongs to the interval $[0, 1/2]$. This arrival process captures the effect of the variability in the expected number of clients of each type. If p is low, then each salesman is likely to find one client per period of each type. When p is high, although on average still 1 client is arriving, it is quite likely that either none or 2 will arrive. Thus p measures the importance of the synergy between the two services: a high p means that the services are likely to need to share clients, while a low p means that each service is likely to have its capacity fully utilized. As before, we assume a linear function of the diagnosis cost with a constant coefficient $\varphi \in (1, 2)$.¹⁰

An *integrated organization* requires that a salesman from service unit A explain to an engineer in B the needs of his customer. Such a cross-unit explanation requires a common code in both services. It is intuitive that the common language is the one that would be chosen when the density of tasks is the average of the two densities of the two services.¹¹ In this simple example, since both services have opposing distributions, the average problem density is uniform. The optimal code has two equally imprecise words, with each word identifying the sales lead as coming from one half of the distribution. The total profits then are:¹²

$$\Pi(p, b, \varphi | \mathcal{C}_I) = 2(1 - p(1 - p))(1 - \frac{\varphi}{2}).$$

In a *separated organization*, where the two services use different codes, the expected profit is:

$$\Pi(p, b, \varphi | \mathcal{C}_S) = 2(1 - p)(1 - \varphi D^*(b^2)).$$

The organization should be integrated rather than separated if the between service improvement in communication (measured by the synergy gain) is larger than the within service loss in precision due to the worsening of the code used:

$$\frac{1 - p(1 - p)}{1 - p} \geq \frac{1 - \varphi D^*(b)}{1 - \frac{\varphi}{2}}.$$

¹⁰The restriction on φ ensures positive profits. It also ensures that information must transit through a salesman before being sent to an engineer; indeed an engineer without information on the client's problem would have diagnosis costs greater than the profits obtained from solving it.

¹¹For a formal proof, see Corollary 1 in Cremer, Garicano and Prat (2007).

¹²The probability that a problem is solved the sum of 1) $1 - 2p$, the probability that only one problem arrives and is passed to the engineer within the same unit; 2) p , the probability that two problems arrive and one is always passed to the engineer within the same unit; 3) p^2 , the probability that two problems arrive and one is passed to the engineer in other unit that has no problem arriving.

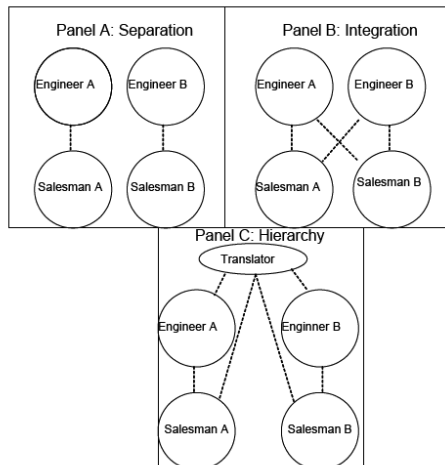


Figure 3: Communication in Three Possible Organizational Forms

It can be shown that an increase in the synergy parameter p , a decrease in the diagnosis cost φ or a decrease in $|b|$, the divergence in the distribution of tasks, makes the integrated organization more profitable. The result characterizes the determinants of the trade-off between separate, well-adapted codes optimized for within-service communication, and broader common codes that allow for between-service communication. Separate codes are preferable when synergies are relatively low, when the underlying probability distributions confronting the different units are sufficiently different, or when diagnosis costs are high so that there is a high premium on communicating precisely. As a result, increases in synergies, in the equality of the distributions or decreases in diagnosis costs increase code commonality.

4.4.3 Translator and Hierarchy

An alternative to integration to exploit the synergy between two distinct units is to introduce a hierarchical superior as a translator, who enables services with different codes to cooperate. For instance, if salesman A has two customers, he communicates to the translator the type of the "extra" customer in the code used in service A . The translator will search for z , and then he will transmit the information to engineer B in the code used in service B . (Panel C in Figure 3).

Assume that hiring a translator requires incurring a fixed cost μ , but since the translator is specialized in language, her diagnosis cost is lower than that of the engineers. The optimal organization choice depends crucially on communication costs and the translator's advantage. Hierarchies are more efficient when communication costs are high, whereas low communications costs favor their replacement by common codes and horizontal communications. Consider first the comparison between translation and separation. Translation incurs the fixed cost μ and increases diagnosis costs, but makes inter-service communication possible and thus allows the services to profit from the existing synergies. If the diagnosis cost

φ is low, the extra communication cost incurred by translation is low and the net benefit is likely to be high. Thus, translation is more likely to beat separation when φ is low. Consider the choice between translation and integration. Translation saves on communication cost by allowing services to keep efficient service-specific codes – thus translation is likely to beat integration when φ is high, since communication savings are more important when φ is high. Thus if the fixed cost μ of hiring a translator is low enough, there exists an interval of φ for which the hierarchical structure is optimal.

4.5 Managerial Implications

1. The role of management in knowledge usage. We have analyzed the role of communication as organizational process to integrate disperse knowledge and its effects on organizational structure. For different types of knowledge, different modes of communication, horizontal, vertical or a hybrid of both, are adopted. Regardless of the communication modes, the general function of communication is to allow for specialization of knowledge and division of labour. The role of management (and of firms) is very different in each case:

- **Tacit Knowledge:** The role of management is to participate in the acquisition and optimal use of knowledge, by dealing with exceptions. Hierarchies are thus devised to facilitate the leveraging of knowledge.
- **Codifiable knowledge:** Management still has the management by exception role above for the knowledge that is within a particular area. But management serves also to facilitate communication between areas of knowledge by translating the different codes. Managers are here both leveraging their own knowledge but are also ‘traffic cops’ able to help workers communicate across areas.
- **Coded Knowledge:** In this case, horizontal specialization is the norm; each individual learns a narrow interval and knows which specific horizontal expert to ask if he comes up with something he does not know. Managers do not have a role in the knowledge acquisition process in this case

2. Knowledge hierarchies and management by exception: Knowledge hierarchies allow high talent can specialize in exceptional problems. This "management by exception" was well stated by Alfred Sloan (1924, P. 195), who in describing his job, claimed that “we do not do much routine work with details. They never get up to us. I work fairly hard, but it is on exceptions..., not on routine or petty details.” In the presence of communication costs, knowledge chains or hierarchies emerge with the more knowledgeable placed on the top as managers. These managers acquire knowledge about exceptional problems and specialize in solving problems from their subordinates. A knowledge hierarchical structure is advantageous only if the size of organization is large enough– leveraging the knowledge of highly skilled managers (where knowledge can be broadly construed as knowledge of opportunities, clients

etc.) requires assigning them better workers so that they can be protected from the ‘dumb’ questions anyone else could deal with.

3. Tacit knowledge and skill complementarities. The theory also generates differing managerial implications when firms’ main knowledge has different technological aspects. One important feature of managerial practices in Japanese firms is the emphasis on tacit knowledge (Nonaka and Takeuchi 1995). We have shown that when the knowledge is tacit, the manager’s knowledge is endogenously complementary to the workers’ knowledge. In order to sustain a larger organization, both the manager and workers have to acquire more knowledge.¹³ This suggests that when tacit knowledge is important in the production and communication process, an expansion of firm size by hiring superstar top managers may lead to organizational failure as mediocre subordinates may compete away too much time of high talents. A rapid expansion of firm size is more likely to succeed when knowledge is codifiable because hiring less knowledgeable workers is less likely to tax top managers (as the knowledge of different workers is easy to substitute for). Thus a higher level of overall knowledge can be obtained by increasing the team size without increasing each worker’s knowledge level. When an organization is able to determine the adoption of codes, the problem-solving capabilities of the organization depend on the codes that are used by its members. An improvement of communication codes, which can become either more specialized or more broad depending on the tasks, allows an organization to economize on communication costs and exploit synergies.

4. Impact of Information and Communication Technology. The models yield rich and perhaps surprising implications about the interplays between organizational change and the improvements in information and communication technologies (ICT). Unlike the usual treatment of ICT as homogeneous, we distinguish two types of progress in ICT. One type is related to cheaper acquisition of knowledge, resulting, for example, from the introduction of Enterprise Resource Planning (ERP). The other is related to more efficient communication resulting, for example, from improvements in IP-based and wireless communications. Decreases in the cost of both communicating and acquiring knowledge increase the level of organizational knowledge and in general lead to an expansion of organization. However, they have opposite impacts on the discretionality of the production workers (bottom at the knowledge hierarchy or chain) and the managers (at the upper positions of the knowledge hierarchy or chain). Cheaper acquisition of knowledge increases the knowledge scope of production workers and thus reduces the frequency of interventions from above. On the other hand, better communication of the knowledge reduces the knowledge scope of the production workers and increases the need for interventions. This challenges the view that improvements in ICT leads to more delegation of power and flattened organization. Bloom et al (2009) use detailed international plant-level data and ICT information to show evidence consistent with the theory that we have described.

¹³Garicano and Rossi-Hansberg (2006) develop a general equilibrium version of the model with heterogeneous workers, where workers must sort into teams.

The theory on optimal communication codes illuminates the relationship between decentralization and information technology which have been widely discussed both in the economics literature and in the business press. Accounting systems, human resource and other organizational databases are codes, in the sense in which economics understands them. In recent years, the management of these codes within firms has become more centralized, while communications have become less hierarchical and while, at the same time, decision making has become more decentralized. Robert J. Herbold, Chief Operating Officer for Microsoft from 1994 to 2001, described this apparent paradox as follows: “standardizing specific practices and centralizing certain systems also provided, perhaps surprisingly, benefits usually associated with decentralization.” This paradox reflects the rationale behind the theory: better management of communication codes substitutes bureaucracies and allows for decentralizations.

5 Decision Bias and Organizational Architecture

The previous section establishes the third point of this article: communication shapes the relation between individual talent and integrates disperse knowledge to perform tasks more efficiently. Organizational structure is an endogenous outcome of interactions between people. However, organization can also be deliberately designed ex ante to complement limitations to human knowledge and judgement, the extent to which is dependent on the attributes of tasks. This is the fourth point of our article. Following the spirit of March and Simon (1958) and Cyert and March (1963), we consider the context of decision making in organizations. Two issues are of particular interests: how should decision makers be organized to minimize aggregate errors or bias in decision making? how much knowledge should decision makers acquire in order to take advantages of the organizational choice? We adopt a simplified variant of a model developed by Sah and Stiglitz (1986) to illustrate the main insights and extend it to address the issues about knowledge acquisition, talent allocation and the impact of the complexity of task.

5.1 A Simple Model

Agents in an organization need to evaluate and decide whether to accept a project that possesses stochastic knowledge content Z and yields random outcome X .¹⁴ As in the previous sections, Z follows a distribution function $F(z)$ with a probability density function $f(z)$, which is again assumed to be decreasing in z , $f'(z) < 0$. Suppose that X is a strictly monotonic transformation of Z to capture the idea that more knowledge yields larger output. For simplicity, we assume $X = Z + \theta$, where θ can be fixed value or a noisy random variable.

¹⁴Alternatively, we can assume that agents need to evaluate a continuum of projects, which are generated by certain stochastic process. A project can be regarded as a task with broad interpretation, for instance as hiring talents.

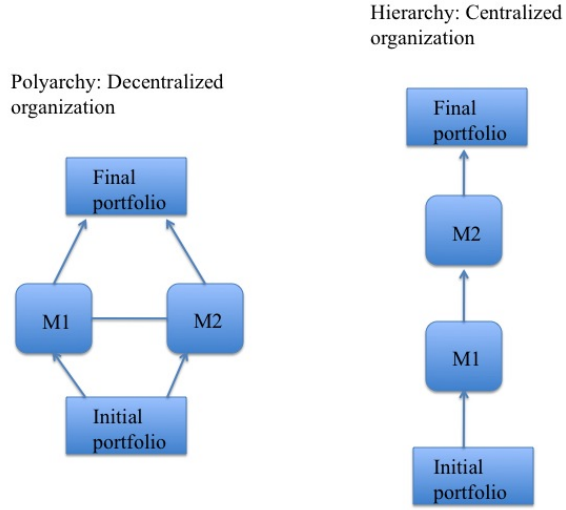


Figure 4: A poliarchy/market/decentralized architecture versus a hierarchy/centralized one

Limited rationality of the agents means that when evaluating the project, they do not know the exact knowledge content but only the knowledge distribution. Potentially they may form two types of bias: reject a good project (Type-I error in terms of statistics inference) or accept a bad project (Type-II error). The agents try to reduce potential errors by a screening function s , which assigns a nonnegative probability to an "acceptable" project based on individual judgement. We assume that s is a continuous increasing function in z for two reasons: 1) more knowledge yields larger output, which makes the project more acceptable; 2) more knowledge allows better screening. Following the literature of statistical discrimination, a screen $s^1(z)$ is said to be slacker than a screen $s^2(z)$ if $s^1(z) > s^2(z)$ and more discriminating if $\frac{ds^1(z)}{dz} > \frac{ds^2(z)}{dz}$.

With perfect screening, all projects with $x > 0$ are accepted while those with $x < 0$ are rejected. The system of screening does not mater. However screening always has defects as "to err is human" and information is never perfect. We consider two alternative screening systems: a polyarchy and a hierarchy (See Figure 4). In a polyarchy, decision making is decentralized to multiple independent screens. So a project is accepted if it is approved by any evaluator. In a hierarchy, decision making is centralized to the top through successive screens. A project is accepted only if it passes all evaluators' screening. Note that there is no communication in a polyarchy as all evaluators work independently and make their decisions simultaneously. In a hierarchy, the communication between the evaluators is limited to a binary signal "Accept, Reject". Implicitly the evaluators' decisions are substitutes under polyarchy and complements under hierarchy. In the following discussion, we focus on a simplest case in which there are only two level of evaluators. Then the probability that a project is approved is $p^P(z) = s(z) + s(z)[1 - (s)] = 2s(z) - s^2(z)$ under polyarchy and $p^H(z) = s^2(z)$ under hierarchy. Immediately we can see the result that with the same

screening criterion a polyarchy is more likely to accept the project than a hierarchy. In other words, the incidence of making type-II error is relatively high under polyarchy while the incidence of type-I error is relatively high under hierarchy.

We proceed to examine the optimal organizational structure when the screening function $s(z)$ is exogenously given; the reader is directed to Sah and Stiglitz(1986) for the case where it is endogenous. Moreover, we assume the outcome $X = Z + \theta_0$, where θ_0 is a fixed number that can be negative. As the screening rule is exogenous, knowledge acquisition does not matter for decision making. Hence we only consider the expected return of the organization that evaluates the project:

$$y^O(z) = \int (z + \theta_0)p^O(z)dF(z), \quad (11)$$

where $O = H, P$ denotes hierarchy and polyarchy respectively. The comparison of the performance under two organizations $\Delta y = y^L - y^H = \int (z + \theta_0)[p^L(z) - p^H(z)]dF(z)$ is in general ambiguous since $p^L(z) - p^H(z)$ can be either concave or convex in z . In the case that $s(z)$ is linear in z , a polyarchy performs better than a hierarchy depending on the tightness of screening. If the screening function is sufficiently tight (small $s(z)$), a polyarchy will outperform a hierarchy as the latter tends to kill many good ideas (more incidence of type-I errors). On the other hand, a hierarchy will achieve better performance through disciplining Type-II errors when the screening function is slack. Moreover, it can be shown that the relative organizational performance depends on the tension between the mean, the variance and the skewness of the knowledge distribution of the project. Generally, a polyarchical decision structure has more advantages when a project is more innovative, in the sense that it is less predictable and has lots of upsides in the right tail of the knowledge distribution.

5.2 Managerial Implications: Why Established Companies Do Not Innovate

When making decisions regarding innovative projects or more generally activities that yields uncertain outcome, people make mistakes even if they do not distort their incentives. They may turn down projects that are actually valuable or approve projects that have no merit. Different organizational designs have different advantages in handling each type of these errors. Essentially, organizations can choose to devolve authority for project approval down to the bottom of the hierarchy (decentralization) or they can force decisions to travel up the hierarchy (centralization). In a decentralized system, an agent makes decision without intervention from others. The lack of control means ‘everything goes’: projects are more likely to be accepted. But this is not necessarily bad, even though there is a risk that too many worthless projects will be undertaken. If a project or an activity has a lot of upside at the very knowledge intensive stages, a polyarchy tends to outperform a hierarchy. In a more centralized architecture, where projects have to pass through multiple steps in order to be

approved, few projects will be accepted. It is likely that whatever passes the multiple screen will be good, but some valuable projects will get turned down by the bureaucracy. Again hierarchy does not mean "bad" although bureaucracy does kill ideas. It is simply the result of a trade-off between killing too many good ideas and letting pass too many bad ones.

This partially explains the stylized fact that well-established firms are not prolific at innovating. In an established firm, reputation increasingly becomes important to sustain the coherence between a corporate image and products. Making mistakes could have serious negative impact on the firm. Therefore a hierarchical structure is needed to maintain and enhance the reputation. For example, approving new products in a mature firm with a strong reputation will involve a highly bureaucratic process with numerous steps and procedures. Other examples may be an industry subject to a lot of public scrutiny or activities such as risk management where loss is potentially large but gain is little.

In terms of talent allocation, talent is more valuable and more knowledge is acquired in a decentralized organization, where no other agent is located to check whether mistakes are made. Conversely, centralized organizations with multiple screens are more likely to correct early mistakes, and thus do not need too much knowledge or very talented agents in each layer.

6 Organizational Capital, Rent and Growth

We have gone through a journey to discuss how to organize things right. A large empirical evidence has demonstrated that the extent of "organizing right" is one of the determining factors explaining the large heterogeneity in firm performance in the same industry (Brynjolfsson and Hitt 1996, Ichiniowski et al 1997, Black and Lynch 2001, Bloom and Van Reenen 2007 among a rapid expansion of systematic empirical studies and detailed case studies). Industrial leaders are usually not only technological leaders but also organizational leaders. Organizational practices or more broadly managerial practices are important capital that can be accumulated, generate rent and sustain organizational growth.

6.1 Organizational Capital

There exist various views of organizational capital. Prescott and Visscher (1980) define organizational capital as information: "what the firm knows about the abilities of its personnel ...the potential for improving matches between employees and jobs." They also include human capital into organizational capital, regarding organizational capital as embodied in employees as in Becker (1993). Evenson and Westphal (1995) consider "organization capital...[is] the knowledge used to combine human skills and physical capital into systems for producing and delivering want-satisfying products." Amit and Scoemaker (1993) think of organization capital as strategic assets that is "the set of difficult to trade and imitate, scarce, appropriable

and specialized resources and capabilities that bestow the firm's competitive advantage."¹⁵

The task-based approach recognizes the organization process that optimizes the relations between tasks, between talents and between tasks and talents as the core of organizational capital. It is true that information of personnel and knowledge of organizational process are important for the formation of organizational capital. But information and knowledge per se may not be specific to a firm and may not be accumulated. It is the process of acquiring, storing, transferring and integrating information and knowledge that is specific to a firm and whose value is not attributed to other production factors such as physical capital, human capital or information. We have shown that communication is an crucial mechanism that integrates knowledge and coordinate talents. Thus communication rather than the communication technology is the organizational capital. For example, a new information system (e.g. ERP) that is introduced in a firm is not organizational capital. It is the process of deploying this information system, which facilitates the communication of knowledge and improves division of labor and leverage of talent, that forms organizational capital. Organizational processes always involve personal interactions. Therefore organizational capital is accumulated through formally designed process as well as repeated tacit interactions among workers.

We distinguish organizational capital from human capital for theoretical and practical reasons although they are always inter-wined. The relative mobility of human capital in the market allows managers to identify organizational failure. A sudden collapse of a firm due to brain drain is a signal for weak organizational capital. In other words, a firm with strong organizational capital should be able to replace human capital from the market to mitigate shocks and avoid failure.

Two factors make it hard to measure organizational capital. First, organizational capital is intangible assets and difficult to measure directly. Second, organizational capital is specific to a firm and its value can not be explicitly priced in the market. As a result, one has to rely on some indirect measures or variations to identify organizational capital and its value.

The most common way of measuring organizational capital is to treat organizational capital as "Solow residual" at the firm or plant level(Corrado et al 2005). That is to net out the contribution of others inputs such as physical capital and human capital in a specified production function. However the "residual" can be contaminated by the technology and knowledge factors that are not contained in the measures of physical capital and human capital. Moreover it is not easy to tease out the effects of market demand and supply. The task-based approach provides new scopes to identify organizational capital, for organization process varies substantially across tasks, which are defined by industrial characteristics, production stage and product cycle. Furthermore, technologies in particular information and communication technologies have significant impact on organization process. Variations in-

¹⁵Amit and Schoemaker do not define organization captial directly. Rather they define "organizational rents" as economic rents generated by strategic assets.

duced by technological change may allow for identification of the value of organizational capital.

6.2 Organizational Rent

Organizational rent is the economic return to organizational capital. The distribution of firm profits between organizational rent and returns to other factors in particular human capital is an important theme in organizational economics that is to be explored.

One key factor that generates and maintains organizational rent is complementarities. The discussion in Section 3.1 shows that complementarities amplify individual talent through two channels. First, complementarities mitigate the extent of decreasing returns to scale at the individual level. Second, the positive sorting induced by complementarities matches high talent with high talent and facilitates the multiplication of individual talent. The amplification effect provides a mechanism through which small differences in individual skill create large differences in performance at the firm level. To the extent that competition is intensified by the availability of sufficiently close alternatives and the homogeneity of workers in the market, each individual can not capture the overall surplus by leaving the firm.¹⁶ In general, the distribution of surplus among production factors is determined by the bargaining between the organization and the workers. In contrast, when talents are substitute to each other, the surplus is mostly created by the superstars, who can easily appropriate the rent. The task-based approach also identifies communication as a source of organizational rent since communication works as a mechanism to integrate knowledge and create complementarities among talents.

6.3 Organizational Growth

The idea that organization can grow through accumulating organizational capital stems from the seminal work by Penrose (1959), who pointed out the significant role of managerial service in the growth of the firm. The theory has been elaborated by the evolutionary view of the firm (Nelson and Winter 1982) and the dynamic capabilities theory (see Augier and Teece 2006 for a recent review). The task-based approach articulates several points that complement to the existing theory.

As emphasized by the resource/knowledge-based view of the firm, organizational knowledge, which is embodied in the human capital in the organization, is a driver of organizational growth. Organizational process, which is the core of organizational capital, acts as an augmented factor to organizational knowledge through efficient utilization of existing talent and optimal acquisition of knowledge. In particular, organization capital enhances complementarities of production factors inside the firm. Organizational growth often starts with a technology shock that releases existing firm resources such as knowledge and talent.

¹⁶However, even organizational rents generated by strong complementarities may be dissipated by market competition, as Kremer (1993) shows in his analysis of O-Ring production functions.

The "excess" resources, maybe in a minor scale, can trigger resource accumulation through a complementary chain and become a significant source of capabilities. For example, an improvement in communication of tacit knowledge allows managers to better leverage their knowledge and increase the returns to their talent, which incentivizes the managers to acquire more knowledge and enforces further leverage of their knowledge. As a result, organization gradually expands to reach the new equilibrium. Thorough analyses of how exploring complementarities enhance firm performance are pursued by Milgrom and Roberts in a series of influential research (Milgrom and Roberts 1990, 1992, 1995, Roberts 2004). The danger of ingrained complementarities is that of falling into the traps of bad equilibria. Organizational processes may facilitate the decumulation of organizational knowledge and the pace towards bad equilibria.

Organizational capital itself is accumulable. This is one of the fundamental ideas in the evolutionary theory of the firm. Nelson and Winter (1982) claim that "organizations remember by doing" and propose that "the routinization of activity in an organization constitutes the most important form of storage of the organization's specific operational knowledge." In the context of the task-based approach, communication as an integrating mechanism stores the memory of organizational process. The memory can be expanded through repeated interactions and routinization of managerial practices.

7 Concluding Remarks

In this article, we have developed a task-based approach to analyze organizational knowledge, process and structure. Figure 5 articulates the procedures and mechanisms left blank in Figure 1. The theory implies several general lessons.

1. Organization emerges to integrate disperse knowledge and coordinate talent in production and is designed to complement the limitations of human ability. Organization is sustained by acquiring relevant knowledge and allocating talent to right positions.

2. Organizational knowledge is task-oriented. The complexity of task determines the optimal level of knowledge acquisition and talent. The relations between tasks, namely, complementarities (substitutability) and synergies, determine the allocation of knowledge among members of the organization.

3. Communication shapes the relation between individual talent and governs the organizational process and structure that integrates disperse knowledge to perform tasks more efficiently.

4. Organizational structure can also be deliberately designed ex ante to correct bias of individual judgement, the extent to which is dependent on the attributes of tasks.

5. Organization process and the routinized organizational structure are the core of organizational capital, which generates rent and sustains organizational growth.

We believe that the task-based approach enriches the existing body of organization stud-

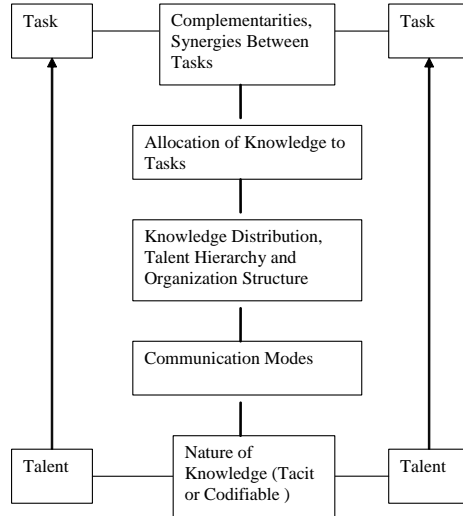


Figure 5: A Task-Based Organization Process and Structure

ies, in particular the knowledge-based theory of the firm and the dynamic capabilities theory. One main contribution of this approach is that it generates empirically testable results that may uncover the underlying mechanism that shapes existing organizational structure and managerial practices. This is on the agenda for further research. Also, the task-based approach is confined within the traditional team theory framework where coordination is the sole concern of the organization. Future research is intended to incorporate the growing incentive-based theory of the firm.

References

- [1] Amit, R., and P. J. H. Schoemaker. 1993. "Strategic Assets and Organizational Rent". *Strategic Management Journal*. 14: 33-45.
- [2] Arrow, K. J. 1974. *The Limits of Organization*. New York, NY: Norton.
- [3] Augier, M., and D. J. Teece. 2006. "Understanding Complex Organization: the Role of Know-how, Internal Structure, and Human Behavior in the Evolution of Capabilities," *Industrial Corporate Change*. 15(2), 395-416.
- [4] Barney, J.B. 1991. "Firm Resources and Sustained Competitive Advantage". *Journal of Management*. 17(1): 99-120.
- [5] Becker, G. 1993. *Human Capital*. Chicago University Press.

- [6] Becker, G.S. and Kevin M. Murphy. 1992. "The Division of Labor, Coordination Costs, and Knowledge" *The Quarterly Journal of Economics*, 107(4), 1137-1160
- [7] Bloom, N., L. Garicano., S. Raffaella., and J. Van Reenen. 2009 "The distinct effects of information technology and communication technology on firm organization." CEP Discussion Papers, 927. Centre for Economic Performance, London School of Economics and Political Science.
- [8] Bloom, N., and J. Van Reenen. 2007. "Measuring and explaining management practices across firms and countries." *Quarterly journal of economics*, 122 (4). pp. 1351-1408.
- [9] Brynjolfsson, E., and L. Hitt. 1996. "Paradox Lost? Firm-level Evidence on the Returns to Information Systems Spending." *Management Science* 42(4), 541-58.
- [10] Conner, K. R., and C. K. Prahalad. 1996. " A Resource-based Theory of the Firm: Knowledge versus Opportunism, " *Organization Science*. 7.5, 477-501.
- [11] Corrado, C., J. Haltiwanger, and D. Sichel ed. 2005. *Measuring Capital in the New Economy*. University of Chicago Press.
- [12] Cremer, J. 1993. *Corporate Culture and Shared Knowledge*. *Industrial and Corporate Change*. 2, 351-86.
- [13] Cremer, J., L. Garicano., and A. Prat. 2007. *Language and the Theory of the Firm*. *Quarterly Journal of Economics* 122, 373-407.
- [14] Cyert, R. M., and J. G. March 1963. *A Behavioral Theory of the Firm*. Englewood Cliffs, N.J.: Prentice-Hall.
- [15] Evanson, R. E., and L. E. Westphal. 1995. *Technological Change and Technology Strategies*. *Handbook of Development Economics*. Elsevier.
- [16] Garicano, L. 2000. *Hierarchy and the Organization of Knowledge in Production*. *Journal of Political Economy*.
- [17] Garicano, L. and E. Rossi-Hansberg. 2006. "Organization and Inequality in a Knowledge Economy", *Quarterly Journal of Economics*, 121(4): 1383-1435.
- [18] Garicano, L. and Y. Wu. 2012. "Knowledge, Communication, and Organizational Capabilities," *Organization Science*, 23(5),1382-1397.
- [19] Grant, R. M. 1996. "Toward a Knowledge-based Theory of the Firm," *Strategic Management Journal*. 17 (December), 109-122.
- [20] Groysberg, B., A. Nanda and N. Nohria. 2004. "The Risky Business of Hiring Stars," *Havard Business Review*. May.

- [21] Grossman, G., and G. Maggi. 2000. Diversity and Trade. *The American Economic Review*. 90(5), 1255-1275.
- [22] Hayek, Friedrich A. von. 1945. "The Use of Knowledge in Society." *American Economic Review*. Vol. 35: 519-30.
- [23] Holmstrom, B. 1999. The Firm as a Subeconomy. *Journal of Law, Economics and Organization*.
- [24] Huselid, M., R. W. Beatty and B. E. Becker. 2005. " "A Players" or " A Positions"? " *Harvard Business Review*. December.
- [25] Ichniowski, C., K. Shaw., and G. Prennushi. 1997. "The Effects of Human Resource Management Practices on Productivity." *American Economic Review*. 87(3): 291-313..
- [26] Kogut, B., and U. Zander. 1992. "Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology." *Organization Science*, 3, 383-397.
- [27] Kremer, M. 1993. "The O-ring Theory of Economic Development." *The Quarterly Journal of Economics*. CVIII, 551 – 575.
- [28] March, J., and H. A. Simon. 1958. *Organizations*. New York: John Wiley&Sons.
- [29] March, J. G. 1991. "Exploration and Exploitation in Organizational Learning." *Organization Science* 2: 71-87.
- [30] Marschak, J., and R. Radner. 1972. *Economic Theory of Teams*. Yale University Press.
- [31] Milgrom, P., and J. Roberts. 1990. "The Economics of Modern Manufacturing: Technology, Strategy, and Organization." *American Economic Review*. June, 511-528.
- [32] Milgrom, P., and J. Roberts. 1992. *Economics, Organization and Management*. Englewood Cliffs, NJ: Prentice Hall.
- [33] Milgrom, P., and J. Roberts. 1995. "Complementarities and Fit Strategy, Structure, and Organizational Change in Manufacturing." *Journal of Accounting and Economics*.
- [34] Nelson, R., and S. Winter. 1982. *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.
- [35] Nonaka, I., and H. Takeuchi. 1995. *The Knowledge-creating Company: How Japanese Companies Create the Dynamics of Innovation*. Oxford University Press, New York.
- [36] Penrose, E. T. 1959. *The Theory of the Growth of the Firm*, Oxford, UK, Oxford University Press.
- [37] Polanyi, M. 1967. *The Tacit Dimension*. Anchor Books, Garden City, NY.

- [38] Prescott, E. C., and M. Visscher. 1980. "Organizational Capital." *Journal of Political Economy*. 88(3): 366-82.
- [39] Roberts, J. 2004. *The Modern Firm*. Oxford University Press.
- [40] Rosen, Sherwin, 1983. "Specialization and Human Capital" *Journal of Labor Economics*, 1(1), 43-49
- [41] Sah, R., and J. Stiglitz. 1986. "The Architecture of Economic Systems: Hierarchies and Polyarchies," *The American Economic Review*. LXXVI, 716 – 727.
- [42] Simon, H. A. 1991. "Bounded Rationality and Organizational Learning." *Organization Science*, ", 125-134.
- [43] Sloan, Alfred. 1924. "The Most Important Thing I Ever Learned about Management." *System* 46 (August).
- [44] Teece, D. J. 1982. "Towards An Economic Theory of the Multiproduct Firm". *Journal of Economic Behavior and Organization*. 3: 39-63.
- [45] Teece, D. J., G. Pisano and A. Shuen. 1997. "Dynamic Capabilities and Strategic Management," *Strategic Management Journal*. 18(7): 509-533.
- [46] Wernerfelt, B. 1984. " A Resource Based View of the Firm". *Strategic Management Journal*. 5: 171-180.
- [47] Womak, James, Daniel T. Jones, Daniel Roos. 1991. *The Machine That Changed the World*. Harper Perennial. New York.
- [48] Wu, Y. 2015. "Organizational Structure and Product Choice in Knowledge Intensive Firms," *Management Science*, 61(8):1830-48.