

The Knowledge Economy at the turn of the Twentieth Century: the Emergence of Hierarchies

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I INTRODUCTION

The knowledge economy is nothing new. As Chandler's (1977) classic study documents, improvements in communication technology (e.g. mail via railways, the telegraph, and later the telephone) played a key role in the emergence of the modern American corporation in the late 19th century and the start of the 20th century. These technological changes revolutionized the organization of production thereby changing the demand for skilled and unskilled agents by creating a new class of professional salaried managers and a class of blue collar workers under their supervision. In this paper we present a simple equilibrium theory based on Garicano and Rossi-Hansberg (2005) in which organization is endogenous and depends crucially on the state of communication technology. With this theory we are able to study the emergence of hierarchies and the implications for the demand for workers of different skills and, therefore, wages.

We present a very simplified version of the theory in Garicano and Rossi-Hansberg's (2005) where improvements in communication technology allow individuals of different skills to abandon self-employment and form teams with each other. The idea is that low communication costs allow high skill agents to leverage their knowledge by specializing in the hardest tasks and hiring low skill agents to do the routine tasks.

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Organization then exploits the complementarities between individual skills which in turn affects the distribution of earnings.

Organization allows high skill agents to better leverage their knowledge, and thus it initially increases the returns to skill. However, this increase in the ability of managers to leverage their talent eventually turns against them. As communication technology improves further and the size of production teams that can be managed by a single manager increases, the demand for production workers, and therefore their wages, increase; in contrast those able to perform managerial jobs become, by the same process that made them more productive, less necessary. Thus our analysis implies a constant increase in the wages of low skill/production workers as communication costs decrease, and a U shaped change in the wage of high skill workers and managers, who first see gains due to their ability to leverage their knowledge and then experience a drop in the demand for their services.¹

We present the model in the Section II and show that our theory provides a link between communication technology, the emergence of organization, the relative demand for skills, and wages. We then argue in Section III that this is consistent with the evidence for the turn of the 20th century in the US.

II THE MODEL

II.A Production, Communication and Organization

The model is a simplified version of Garicano and Rossi-Hansberg (2005). In particular, here teams have only two layers rather than many, agents have only two skill levels rather than a continuum, and the supply of skills is exogenous. The economy is formed by two types of agents of different skills who can choose their occupation and join a team or work on their own. The occupations that are available are problem solving and production. All agents supply one unit of time, which can be used in production or communicating with others. The equilibrium in the economy determines

¹Supply reactions are, of course, also very important and missing in our analysis. See Garicano and Rossi-Hansberg (2005) for a general theory with a continuum of ability, multiple layers, and endogenous skill acquisition.

the occupations of individuals (workers, managers and self-employed) and their wages

Production requires labor and knowledge. Agents with skill q can solve a problem with probability q . Agents who specialize in production draw one problem per unit of time. There are two types of agents, low skill agents with skill q_l and high skill agents with skill q_h . The economy-wide ratio of low to high skill agents is exogenously given by ρ . We normalize output of a team when production takes place to one, and thus expected output of an agent with skill q_i working alone is $y = q_i$.

Agents can also communicate their knowledge to others, and thus help them solve problems. This possibility allows them to form organizations in which several individuals combine their time and knowledge to produce together. Such organizations are composed by production workers, who draw problems, and problem solvers, who can answer questions and thus help workers solve the problems they cannot solve. Workers draw a problem, and try to solve it; if they can, they produce; if they cannot they ask for help to the managers, in which case these managers incur a communication cost h . If the manager knows the solution the team produces one unit of output.

Thus the organization of production is in knowledge based-hierarchies, with some agents specialized in production and some in management; and management by exception, whereby production workers deal with the most common problems and problem solvers with the exceptions. These characteristics are optimal under the assumption that agents do not know who may know the solution to problems they cannot solve, as Garicano (2000) shows in a model with homogeneous workers. The purpose of the hierarchy is to protect the knowledge of those who are more knowledgeable from easy questions others can solve.

A manager with knowledge q_1 can help a team of n_0 production workers. These workers draw one problem each, and solve a fraction q_0 of them. Hence they pass on a fraction $(1 - q_0)$ of all problems. Managers are thus asked to solve $n_0(1 - q_0)$ problems, which they can address in $n_0(1 - q_0)h$ units of time. Optimally, managers join teams with precisely the right number of production workers so that they use all their time. Since all agents have one unit of time available, the team size n_0 is implicitly given by

$$n_0 h (1 - q_0) = 1.$$

The time constraint implies that the span of the manager is limited by the knowledge of their subordinates.

Output is produced whenever either workers or manager know the solution to the problems, so

$$y = q_1 n_0. \tag{1}$$

Note the source of complementarity between skills in our model: An able top managers increases the productivity of all workers in the team. The more knowledgeable are subordinates, the larger the team and the more can managers leverage their knowledge.

Given zero profits, we can denote the earnings of low skill agents by w_p and let those of high skill agents be given by

$$w_h = n(q_m - w_p) = \frac{q_m - w_p}{h(1 - q_p)}.$$

II.B Team size and occupational choice

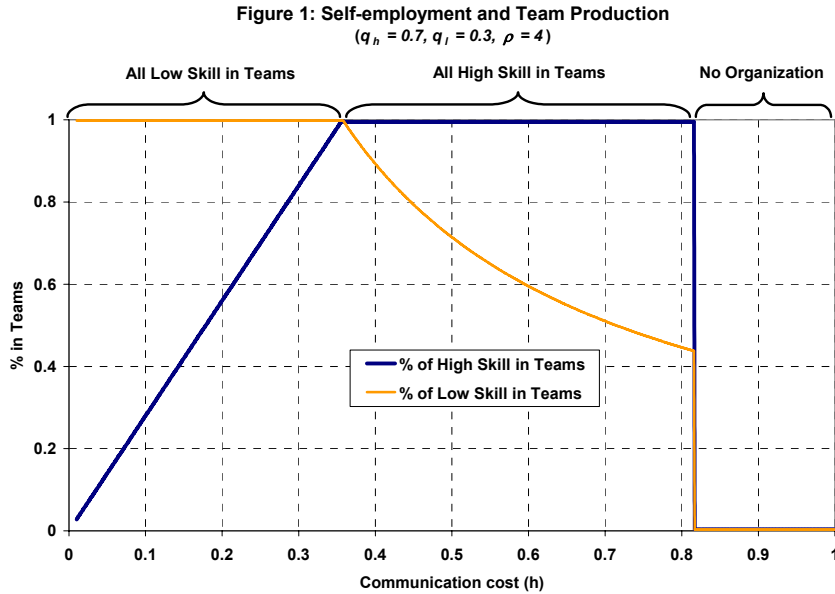
Agents are income maximizers. They organize in teams if they earn more in a team than as self-employed. First, note that this can never be the case with teams of identical workers, since a worker cannot add value to someone of his same skill. Formally, a team of n production workers with skill q_l and a manager of skill q_l produces nq_l , which is lower than than the autarchy output $(n + 1)q_l$. Similarly, a team will never optimally have a manager who is less skilled than his subordinates. Then, a team of $n(h, q) \equiv 1/(h(1 - q))$ low-skill workers and a high skill manager will be formed if $n(h, q_l)q_h > n(h, q_l)q_l + q_h$, that is if

$$h < \bar{h}(q_h, q_l) \equiv \frac{q_h - q_l}{q_h(1 - q_l)} < 1 \tag{2}$$

So for $h < \bar{h}(q_h, q_l)$ some teams are formed and if $h > \bar{h}(q_h, q_l)$ everyone is self-employed. Intuitively, for teams to form communication technology must be good enough to justify removing one person from production and allowing them to specialize in solving problems for others.

Skills and technology jointly determine the demand for skills. As h goes down, more workers and less managers are needed to form teams; as q_l goes up, more low skill workers are demanded per high skill worker. The supply of skills is exogenously given by the relative quantity of low to high skill workers ρ . In equilibrium, if the relative demand for low skill agents (n) is higher than the relative supply (ρ), some high skill agents do not form teams and remain self-employed; alternatively, if the demand for low skill agents per high skill agent (n) is low relative to ρ , then some low skill agents are production workers in teams and some remain self-employed. Let s_i be the share of agents of a given type who work in organizations for $i = \{l, h\}$. Thus, $1 - s_i$ is the share who are self-employed. Then the unique equilibrium is of one of three types:

$$\begin{aligned}
 s_l = 0, s_h = 0, & & \text{if } h > \bar{h}(q_h, q_l) \\
 0 < s_l < 1, s_h = 1, & & \text{if } h < \bar{h}(q_h, q_l) \text{ and } \rho \geq n(h, q_l) \\
 s_l = 1, 0 < s_h < 1, & & \text{if } h < \bar{h}(q_h, q_l) \text{ and } \rho < n(h, q_l)
 \end{aligned}$$



This characterization implies directly the following result which is illustrated in Figure 1.

Result 1: *As communication costs, h , decrease:*

- (i) *The proportion of low skill agents working in organizations, s_l , weakly increases.*
- (ii) *The proportion of high skill agent working in organizations, s_h , weakly increases if $h > 1/(\rho(1 - q_l))$ and decreases otherwise.*

In sum, as communication costs fall, we move from an equilibrium in which everyone is self-employed, to one in which there is organization. In this second stage all high skill agents work in teams and some low skill agents remain self-employed since teams are small and require many managers per worker. As communication costs fall further managers lead larger teams and so the demand for low skill workers increases and incentivates some low skill agents to leave self-employment and join organizations. Eventually all low skill agents work in teams and further decreases in communication costs imply that some high skill agents cannot find workers to form teams and so they go back to self-employment. Figure 1 presents an example where these three stages are evident.

II.C Wages and Inequality

We now turn to equilibrium wages. The type of agents in excess supply have their wages pinned down at their self-employment levels, and the other agents earn the rents associated with producing in teams relative to producing alone. In particular, if some high skill agents are self-employed, then the low skill wage, w_l , is obtained from $w_h = q_h = (q_h - w_l) / (h(1 - q_l))$; while if some low skill agents are self-employed then $w_l = q_l$ and therefore $w_h = (q_h - q_l) / (h(1 - q_l))$.

This allows us to characterize equilibrium earnings as follows:

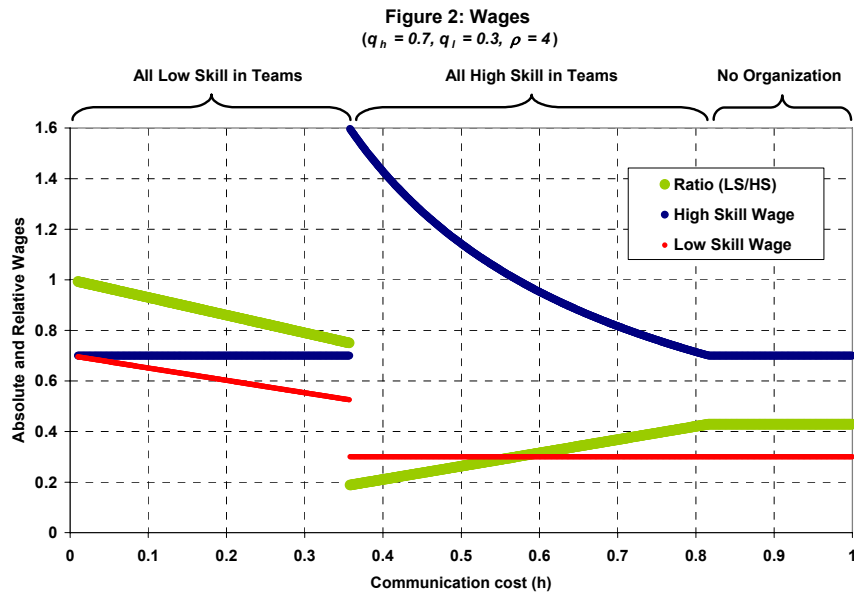
$$\begin{array}{ll}
 w_h = q_h, w_l = q_l, & \text{if } h > \bar{h}(q_h, q_l) \\
 w_h = \frac{q_h - q_l}{h(1 - q_l)}, w_l = q_l, & \text{if } h < \bar{h}(q_h, q_l) \text{ and } \rho \geq n(h, q_l) \\
 w_h = q_h, w_l = q_h(1 - h(1 - q_l)), & \text{if } h < \bar{h}(q_h, q_l) \text{ and } \rho < n(h, q_l)
 \end{array}$$

It is then immediate to obtain the following result which is illustrated in Figure 2.

Result 2: *As communication costs h decrease:*

- (i) *The wages of low skill agents weakly increase.*
- (ii) *The wages of high skill agents increase weakly if $h > 1/(\rho(1 - q_l))$ and decreases otherwise.*

The effect of h on the wages of low skill agents is clear. Low skill are increasingly needed to take production jobs in teams with high skill agents as high skill agents form larger teams. This can also be seen in Figure 1 – as h goes down, the proportion of low skill agents in self-employment always declines.



The effect on the earnings of high skill agents is more subtle. First, as communication costs decrease, the productivity of teams goes up, and eventually high skill agents start forming teams with low skill agents. If low skill agents are relatively plentiful, then high skill agents capture gains from forming these teams. They benefit from the leverage effect, which allows them to spread their knowledge over an entire

team. However, the leverage effect eventually turns against them. As managers become more and more productive at solving problems, less problem solvers are needed, and some high skill agents have to turn to self-employment. As a result, the wage of high skill agents is determined by their self-employment earnings, and the low skill agents capture the benefits from organization. As a result wage inequality exhibits a U-shaped pattern as a function of h , as illustrated in Figure 2.

III THE TURN OF THE CENTURY

This simple supply and demand model allows us to study the emergence of the modern corporation at the turn of the century, and provides some additional empirical implications on wages. As communication costs decrease, with the emergence of the telegraph and the improvement of railway and other land and water-based communication, managers can leverage their talent by having large teams.² To illustrate this consider, for example, the account of Chandler 1977 on the first development of hierarchies, which took place in the 1840s in the railroad sector. In the Erie railroad information flowed through the hierarchy as follows: “Hourly reports, primarily operational and sent by telegraph, gave the location of trains. (...) Just as importantly, the information generated on these tabular forms was filed away to provide an excellent source of operational information which, among other things, was useful in determining and eliminating ‘causes of delay’. Similarly, daily reports were required from conductors, agents and engineers...” (p. 103). The success of such a system relied on the emergence of agents with special skills and training: the salaried manager. By 1850 Chandler (1977, p. 87) documents that large roads were already employing from forty to sixty full-time salaried managers by 1850 and some more by the 1870’s.

The creation of these hierarchies resulted in an increase in the demand for both managers and production workers, who left previous self-employed positions and joined larger teams. However, our theory suggests that the initial stages of the process

²The first telegraph line was officially opened by Samuel Morse on May 24, 1844. Simultaneously, improving transportation allowed for the ‘sharpest reductions in mail rates in history’ – between 1851 and 1855 first-class mail rates of 5 cents an ounce up to 300 miles carried, and 10 cents beyond, were reduced to 3 cents an ounce up to 3,000 miles (Chandler 1977, p. 195).

favor high skill agents, who can leverage their talent through large teams, thereby increasing the skill premium. Eventually, however, communication should become so cheap, and teams so large, that the scarcity should shift from high skill to low skill workers. This in turn would reduce wages of high skill agents and therefore inequality. Hence, according to our theory continuous declines in communication technology first increase and then decrease inequality across salaried managers and production workers.

The existing evidence on the evolution of wages at the end of the 19th century and the start of the 20th century suggests that some of these effects may be present in the data. Goldin (2001) argues that large increases in the demand for skill at the turn of the century resulted in large increases in the skill premium. After that, several studies have documented a substantial and continuous decline in skill premia, whether measured by the white-collar/blue collar differential or the premium to education (see Douglas (1930), Goldin (2001), Goldin and Goldin and Katz (1999)). As Goldin and Katz (1999 and 2003) have pointed out, the drop in the relative wages of white collar workers is in part a response to the large increase in the supply of skills during the start of the century. Our model suggests another mechanism that may have contributed as well: increasing relative demand for production labor relative to highly skill labor, due to larger spans of control as a result of better communication technology.

Of course, in interpreting such long run data our model has an important limitation: the fact that it fixes the supply of skill. Garicano and Rossi-Hansberg (2005) generalizes the model to allow individuals to invest in knowledge at a cost, and the underlying heterogeneity is heterogeneity in cognitive ability or cost of acquiring knowledge. This modification implies that decreases in communication costs lead to less inequality among agents in production and lower layers of management, since they acquire less knowledge, but more inequality between them and top managers. Hence, while the role of communication costs h on flattening the lower part of the wage structure must always be part of the analysis, the simple model in this paper eliminates a second effect in the opposite direction: decreases in communication cost can favor some super-star managers that lead very large teams. However, we believe that the evidence at the turn of the century refers mainly not to the top managers of

the new corporations but to a large white collar managerial class.

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