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Connective Capital:
Building Problem-Solving Networks Within Firms

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"Capital consists in a great part of knowledge and organization."
-- Alfred Marshall, Principles of Economics

Team problem solving is becoming a common activity for many employees. Whether it is the continuous improvement work of teams of factory workers, or scientists and engineers in R&D teams developing a new product or production method, or white collar professionals working on new business initiatives, or even the top board members of firms, employees often work together in teams to develop new ideas for improving the firm's products or its operations. However, standard models of a firm's production function do not capture these interactions among workers. Models that consider why different employees would work together and data to examine specific worker-to-worker interactions are rare.

In this paper, we open up the production function and model the extent to which individual employees inside the firm work together. We first introduce "connective capital" as an important determinant of a firm's productivity, where a worker's connective capital is that part of the human capital that resides with his co-workers but which he can tap into via his own network of connections with these co-workers. After incorporating connective capital as an input in the production function, we model the determinants of the levels of connective capital and consider why this type of capital can vary from one firm to another. Here, we emphasize how the human resource management (HRM) policies that a firm adopts can affect its level of connective capital.

Given some predictions from the model concerning the worker's and firm's decisions to invest in these connections among co-workers, we analyze a unique data set that measures the presence and absence of connections among co-workers in a sample of 642 production workers employed at any of severe comparable steel production lines. We measure the amount of connective capital in these organizations, and test several predictions of the models by investigating the effects of the organizations' HRM practices and of the workers' personal characteristics on connective capital. Consistent with the model, we find that workers with lower costs of communicating and sharing knowledge and organizations with more innovative HRM, practices form significantly more connective capital.

I. A Model of Investments in Connective Capital

This section develops a model of connective capital inside organizations. After defining connective capital, we incorporate it as an input in the firm's production function. Since individuals or firms do not simply maximize investments in productive capital inputs, the model of this section also considers the optimal investment in connective capital for individuals and firms.

Defining Connective Capital and the Production Function

The idea that workers' human capital raises productivity is a bedrock principle of economics. The idea of "connective capital" elaborates on this idea by arguing that spillovers of knowledge among co-workers serve as a way to multiply the expertise of skilled workers. A knowledgeable or experienced worker may indeed perform work tasks well, but he can also improve the performance of others if that expertise is shared. We capture this mechanism for increasing productivity with the basic idea that connective capital is shared human capital, and define *connective capital* for worker i, CC_i, as: [1]

$$(1)\quad CC_i = \sum_{j \neq i}^{N} cc_{ij}\, HC_{ij}$$

where

$$cc_{ij} = 1 \quad \text{if worker i communicates with worker j}$$
$$= 0 \quad \text{if worker i does not communicate with worker j}$$

and HC_{ij} is difference between the human capital of person j and i, or $HC_{ij} \equiv HC_j - HC_i$. Thus, to calculate worker i's connective capital over a given time period, one first measures whether or not he communicates with each of his coworkers, j=1,..,N (j≠i), and weights each existing communication connection by the human capital he gains (or $HC_j - HC_i$) through those communications. The definition of an individual's connective capital therefore has two main components – worker i's cc_{ij} vector measures the worker's communication network, while the $HC_j - HC_i$'s reflect gains in human capital that are transmitted over those network channels that do exist.

Next, denote the general production function for firm output (Q) as:

$$(2)\quad Q = f(\mathbf{HC}, \mathbf{CC}; K)$$

[1] Because we will be focusing on differences in productivity in technologically comparable production processes, we assume that number of labor hours is comparable across observations and therefore is not included in the L function.

where **HC** and **CC** are the vectors of traditional human capital and connective capital, respectively. According to (2), increases in connective capital raise output as long as $f'_{CC} > 0$, conditional on physical capital, K.[2] An example helps illustrate how knowledge transfer among workers improves productivity beyond the direct effects that knowledge and skills have on an employee's own individual performance. The example we develop below focuses on the problem-solving activities of production workers in a sample of steel finishing lines.

Employees routinely encounter problems in the steelmaking production process, such as deteriorating steel surface quality during a production run. But to identify the actual reason for this problem from among many possible sources and then solve the problem, an employee can draw upon his own training and experience, but can also tap into expertise and experience of others. Co-workers can have different human capital that is relevant for this problem for many reasons. Co-workers may have superior technical knowledge of chemical coatings or they may simply be working in different areas where steel inputs had previously been treated. Worker i may not be able to solve the surface quality problem on his own and worker j may not even be aware of the problem if it shows up elsewhere in the plant. Communication (cc_{ij}'s) and differences in knowledge (HC_j-HC_i's) are both important for problem solving and together these factors determine a worker's connective capital. The central point here is that access to others' knowledge and skills can promote problem solving and therefore elevate overall levels of productivity in many organizations, just as it does in the illustration from steel mills.

Since connective capital is a function of human capital, output is a non-linear function when we rewrite (2) as

$$(2') \quad Q = f(g(HC);K)$$

where g(HC) = g(HC,CC) since CC is a nonlinear function of HC.

Given this production function arising from the definition of connective capital, below we develop the model of connective capital to show not only that $f'(HC)>0$, but that the effect of human capital on output is likely to accelerate in some range of HC before turning down, or that $g''(HC)>0$ and $g'''(HC)<0$. An individual who is very good at problem-solving will be asked to solve numerous problems and his human capital will multiply throughout the organization. Thus, as human capital is increased, the productivity of human capital accelerates before

[2] The equations (1)-(2) model is analogous to models of the productivity effects of spillovers of R&D knowledge across firms in an industry. See for example Griliches (1979).

decelerating in the production function. That is, the creative problem-solvers are extremely valuable to firms that value problem solving.

The Worker's Investment in Connective Capital

If connective capital does increase productivity, what determines the decisions of two workers to connect and what determines the overall extent of connections and knowledge sharing within the firm? Let workers i and j be two employees faced with a problem – the former is the "asker" and the latter is the potential "sharer. Aij = 1 if worker i decides *to ask* for information from worker j and is zero otherwise, and Sji = 1 if worker j decides in turn *to share* with the asker and is zero otherwise. Rewrite the communication link between i and j as:

(3) $cc_{ij} = A_{ij} \bullet S_{ji}$

The connective capital for worker i (cc_{ij}) is the amount of new human capital shared by worker j when a communication link is established between the two workers ($cc_{ij} = 1$).

The firm's quality output, Q, is a function of traditional human capital and connective capital of all employees, so rewrite (2) assuming linearity in human capital and connective capital

(4) $Q_t = \boldsymbol{\alpha}'\mathbf{HC}_t + \boldsymbol{\delta}'\mathbf{CC}_{t-1}$

Period t quality output,[3] Q_t, is a function of both the vector of human capital of the N-person workforce, $\mathbf{HC}_t$,[4] and of the prior problem-solving activity $\boldsymbol{\delta}'\mathbf{CC}_{t-1}$. The vector $\mathbf{CC}_{t-1}$ is also an N-element vector. These elements equal zero for workers who have not received any human capital from co-workers and are positive for any worker who has developed connective capital in period t-1. Connective capital, CC_{t-1}, is weighted by the vector of coefficients $\boldsymbol{\delta}$ in the production function, and these coefficients have an important interpretation. We assume that $\boldsymbol{\delta}$ is an index of the value of problem-solving activity: $\boldsymbol{\delta}$ is higher when the firms' profits rise because

[3] Q_t should be considered as quality-adjusted output because problem-solving activities in many production settings are associated with seeking methods to improve product quality.

[4] For simplicity, we assume that human capital HC is separable from connective capital CC_i, though multiplicative interactions between all these forms of human capital would complicate the analysis but not change the essential points. Note also that past stock of connective capital should lower the costs of investing in current connective capital, because workers build knowledge about who to contact to solve problems. Such a state dependence effect – past CC builds current CC – is assumed here to occur within the first period. Adding a state dependence effect would significantly complicate the model, but would imply that there are adjustment costs that further limit firms ability to jump between different states of CC.

the market values the quality of the output (so low-quality products have low **δ**). Thus, we assume that all firms face continuous shocks to production – problems arise constantly. Firms with high **δ** are those firms that have a high return to solving the problem that has surfaced.

We also make some assumptions about the nature of the problems that arise and the distribution of human capital in solving these problems. We assume that problems of different types arrive randomly for person i and then that person seeks the person j who is the expert in solving that problem, or seeks the person for whom (HC_j-HC_i) is greatest for the relevant problem that j can solve. Clearly, if there were only one type of problem, then there would be only one person j whom every i person in the firm would call. Furthermore, we assume that different people are experts on different problems, so that once again, multiple people are called. Clearly, it is important to view human capital as having many different types, and we do so shortly in a subsection below, but for simplicity, we avoid the messy introduction of vectors of human capital types at this point.

There are two types of costs associated with the investment in connective capital. The first is direct opportunity cost of time – the time spent solving a problem that could have been spent directly producing output instead: $t(\alpha_j HC_j - \alpha_i HC_i)$, where t is the percent of time spent on joint problem solving activities by i and j. The second cost is the person-specific personal disutility of communicating (or the utility for those who enjoy it). These costs are things like the following. Askers face costs associated with identifying co-workers, with contacting people, pulling co-workers together, and other search costs. Sharers also face the logistical costs of responding to the request for assistance, such as attending a meeting, or putting other work aside. These workers may also experience disutility later on if sharers receive less credit or compensation than askers for solving problems. Askers and sharers therefore incur personal costs C^A_i and C^S_j of communicating.

Workers maximize the net benefits of connective capital investments. Output is reduced during the period when the communications occur, individuals bear the personal costs of communicating, and then there is a payoff in increased problem-solving productivity in subsequent periods. We illustrate the worker's cost-benefit calculation in a two period model in which workers can decide to ask and share during the first period. To capture the idea that problem solving is a team-based activity that affects the output of groups of workers, let worker compensation be determined by a group-based incentive pay so that all workers divide net revenue among themselves—each worker gets Q/N.[5] Asking and sharing would then take place for representative workers i and j according to:

(5) $A_{ij} = 1 \text{ if } P_{ji}R\left[d(\delta HC_{ij}) - t(\alpha_i HC_i + \alpha_j HC_j)\right]/N > C_i^A$

(6) $S_{ji} = 1 \text{ if } R\left[d\delta_i HC_{ij} - t(\alpha_i HC_i + \alpha_j HC_j)\right]/N > C_j^s \text{ given } A_{ij} = 1$

where (5) is the expected gain to worker i from asking j, P_{ji} is the probability that worker j will share (or $\Pr(S_{ji}=1)$), R is the percent of net revenue allocated to workers as compensation,[6] d is the discount factor (1/(1+r)), and t is the percent of time (or percent of base period human capital) that is spent communicating rather than producing. The probability of sharing is $P_{ji} = \int_o^{Bij} f(\varphi_j^s)d\varphi_j^s$. Workers are risk neutral, so workers ask when the expected monetary gains exceed the monetary and personal costs. Thus, $Rd\delta_i HC_{ij}/N$ is the income gain in period 2 and $Rt(\alpha_i HC_i + \alpha_j HC_j)/N$ is the opportunity cost of communicating time in period 1.

Assume that the person-specific costs of asking and sharing are distributed randomly across the population, so that $C_i^A = \varphi_i^A$ and $C_j^s = \varphi_j^s$, with density functions $f(\varphi_i^A)$ and $f(\varphi_i^s)$, and for the moment assume φ_i^A and φ_i^s are be independently distributed. Then (5) becomes:

(7) $A_{ij} = 1 \text{ if } B_{ij}\int_o^{B_{ij}} f(\varphi_j^s)d\varphi_j^s > \varphi_i^A$

(8) $S_{ji} = 1 \text{ if } B_{ij} > \varphi_j^s \text{ given } A_{ij} = 1$

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[5] In problem-solving contexts, group-based pay is commonplace (Cite??) perhaps because of limits on observability of sharing or on abilities to measure the contributions from different ideas. Undoubtedly, alternative compensation schemes could be developed that focus on eliciting optimal levels of connective capital. For example, if sharing is observed, then 360% peer evaluations could be used to reward sharing. Subjective evaluations have also been suggestive as a possible way to reward hard-to-measure inputs like 'teamwork' (Baker, Gibbons, and Murphy, 200x). Here, we assume that, on average, it would be too costly to develop reward schemes due to limits on observability or measurement, and assume the Q/N compensation levels to emphasize the problem-solving is a team process that affects a group's output. Moreover, we assume that groups of askers and sharers are large enough that each (i,j) pair does not form a long term relational contract – such as, if you help me today, I'll help you tomorrow. The point of connective capital is that people from many parts of the organization share even when they will not be directly rewarded in the next round by their asker.

[6] Thus, we assume that the firm allocates a percent (R) of net revenue to workers and retains a percent for shareholders, as is typical for profit-sharing plans or worker-owned firms. We will assume R is fixed (obviously related to workers' alternative wages, etc.) and not address its value herein.

which states that worker i will ask when the benefits, $B_{ij} \equiv (R[d\delta HC_{ij} - t(\alpha_i HC_i + \alpha_j HC_j)]/N)$, times the probability of sharing, P_{ji}, exceed the costs of asking, φ_i^A. When we turn to the firm's decision to invest in connective capital below, we will emphasize how the firm will tend to choose human resource practices to shift the distribution of costs relative to benefits and thus to induce employees to choose higher levels of connective capital.

Thus, the model implies that connective capital is higher when the expected costs of both asking and sharing are less than the minimum benefit threshold of B_{ij}. Or, problem-solving occurs when $cc_{ij}=1$, which by combining (7) and (8) with equation (3) above can now be expressed as:

(9) $$cc_{ij} = 1 \text{ if } B_{ij} > \varphi_i^A / P_{ji} \text{ and } B_{ij} > \varphi_j^s$$

Thus, connective capital increases when individuals have different skills, or when $HC_j - HC_i$ is large (all else constant, such as the opportunity cost of time, which rises with HC_j), and when sharing costs are low.

In this model, there are two reasons for the underprovision of connective capital. First, there is the free-rider effect, or the underprovision of effort in any workplace that is governed by group-based incentive schemes. The level of sharing implied by (8) will be suboptimal from the group's (and firm's) perspective because the worker is only taking into account his share of benefits, and this underprovision increases with the number of workers, N (Kandel-Lazear (1992), other references…). That is, when worker i decides whether to ask worker j for assistance, worker *i* asks only if the marginal cost of this effort equals 1/N of the expected marginal benefits to the firm.

Second, the most important underprovision outcome in our model of connective capital comes from the network externality in the model. The network effect is as follows: an increase in sharing, S_{ji}, by one person j will increase the asking and sharing of all other workers. One can see these network effects by considering the effect of an exogenous drop in the sharing costs φ_j^s of person j so he shares more. The increase in his sharing increases the overall probability of sharing, P_{ji}, which increases the probability of asking for all employees. These network effects reflect the standard externality of networks: sharing is contagious. An increase in the communications of one person will increase the connective capital of all others.

<u>Extensions of this Basic Model</u> A few additions to the model are useful in adding further implications. Expand the cost functions:

(10) $C_i^A = a^A Z_{ij} + \varphi_i^A$

(11) $C_j^S = a^S Z_{ji} + \varphi_j^S$

where for some people, there is a utility or disutility associated with who they are calling – for example, women may be more comfortable calling women, so that costs are a function of vector Z_{ij} characteristics that are specific to the (i,j) pair of communicators. Some characteristics of the j 'partner,' such as demographic similarity or physical proximity, imply lower costs to person i.

The implications of this extension are clear. When people are 'close,' or have low costs arising from the Z_{ij} effect, connective capital will rise. Moreover, if we drop the assumption that assume φ_i^A and φ_j^S are be independently distributed, permitting the joint distribution f(φ_i^A , φ_j^S) then communications will rise when costs are positively correlated. That is, connective capital will rise either when firms pair (i,j) workers who have similar costs of communicating, or it will rise when 'low-cost' workers select firms in which existing employees have low costs of communicating. In other words, firms will have an incentive to match workers based on communications costs and workers will tend to self select into firms based on low costs.

A second extension is to recognize that workers have different types of expertise in solving problems. That is, some workers may have an expertise at solving 'operating' problems, whereas others might be experts at solving 'design' problems. Then the output from person i now looks like:

(12) $Q_i = \alpha HC_i + \delta^o p^o \sum_{j=i}^{J} cc_{ij}(HC_j^o - HC_i^o) + \delta^d p^d \sum_{j \neq i}^{K} cc_{ik}(HC_k^d - HC_i^d)$

Where individual i faces a probability of operating problems arising, equal to ρ°, and chooses to communicate with workers from a set of workers, J, who are the operating experts; or when workers i faces a design problem with probability ρ^d and chooses to communicate from a set K of workers who are the design experts. The basic model is unchanged, expect that now we recognize that connective capital is valuable when there are different types of human capital forming the human capital gap, $HC_j - HC_i$, and therefore when person j has the skills that are <u>relevant</u> to solving the operating problem, or that come from set J for operating problems or K for design problems (Lazear, 1999).

Given multiple types of problems and skills associated with solving these problems, the value of CC to the firm or individual depends on the levels of δ^k, p^k, and $HC^k_j - HC^k_i$, for k=O and D: higher levels of all of these variables produce more value to CC all else constant. However, it is the distribution of these variables that is particularly important in assessing the value to the firm of connective capital. Skill distributions are shown in Figures 1 and 2. In Figure 1, there are four types of individuals, where individuals have two skills each – (HC^O_i, HC^D_i). In Figure 1, Person 4 has more of both skills, Person 1 less of both skills, Person 3 is a relative expert at design, and Person 2 is a relative expert at operating. Assume Person 1 randomly receives a problem that requires both an operating and design solution – then he will always call Person 4 because Person 4 is better at solving both design and operating problems. In other words, if skills are positively correlated (note in Figure 4, the regression line through individual skill sets would be upward sloping to reflect this correlation), that implies that there are some people who are experts at everything, and everyone calls the expert. For example, everyone would call the engineer or plant manager if he is good at solving all problems – he is person 4 in Figure 3. Therefore, when Person 1 receives a problem that is design and operating, he will make only one call to 4, or he will have only one $cc_{14}=1$ link to the expert and no other links ($cc_{12}=0$, $cc_{13}=0$). That is a hierarchical firm.

On the other hand, in Figure 4 there is no Person 4 – no expert at everything. In this case, when faced with an operating and design problem, Person 1 will call both Persons 2 and 3 – CC will have two links ($cc_{12}=1$, $cc_{13}=1$). As you can see in Figure 2, skills are negatively distributed across individuals. So the point is, if skills are negatively distributed, then there are no experts at everything, and the total value of CC is higher. This is a 'flat' firm with fewer layers and more connective capital.

Note finally that the value of CC depends on the distribution of problems to solve. If a firm only faces only design problems, then Person 1 will always call only Person 3, and will never communicate with Person 2 (given skill distribution of Figure 2). Therefore, connective capital is higher when the problems to be solved require multiple skills.

In summary, connective capital will be higher when

1) Skills are negatively distributed – there are no experts at everything, each employee has a different expertise that is valued as different problems arise. In the world of manufacturing, this means that operators know more about some problems than do engineers.
2) Problems arise that constantly require a combination of skills to be solved, not just one skill. Then the person receiving the problem will call several individuals to solve the problem (assuming point 1, that there are no experts on everything).
3) Time costs of communicating are not prohibitively high. For example, if the operating expert's time costs are too high, then Person 1 will solve the problem alone.

This detailed example does not change any of the conclusions of our basic model, but simply clarifies the structure of the problem. In the basic model, we are assuming that problems arise randomly and continuously, that they require multiple skills, and that skills are not positively correlated across the workers. Thus, when worker i receives a problem, he will know to call worker j for that particular problem, and then worker k for a different problem. We assume that all i workers have the same rates of problem arrival and that they know whom to call. Of course, a very important part of networking is knowing who to call. We assume here that knowing who to call is a function of tenure (or firm-specific human capital) and do not emphasize it here, but clearly calling different people while searching for the right person will increase CC. Finally, our basic model then uses δ as the index for the firm of the value of problem solving, and thus is a function of product quality and the likelihood that quality problems arise.

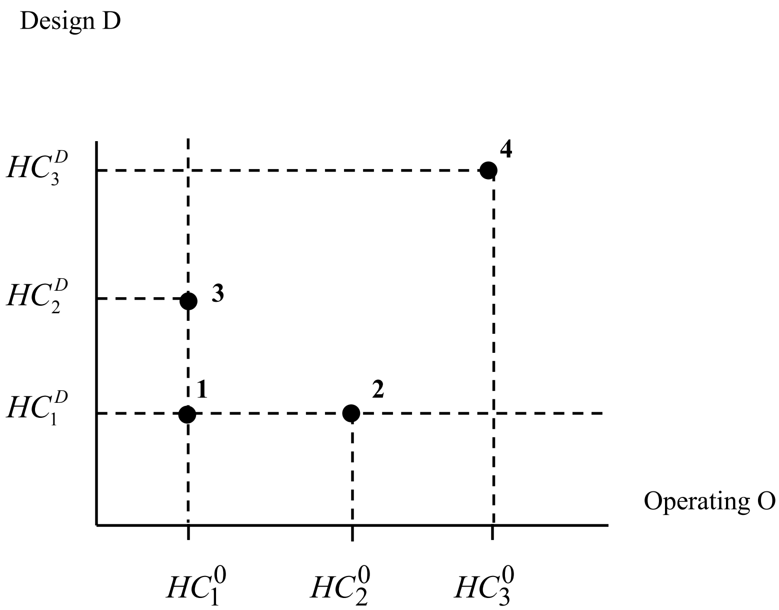


Figure 1

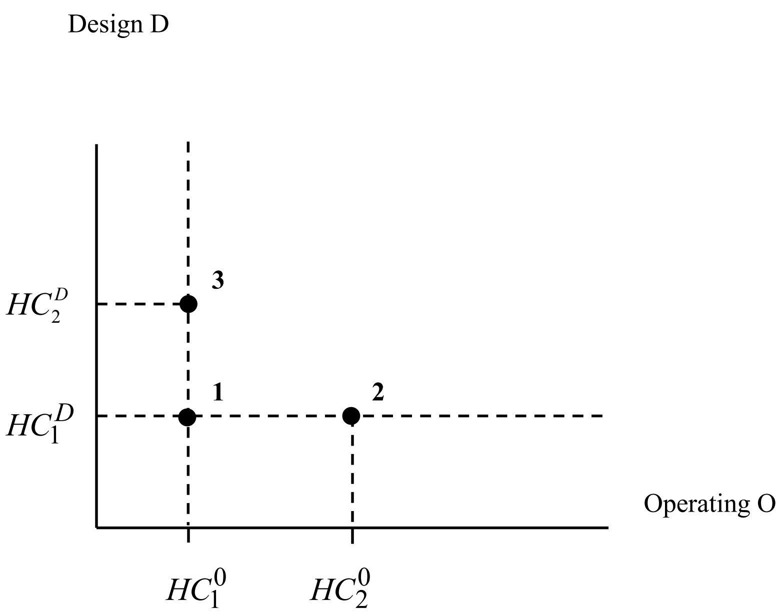


Figure 2

The Firm's Decision to Invest in Connective Capital

The firm is ultimately making the decision to invest in connective capital, as it determines the returns to connective capital by choosing the technology, **δ**, that values problem solving, or by selecting the human capital of its workforce, **HC**, that raise the value of connective capital. However, we focus primarily on the short run: given the production technology and human capital, how can firms influence the workers' decisions to invest in connective capital?

The primary way in which the firm influences workers' investments in connective capital is by choosing its human resource (HR) management practices to increase the return to connective capital. A key HR practice here is the indoctrination of workers to believe that the "norm" of workplace behavior is one of reciprocity or sharing. The peer pressure model of Kandel and Lazear (1992) emphasizes the value of norms and indoctrination under conditions when individuals have the incentive to free-ride or underperform, as is the case here with connective capital. Firms can reduce free-rider problems by instituting standards or "norms" of workplace behavior – where the "norm" is the expectation that all workers will to contribute effort towards achieving the group reward (and thus all will gain from the higher effort levels).[7] Numerous HR practices – such as effort norms, indoctrination, and peer pressure– raise the probability that workers will exert effort in response to the incentive pay, and thus will share their knowledge. Akerlof and Kranton (2003) elaborate on the use of norms by hypothesizing that a worker's personal utility is higher when his self image, or "identity," matches the firm's ideal behavior for its employees. When the workers' actions fail to live up to the firm's ideal behavior, the worker's utility falls because his self image fails to live up to his ideal which reflects the firm's ideal. Thus, firms can use indoctrination or norms to define the ideal identity and thus influence workers' behavior.

Firms can invest in indoctrinating workers with the ideal norm of behavior that workers should assist others in solving problems even when the worker does not directly benefit from this sharing behavior, but does benefit indirectly through higher group-based pay in the long run. As

[7] See MacLeod (1988, 1987) for an alternative approach to solving the free-rider problem in teams. Note that Kandel and Lazear (1992) emphasize that firms do two things to enforce this norm. First, they convince employees to use peer pressure to monitor behavior: workers who free-ride are shamed by their peers into performing. Second, firms use heavy up-front indoctrination to make workers feel guilty when they underperform, so no direct monitoring is needed because workers self-monitor.

a result, workers' cost of effort functions depend upon the level of the sharing ideal. If a worker believes the norm is a high SharingIdeal, his costs of sharing are lower.

(13) $\varphi_j^s = \gamma_j^s\left(Effort_j^s - (SharingIdeal)\right)$

Thus, the firm can invest in HR practices that shift the cost of sharing distribution for workers—the distribution of costs of sharing conditional on HR practices become:

(14) f(φ_j^S ; HR) = f($\varphi_j^S \big|$ Sharing Ideal or Reciprocity Norm)

so that workers in firms with a 'norm of reciprocity' will have lower sharing costs, because they gain utility from sharing when sharing is part of the their identity or when peer pressure rewards sharing.

The firm bears two costs in period 1 – the costs of investing in HR practices to support connective capital, and the opportunity cost of the employees' communications time. In period 2, the firm earns the returns to these investments as returns to problem solving. The firm's expected profit function in the two-period model

(15) $E(\pi) = (1-R)[\left(1+d\right)(\boldsymbol{\alpha HC}\text{-}W) + \sum_{i}^{N} \sum_{j \neq i}^{N} pr(cc_{ij} = 1)[d\delta HC_{ij} - t(\alpha_i HC_i + \alpha_j HC_j)] - \eta HR\ ]$

where (1-R) is the percent of the firms net revenues reserved for shareholders, α_0 is $\boldsymbol{\alpha' HC}$ minus wage and material costs, ηHR is the cost of investing in the selected level of HR practices, and d is the discount rate for the period 2 profits. Substituting for the probability that cc_{ij} is equal to one

(16) pr(cc_{ij})=1 is $\int_0^B \int_0^{BP} f(\varphi_i^A, \varphi_j^S \big| HR)\partial\varphi_i^A \partial\varphi_j^S$

produces

(17) $E(\pi) = (1-R)[(1+d)\,(\boldsymbol{\alpha HC}\text{-}W)$

$+\sum_{i}^{N} \sum_{j \neq i}^{N} \int_0^B \int_0^{BP} f(\varphi_i^A, \varphi_j^S \big| HR)\partial\varphi_i^A \partial\varphi_j^S [d\delta_i HC_{ij} - t(\alpha_i HC_i + \alpha_j HC_j)] - \eta HR\ ]$

where the firm chooses the optimal level of HR practices to maximize profits, or

$$\frac{\partial E(\pi)}{\partial HR} = \frac{\partial \text{ (Total Expected Gains)}}{\partial HR} - \eta$$

where the total expected gains are

$$(1-R)(\sum\sum \iint f(\varphi_i^A, \varphi_j^S \big| HR) \partial\varphi_i^A \partial\varphi_j^S [d\delta_i HC_{ij} - t(\alpha_i HC_i + \alpha_j HC_j)]$$

and for simplicity wage and material costs are assumed to be fixed.

Figure 3 displays a total expected gain function and potential alternative cost functions based on (17)

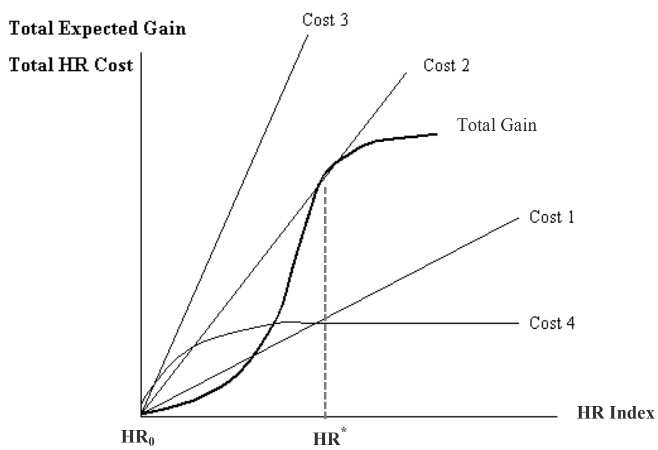
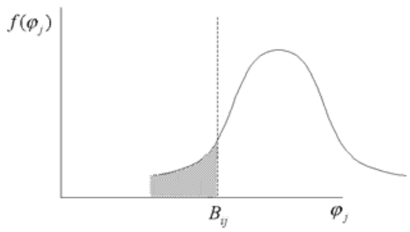


Figure 3: The Total Gains to Investing in Connective Capital Relative to the HR Costs

where the costs of HR, ηHR, are linear, but could be nonlinear as shown in cost function Cost 4.

The total gains to CC as a function of HR increase gradually, then accelerate and plateau, for two reasons. First, the individual's decision to share his knowledge is discrete, or $S_{ji}=1$ when $B_{ij} > \varphi_{j,}$, so the amount of sharing across workers depends on the location of the distribution of the personal costs of sharing across workers in the firm relative to benefits. As shown in Figure 4, given a unimodal distribution of costs across the firm's workforce, as the distribution of costs shifts lower (leftward) and passes through a fixed benefit line, the probability of sharing first accelerates, then decelerates.



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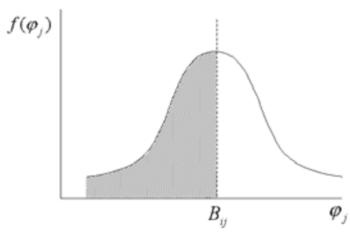

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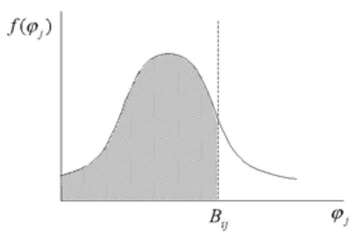
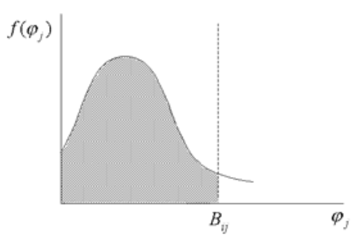


4c



4d

Figure 4: Shifting the Cost Distribution Left Through the Benefits Line

Therefore, the biggest gain to reducing costs via HR comes from the point at which new HR practices move the mean distribution of costs below the benefit level B. Of course, if the firm is already at the position of Figure 4d, perhaps because they selectively hired workers with low sharing costs, then increasing HR will have little effect on CC.

Thinking of this in terms of specific HR practices, remember that one way of lowering the costs of sharing is through peer pressure – in an environment of effective peer pressure, costs of not sharing rise, or costs of sharing fall. Recall that

$$\varphi_j^s = \gamma_j^s\left(Effort_j^s - (SharingIdeal)\right)$$

However, if the firm decides to indoctrinate to raise the SharingIdeal, indoctrination will only have an effect if the worker is 'close to the margin' in sharing, or if costs φ_j^s, are close to B_{ij} for worker j. Thus, small investments in indoctrination or peer pressure will have no effect on connective capital if these investments are not sufficient to induce sharing. In Figure 4a, very few workers are close to the margin, and there is not much increase in sharing when costs are lowered with HR from that point. But moving from position 4a to 4c induces a big jump in sharing as many workers costs fall below the fixed benefit B_{ij}. So the effect is nonlinear, or at low levels of peer pressure there is no effect of HR on connective capital, but as peer pressure rises and to induce more workers to share, HR begins to have an effect.

Second, the nonlinearity in the gains to connective capital in Figure 3 arise from the network effects of sharing. If innovative HR practices lower the costs of sharing for a few workers, that raises the probability of sharing for all, so that the probability of asking rises for all employees, which will in turn increase the probability of sharing, and so on. As a result of the network effect described above for worker investment in CC, the $pr(cc_{ij})=1$ rises slowly then accelerates:

$$pr(cc_{ij})=1 \text{ is } \int_0^B\int_0^{BP} f(\varphi_i^A, \varphi_j^S \mid HR)\partial\varphi_i^A\partial\varphi_j^S$$

and thus the total gains to investing in HR practices are small at low values of HR, but accelerates as increases in HR induce network effects to accelerate.

Given these two sources of nonlinearity in the gains to CC as a function of HR practices, firms will tend to be either low HR firms or high HR firms, as shown in Figure 3. Figure 3 shows that with the total cost function is either Cost 1 or Cost 2, firms will choose to be high HR (HR* in the figure), or a 'high performance HR system', but if costs rise to Cost 3 then will immediately drop to a low HR system (HR_0) – there is no value in making intermediate choices of HR practices. This is true as well if the firm has a nonlinear HR cost schedule (Cost 4), in which there are high fixed costs of HR that rapidly diminish. And because HR must reach a critical level before it induces CC, firms may find it optimal to introduce multiple HR practices simultaneously to increase the likelihood of reaching that critical level. [8]

A careful selection of HR practices can also shift the costs or the benefits line, Bij, leftward. First, a more homogeneous workforce will increase the probability that firms will move from the low-HR to the high-HR workplace by shifting the gains function left in Figure 3. If the distribution of costs in Figure 4 are more homogeneous, so the distribution has a lower variance and higher peak, the lowering of costs as in Figures 4a through 4d will be accelerated. Thus, if firms select more homogenous workers, they will select more innovative HR practices (or none at all), because in this case, small increases in HR will have a big effect on connective capital. Second, if firms match a subset of workers from type i who have low costs of asking with a subset of workers from type j who has low costs of sharing, then for each value of HR, the gains to HR are greater, or the total gains function shifts leftward. In effect, this matching introduces a positive correlation between the costs distributions of askers and sharers, so that cov(φ_i^A, φ_j^S) > 0 and thus F(φ_i^A, φ_j^S) > F(φ_i^A) F(φ_j^S) for independent distributions of forming F(φ_i^A) and F(φ_j^S). Third, firms can also shift the gains distribution leftward by hiring workers selectively – by hiring those with low costs, or by hiring a more diversely skilled workforce (large HC_j-HC_i). Firms with high returns to problem solving, δ, but low HR costs of selecting workers, will gain more from this selection process.

II. Empirical Evidence on Connective Capital Using Data from Steel Mills

The model of the firm's and worker's decision to invest in connective capital produced a series of implications above, and a number of these implications can be examined using data that we have gathered from steel mills. We focus first on the link between HR practices and

[8] The nonlinearity of the effects of HR on connective capital can also be produced by models of the complementarity of HR practices. In the discussion above, we emphasized that multiple HR practices are valuable in increasing the likelihood of reciprocity. For example, firms need to establish a norm of reciprocity, encourage peer pressure when that norm is ignored by an employee, train the employees for problem solving activities, organize them in teams to undertake activities and monitoring, and lastly to select workers who have low cast so of communicating. As emphasized by Milgrom and Roberts (19xx), these individual HR practices are complements: increasing the value of any one practice will increase the value of the others. Thus, as in Figure 1, the nonlinear nature of returns to HR practices implies that firms will either have low levels of these practices, or high levels of these practices.

connective capital, then on the worker's investment in connective capital, and finally on the link between connective capital and productivity. First we describe the data.

The Production Process

Our goal is to confine our analysis to technologically comparable production lines, so that we can examine the extent of connective capital and the effects of HR practices on CC with no variation in technology. Of course, the disadvantage is that we cannot test the degree to which technology, or differences in the value of problem-solving, δ, cause differences in connective capital. The sample for this study comes from finishing lines in the integrated steel industry. In this production process, very thin sheets of steel are treated in some manner, such as coating or softening or stretching the steel. The sheets of steel are typically four feet wide, about 1/16 inch thick or less, and about a mile long, so the steel is stored in coils weighing about 12 tons each. To process it, the coil is loaded on to the entry end of the line and the end of the new coil is welded to the steel that is currently running in the line. The new coil unrolls as the strip is processed continuously through the line. Machinery on the line cleans, heats, stretches, or coats the steel, and finally the steel is recoiled and cut at the end of the line. It is a continuous process that is very capital intensive.

If connective capital is to have any value on these lines, it is important that workers' efforts at problem solving can potentially raise productivity. The productivity of these finishing lines can vary in a number of ways. Often the line shuts down due to a "delay," where a delay is an unscheduled line stoppage when some problem is found on the line. For example, delays occur if the steel has a surface quality problem requiring correction, or a tracking problem causing the steel edges to crumple. Coils that break in the line or mechanical failures in the rolling process also cause line delays. Productivity is also lower if the line is up and running but producing poor quality steel that cannot be sold to its intended customer—which is a loss in line "yield." Thus, worker activities to solve problems in delays or surface quality will increase the productivity of the line.

Site Selection and Survey

To obtain information on workers' communications regarding problem-solving issues, we survey all the employees in seven of the types of integrated steel lines described above. These seven lines were selected so that three of the lines have the most innovative HR practices – we refer to these three innovative-HRM lines as *involvement-oriented (IO) lines*. The other four steel lines have traditional HR practices – we refer to these lines as *control-oriented (CO) lines* because they are run with more managerial control and less emphasis on employee involvement. These lines were chosen from the set of 36 steel lines that we visited and used in our previous study of the productivity effects of HR practices (Ichniowski, Shaw, and Prennushi, 1997). In that study, we identified four types of HR systems, from traditional having no innovative HR practices, or high-performance having all the innovative HR practices. From this set of 36 mills we randomly selected the seven to represent the high and low end or the HR spectrum.[9]

The survey of workers has three main features (see Appendix A for a sample of the survey). First, it asks the employee put a check mark next to the name of each person with whom he typically communicates, where the names of all people with responsibilities for running or managing the line with whom the respondent works are listed. Second, as the respondent checks off these names, the survey asks employees to identify the topic area of the communications with other employees: operation-related issues, customer-related issues, and work routines. Third, respondents identify the frequency of their interaction with other workers for the various communication topics. The three categories are "daily", "weekly", or "monthly."

There are typically about 90 workers per line, ranging from 87 to 118 workers. The number of blue-collar workers – operators and maintenance workers – ranges from 47 to 51 workers across most lines. Samples in regression analyses below include responses for up to 642 employees across the seven lines.

The Firm's Investment in HR Practices and Connective Capital

Our model of the firm's investment in innovative HR practices and thus in connective capital, implies that:

<u>Hypothesis H1</u>: Firms with higher levels of innovative HR practices will have greater amounts of connective capital – firms will use indoctrination, norms, peer pressure, training,

[9] We conducted new visits to these steel finishing lines between May 1996 and May 1998. Initially, we spent about three weeks in one IO mill and three weeks in one CO mill observing the day-to-day activities and talking with production workers, supervisory staff, and managers about their jobs. During this period, we conducted pilot tests of data collection survey instruments. After these initial visits to two of the sites, we visited each mill site between June 1996 and October 1997 for about one week each. During these visits, we made more direct observations of the workers, conducted further interviews, and collected certain survey data. A final set of visits to each site was conducted between March 1998 and May 1998, with each visit lasting about three days.

careful selection of employees, information sharing, and incentive pay to induce greater investment in connective capital by workers.[10]

Hypothesis H2: Connective capital is not equivalent to Human Capital – they may or may not be correlated.

Recall that our measure of connective capital, from equation (1), is

$$\text{Connective Capital}_i \equiv CC_i \equiv \sum_{j\neq i}^{N} cc_{ij}\, HC_{jj}$$

for person i, where

$$cc_{ij} = 1 \quad \text{if worker i communicates with worker j}$$
$$= 0 \quad \text{if worker i does not communicate with worker j}$$

and $HC_{ij}=HC_j-HC_i$. Because it will be hard to measure human capital, we also consider an alternative proxy for connective capital, that we call 'connective capital ties %:'

$$\text{Connective Capital Tie\%}_i \equiv (\text{CC Tie\%})_i \equiv \sum_{j\neq i}^{N} cc_{ij} / N$$

where in equation one we set $HC_{ij}=1$, so that we assume that the gains of worker i talking to j are the same across all j workers (and thus normalize the value to 1). Because finishing lines can be of slightly different size, we divide the number of ties by the size of the mill, N, to create a variable that is comparable across mills – Connective Capital Tie% is simply the percent of all people in the mill whom worker i talks to within a specified period about specific problems.

The basic means in our data seem to support Hypothesis H1: high HR lines have much more connective capital. Using traditional measures of human capital, of either education or tenure as proxies for HC_i and HC_j, we find that the IO lines have approximately twice as much connective capital as the CO lines (Table 1, columns 1 and 2). However, these proxies for human capital are likely to be very inadequate measures of individual-specific problem-solving skills in steel mills. Therefore, we assume no differences across individuals in human capital, and look only at the CCTie%. Once again, IO mills have much greater amounts of connective

[10] There is one set of implications of the model that cannot be tested using the steelmill data. We cannot test whether mills are selecting workers or training workers to encourage connective capital development (for example, selecting workers with more homogenous costs of sharing). In other words, we cannot test whether there are specific HR practices that are used to enhance the development of connective capital.

capital as measured only by their volume of communications (column 3, Table 1): the CCTie% is more than three times as great on IO lines as on CO lines across all individuals.

In Hypothesis H2 we ask whether human capital and connective capital are correlated— in our data there is very little correlation between human capital and connective capital across these lines. Though these IO and CO lines have very different apparent amounts of connective capital, they are essentially identical in terms of their mean values of measured human capital. The mean values of education (and their distribution) are virtually identical for the IO and CO lines: the mean education levels are 13.26 and 13.22, respectively (columns 4 and 5 of Table 1). Tenure levels are a little bit different – CO lines are older and thus have a subset of workers who have considerably higher tenure. The conclusion is clear: *IO lines and CO lines have basically equivalent amounts of human capital*, when human capital is measured by traditional measures of education and tenure. Moreover, because IO lines have the same measured human capital as CO lines, the second conclusion is clear: *the IO lines have nearly twice as much connective capital than do CO lines because workers on IO lines communicate more with fellow workers.*

Reinforcing these conclusions, when we add controls for differences in job acitivity (operators vs. managers) and other factors, our regression results show that high-HR IO lines continue to have much greater amounts of CC Ties than do CO lines. In Table 2, we regress of CCTie% as a function of HR environment (IO vs. CO) and introduce controls for differences in the types of communications (operating vs. customer vs. work routines), the strength of the ties (daily vs. weekly vs. monthly), and the job-class of the worker. Across all jobs, IO lines communicate 18 percentage points more (column 1). The greatest gains are for production workers and team leaders on IO lines (column 2). In fact, if we focus only on Strong Ties (daily communications), managers have no difference in communications across the IO vs. CO lines.[11]

Finally, in Table 3 we add controls for the workers' human capital, and show that the conclusion that high-HR IO lines have much higher levels of connective capital remains true.

Thus overall, our communications data suggests that in highly innovative HR plants, both workers and firms are investing in greater amounts of connective capital. Our data also shows

[11] We also estimate regressions in which we omit observations in IO lines with very large numbers of ties to test whether the positive IO effect is driven by the higher communications for a subset of the workforce. Even eliminating these outliers in IO lines, we find that the IO effect is very positive for all groups of workers.

that connective capital is very distinct from human capital – plants with equivalent human capital have very different connective capital.

The Worker's Investment in Connective Capital

We can examine the outcomes of the workers' investment in connective capital in two ways, by modeling the probability of each (i,j) worker pair communicating, and by modeling the volume of communications for individuals. Our model above suggests that following hypotheses:

<u>Hypothesis H3</u>: Considering the level of communications between the i,j pair:

a) Connective capital will be greatest between i and j if they are 'different types' – for example, when they have very different educational levels or tenure levels. These differences raise the productivity of connective capital – worker i with HC_i has the greatest gains from asking a worker j who has more human capital, HC_j.
b) Connective capital will be greatest if the i and j are 'similar types' – for example, when they are the same age, gender, race, or same occupation. In this case, they are more likely to have either similar costs of asking and sharing, where these similar costs could arise because firms choose HR practices that make workers more similar, or that match workers with similar costs of sharing and asking, or because they work near one another. Moreover, in our extended model above, workers in the same occupation may have more relevant knowledge – operators have knowledge that is relevant to other operators than it is to staff employees doing product design.[12]

<u>Hypothesis H4</u>: Considering the level of communications for worker i:

a) Connective capital will be highest if he has high levels of HC_i because that raises the value of asking for his input. However, it also raises the costs – workers with high HC_i have a greater opportunity cost of their time, and thus will be less likely to communicate.
b) Connective capital will be highest if he has low costs of communicating, all else constant. For example, if he is sensitive to peer pressure, so his costs will fall with peer pressure.

[12] Lazear (1999) makes these same points in his model of who should join teams—that teams should be composed of workers who offer diverse skills, but whose costs of communicating are also low. He makes the added point that team members must also have skills that are relevant to the problem to be solved—someone in marketing might not be very valuable to someone in operations. We return to this point later in the empirical work below.

This is most likely to happen if other workers physically near him can monitor his behavior (which is true of operators, but not managers).

c) Connective capital will be highest if he has is young, because the long run returns to investing in CC are greater. Add Glaeser…

<u>Who Talks to Whom?</u>

Do workers communicate more when they are "similar" or when they are "different?" In Table 4, we regress the probability of communicating for all possible i,j pairs of workers, separating the IO lines (columns 1,2) and the CO lines (columns 3, 4).

For the innovative IO lines, workers talk to each other if they hold the same job. That is, operators talk to operators, managers to managers, etc. In some sense, this result is surprising – our model implies that people should communicate more when their human capital is different (or $HC_j - HC_i$ large), all else constant. Our results suggest instead that people communicate more when they have low costs of communicating – as they would if they worked near each other, or if they are similar in tastes or demographics. Alternatively, because we don't observe true human capital that is valuable for problem solving, it is quite possible that operators talk to operators because they know the most about solving operating problems, and the 'human capital' skills that managers would offer in solving operating problems are less valuable to operators.

For CO lines, employees are more likely to communicate when they are of the same tenure cohort. That is, workers with the most tenure ("senior" workers) talk to each other the most, followed by the least tenure ("new" workers) talking to each other as well. Again it would seem that he costs of communicating are influencing the outcome the most, rather than the human capital informational gains from communicating with particular partners.

In examining the results in Table 4, remember that all workers talk more to each other in the IO lines than in the CO lines. Thus, even though operator-operator communicates are higher than manager-maintenance communications on IO lines, all these pairs are more likely to communicate on the IO lines than on the CO lines. And recall that, in general, operators talk the least on CO lines, so that is why they have negative effects in columns (3) and (4).

Overall, in addressing Hypothesis H3, it appears that workers who are 'similar types' communicate the most to solve problems. However, since we have very inadequate measures of human capital for production workers, we certainly cannot rule out the potential importance of diversity in human capital as a cause for communicating to solve problems – surely that is important as well, as shown next.

Individual Investment in CC.

As displayed in Table 5, among production workers there are no human capital variables that predict the volume of communications. In other words, among production workers, communications between production workers on IO lines are much higher than on CO lines, but education and tenure have no effects on these volumes within lines. In contrast, there are human capital effects for non-production workers (managers, staff, foreman). Those workers with more education or more tenure tend to communicate more. Moreover, communications tend to decline with age for non-production workers.

Thus, there is some confirmation for Hypothesis H4 – workers with more skills, or younger workers, communicate a bit more when our measures of skills are useful (or when education and tenure could be considered reasonable measures of skills). Among operators, for whom we have no reasonable measures of skills, we have no evidence on skill effects on communications.

Communications Networks for Individuals

We finally provide additional evidence of differences that exist between the individual workers on IO and CO lines by presenting graphic illustrations of the ties that exist among workers within these lines. In Figures 5 and 6, we look first at communications within crews (Figure 5) then communications between crews and managers (Figure 6). We are restricting our attention to two representative IO lines and two representative CO lines in our sample.[13]

Figures 5a-5d show dramatically higher amounts of communication between the operators within the crews of the IO lines compared to the CO lines. The finishing lines in our sample run continuously, and allowing for days off during the week, four operator crews (A, B, C and D crews) are required to man the line on a continuous basis, and crew sizes range from 6 to 10 at these sites. As reflected in the figures, nearly all IO crew members communicate with 70% to 100% of employees on their own crews. In contrast, on the CO lines, the extent of

[13] For the purpose of these illustrations, we focus on operations-related communications of any frequency (daily, weekly or monthly) but diagrams for other communication topics would show a similar pattern of extreme differences in the number of inter-worker communication ties between IO and CO lines.

within-crew interaction is much lower.[14] On CO line 2, between 10% to 15% of all possible within-crew ties exist in the four crews. Furthermore, out of 35 operators across the four crews at CO line 1, 20 workers communicate with either no other crew workers or one other crew worker *on his own crew*. Similarly, on CO line 2, 67% of the crew operators across the four crews communicate with two or fewer fellow crew members. *Employees on the CO lines are doing their own jobs on their own.*

Figures 6a-6d display the amount of communications between groups. Each network diagram shows eight nodes—one each for the four crews and for maintenance workers, foremen, management, and staff. High levels of inter-group interaction (indicated with bold lines) exist when at least 60 percent of all possible two-person ties between the two groups exist.[15] Medium levels of interaction (indicated with thin lines) mean that between 36% and 59% of all possible inter-group ties exist. Low levels of interaction (indicated with dashed lines) mean that no more than 35% of all possible ties inter-group ties exist.

Figures 6a-6d show dramatically higher amounts of communications between different crews and between operating crews and maintenance on the IO lines compared to the CO lines. For CO line 1, the average of the cross-group tie percentages is 23.1%, and the range is from a low of 9% to a high of 42%. For CO line 2, the average cross-department communication tie percent for these five blue-collar worker groups is only 10%, ranging from a low of 0% to a high of only 19%. In contrast for the IO lines, the average cross-crew ties percent among production and maintenance worker groups is 76.2% at IO line 1 and 71.6% at IO line 2. Across both IO lines, these cross-crew tie percentages range from a low of 53% (or, 11 percentage points above the maximum cross-crew tie percent at the CO line) to a high of 90%. *Horizontal communications, either among production workers on the same crew or among operators and maintenance workers on different crews is substantially higher in IO lines than in CO lines.*

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[14] At IO line 1, the average crew member communicates about operations issues with 86% fellow crew members on the A crew, 78% on the B crew, 90% on the C crew, and 61% on the D crew. For IO line 2, the corresponding figures for the four crews are 76%, 86%, 70% and 73%. On CO line 1, the A crew at the CO line has the highest level of intra-crew interaction of any crew at either of the CO lines at 44% of all possible intra-crew ties, but this is only about half the level of communication for the IO line crews. For the other three crews at CO line 1, an average crew member communicates with only 12% of his fellow crew members on the B crew, 19% on the C crew, and 16% on the D crew.

[15] We calculate this "average" level of inter-group interaction by first determining the number of possible worker-to-worker ties between any two groups. For example, the total number of possible two-person ties between the six-person A crew and the six-person B crew at IO line 1 is 36 ties. The actual number of two-person ties between the A and B crews divided by the 36 potential ties gives the percentage for the inter-group level of interaction for those two groups.

The patterns of communications between the managerial groups (the foremen/team leader or manager) and the various production-worker groups is not higher on IO lines than on CO lines. The average tie percentage of inter-group interactions between managers and the six other employee groups is actually higher in CO line 1 (52% on average across the six non-manager groups) than it is in either of the IO lines (42% in IO line 1 and 45% in IO line 2). At CO line 2, manager interaction with the six other employee groups is lower (or 21% on average). On all lines, managers must communicate with workers to do their jobs. As in Table 2, there is little significant difference between the communications patterns of managers on IO versus CO lines.

The Productivity Gains from Connective Capital and Innovative HR Practices

Our model has two general implications:

H5: Firms with greater amounts of connective capital will tend to have higher levels of productivity (all else constant). And therefore, firms with higher levels of HR practices will tend to have higher levels of productivity.

H6: Firms will tend to be either high-HR or low-HR firms.

In our previous research for integrated steel finishing lines, we show that innovative HR practices appear to raise workers' productivity on these lines (Ichniowski, Shaw, and Prennushi, 1997). Moreover, these productivity gains amount to very large differences in operating income for the lines. Thus, the paper establishes a link between innovative HR practices and productivity, but does not empirically identify the cause of that link. In this paper, we show that high-HR lines have more connective capital. We are never able to show that connective capital is the cause of the higher productivity on innovative HR lines. To show that would require that we obtain individual communications data for all workers on all 36 steel lines, which would never be possible. However, since we are looking at exactly the same sets of production lines, and connective capital is higher in the high-HR lines, it seems very plausible that connective capital produces problem solving that contributes to the higher productivity of these lines.

In this paper, we cannot test whether firms tend to be high-HR or low-HR and thus high-CC and low-CC (Hypothesis H6). However, note that the steel mills that have high CC have much higher levels of CC and HR than do the traditional HR mills.

III. Is Connective Capital a Form of Social Capital?

This notion of connective capital is similar to the concept of "social capital." Nahapiet and Ghoshal (1998, 243) define social capital as "the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or a social unit. Social capital thus comprises both the network and the assets that may be mobilized through that network." However, social capital is a not a precisely defined term with many competing definitions available (see Manski, 2000, 13-14). Here, we define connective capital more specifically as human capital that workers share with other workers to solve problems.

While more specific than the idea of social capital, connective capital shares many features with commonly held views about social capital. Connective capital is a group or firm characteristic, yet determined by decisions of each individual in the group. There are positive externalities to connective capital – when a worker shares ideas and knowledge with other workers, it makes others more productive. Network effects are important in connective capital, since a worker who gets ideas from a co-worker can pass that information along to others in his or her set of contacts.

IV. Conclusion

Connective capital is the information flow obtained by worker i that is used by him to solve problems. Such capital is costly to develop – the cost is the worker's own opportunity cost of time as well as the cost of time for all who communicate with him. Moreover, because some of the returns to CC accrue to the firm and not the individual worker, workers will tend to underinvest in connective capital. Firms can enhance workers' CC investment if the firm invests in innovative HR practices that raise workers' optimal values of CC. Thus, the short run costs, of time and HR practices, earn returns over the long run as problem-solving raises output. Overall, innovative HR practices will produce higher levels of connective capital. However, firms will want to specialize – to be either high-connective capital high-HR firm or low-connective capital low-HR firm. The cause of the specialization is twofold – workers' investments in CC produce externalities, so that CC investments by one person can spill over and raise CC investments by others; and as firms' invest in more HR to build connective capital, the amount of connective capital will accelerate with increases in HR. Firms should invest in either high amounts of CC and HR or low amounts.

Data from the steel industry provides some evidence that firms with innovative HR practices are investing in the "connective capital" of their workforces. Workplace communications among employees, especially among production and maintenance workers, are much more extensive under innovative and participatory HR practices than under traditional HR practices. In innovative HR lines, all workers communicate more extensively to solve operating problems on the lines. These differences in the behavior of workers across workplaces with similar technologies but different HR practices help account for the finding in the literature that manufacturing firms with systems of innovative HR practices achieve higher levels of productivity.

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Table 1

Mean Values Human Capital and Connective Capital

TYI	Aggregate Human Capital				
	CONNECTIVE CAPITAL[a]			HUMAN CAPITAL	
	By Education	***By Tenure***	***Tie%***	**Education**	**Tenure**
Control-Oriented	340.9 (152.3)	298.8 (349.5)	.117 (.161)	13.26 %hs=56 %coll=17	13.67 (7.4)
Involvement-Oriented	664.7 (133.3)	535.4 (228.3)	.387 (.275)	13.22 %hs[b]=59 %coll[c]=20	11.86 (5.7)

a-standard deviations in parantheses
b - %hs is the percent of workers with a high school degree or less;
c - %coll is the percent of workers with a college degree or more.

Table 2
Determinants of Connective Capital Tie%
Dependent Variable = (No. of Ties)$_i$/(N_{plant})

	Connective Capital Tie%			
	All Ties (1)	**All Ties (2)**	**Strong Ties (3)**	**Weak Ties (4)**
Production Workers	.092 (6.28)	.091 (10.88)	.062 (8.12)	.067 (6.58)
Managers	.078 (4.39)	.103 (6.30)	.071 (6.41)	.061 (4.03)
Non-Production Staff	.053 (5.34)	.064 (4.21)	.055 (3.78)	.039 (2.08)
Foremen/Team Leaders	.149 (4.51)	.084 (2.59)	.052 (1.98)	.047 (1.92)
Involvement-oriented HRM Practices (IO)	.175 (15.18)			
Production Workers*IO		.199 (13.47)	.118 (5.57)	.169 (9.65)
Managers*IO		.151 (5.44)	.023 (1.50)	.201 (5.96)
Non-production Staff*IO		.176 (7.65)	.114 (3.19)	.163 (7.42)
Foremen/Team Leader*IO		.283 (5.55)	.205 (4.31)	.253 (3.80)
R^2	0.49	0.50	0.37	0.55
N	5688	5688	1896	1897

Standard errors are adjusted for worker-specific clustering; t-statistics are in parentheses. Also included are controls for type of communication topic (the data is stacked by communication topic, so there are three observations per person for three topics).
Strong Ties refers to the sample of daily communications; Weak Ties refers to the sample of monthly communications; All Ties refers to the daily, weekly, and monthly communications (stacking the data across all three types).

Table 3
Connective Capital Tie% with Human Capital Variables
Dependent Variable = (No. of Ties)$_i$/(N_{plant})

	Connective Capital Tie%		
	All Ties (1)	**Strong Ties (2)**	**Weak Ties (3)**
Production Workers*IO	.211 (11.22)	.096 (4.76)	.198 (8.12)
Managers*IO	.282 (7.89)	.098 (3.52)	.296 (5.65)
Non-production Staff*IO	.260 (8.31)	.160 (2.87)	.250 (7.90)
Foremen/Team Leader*IO	.323 (9.80)	.238 (5.59)	.289 (4.46)
Age – Operators	.0003 (0.25)	-.0025 (-1.80)	.0017 (0.91)
Non-operators	-.0040 (-3.18)	-.0043 (-2.14)	-.0034 (-2.58)
Tenure – Operators	.0016 (1.11)	.0021 (1.66)	.0009 (0.49)
Non-operators	.0038 (2.45)	-.0011 (-1.16)	.0068 (2.73)
Education – Operators	.0050 (0.61)	.012 (1.92)	-.003 (-0.25)
Non-operators	.021 (2.07)	.032 (2.12)	.007 (0.61)
(Education) ^{2} – Operators	-.0001 (-0.38)	-.0004 (-1.51)	.0001 (0.21)
Non-operators	-.0007 (-1.45)	-.0013 (-1.81)	-.00003 (-0.06)
R^2	0.54	0.41	0.60
N	2657	885	889

Standard errors are adjusted for worker-specific clustering; t-statistics are in parentheses. Also included are controls for type of communication topic (the data is stacked by communication topic, so there are three observations per person for three topics).
Strong Ties refers to the sample of daily communications; Weak Ties refers to the sample of monthly communications; All Ties refers to the daily, weekly, and monthly communications (stacking the data across all three types).

Table 4

Who Talks to Whom: The Probability of Communication

Dependent Variable: Tie =1 if Communication Between Worker (i,j) Pair
Tie =0 if No Communication

	IO Lines		CO Lines	
	(1) strong ties	(2) weak ties	(3) strong ties	(4) weak ties
Mean of Dependent Variable	.368	.302	.075	.052
Independent Variables				
Occupations				
1. Operator-Operator	.311	-.013	-.109	-.124
	(4.12)	(-2.65)	(-3.20)	(-2.97)
2. Manager-Manager	.326	-.011	-.053	.014
	(2.52)	(-0.09)	(-1.16)	(0.97)
3. Operator-Manager	.291	-.001	-.077	-.082
	(3.76)	(-0.02)	(-2.60)	(-2.48)
4. Staff-Manager	.122	.122	-.064	-.052
	(1.50)	(1.75)	(-2.02)	(-1.55)
5. Staff-Staff	.154	-.043	-.082	-.125
	(2.21)	(-0.71)	(-2.25)	(-3.09)
6. Staff-Operator	.173	.013	-.093	-.132
	(2.46)	(0.20)	(-2.68)	(-3.25)
7. Staff-Maintenance	.095	.027	-.032	-.059
	(1.20)	(0.42)	(-0.95)	(-2.44)
8. Operator-Maintenance	.125	.029	-.070	-.049
	(1.86)	(0.42)	(-2.38)	(-2.21)
9. Maintenance-Maintenance	.471	-.201	.038	.041
	(4.47)	(-2.44)	(0.82)	(1.23)
10. Supervisor-Supervisor	--------	--------	-.041	-.037
			(-0.70)	(-0.47)
11. Supervisor-Staff	--------	--------	-.032	-.111
			(-0.78)	(-2.73)
12. Supervisor-Operator	--------	--------	-.063	-.121
			(-1.64)	(-2.92)
13. Supervisor-Maintenance	--------	--------	.008	-.054
			(0.18)	(-1.35)
14. Manager-Maintenance	--------	omitted dummy variable		--------
Education				
15. Both High School	.189	-.116	-.010	.010
	(3.58)	(-2.65)	(-0.59)	(0.61)
16. Both Post High School	.055	.064	-.001	.024
	(1.20)	(1.65)	(-0.08)	(1.99)
17. Both College	-.008	-.025	0.19	.007

	(-0.16)	(-0.67)	(0.90)	(0.38)
18. HS-Post High School	.143	-.068	-.009	.008
	(4.09)	(-2.45)	(-0.68)	(0.68)
19. HS – College	-.075	-.032	.009	.014
	(-1.47)	(-0.63)	(0.59)	(0.97)
20. Post High School-College	--------	omitted dummy variable		--------
Age				
21. Matching Age	.020	-.010	.005	.012
	(1.09)	(-0.60)	(0.94)	(1.89)
Tenure				
22. Both New	-.063	-.071	.045	.010
	(-1.32)	(-1.42)	(2.35)	(0.48)
23. Both Average	-.037	.068	-.019	.014
	(-0.63)	(1.37)	(-1.87)	(1.43)
24. Both Senior	.058	-.071	.147	.026
	(0.72)	(-1.17)	(4.34)	(1.92)
25. New- Average	-.044	.010	-.009	.022
	(-1.14)	(0.28)	(-0.81)	(1.36)
26. New- Senior	-.153	.086	.031	.020
	(3.18)	(1.56)	(2.31)	(1.19)
27. Average- Senior	--------	omitted dummy variable		--------
R^2	.09	.05	.05	.04
N	3893	3893	12549	12549

Note to Table 4: The omitted categories for categorical variables above are manager-maintenance for occupations; post high school-college for education, average- senior for tenure, and non-matching age for age.

Table 5
Who Talks to Whom: The Probability of Communication

Subsample: Operators Who Talk to Operators Only

Dependent Variable: Tie =1 if Communication Between Worker (i,j) Pair
Tie =0 if No Communication

	IO Lines		CO Lines	
	(1) strong ties	(2) weak ties	(3) strong ties	(4) weak ties
Mean of Dependent Variable	.530	.278	.032	020
Independent Variables				
Education				
1. Both High School	.032	-.133	.011	.196
	(0.27)	(-1.08)	(0.39)	(4.21)
2. Both Post High School	.085	.007	.026	.220
	(0.75)	(0.06)	(1.12)	(4.61)
3. Both College	-.069	-.203	-059	-.121
	(-0.38)	(-1.57)	(-1.05)	(-3.72)
4. HS-Post High School	.159	-.157	.028	.208
	(1.31)	(-1.32)	(1.02)	(4.44)
5. HS – College	-.317	.119	-.067	-.064
	(-3.10)	(0.96)	(-3.50)	(-1.83)
6. Post High School-College	--------	omitted dummy variable		--------
Age				
7. Matching Age	-.018	.004	.015	.011
	(-0.34)	(0.10)	(1.90)	(2.77)
Tenure				
8. Both New	-.290	.162	.035	.002
	(-2.48)	(1.71)	(1.79)	(0.09)
9. Both Average	-.297	.280	.004	.003
	(-2.27)	(2.46)	(0.34)	(0.49)
10. Both Senior	.005	.013	.185	.023
	(0.03)	(0.11)	(2.08)	(1.35)
11. New- Average	-.232	.211	-.003	.007
	(-3.16)	(4.28)	(-0.27)	(0.85)
12. New- Senior	-.311	.190	-.014	.009
	(2.53)	(1.72)	(-1.13)	(0.85)
13. Average-Senior	--------	omitted dummy variable		--------
R^2	.12	.09	.05	.20
N	381	381	2688	2688

Table 6
Means of Selected Variables in Sample of Worker Communications Pairs

Variable	*Mean* IO	CO
Strong Ties	.368	.075
Weak Ties	.302	.052
Both HS	.329	.328
Both Post HS	.222	.230
Both College	.078	.040
HS- Post HS	.219	.301
HS- College	.276	.190
Both New	.427	.143
New- Average	.292	.333
New- Senior	.140	.139
Both Average	.101	.189
Both Senior	.012	.048

Appendix A - Summary of Communication Survey Questions

Here is a summary of the questions that are included in the communication survey. The survey is relatively easy to fill out and takes between 10-15 minutes. The survey is organized with one question per page. The rest of the page contains the names of all of the employees. Beside each employee name are three check boxes indicating the frequency of communication. Each respondent will be asked to read each question and place a check mark by the name of each employee's name that meet the question's criteria.

For example, below is a brief illustration of one page from the survey.

With whom do you typically communicate?

Please check as many names as may be appropriate.

	Daily	Weekly	Monthly or less		Daily	Weekly	Monthly or less
Adams, Fred	[ ]	[ ]	[ ]	Hurley, Stanley	[ ]	[ ]	[ ]
Christopheson, Bill	[ ]	[ ]	[ ]	Marshall, Jim	[ ]	[ ]	[ ]
Haynes, Lester	[ ]	[ ]	[ ]	Smith, Don	[ ]	[ ]	[ ]
Lieman, Mary	[ ]	[ ]	[ ]	Norville, David Jr.	[ ]	[ ]	[ ]
Jordan, Barb	[ ]	[ ]	[ ]	Ostertag, John	[ ]	[ ]	[ ]
Childs, Tim	[ ]	[ ]	[ ]	Patton, Mike	[ ]	[ ]	[ ]

The survey questions include:

1. With whom do you typically communicate?
2. Who do you communicate with about operational issues?
3. Who do you communicate with about safety issues?
4. Who do you communicate with about quality issues?
5. Who do you communicate with about maintenance issues?
6. Who do you communicate with about customer issues?
7. Who do you communicate with about supplier issues?
8. Who do you communicate with about job related routines that you have developed?
9. Who do you communicate with about the performance of the company issues?
10. Who are you dependent on for critical information in doing your job?
11. Who is dependent on you for critical information in doing their job?
12. How much training would you need to fill-in for the following employees
13. With whom would you feel comfortable filling-in for you?

All of the surveys will be handed out by the research team along with an envelope. The respondents will be instructed to return the survey in this envelope and seal it to members of the research team. This will help to protect the confidentiality of the responses.

Figure 5a - intra-crew Communication Interactions for IO Line 1

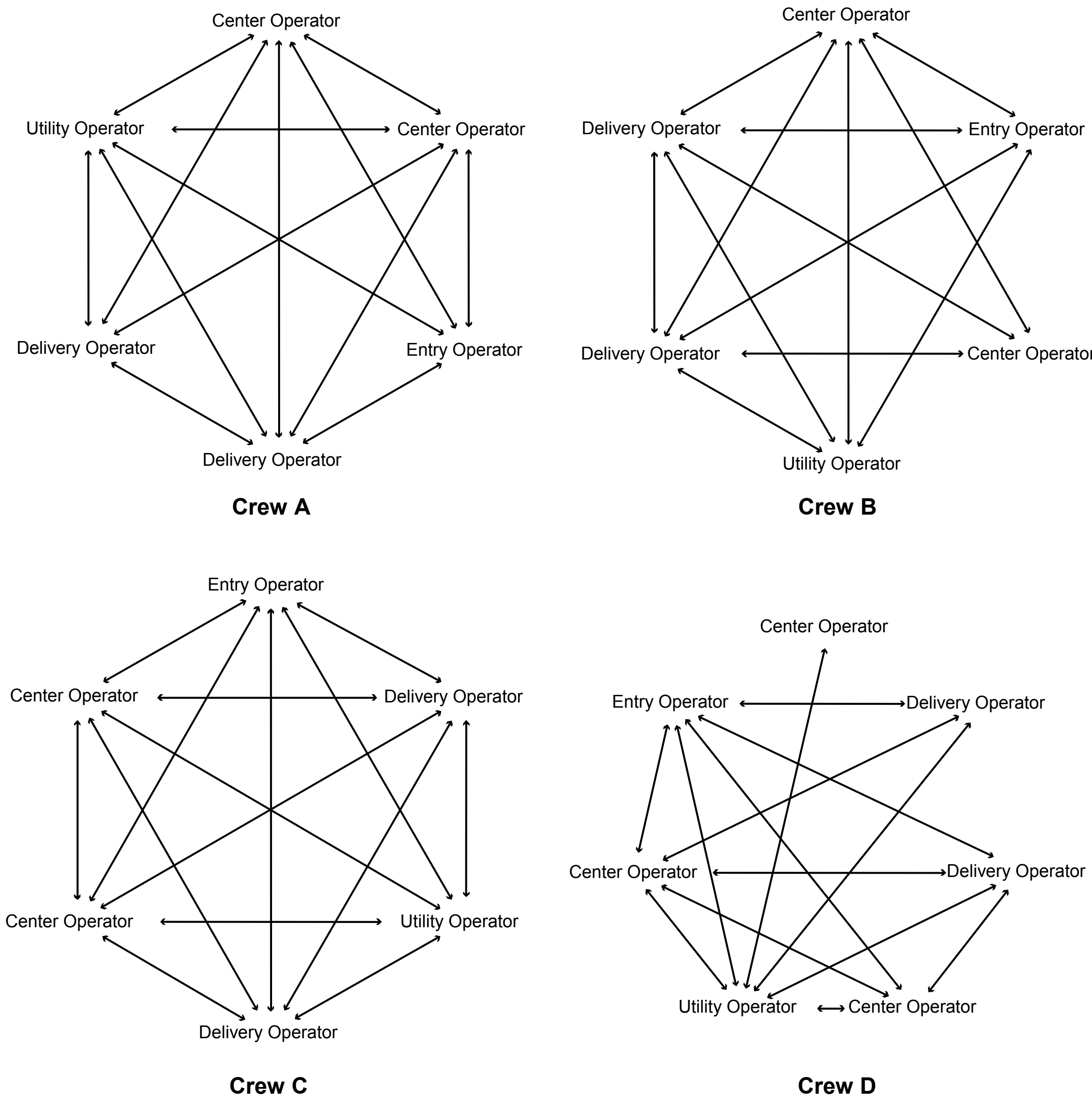
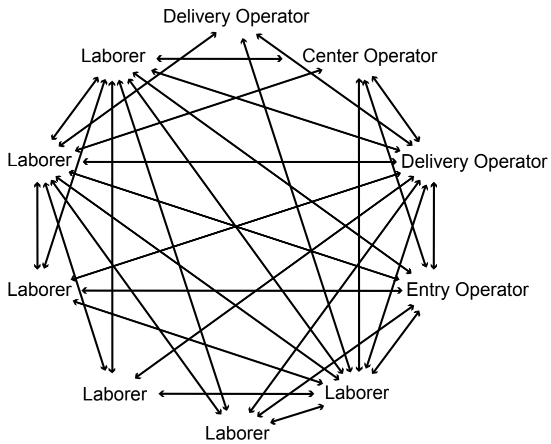
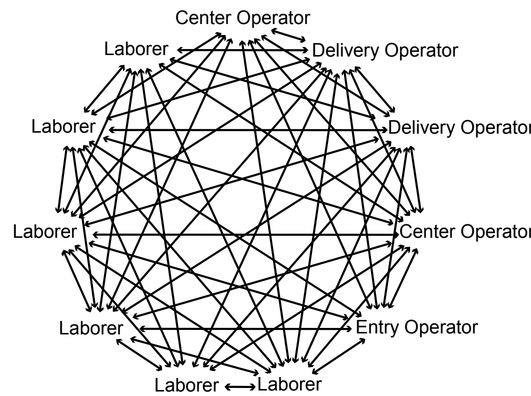


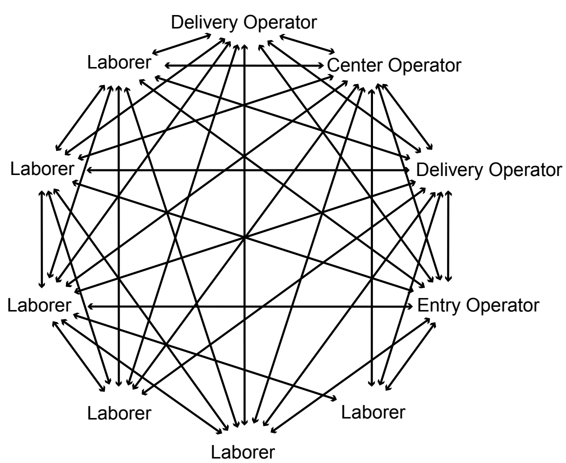
Figure 5b - intra-crew Communication Interactions for IO Line 2



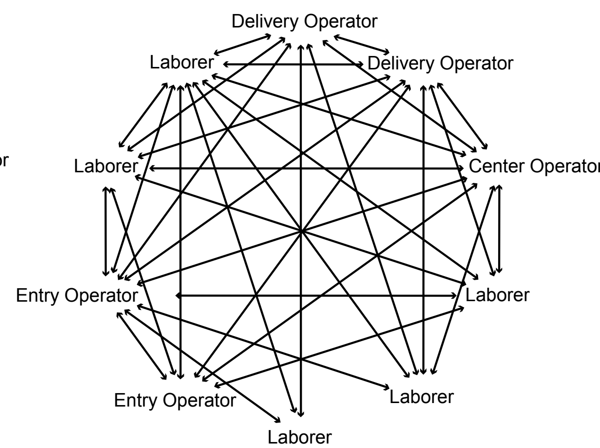
Crew A



Crew B



Crew C



Crew D

Figure 5c - intra-crew Communication Interactions for CO Line 1

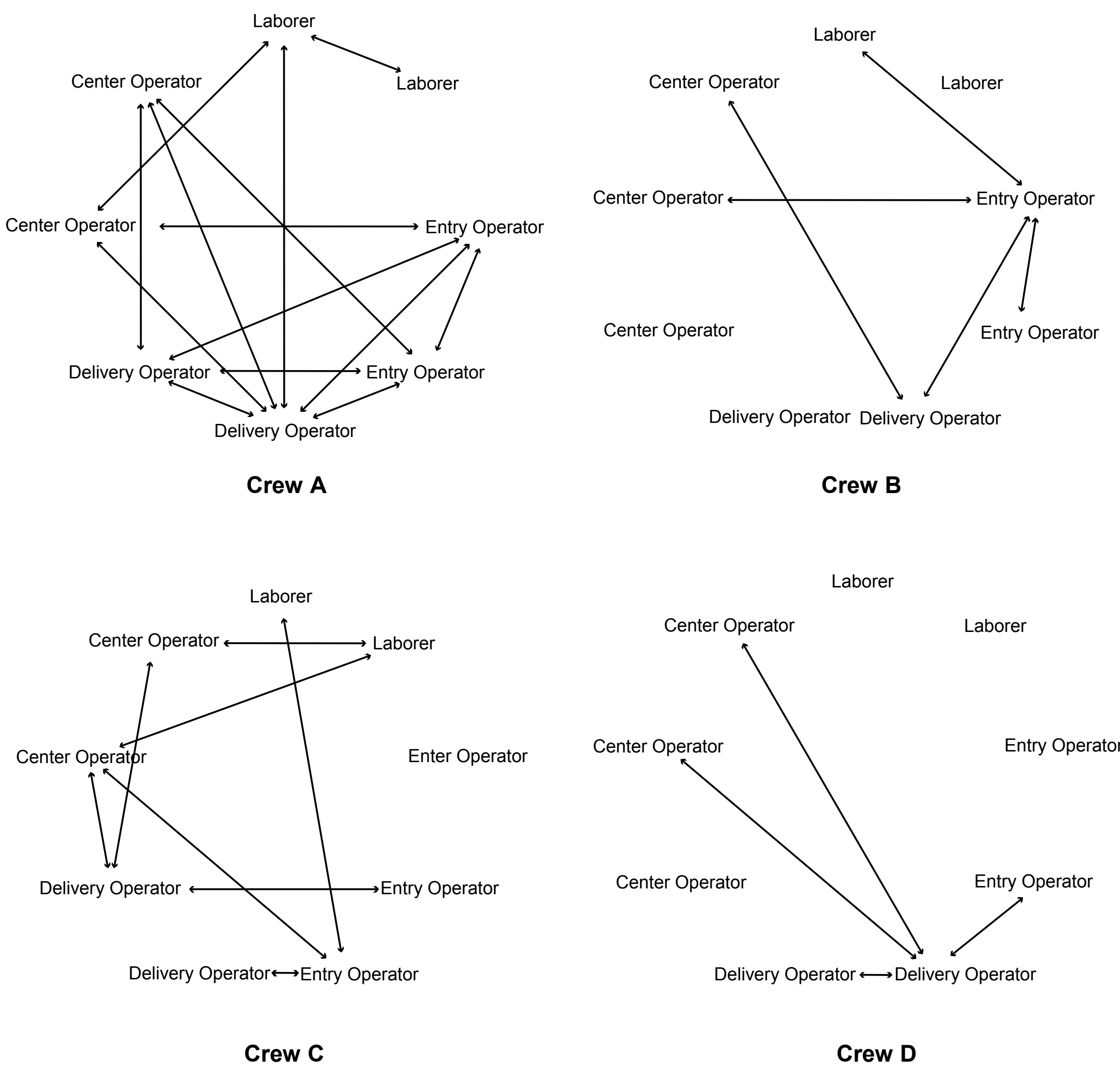


Figure 5d - intra-crew Communication Interactions for CO Line 2

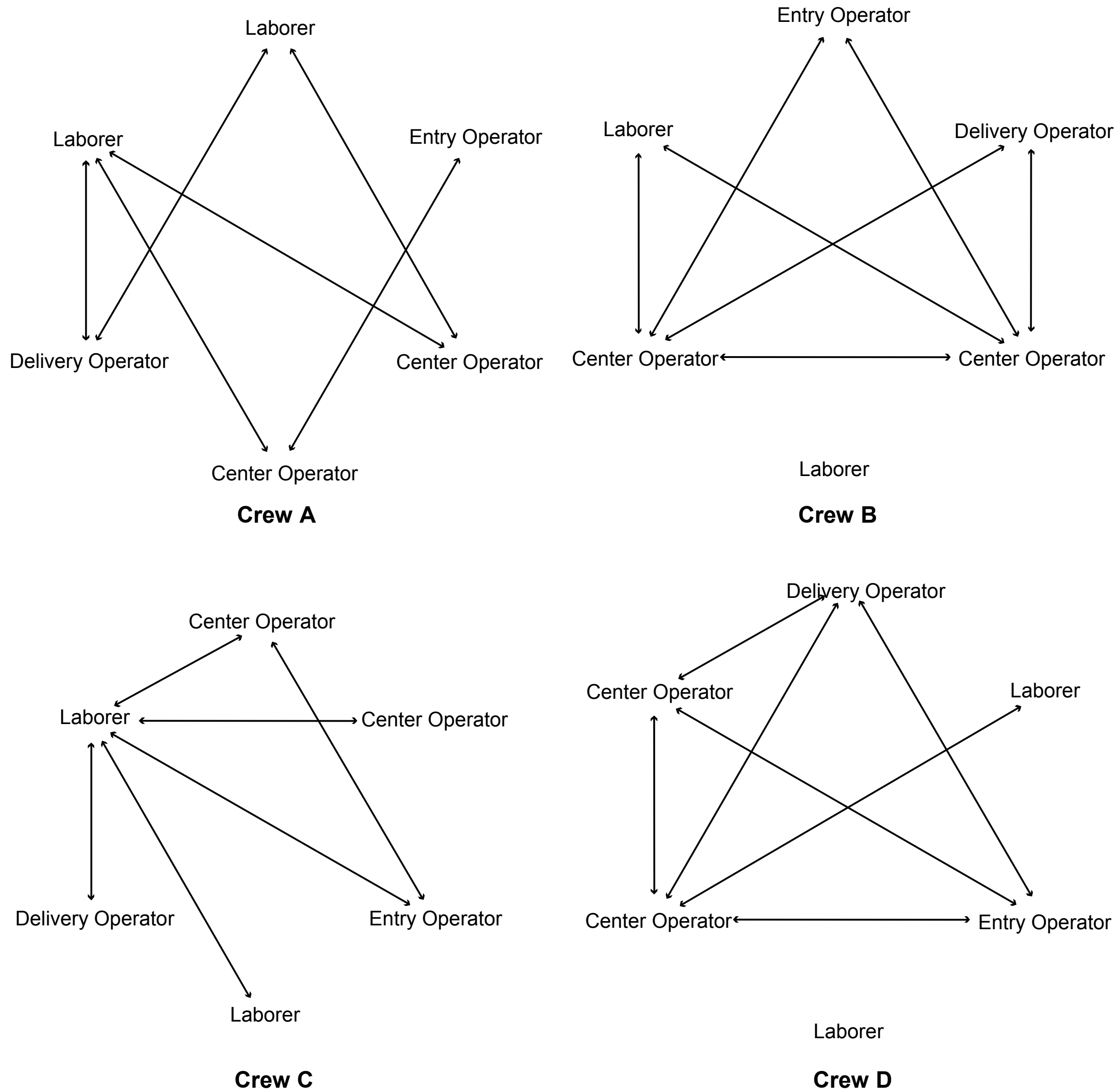
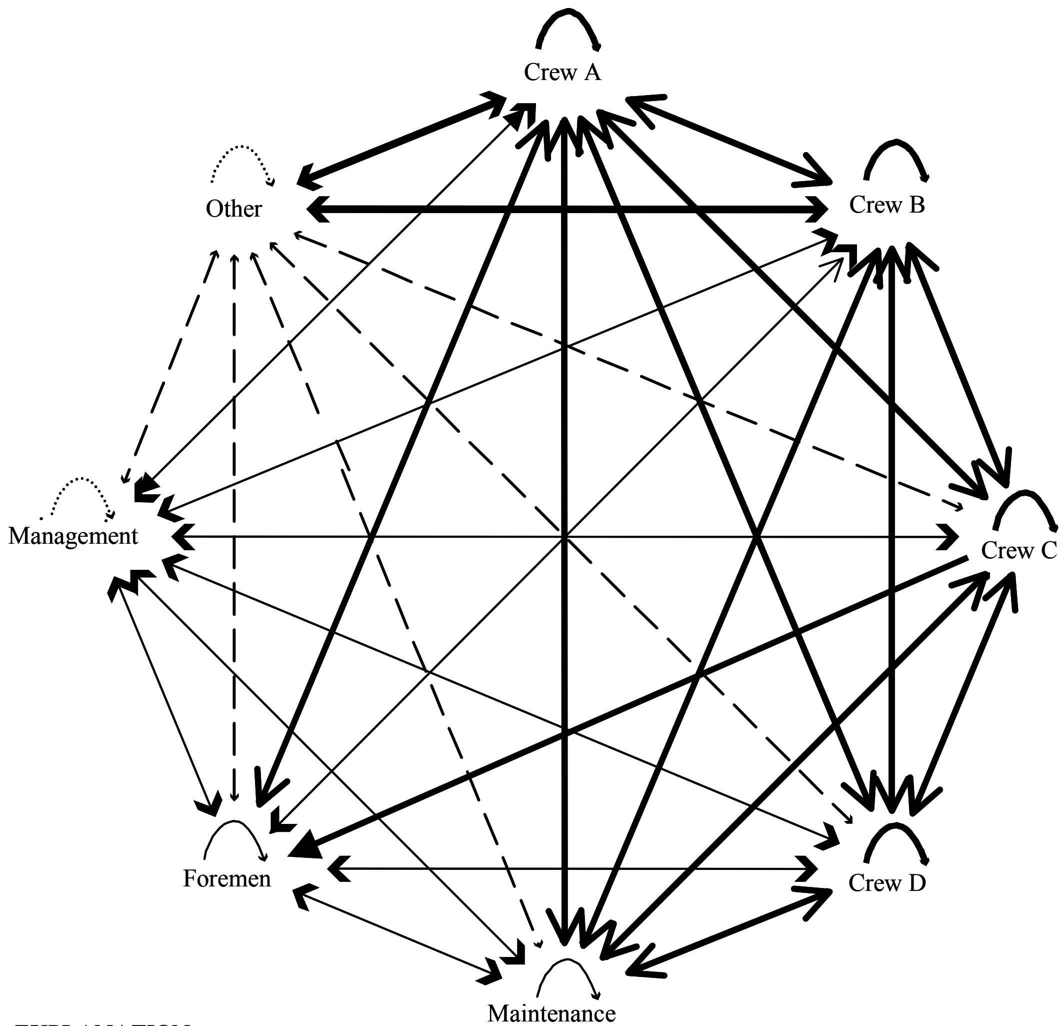


Figure 6a – Inter-group Communication Interactions for IO Line 1



EXPLANATION

Intra-group communication

Level of Inter-group Communication

High

Medium

Low

Figure 6b – Inter-group Communication Interactions for IO Line 2

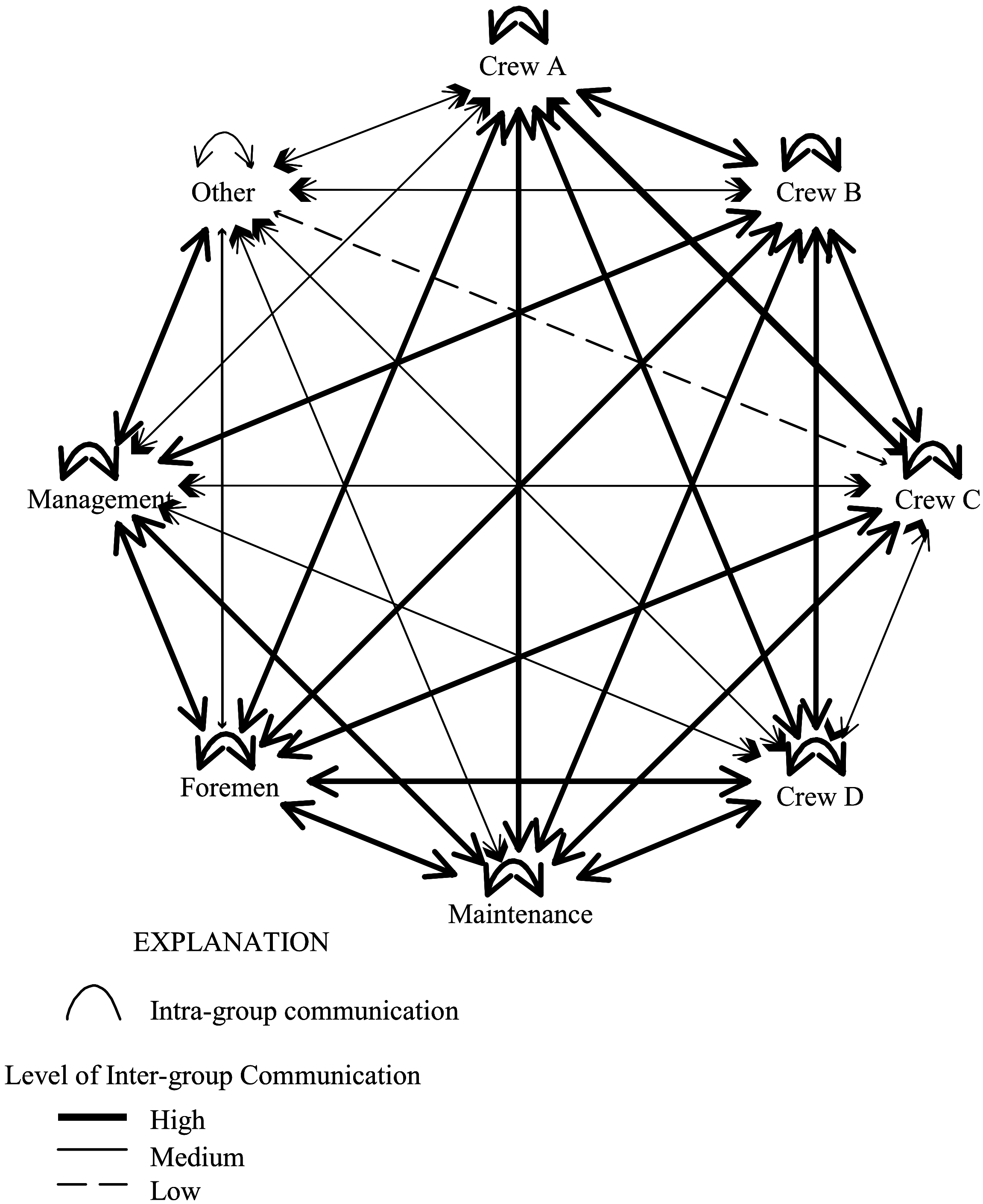
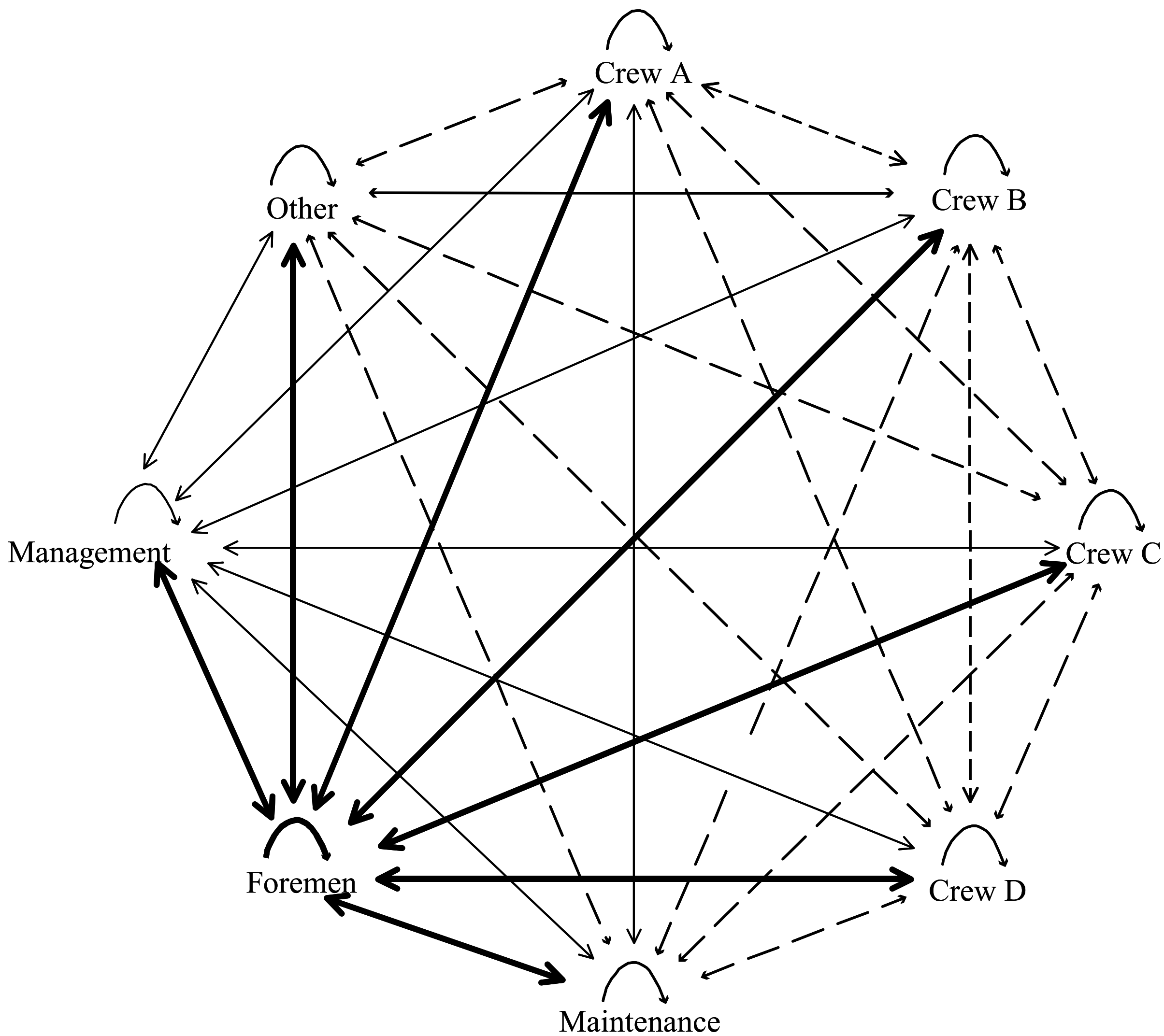


Figure 6c - Inter-group Communication Interactions for CO Line 1



EXPLANATION

Intra-group communication

Level of Inter-group Communication

High

Medium

Low

Figure 6d – Inter-group Communication Interactions for CO Line 2