Training and Turnover in the Evolution of Organizations
Author(s): Natalie S. Glance, Tad Hogg and Bernardo A. Huberman
Reviewed work(s):
Source: *Organization Science*, Vol. 8, No. 1 (Jan. - Feb., 1997), pp. 84-96
Published by: INFORMS
Stable URL: http://www.jstor.org/stable/2635230
Accessed: 13/12/2012 02:55

Training and Turnover in the Evolution of Organizations

Natalie S. Glance • Tad Hogg • Bernardo A. Huberman
Xerox Palo Alto Research Center, 3333 *Coyote Hill Road*, *Palo Alto*, *California* 94304

There are two reasons why you should read this paper. First it addresses an interesting and important issue. Second it shows how the dynamics of organizations can be studied and understood by using mathematical modelling and computer simulation. Thus the paper provides a methodology to study problems that would otherwise be difficult to investigate.

Børge Obel

Abstract

An organization's decision whether or not to train its workers affects the overall economy, even if the firm does not factor the economy into its decision. If all firms within an industry fail to train their workers, the whole economy suffers. Hence, training workers is a type of public good, a category that encompasses a broad range of social dilemmas. Employees face a similar dilemma in their choice of how much to contribute to the overall productivity of the organization. If employees receive a share of the profits regardless of their contribution, some may decide to free ride on the efforts of their fellow workers. If all employees decide to do so, the company will fail.

The two dilemmas on the employee and organizational levels are closely interrelated. On one side, the benefits of training accrue only to the extent that employees contribute to the organization. Thus, a firm should take into account how it expects a training program to affect employee effort as well as employee turnover. On the other side, trained workers produce at higher rates, which in turn may affect how much they contribute and how often they migrate to other firms in comparison with untrained workers.

The authors study the dynamics of training and turnover in firms facing both organizational- and employee-level dilemmas. First they establish a simple model that captures those conflicts and incorporates imperfect information and both worker and organizational expectations. Organizations can be both created and dissolved, and employees can move between firms, start new ones, or leave the industry for good. Next the authors summarize the different ways the dilemmas can unfold over time, collated from a number of computer experiments. For example, under one set of conditions, the double dilemma can be resolved for the industry as a whole and productivity then increases steadily over time. Alternatively, the organizational-level dilemma may remain unresolved and workers may contribute at fluctuating levels. In that case the overall productivity stays low. The authors find a positive correlation between high productivity, low turnover, and enterprise size, a relation that has also been observed in the empirical literature on training, stability, and turnover in organizations.

(*Social Dilemmas*; *Training*; *Turnover*)

Introduction

During periods of slow growth and a weak economy, corporations commonly cut programs to maintain profitability. Training programs in particular are often targeted because employee turnover is generally higher during times of economic uncertainty (OECD 1993). Even in the best of times, organizations must decide how much to invest in on-the-job training, balancing the benefits of increased productivity against the costs of training. Because trained workers can migrate easily between competing firms, another firm can potentially benefit from the increased productivity of workers trained by the former employer without paying the costs. For example, a survey of metalwork firms in Wisconsin indicated that managers are reluctant to train their workers because they fear competitor firms will lure their employees away before their investment costs are recouped (Jobs for the Future 1991). Consequently, fear of losing trained employees to competitors can lessen a company's incentive to train and lead to less investment in skills than is economically desirable (Blinder and Krueger 1991, Bishop 1991).

1047-7039/97/0801/0084/$01.25

Ironically, numerous studies have shown that untrained workers change jobs more often than trained ones (OECD 1993, Lynch 1991). The negative correlation between training and turnover has been documented in several companies, such as the Marriott Corporation, Florida Power Corporation, IDS Financial Services Inc., and Target (Hequet 1993). All of those firms had increases in retention rates after investments in various training programs. Unfortunately, many firms are reluctant to train until some degree of stability is achieved within their workforce, and their hesitation may in turn be reinforced by observed high turnover rates (Lynch 1991). Can the vicious circle be broken?

An organization's decision whether or not to train its workers also affects the economy, even if the firm does not factor the economy into its decision. If all firms within an industry fail to train their workers, the whole economy suffers. Hence, training workers is a type of public good (OECD 1993), a category that encompasses a broad range of social dilemmas from the support of public radio to the so-called "tragedy of the commons" (Hardin 1968) to recycling programs. There is a long history of interest in such problems in political science, sociology, and economics (Schelling 1978, Hardin 1982). Any resolution of the training dilemma will depend not only on the benefits and costs associated with a particular training program, but also on the firm's expectations about employee turnover and the policies of competing firms.

Employees face a similar dilemma in their choice of how much they contribute to the overall productivity of the organization. If employees receive a share of the profits regardless of their contribution, some may decide to free ride on the efforts of their fellow workers. If all employees decide to do so, the company will fail. Profit sharing and employee ownership can exacerbate the dilemma (Cooper et al. 1992), and indeed the gains from profit-sharing plans are frequently lower than expected (Bullock and Lawler 1984, Kanter 1987). In principle, the problem could be resolved by strict management, but in practice, worker monitoring is always imperfect and employee effort can vary from high to low within the range allowed (Osterman 1987).

The two dilemmas on the employee and organizational levels are closely interrelated. On one side, the benefits of training accrue only to the extent that employees contribute to the organization. Thus, a firm should take into account how it expects a training program to affect employee effort as well as employee turnover. On the other side, trained workers produce at higher rates, which in turn may affect how much they contribute and how often they migrate to other firms in comparison with untrained workers.

Because the two dilemmas are strongly coupled, studying them in a natural organizational setting is difficult. Computer simulations provide an effective way of studying such problems and their evolution. If the assumptions are clearly stated, many scenarios can be explored without the disruptions they would cause if tried in a firm.

We explore the dynamics of training and turnover in firms facing both organizational- and employee-level dilemmas. First we establish a simple model that captures the conflicts and incorporates imperfect information and both worker and organizational expectations. Organizations can be both created and dissolved, and employees can move between firms, start new ones, or leave the industry for good. Next we summarize the different ways the dilemmas can unfold over time, collated from several computer experiments. For example, under one set of conditions, the double dilemma can be resolved for the industry as a whole and productivity then increases steadily over time. Alternatively, the organizational-level dilemma may remain unresolved and workers may contribute at fluctuating levels. In that case the overall productivity stays low. We find a positive correlation between high productivity, low turnover, and enterprise size, a relation that has also been observed in the empirical literature on training, stability, and turnover in organizations (OECD 1993, Price 1977).

Our dynamic model of training and turnover in organizations both confirms the empirical observation that the two variables are tightly interlinked and reveals how the connections might be understood. In addition to supporting the empirical data on firms, it provides a way to understand how the interplay between different variables, such as turnover, training, enterprise size, and productivity, comes about and evolves over time.

Modeling Organizational and Employee Strategies

In this section, we describe our model of organizational training, individual learning, and decision-making on both the worker and organizational levels. In our model, all organizations within an "industry" produce the same good, for which there is a completely elastic demand outside the industry. That assumption means the industry can grow indefinitely as there is no ceiling for production. Employees, or "agents," can move between organizations, within the bounds allowed by the organizations' "managers." The managers must decide whether or not to train the agents in their own organization, and the agents must decide whether or not to contribute to production.

Interwoven Social Dilemmas

Our model of management training and employee production is a two-level social dilemma. At the level of the agent, each individual must decide whether or not to contribute to production (a binary approximation to the continuous range of effort they can deliver). For the case of profit-sharing assumed by the model, the agents receive equal shares of the organization's total production, independent of its contribution. Each agent is tempted to free ride on the industriousness of the other agents, but if all agents do so, nothing is produced and everyone loses.

On the higher level of management, organizations must decide whether or not to train their agents. If a manager decides to train, members of the organization learn over time, and when its members do contribute to production, they do so at progressively higher levels as time passes. However, training agents comes with a cost to the total utility produced by the organization, which managers must take into account. An organization does not want to train its agents only to have them stolen by a competitor, but if all agents receive training the entire industry is better off, garnering higher utility over time.

Expectations

Recent work on the dynamics of single organizations coping with the agent-level social dilemma has shown that high levels of production can be sustained when groups are small or hierarchically structured into smaller groups with fluid boundaries (Glance and Huberman 1993, 1994a, b). The ongoing nature of the social dilemma lessens its severity if the agents take the future into account when making decisions in the present. How agents take the future into account is wrapped into what we call their "expectations." The barest notion of expectations comes from the economic concept of horizon length. An agent's horizon length is how far he or she looks into the future or expects to continue interacting with the other agents in the organization. The agent's horizon may be limited by his or her lifetime, projection of the organization's lifetime, bank interest rates, and other factors.

Our notion of expectations differs from the standard rational expectations treatment in economics (Blanchard and Fischer 1989) where by agents are assumed to form expectations about the future by using near-perfect knowledge of the underlying model. That notion is self-consistent, but circular: the agents predict the future exactly. In our model of expectations, agents believe their present actions will affect those of others in the future. The extent of the effect depends on the size of the organization and the present level of production. The larger the group, the less significance an agent accords his or her actions; the benefit produced by the agent is diluted by the size of the group when it is shared among all agents. An agent who free rides can expect the effect to be very noticeable in a small group, but less so in a larger group. The reasoning is similar to that a student uses when deciding whether or not to attend a lecture he or she would prefer to skip. Among an audience of 500, the student's absence would probably go unnoticed (and if all students in the class reason similarly...). In a small seminar of 10, the student might incur the personal censure of the professor.

In our model, the agents expect that their actions will be imitated by other agents and that the extent of the mimicry will depend on present levels of production. An agent expects that if he or she decides to free ride ("defect") in a group of contributors, or "cooperators," others will eventually choose to defect as well. The agent also believes that the rate at which the switchover will occur over time depends on the fraction of the group currently cooperating. The greater the number of agents already cooperating, the faster the transition to defection. Similarly, an agent expects that if he or she starts cooperating in a group of free riders, others will start cooperating over time. Again the agent believes that the rate depends on the proportion of cooperators, which in this case is very low. Our key assumption is that agents believe their actions influence contributors or "cooperators" more than sluggards or "defectors." The difference in influence is taken to be proportional to the fraction of agents already cooperating, and is used in deriving Equation (6).

To some extent, that set of beliefs is arbitrary. We can imagine other scenarios for which another set of expectations would be more appropriate, but there is a class of expectations wherein the general conclusions of our work hold. Specifically, our model can accommodate the class of expectations for which agents believe that the strength of their influence on the amount of cooperation extends into the future as far as their horizon, decreases with the size of the group, and increases *roughly* with the current proportion contributing. Perhaps agents believe instead that their influence is greatest when a certain fraction cooperates, but declines at both extremes of full cooperation and full defection. Thus, they imagine their influence grows with the fraction cooperating only when that proportion is small. Alternatively, perhaps agents believe their influence is greatest at the extremes and declines when the group is a mix of cooperators and defectors. In that case, the agents imagine their influence grows with the fraction cooperating only when that proportion is large. Both of those cases are within the range of expectations compatible with our model.

In our interlocking model of organizational training and agent cooperation, we extend the formulation of expectations to the organizational level. Managers decide to train or not on the basis of the number of organizations in the industry and the number that currently train their agents. Folded into that decision and into their expectations is the behavior of the agents who make up a manager's organization. A manager's horizon length depends on the tenure lengths of the agents: the longer the agents stay, the longer the manager expects them to stay in the future, and the more reason the manager has to train them. Likewise, a manager predicts greater future value from training when more of the agents are actively contributing instead of free riding.

Conditions for Cooperation

In a profit-sharing organization in which individual agents receive equal shares of the utility produced, the utility to an agent is the share minus the costs. An agent who contributes incurs a cost that reduces his or her net gain; an agent who does not contribute incurs no cost but causes the total production of the organization to decline. That is, the utility U_i to agent i in organization m is the agent's share minus its cost c for cooperation:

$$U_i = \frac{1}{n_m} \sum_{j=1}^{n_m} b_j^m k_j - ck_i \tag{1}$$

where k_i is one if the agent contributes and zero otherwise, n_m is the size of the organization, and b_j^m is the benefit produced when agent j cooperates. The individual agent utility also depends indirectly on the managerial policies of the organization. If an organization trains, its agents will learn over time and produce at progressively higher levels. Otherwise, the benefit of cooperation for the agents remains fixed over time. Specifically, we use a linear model of learning, which is given by the differential equation

$$\frac{db_i^m}{dt} = \gamma \kappa_m \tag{2}$$

where γ is the learning rate and κ_m is one if the organization trains and zero otherwise.

All agents in the industry start at the same baseline benefit for cooperation, $b_{\min}$. When agents move between organizations within the industry, they retain only a fraction of the gain in their benefit for cooperation obtained over time through training, although the benefit is not allowed to fall below the baseline level. The loss in learning when agents migrate models the incomplete transfer of knowledge between organizations, that is,

$$b_i^l = r(b_i^m - b_{\min}) + b_{\min}, \tag{3}$$

so that r gives the fraction of learning that is transferred.

The organizational utility is the total utility produced by an organization's constituent agents minus any training costs. For each agent who contributes, the organizational utility increases by that agent's contribution. If the agent is learning over time, the agent's contribution also increases over time, but is offset in part by the costs for training that agent. Organizational utility is given by

$$U^m = \sum_{j=1}^{n_m} b_j^m k_j - n_m T \kappa_m \tag{4}$$

where T is the training cost per agent.

Agents and managers use their respective utility functions to guide their decisions to contribute or not contribute and to train or not train. They project future earnings in accordance with their expectations and their horizon lengths. For individual agents, the criteria for cooperation were derived by (Glance and Huberman 1994b) for a simpler model and extend easily to the present case. Individuals cooperate if their observed share of production

$$\langle b \rangle^m = \frac{1}{n_m} \sum_{j=1}^{n_m} b_j^m k_j \tag{5}$$

exceeds the critical amount

$$b_{\text{crit}}^m \equiv \frac{b_{\min}}{H\alpha} \left(\frac{n_m c - b_i^m}{b_i^m + \gamma \kappa_m H - c} \right) \tag{6}$$

where H is the evaluation horizon and α is the rate at which agents reevaluate their choices. That critical amount was derived by computing the net benefit an individual would accrue by deciding to cooperate, based on the fraction of individuals perceived as cooperating at that time and how long the game is expected to last, as given by the horizon H. If the individual cooperates only when the benefit is positive, defects when it is negative, and chooses at random when the benefit is zero, the condition for cooperation can be expressed in terms of a critical size. According to that criterion, beyond a critical group size, no agent will cooperate, and below a second critical group size all agents will cooperate. Notice that the longer the horizon, the smaller the critical group for agent cooperation. Conversely, the larger the group, the larger the critical size and the more difficult it is to secure voluntary cooperation. Between the two limits are two equilibrium points, one of mostly cooperation and the other of mostly defection. The group dynamic tends toward the equilibrium closest to its initial starting point. Generally, one of the equilibria is metastable, whereas the other is the long-term equilibrium. By metastable we mean an equilibrium that is stable against small perturbations but unstable against large ones. (An example is a ball in a trough situated on top of a hill.) If a group falls into a metastable state, it may remain there for very long times (exponential in the size of the group). Because of uncertainty the group eventually will switch to the global equilibrium very suddenly (in time logarithmic in the size of the group), as shown by Glance and Huberman (1993).

The training criterion for organizations follows by analogy. A manager trains when the observed fraction of organizations training exceeds the critical amount

$$f_{\text{crit}}^m \equiv \frac{1}{H_m \alpha_m}\left(\frac{NT - \gamma f_c^m}{\gamma f_c^m - T}\right) \tag{7}$$

where N is the number of organizations, f_c^m is the estimated fraction cooperating in the organization, and H_m and α_m are the horizon and reevaluation rate for the managers, respectively. The criterion has the following properties. Managers are more likely to train when their horizon lengths are long, training costs are low in comparison with the agents' learning rate, the number of organizations is small, and they estimate a large proportion of their agents to be cooperating. A manager can estimate the fraction cooperating from the production level observed by inverting the organizational utility given by Equation (4). The estimate will differ from the actual fraction cooperating because an organization's agents may have received different amounts of training and will consequently have different benefits for cooperation. However, for simplicity, we model the manager's estimate of the fraction cooperating by using Equation (5) as

$$f_c^m = \frac{\langle b \rangle^m}{b_{\min}}. \tag{8}$$

Although this estimate somewhat overstates the amount of cooperation and worsens as the agents learn over time, it captures the essential feature that the manager's perception of the workers is based on their overall production.

Fluidity parameters are as follows.

μ: moving threshold;
η: break away threshold;
Ω: entrepreneurial rate;
ρ: joining threshold.

We intend the two conditions for action to be taken as heuristic guidelines rather than precise formulas. The agent-level condition for cooperation was derived from the expectations set forth previously, but its qualitative features are what interest us. We expect the heuristic form of the criteria to hold for a wide range of expectations. For some sets of expectations they may not hold, in which case a different model would then be appropriate. Although the heuristics may differ from those used by real organizations, we believe they are indicative of the qualitative behavior that one expects to see in the real world.

Fluidity

We also model the changing structural nature of industries over time. We use the term "fluidity" to describe the ease with which structure can change. The parameters governing the amount of fluidity in an industry are listed in the following table. For the purpose of our model, we consider them as given exogenously; they could also be thought of as under the control of some metalevel agent (say, some regulatory mechanism) that adjusts the fluidity parameters to optimize the overall utility of the industry, or perhaps even as under individual agent control.

Fluidity describes the ease with which agents can move within an organization from subgroup to subgroup, how promptly they leave the organization for another one or leave the industry completely seeking higher personal utility, and how readily they start an organization of their own. Organizations restrict structural fluidity to the extent that they make it difficult for agents to join and difficult for them to leave or move within their organizations.

In our model of structural fluidity, managers control the rate at which constituent agents choose to move between organizations and the rate at which agents from a pool of agents exterior to the industry can join, but do not restrict agents from leaving. Specifically, agents move between organizations or join an organization only when invited by a manager. Agents accept or decline the invitation according to moving and joining strategies that optimize utility and take into account moving and joining costs (set at the metalevel). Say agent i in organization m is invited to join organization l. Agent i compares his or her organization's production level with that of organization l. Agent i will move only if

$$\langle b \rangle_l - \langle b \rangle_m > \mu b_{\min}, \tag{9}$$

where $\langle b \rangle_m$ is as defined in Equation (5) and $\mu < 1$. Similarly, if agent j is invited to join organization m from the outside pool of agents, the agent will join organization m only if the organization's production level exceeds the agent's costs:

$$\langle b \rangle_m > \rho c, \tag{10}$$

with $\rho > 1$ generally.

Agents can also decide to "break away" or leave the industry for good. In our model, an agent will break away when the organization's production level falls below a lower threshold parametrized by the break-away variable η:

$$\langle b \rangle_m < \eta c. \tag{11}$$

Some (small) fraction of the time, parametrized by the entrepreneurial rate, Ω, the agent will start a new organization within the industry instead of leaving. Thus the number of organizations in the industry can grow over time. The number of organizations decreases whenever all agents of one organization leave.

In previous work, we described how structural fluidity within a single organization makes agent-level cooperation possible (Glance and Huberman 1994b). Here we assume that the time scale of structural change is much shorter on the organizational level than on the industry level so that we can ignore intraorganizational fluidity and better pinpoint the effects of training and interorganizational fluidity.

Computer Experiments

As described in detail in the Appendix, the simulation of our model runs on two levels; the agent level and the organizational level. Agents begin their reevaluation asynchronously according to a Poisson process described in the Appendix. When they begin, they either (1) reevaluate their decision to cooperate or not according to the condition for cooperation or (2) reevaluate their choice to stay in their organization, or start a new organization, or break away from the industry completely.

Managers also begin their reevaluations asynchronously, but according to a Poisson process whose mean time increases linearly with the size of the organization. That process reflects both the more ponderous decision-making of larger organizations and the longer time scales over which organizations reevaluate their decisions in comparison with agents. When a manager begins, he or she either (1) reevaluates the decision whether or not to train the agents or (2) invites an agent from a competitor organization to join. In the second case, if the invited agent refuses to join, the manager invites an agent from the outside pool to join. Organizations prefer to steal agents from competitors because those individuals are likely to produce at higher levels as a result of training, but agents will switch only if they perceive a gain in personal utility.

That is only one of many ways to simulate such a model. Our experience running similar types of simulations indicates that one of the most important features is that the agent and managerial states be updated asynchronously (Huberman and Glance 1993), not synchronously, for accurate modeling of continuous time.

Results

The dynamics on the organizational level mirror the agent-level description: when the number of organizations in the industry exceeds a critical number, none train, and when it falls below another critical number, all train. Between those two critical numbers is a middle region in which there are two equilibria: one in which all managers train and one in which none train. The transition from the metastable state to the global equilibrium may not happen for a time exponential in the number of organizations and is very sudden when it finally occurs. The critical numbers depend on the learning rate of the agents and the training cost for the organizations.

However, for fluid industries in which agents can move in and out of various organizations, the critical regions for cooperation and defection shift for both agents and organizations. For agents, the critical regions shift because the size of their parent organizations changes over time. A small cooperating organization will tend to grow over time because outside agents see its high productivity. If the organization becomes too large and its agents do not receive training, eventually a transition to overall defection will take place. Once all the agents in the organization are defecting, the group's size will shrink because many (or all) will break away from the industry or move to another organization. At some point, the group will again be small enough to support cooperation. The cycle of cooperation-growth to defection-attrition and back again repeats over and over for each organization when managers do not train. The amount of cooperation within different organizations and is coupled to their sizes because of the agents moving between organizations.

The critical regions also shift in time for each organization, depending on how many of its agents cooperate and how long the agents stay in the same organization. Over time, what was originally an unresolvable dilemma for the managers (so none train) becomes resolvable, and eventually the dilemma can disappear completely. The behavioral regions shift (1) as the agents' tenure lengths change and (2) as the agents' production levels increase. The agents' tenure in a particular organization increases when agents remain loyal to their parent organization. Generally, agents are loyal when their colleagues cooperate. Tenure lengths are short when few cooperate within an organization because agents will move often or break away. Agents' production levels increase when their parent organizations train them and when the agents cooperate among themselves.

The detailed parameter values used in Figures 1 through 6 are included in the Appendix.

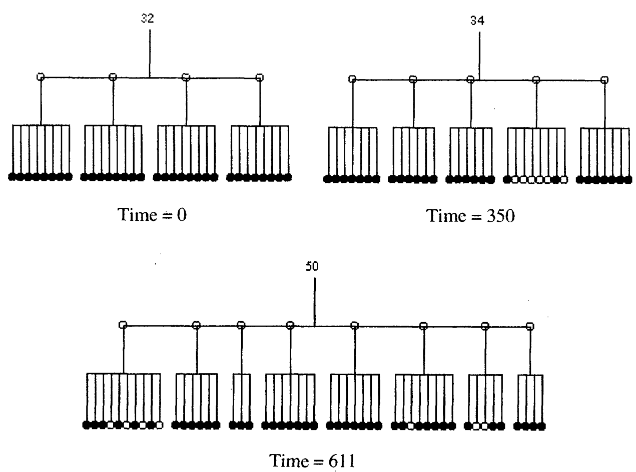
Dynamics of Industry Growth

The dynamics of agent and organizational behavior are closely coupled. Cooperation at one level encourages cooperation on the other level, and the same is true for defection. At both levels, metastable states can trap the industry in lower-performing states (or higher-performing states). For certain parameters the industry is in the two-equilibria region on both the agent level and the organizational level. We concentrate primarily on the behavior of the industry for that regime.

The dynamics of the industry are highly path dependent, a phenomenon observed in several economic systems, particularly those influenced by technological innovation (Schumpeter 1961). For the same initial conditions and parameter choices, the industry can evolve to a number of different states. Figures 1 and 2 are a series of snapshots of the time evolution of two industries that start from the same initial conditions. Initially, both industries consist of four organizations with eight agents each. The total number of agents in the industry is printed at the top of the schematic tree. The agents cooperate initially, as indicated by the filled lower-level circles; none of the managers are training, as indicated by the open upper-level circles (filled circles for cooperation/training and open circles for defection/no training). Both industries grow in size at first because their agents cooperate and new agents from outside the industry are attracted by the high levels of production (increasing the size of the industry as a whole). Once an organization grows too large, its agents switch to defection and move to another organization or break away completely (decreasing the size of the industry).

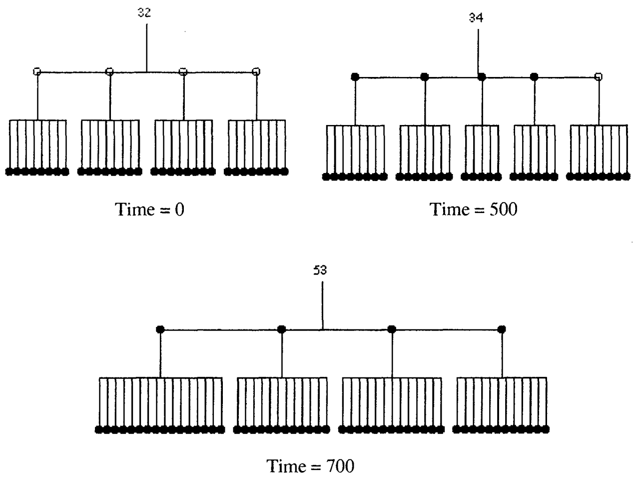
The number of organizations varies stochastically: organizations die whenever all of their constituent members leave, and new organizations form because entrepreneurs strike out on their own. The balance between those two trends depends on the average rates of the various events and on chance. When the number of organizations happens to grow over time, the dilemma on the organizational level becomes untenable: the switchover to overall training never occurs.

Figure 1 **Snapshots of the Time Evolution of an Industry Faced with Social Dilemmas at Both the Individual Agent and Organizational Levels.**



Agents must decide whether or not to cooperate knowing that they receive a share of their organization's production regardless. Organizations must decide whether or not to train knowing that the costs of training will be lost if their agents switch to another organization. The dynamics of the industry are highly path dependent. For a single set of initial conditions and parameters, the industry can evolve to several different states. The snapshots are taken from a simulation in which the number of organizations increases over time and the dilemma on the organizational level becomes untenable there is no training of the agents. Without training, the industry's utility can increase only because agents join.

Figure 2 **Snapshots of the Time Evolution of an Industry Starting from the Same Initial Conditions and with the Same Choice of Parameters as in Figure 1.**



The dynamic path followed in this case is very different. The number of organizations remains small long enough that the organizations switch to the equilibrium in which all organizations train. Once settled in the training equilibrium, the agents produce at ever-higher levels, attracting more agents from outside the organization to join, further increasing the total utility produced by the industry as a whole.

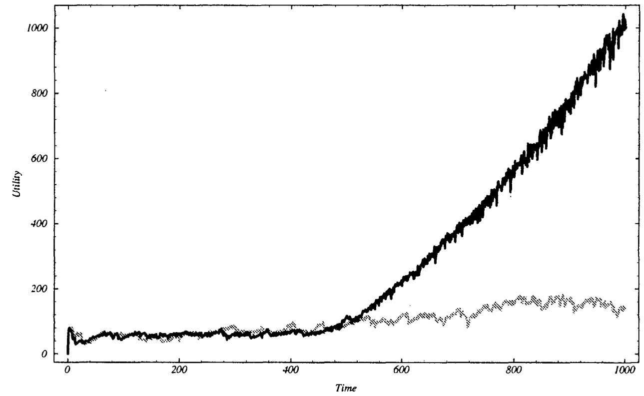
Instead, the number of organizations increases over time and the industry tends toward a state of many organizations, each with a small number of members who cycle between states of cooperation and defection. Figure 1 represents such a process. In contrast, if the number of organizations happens to stay constant or shrink, all managers eventually decide to train their agents. In that case, the industry tends toward a state with a small number of very large, highly productive organizations. Figure 2 represents such an industry.

The overall utility to the industry over time depends strongly on the path the industry follows. Figure 3 shows the abrupt deviation in overall utility between the two industries of Figures 1 and 2. Once the organizations in the second industry switch to the training equilibrium, the industry's utility rises steadily as the industry attracts more agents who learn and produce more over time.

Maximizing Industrywide Productivity

Is there a relation between the utility produced by the industry as a whole and the average tenure lengths of its members? This question is very relevant in today's world of downsizing and rapid turnover. We ran 100 simulations with the model, using the same parameters

Figure 3 **Utility as a Function of Time for the Two Industries Described in Figures 1 and 2 (in Gray and Black Respectively).**



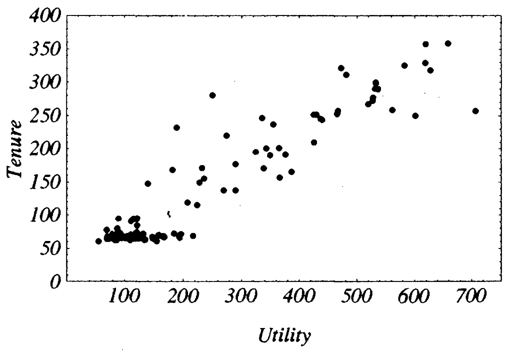
The utility at time step 1000 for the industry of Figure 2 is more than seven times greater than that of the industry of Figure 1 (1000 vs. 140).

and initial conditions given in the Appendix, to address the question. Figure 4a is a scatterplot of the correlation found between short tenure lengths and lower overall utility for the industry.

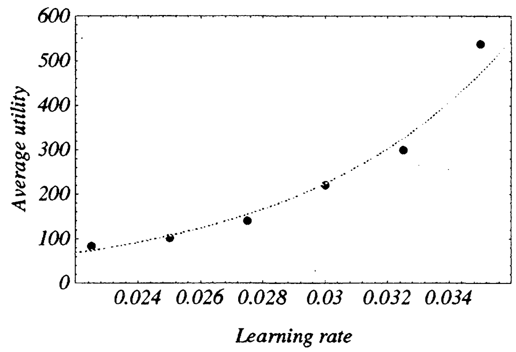
We also studied how sensitive the performance of the industries is to the values of various parameters in the model. We found two parameters to be most significant, given the constraint that the model be kept in the regime of the two-level social dilemma: the entrepreneurial rate (the rate at which agents who break away start a new company) and the ratio of the learning rate to the training costs. When the entrepreneurial rate is high, the number of organizations increases rapidly and the likelihood that the organizations spontaneously decide to train drops. In contrast, if the entrepreneurial rate is low, the number of organizations remains small and the transition to overall training becomes much more likely. Low entrepreneurial rates also limit the overall size of the industry.

The effect of varying the learning rate is more interesting because companies or industries may have some control over that variable through their policies on the level of training. To determine the average effect of increasing the learning rate while keeping training costs fixed, we ran the simulation many times for the same choice of parameters and initial conditions. Figure 4b shows the average utility over 30 runs for each datapoint. The average utility increases exponentially with increasing learning rates. Increasing the learning rate by less than 50% results in a factor of six explosion in average utility for this set of simulations. The large

Figure 4 **(Left) Scatter Plot of Average Utility Versus Average Agent Tenure Length. (Right) Average Utility Produced by an Industry over Time as a Function of Agent Learning Rates.**



For 100 simulations of an industry starting from the same initial conditions and identical parameter choices.



The data points were obtained by averaging over 30 runs for each value of the learning rate. The curve is an exponential fit to the data.

increase in utility is the expected value; the actual change in utility for a given industry can vary widely because of the path dependency described previously. Such behavior has been observed in other organizational models with different assumptions (Carley 1992).

Changing Environments and Exogeneous Shocks

Because the number of firms, their sizes, and the extent of cooperation and training all change over time, we can say that the environment of the industry changes endogenously. We have seen that the qualitative aspects of the changes are case dependent. However, the environment of the industry could also change exogenously.

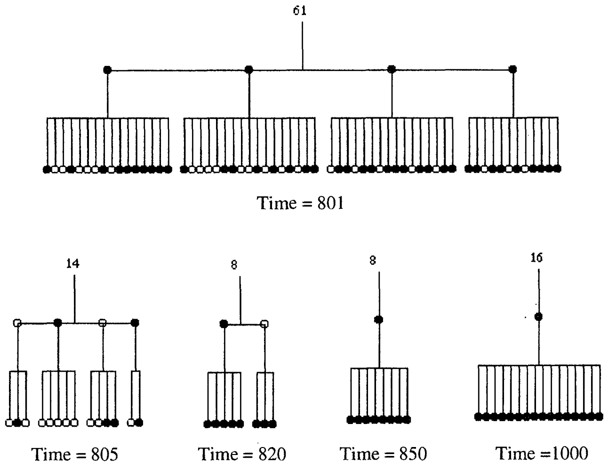
We chose to model the changing environment as affecting the increased benefits of cooperation due to training. Alternatively, a changing environment could affect the baseline benefits and costs of cooperation or the costs of training. However, we are most interested in the effects of the environment on learning. For example, the introduction of a new technology may render past training more or less useful. If the introduction is gradual, the industry can adapt to it smoothly. If the introduction is sudden, the change may be very disruptive.

When the environment changes, agents who have been trained may partially lose their advantage over agents who have not been trained. Alternatively, the advantages of training may be heightened. Agents who have not been trained are assumed to be unaffected. If the external environment changes smoothly over time, the dilemmas on the organizational and employee levels will gradually become either harder or easier to resolve for firms that train, depending on the direction of change. However, industries that train will still perform better on average than ones that do not. If the changing environment acts to lessen the benefits of training, the likelihood that the firms will train decreases, but as long as the rate of environmental loss is not too high, industries that train will accrue higher utilities on average than ones that do not.

If the environment changes abruptly, the effect on trained agents can be sudden and large. For example, if the agents were trained to exploit one technology, they may not have the set of skills necessary to deploy a radically new one. We model this extreme case by imagining that an exogenous shock decimates the accumulated learning of trained agents. Before the shock, trained agents are much more productive than untrained agents. After the shock, trained and untrained agents produce at equal levels.

Consider as a concrete example an exogenous shock that occurs at time step 800 for the industry in Figure 2. By time step 800, the industry is made up of four large firms. All of the firms are training, and all of the 62 total employees are cooperating. An exogenous shock will render all of the employees' learning useless, lowering their benefits of cooperation to the baseline level; that is, the agents are now basically untrained. The sudden downward change in the benefit of cooperation makes it impossible for the firms to sustain employee cooperation because of their large size. In Figure 5, we see in the first snapshot a sudden burst of defection by time step 801. Four time steps later, most of the employees have fled the industry. The number of firms has decreased to two by time step 820, and then to one by time step 850. However, the one firm remaining still trains, and that firm is able to recover

Figure 5 The Industry of Figure 2 Undergoes an Exogeneous Shock at Time Step 800.

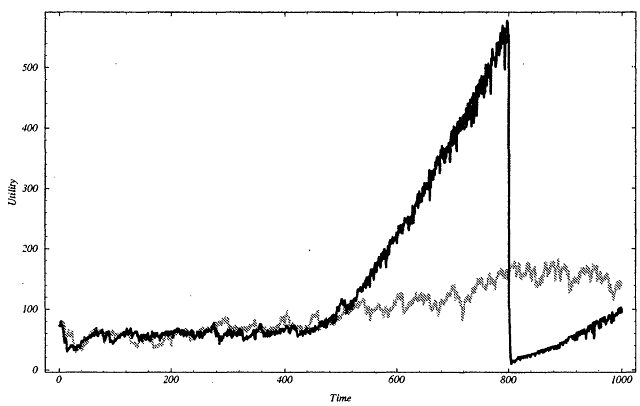


The benefit of cooperation of the trained employees drops back to the baseline benefit of cooperation of untrained employees. One time step after the shock, many of the employees have switched to defection, and by time step 805 many have fled the industry. Over succeeding time steps, the industry contracts further until only one firm remains. Because its manager is still training, the firm slowly recovers from the exogenous shock and gradually grows over time.

slowly as its agents adapt and learn. By time step 1000, the recovery is well underway. However, because only one firm has survived, the rate of growth of the industry will not be as high as for the four-firm industry before the shock.

Figure 6 shows the effect of the exogenous shock on the overall utility produced by the industry. At time step 800, when the shock occurs, there is a sudden and rapid decrease of total utility. As the industry recovers, utility starts to increase, but at a slower rate than previously. The effect of the shock might be somewhat different in other cases because the dynamics of the industry are also highly path dependent. In this case, the number of firms decreased after the catastrophic shock; in other cases, the number of firms might not decrease or might even increase. Whether or not the industry continues to train after the shock depends on what happens to the number of firms.

Figure 6 Utility as a Function of Time for the Industry Described in Figure 5 that Undergoes an Exogenous Shock at Time Step 800.



The utility to the industry falls abruptly but starts to climb again once the industry recovers, albeit at a slower rate than before the shock.

Note that in the example the average utility (over 1000 time steps) for the industry in Figure 5 is still higher than that of the industry in Figure 1, which never trains. We find that the average utility of an industry that is training before a shock is almost always greater than that of one that is not. Thus, the overall increased utility to industries that train generally makes up for the disastrous effect of exogenous shocks over short time scales. In addition, if we run many simulations with an exogenous time shock introduced, we again obtain a tenure-utility similar to profile the one in Figure 4a, but with the axes rescaled.

Discussion

To understand the interplay of social dilemmas at both the organizational and agent levels, we constructed a simple model that encompasses cost-benefit analyses and expectations at both levels. At the organizational level, managers decide whether or not to train on the basis of both the cost of training versus to the benefits and their expectations and observations of the number of other firms that train. Managers take into account the sum of their employees' contributions and the average tenure length within their organization. At the agent level, employees decide whether or not to contribute to company production on the basis of their expectations about how other employees will act. When trained, agents learn over time and fold their increased productivity into their decision whether or not to contribute.

We also modeled how easily employees can move between firms, a property we call "structural fluidity." In addition, agents can leave the industry for good, and new ones can join. Our modeling of turnover as a social dilemma differs from other approaches (Carley 1992). New firms may be created when an agent leaves the parent organization to start a new one. We describe how fluidity relieves the dilemma at the agent level by allowing a large, low-productivity organization to break into smaller pieces. In extreme cases, the organization may dissolve completely. However, when firms break apart in that way, the total number of organizations in the industry increases, exacerbating the dilemma on the organizational level.

The dynamic behavior at the two levels is closely coupled because of the interlinked effects. As a result, the dynamic unfolding of the dilemmas on the employee and organizational levels is path dependent. The evolution of the industry over time depends not only on the characteristics of training programs, learning curves, and cost-benefit analyses, but also on the vagaries of chance. Starting from one set of conditions, an industry can evolve to one of many states. In some cases, it evolves to a stable collection of firms that train their agents and become more productive over time. In other cases, the number of firms increases over time, and each firm has high worker turnover and low productivity because of the lower contributions of untrained, and at times unmotivated, workers. Our results are in line with the widespread empirical observation that enterprise tenure is longer in larger firms and that the extent of training may differ between small and large firms (OECD 1993). Our computer experiments also show a correlation between high turnover and low overall utility to the industry, a correlation that has been observed in several sociological studies that define performance as work-group productivity (Price 1977).

Those results were obtained for both fixed and changing environments. In the more general case, the environment changes over time, perhaps setting the employees back in their training programs or bankrupting firms. An environment that changes continuously may effectively offset some of the benefits of training, but the dynamics of the industry will be qualitatively similar. In such a case, organizations that train still have an advantage over those that do not. The effect of an environment that changes intermittently and abruptly is more dramatic. For industries that are training when the shock occurs, the change is catastrophic: employees stop contributing and flee the industry until the industry and its constituent firms become small enough to again support cooperation. At that point new employees enter the firm, not necessarily those who previously left. However, we found that the effect of an exogenous shock is not disastrous enough to offset the gains of training to the industry over time. Even in an environment that changes abruptly, industries that train generally do better than ones that do not. Note that we did not include in our model of a exogenously changing environment any possible effects on employee and managerial expectations of the future. We expect that any such effects would probably be further destabilizing, perhaps in some way decreasing agent and managerial horizon lengths.

In summary, our results indicate that organizational training can foster spontaneous cooperation in large firms, to some extent obviating the need for more complex management policies of employee monitoring. Training can continue indefinitely if managers are able to constantly exploit improvements in technology, leading to a continuous rise in the organization's productivity. The ever-evolving nature of the dynamics of industries that we observe in our model contradicts the notion of a static economic equilibrium typically assumed in studies of the economics of firms.

How well our results apply to human organizations will depend on the match between a particular industry and the characteristics of our model (Bronson and Jacobsen 1986, Jacobsen et al. 1989). Our assumption of common-good problems on both the managerial level and the employee level will be an approximate description for a variety of industries and a poor description for others. Even for industries that face the situation developed in the model, the dilemmas may remain dormant either because of the firms' small size or because of low costs or because of different managerial and employee decision-making criteria. However, in a variety of cases for which the free-rider component of the problem of organizational training versus worker training is important, we believe our results will provide insights into the dynamics.

In particular, our approach is useful because it addresses the *dynamics* of organizations and indicates how the interplay between organizational variables, such as the extent of training, rate of turnover, enterprise size, and work-group productivity, is manifested as an industry evolves over time. Our method elucidates both the static relationships between organizational variables and the dynamics of path-dependent states, although several simplifying assumptions are necessary. If the model retains enough descriptive power to indicate cause-effect relations, the assumptions are acceptable.

Our study suggests that such computer simulation can be used to design more efficient organizations. As we show, there is an advantage in being able to explore the unfolding of many possible scenarios to choose policies that are conducive to the generation of desired behavior.

Acknowledgements

The research was partially supported by the Office of Naval Research under contract No. N00014-92-C-0046. Portions of the work

were presented at the AAAI-94 Spring Symposium on Computational Organization Design at Stanford University.

Appendix: Computer Experiments

The following parameters were used in our simulations to describe agent and organizational attributes.

Agent Attributes

$b_{\min}$: Baseline benefit (per unit time) of cooperation;
b_i^m: Benefit (per unit time) of cooperation for agent i belonging to organization m;
c: Cost (per unit time) of cooperation;
H: Horizon length;
k_i: Binary variable: $k_i = 1$ if agent i contributes, 0 otherwise;
γ: Learning rate;
r: Fraction of learning transferred across organizations;
t_i^m: Tenure length of agent i in organization m;
α: Reevaluation rate;
p: Measure of uncertainty.

Organizational Attributes

N: Total number of organizations in the industry;
n_m: Number of agents in organization m;
κ_m: Binary variable: $\kappa_m = 1$ if organization m trains, 0 otherwise;
T: Training cost per agent per unit time;
H_m: Horizon length for manager m;
α_m: Reevaluation rate for manager m;
q: Measure of uncertainty;
f_c^m: Estimated fraction cooperating in organization m.

Algorithm

As described in the text, the simulation of our model involves two Poisson processes; one at the agent level with mean $1/\alpha$ and the other for managers with a mean n_m/α that depends on the size, n_m, of the organization. The conditions for the agents to move and join organizations are given in Equations 9 and 10.

Our model has no prescribed limit on the number of agents in the industry; there is an infinite pool outside the industry that supplies the organizations and to which workers can return. The model also has no limit on the number of organizations in the industry. Each time an agent breaks away to form a new organization, the total number of organizations increases. The number of organizations decreases whenever all of the agents in one particular organization break away from the industry completely to return to the external pool of agents.

The actual algorithm we used follows.

□ Initialize

- Structure of industry: number and size of organizations.
- Worker actions over all organizations: contribute or shirk?
- Managerial actions for each organization: train or not train?
- Worker and organizational attributes.
- Wake-up (reevaluation) times Δt for all workers and agents.

i. For manager of organization m, $\Delta t = -\ln(\text{random number})/\alpha n_m$.
ii. For a worker, $\Delta t = -\ln(\text{random number})/\alpha n$, where $n = \Sigma n_m$.

□ While current_time $t <$ final_time

I. Wake up earliest reevaluator and advance current_time

II. Move each worker being trained up learning curve in proportion to tenure length within organization: $b_i^m = b_{\min} + t_i^m * \gamma\kappa_m$.

III. If earliest reevaluator is a worker, pick a worker at random. Worker reevaluates either (1) decision to contribute or shirk or (2) position in industry.
   1. Worker reevaluates decision to contribute or shirk:
      a. Evaluate worker's observed share of production

$$\langle b\rangle^m = \frac{1}{n_m}\sum_{j=1}^{n_m} b_j^m k_j.$$

      Workers intending to contribute do so with probability p ($k_j = 1$ with probability p); workers intending to shirk also do so with probability p.
      b. Evaluate critical threshold for cooperation

$$b_{\text{crit}}^m \equiv \frac{b_{\min}}{H\alpha}\left(\frac{n_m c - b_i^m}{b_i^m + \gamma\kappa_m H - c}\right).$$

      c. If $\langle b\rangle^m > b_{\text{crit}}^m$ worker contributes fully; otherwise worker shirks.
   2. Worker reevaluates position in industry:
      a. Evaluate worker's observed share of production

$$\langle b\rangle^m = \frac{1}{n_m}\sum_{j=1}^{n_m} b_j^m k_j.$$

      b. If $\langle b\rangle^m < \eta c$, $(\eta > 1)$, worker leaves organization.
         i. If *random number* $< \Omega$, $(\Omega \ll 1)$ worker starts a new organization.
         ii. Otherwise worker leaves industry entirely.

IV. Otherwise earliest reevaluator is manager m, who either (1) reevaluates decision whether or not to train members of organization or (2) invites worker from another organization or from outside pool of workers to join:
   1. Manager decides whether or not to train:
      a. Estimate fraction of workers cooperating as

$$f_c^m = \frac{1}{b_{\min}}\left(\frac{1}{n_m}\sum_{j=1}^{n_m} b_i^m k_i\right).$$

      Managers intending to train do so successfully with probability q ($k_j = 1$ with probability p); managers intending to not train also do so with probability q.
      b. Evaluate critical threshold for training

$$f_{\text{crit}}^m \equiv \frac{1}{H_m\alpha_m}\left(\frac{NT - \gamma_c^m}{\gamma f_c^m - T}\right)$$

      where $H_m = 1/n_m \Sigma t_i^m$.
      c. If $f_c^m > f_{\text{crit}}^m$, manager m trains, otherwise not.

2. Manager invites outside worker to join:
   a. Manager picks worker from other organization at random.
      i. Outside worker evaluates current share of production in current organization l,

$$\langle b \rangle^l = \frac{1}{n_l} \sum_{j=1}^{n_l} b_j^l k_j.$$

      ii. Outside worker compares $\langle b \rangle^l$ with share $\langle b \rangle^m$ available to a worker in organization m.
      iii. If $\langle b \rangle^m > \langle b \rangle^l + \mu b_{\min}(\mu < 1)$, then worker accepts invitation to join organization m. Worker retains only part of benefit of any training received:

$$b_i^l = r(b_i^m - b_{\min}) + b_{\min} \quad (r < 1).$$

   b. If worker declines invitation to join, manager recruits from outside pool.
      i. If $\langle b \rangle^m > \rho c(\rho > 1)$, recruit joins organization m.

V. Update wake-up time for worker or manager that just reevaluated strategy.

Parameters

For the results we report, we used the following parameter values. For the agent attributes: $b_{\min} = 2.5, c = 1, H = 5, \gamma = 0.03$ (except in Figure 4b where the learning rate was varied), $r = 0.9$, $\alpha = 1$ and $p = 0.95$.

For the fluidity parameters: $\mu = 0.1$, $\eta = 1.5$, $\Omega = 0.05$ and $\rho = 2$. The organizational attributes were $T = 0.02$ and $q = 0.95$.

Initially, we had four organizations ($N = 4$) each with eight agents ($n_m = 8$), all of whom were cooperating, but none of the managers were training.

References

Bishop, J. (1991), "Employer Training and Skill Shortages: A Review of the State of Knowledge," Working Paper 91-32, Cornell University, Center for Advanced Human Resource Studies, Ithaca, NY.

Blanchard, O. J. and S. Fischer (1989), *Lectures on Macroeconomics*, The MIT Press, Cambridge, MA.

Blinder, A. S. and A. B. Krueger (1991), "International Differences in Labor Turnover: A Comparative Study with Emphasis on the U.S. and Japan," Paper prepared for the Council on Competitiveness and Harvard Business School project on U.S. corporate investment and the time horizons of American industry.

Bronson, R. and C. Jacobsen (1986), "Simulation and Social Theory," *SIMULATION*, 47, 2, 58–62.

Bullock, R. J. and E. E. Lawler III (1984), "Gainsharing: A Few Questions and Fewer Answers," *Human Resource Management*, 23, 23–40.

Carley, K. (1992), "Organizational Learning and Personnel Turnover," *Organization Science*, 3, 1, 20–46.

Cooper, C. L., B. Dyck and N. Frohlich (1992), "Improving the Effectiveness of Gainsharing: The Role of Fairness and Participation," *Administrative Science Quarterly*, 37, 471–490.

Glance, N. S. and B. A. Huberman (1993), "The Outbreak of Cooperation," *Journal of Mathematical Sociology*, 17, 4, 281–302.

____ and ____ (March 1994a), "Dynamics of Social Dilemmas," *Scientific American*, 76–81.

____ and ____ (1994b), "Social Dilemmas and Fluid Organizations," in K. Carley and M. Prietula (Eds.), *Computational Organization Theory*, Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., 217–239.

Hardin, G. (1968), "The Tragedy of the Commons," *Science*, 162, 1243–1248.

Hardin, R. (1982), *Collective Action*, Baltimore, MD: Johns Hopkins University Press.

Hequet, M. (October 1993), "Can Training Stop Turnover?" *Training*, 30, 10, 82–87.

Huberman, B. A. and N. S. Glance (August 1993), "Evolutionary Games and Computer Simulations," *Proceedings of the National Academy of Science USA*, 90, 7716–7718.

Jacobsen, C., R. Bronson and D. Vekstein (1990), "A Strategy for Testing the Empirical Adequacy of Macro-sociological Theories," *Journal of Mathematical Sociology*, 15, 137–148.

Jobs for the Future (December 1991), *New Training Strategies for a High Performance Metalworking Industry*, Cambridge, MA.

Kanter, R. M. (1987), "Pay: From Status to Contributions: Some Organizational Implications," *Personnel*, 64, 12–37.

Lynch, L. (1991), "The Impact of Private Sector Training on Race and Gender Wage Differentials and the Career Patterns of Young Workers," Final Report submitted to the U.S. Department of Labor, Bureau of Labor Statistics.

OECD (July 1993), *Employment Outlook*, Washington, DC: OECD Publications.

Osterman, P. (1987), "Turnover, Employment Security, and the Performance of the Firm," in M. M. Kleiner and S. G. Allen (Eds.), *Human Resources and the Performance of the Firm*, Madison, WI: Industrial Relations Research Association, 275–318.

Price, J. (1977), *The Study of Turnover*, Ames, IA: Iowa State University Press.

Schelling, T. C. (1978), *Micromotives and Macrobehavior*, New York: W. W. Norton and Company, Inc.

Schumpeter, J. (1961), *The Theory of Economic Development*, New York: Oxford University Press.

Accepted by Børge Obel; received February 1994. This paper has been with the authors for two revisions.