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TECHNOLOGY, EFFORT AND THE EFFICIENCY OF PRODUCTION: LABOR-MANAGED VERSUS CAPITALIST FIRMS

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Abstract
We explore how the modeling of effort as a factor in production affects the relative productivity of labor-managed and capitalist firms. Using simple models of privately-owned and labor-managed firms, we show that the more important the role of effort in production, the greater the differences in the efficiency of the two types of firms even if monitoring remains fixed. The results show that even minor differences in the extraction of effort can cause large changes in output and efficiency. We draw implications from our results for the viability of labor-managed firms and cooperatives.

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I. Introduction

The ways in which firms organize themselves in order to elicit effort from workers is a problem that has been extensively studied by economists, who have examined a wide range of incentive and monitoring schemes, internal organizational arrangements and ownership structures. One of the most interesting innovations in firm organization was the labor-managed firm that evolved in, and became the mainstay of, the Yugoslav economy. This innovative way of organizing the firm captured the attention of many economists and social thinkers. Nevertheless, the less-than-stellar performance of the Yugoslav economy, especially in its last years, has cast some doubt on the efficiency of labor-managed firms.[1] While this question of the efficiency of the labor managed firm may seem of mainly historical interest, it is worth noting that, in many of the successor republics of Yugoslavia, the privatization process to a large extent replicated the ownership structure of the labor-managed firm by providing for a distribution of shares mainly among the workers of the firm, thus turning what had been *de jure* ownership by the workers into *de facto* ownership through shareholding (Brada, 1996). Thus, the question of the efficiency of the labor-managed firm remains of more than academic interest even today.

We develop our argument by comparing the efficiency of the so-called capitalist firm and the labor-managed firm in organizing production and motivating workers. To do this, we construct a simple model of these two types of firms, and we show that, as the role of effort becomes more critical to the production process, the productivity differences between private firms and cooperatives increase relative to differences observed when we use more traditional characterizations of the role of effort in production, such as the Cobb-Douglas production function, even if monitoring and incentives remain fixed across organizations.

The coexistence in market economies of privately-owned firms and producer cooperatives, whether in manufacturing or in agriculture, as well as the fact that the labor-managed firm, even if its existence is limited to a single country, must always face competition from capitalist firms due to the intensification of globalization, has led to the emergence of a rich theoretical and empirical literature comparing the economic performance of the two ways of owning and managing productive units. The work of Ward (1958), Domar (1966), Vanek (1970) and Ireland and Law (1981) argued that the cooperative firm can be as economically efficient in its resource use as is its capitalist counterpart. Much less settled, both from a theoretical standpoint and from an empirical one, is whether labor-managed firms are, by virtue of their collec-

1. Whether Yugoslavia's poor economic performance was due more to the shortcomings of the labor-managed firm or to the economy's socialist nature is an open question. See the thoughtful discussion of Estrin and Uvalic (2008).

tive nature, better suited to elicit higher levels of effort from their members than is a capitalist firm from its employees and what the implications of such differences are for the viability of labor-managed firms.[2] Proponents of labor management point to the greater commitment that worker-owners will have to the welfare of their firm, to the higher morale created by the absence of the hierarchical supervision characteristic of capitalist firms, to lower labor turnover and the willingness of the labor-managed firm and its members to engage in firm-specific human capital accumulation, and to the likelihood of its worker-managers engaging in group monitoring of effort and to the emulation of fellow members' supply of effort.[3]

Critics of cooperative firms have argued that the supply of effort depends in part on the way in which labor-managed firms reward their members. As Sen (1966) showed, even if effort were perfectly observable, a payment scheme that shared the net income of the labor-managed firm equally among all members would result in no effort being supplied, and even mixed payment schemes based on a combination of income sharing and reward for work would elicit suboptimal effort. Carter (1987) provided an institutionally richer analysis that also demonstrated how a low-effort-supply equilibrium could come about in agricultural cooperatives, leading to their collapse.[4] A somewhat different basis for the collapse of cooperatives due to low effort was put forward by Lin (1988), who argued that the failure of Chinese collectivization was brought about by the undersupply of effort in an environment where members could not leave collective farms in which shirking was widespread.

To some extent, this theoretical predisposition to the view that cooperatives face problems in eliciting high levels of effort from their members has been borne out by empirical studies of agricultural cooperatives. For example, Boyd (1987) found Yugoslav cooperatives to be much less technically efficient than private farms, Brada and King (1993) obtained similar results for Polish private and socialized farms, and Carter (1987) found private farms in Peru to be more technically efficient than were cooperatives. On the other hand, as the extensive survey of the literature by Bonin, Jones and Putterman (1993) clearly documents, studies of the relative efficiency of labor-managed and capitalist firms in various sectors of manufacturing and services have led to contradictory results about which way of organizing production is more efficient.

In this paper, we take a somewhat different approach, one that stresses a different and, we believe, more realistic way of modeling worker effort. In the development of

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2. See Bonin, Jones and Putterman (1993) for a survey of the literature on this topic.

3. See Bradley and Gelb (1981) and particularly Ireland and Law (1988) for discussions of the organization of monitoring in cooperative firms.

4. Cooperative and labor-managed firms share many of the formal properties of interest to our modeling effort and we use the two terms interchangeably.

the theory of the labor-managed firm, the role that workers' effort plays in the process of production has generally been modeled in only one way; lack of effort is treated as the equivalent of supplying less labor time. Thus, differences in the productivity of capitalist and labor-managed firms were seen as the result of shirking, which reduces the effective labor time worked. One of the paradoxical implications of this formulation is that numerous empirical studies have found large differences in productivity between capitalist and labor-managed firms, some in favor of capitalist firms and some in favor of labor-managed ones. The discovery of such large differences in effort suggests that, in the less productive organizations, shirking would have to be widespread, involve much idleness by workers or members and be highly visible if idleness or shirking were to account for such large differences in labor time supplied, and that such idleness of workers would have been so visible as to be impossible to miss and to control.

In this paper we propose a different formulation of the role of effort in the production process, one that makes effort much more central to output, and we show that such a formulation is able to explain why even small differences between alternative ways of monitoring and incentivizing workers to supply effort and, consequently, small inter-organizational differences in effort supplied, may lead to large differences in output and labor productivity. Thus, the ability of firms with different incentive structures to survive in a competitive industry may depend critically on the technology used by those firms. Technologies where effort is not central to the production process may be compatible with a wider range of monitoring and incentive arrangements than is the case for firms operating in an industry whose production processes place a premium on effort. Thus, if labor-managed and capitalist firms do elicit different levels of effort, such differences should be more evident in more technologically complex sectors of the economy.

Both the theorizing about, and the measurement of, the relative efficiency of private firms and cooperatives have been framed in the context of a single view of the role of effort in production and of the way that effort enters into the production function. In this literature, effort is viewed as being identical with "true" labor time, often viewed as time "actually spent working". That is, in the traditional view of production, if effort cannot be varied, output is seen as a function of available capital services and of (observed) labor time, L, or, with a fixed number of hours of work, the number of workers. If monitoring arrangements are such that workers can supply less than full effort, then output will be lower than suggested by L because the true labor input is eL, where $0 \leq e \leq 1$ is a measure of effort supplied. Such a way of modeling the role of effort in the production process makes effort equivalent to time worked; shirking effectively reduces the number of hours that the worker actually works.

This approach, however, raises some serious questions about the differences in technical efficiency between capitalist and labor-managed production and the amount of shirking that would be required to sustain such differences. For example, in the studies of agricultural cooperatives cited above, cooperative farms' technical efficiency falls short of that of private farms by 10 to 30 percent. If we were to attribute the entire difference to shirking, then, making a reasonable assumption about the marginal product of labor would imply that as much as half the collective farm workers' day was spent in idleness. Such a blatant shirking might possibly occur in the sort of non-coercive environment that characterized the Peruvian cooperatives studied by Carter (1984). However, in the case of collective farms in socialist countries, a degree of shirking such as that suggested by Lin (1988) or implied by Boyd's (1987) estimates of technical efficiency seems implausible. Collectivization was forced on farmers, and Communist Party officials and collective farm managers had both the possibility of using, and the incentives to resort to, a variety of coercive measures to prevent the rampant idleness implied by the empirical research. Moreover, anecdotal evidence shows that such coercion was used. This of course is not to argue that coercion entirely solved the problem of shirking. Nevertheless shirking on a scale that implies idleness for as much as half the work day is inconsistent with the amount of monitoring that authorities could have exercised as well as with the sanctions they could have imposed on shirkers. Much the same argument can be made on the basis of comparisons of the efficiency of capitalist and labor-managed firms in industry and services; the measured differences in efficiency are so large that in one or the other type of firm idleness would have to account for a large part of the workers' time at their workplace.

A conception of effort as equivalent to time spent working may be appropriate for many simple technologies, particularly those where there is little interaction between the output of one worker and that of others. Thus if one worker shirks, she produces less than her fellow workers, but she does not impinge on their ability to produce output based on their own inputs of time and effort. On the other hand, there exist technologies that require a sequence of steps in the production of the final product. In such technologies, the equivalence between effort and labor time breaks down and the amount of effort supplied at each stage becomes critical, so that even small reductions in effort by one worker can have a large impact on the total output of the firm.[5] As we demonstrate in this paper, in firms employing such technologies the ability to elicit effort is much more crucial to the productivity of the firm than it is for firms that employ technologies where there are few or no sequential steps. Thus, if privately-owned and labor-managed firms do differ in their ability to elicit effort, then we would expect to see smaller differences between the efficiency of private and

5. This notion is central to Kremer's (1993) so-called O-Ring technology, which we exploit in this paper.

cooperative firms in industries characterized by the former, simpler, type of technology. Consequently, in industries characterized by these simpler technologies, different ways of organizing production and monitoring workers could coexist even in a competitive environment. For industries where the second, more effort-critical, type of technology is used, there should be large potential differences between the productivity of different types of firms, even if their individual monitoring efforts were to result in relatively small differences in the amount of effort supplied. In such an industry, different ways of organizing the firm could not be sustained in a competitive environment because those firms that elicited less effort would find themselves at a major disadvantage in productivity and, thus, in costs of production.

In the next section of this paper we develop a model of labor-managed and private firms with sequential technologies and show that, when the complexity of the technology, as measured by the number of sequential steps involved in production, increases, even small differences in the ability to elicit effort lead to large differences in technical efficiency.

II. A Simple Analytical Framework

In this section, we develop a simple model to show how moving from a traditional or "one-step" production process to a sequential production technology, even with monitoring and incentives remaining fixed, can magnify productivity differences between a labor-managed firm and a capitalist firm employing the same resources. We motivate the model with an example from agriculture. The production process in farming is sequential, involving a series of steps or stages that are carried out over a lengthy time period. Land is first prepared; crops are then planted; all of this is followed at different times by the application of fertilizers, insecticides, and herbicides, and by the pruning or tending of the plants; all prior to the harvesting of the crop, which itself may consist of several sequential activities. Low or poor quality worker effort at any of these stages may have severe consequences for final output. For instance, failure during planting to carefully cover a seed with dirt so it is not blown away by the wind or eaten by birds will have very large effects on the size of the harvest because all the worker effort devoted to fertilizing, weeding, etc., cannot make up for the failure of seeds to germinate. Moreover, this is true at all stages, as small changes in the quality of a worker's effort at one stage can translate into large changes in production. In some instances, the difficulty of monitoring effort in agricultural production aggravates this effect because it may be very difficult to identify the stage during which the poor quality performance occurred.[6]

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6. To some extent much agricultural production, and, indeed, much non-agricultural production, is characterized by such a sequential connection among stages. However, for some crops and tech-

To illustrate how the organization of production in private or labor-managed firms interacts with this type of production technology, we construct models of cooperatives and private farms that use traditional Cobb-Douglas production functions and the so-called O-Ring (OR) production function of Kremer (1993), which is a characterization of a sequential production process. In each of our examples, we assume that there is only one technology available for producing the product, and thus both firms must use the same technology. We show that, holding incentives that have been proposed in the literature on labor-managed firms fixed, changes in the sequential complexity of the technology used by both firms cause very large changes in the relative performance of private and labor-managed firms. Note that our focus is on the relationship between organizational form and technology, independent of the complications introduced by difficulties in monitoring worker effort. Thus we assume that both private firms and cooperatives face identical difficulties in monitoring workers who are using the same technology.[7]

A. Production Technology

The characteristics of the production technologies that we employ are central to our analysis, so we begin by describing Kremer's (1993) OR production function and adapting it to our needs. In Kremer's formulation, the production process is characterized by N tasks, and, although not essential for the analysis, it is assumed that each task requires only one worker so that N also equals the number of laborers. How a worker is likely to carry out a particular task is represented by a random variable, e_i, whose realization ranges from zero to one and which Kremer (p. 553) defines as "the expected percentage of maximum value the product retains if the worker performs the task" perfectly. For instance, an e_i of 0.80 may mean that a worker has an 80 percent chance of being successful in performing a task or the task is always performed in such a way that the product retains 80 percent of its maximum value. The sensitivity of total production to an individual worker's performance is then captured by assuming that each e_i enters production multiplicatively, so that, for the N workers, output will equal:

$$\prod_{i=1}^{N} e_i$$

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nologies, these connections are much weaker or the number of sequential steps much lower than they are in others. See Bradley and Clark (1972) for an excellent early discussion of these issues.

7. This approach thus differs from the insightful paper by Eswaran and Kotwal (1985), who also consider the problem of worker effort under different technologies and institutional arrangements. Eswaran and Kotwal explicitly introduce a role for monitoring effort, but, by necessity, they introduce assumptions about differences in monitoring ability that in turn drive their results.

Thus, even though workers' effort levels are assumed to be stochastically independent of one another, a low realization of e_i at any point in the production process will dramatically lessen the productivity of all workers.

In our models of capitalist and labor-managed firms, we, too, introduce e_i multiplicatively and assume that it ranges from zero to one; however, we employ a more traditional interpretation of e_i. We assume it is nonstochastic and define it as the quantity of effort exerted by a worker, or, alternatively, it represents an index of the quality of a worker's effort where each worker possesses one unit of time. In either case, the quantity

$$N\prod_{i=1}^{N} e_i$$

can be interpreted as the total "effective" labor input.

Kremer also defines a technological parameter, B, which depends on N and is defined as "output per worker with a single unit of capital if all tasks are performed perfectly" (p.561). Note that in a conventional Cobb-Douglas (CD) production function with two inputs and where α is the nonlabor input's share of output, the parameter B is equal to

$$\left[N\left(\prod_{i=1}^{N} e_i\right)\right]^{-\alpha}$$

conditional on

$$\prod_{i=1}^{N} e_i = 1$$

To see this, rewrite a CD production function as

$$Q^{CD} = K^{\alpha}\left(N\prod_{i=1}^{N} e_i\right)^{1-\alpha}$$

$$= K^{\alpha}\left(N\prod_{i=1}^{N} e_i\right)\left(N\prod_{i=1}^{N} e_i\right)^{-\alpha} \qquad \text{Eq. 1}$$

where Q is output, K is the stock of capital, α is capital's output share, and N is the number of workers. In Kremer's characterization of the OR production function, the term on the far right,

$$\left[N\left(\prod_{i=1}^{N} e_i\right)\right]^{-\alpha}$$

simplifies to $[N]^{-\alpha}$ conditional on

$$\prod_{i=1}^{N} e_i = 1$$

In contrast to Kremer, we include this term with the stock of capital because we hold the stock of capital fixed throughout our analysis. We define t* as the output per worker with *K* units of capital if all tasks are performed perfectly:

$$t^* = K / \left[N \left(\prod_{i=1}^{N} e_i \right) \right] = K / N$$

conditional on

$$\prod_{i=1}^{N} e_i = 1$$

Our form of the OR production is thus expressed as

$$Q^{OR} = \left(t^*\right)^{\alpha} \left(N \prod_{i=1}^{N} e_i \right) \qquad \text{Eq. 2}$$

Note that except for the multiplicative way in which labor's effort enters the production function and the interpretation of *t*, this production function is a Cobb-Douglas production function in *t* and total labor effort and is comparable to the "intensive" form of the CD production function popular in the international trade literature more than three decades ago.[8] It is also related to the "external economies" or "Marshallian factor-generated" increasing returns production function also used extensively in the international trade literature. Indeed, in line with that literature, the derivative of Q^{OR} with respect to e_i is identical to what Panagariya (1983) referred to as the "social" marginal product of the *i-th* worker, which we express as follows:

$$\left(\partial Q^{OR} / \partial e_i\right) = Q_E N \prod_{i=1}^{N} e_i \left(e_i\right)^{-1} N\eta \qquad \text{Eq. 3}$$

where $Q_E = (t^*)^{\alpha}$ captures the change in production in response to a change in total labor effort, *E*, where

$$E = N\left(\prod_{i=1}^{N} e_i \right) \qquad \text{Eq. 4}$$

and

$$\eta = \left(1/N\right)\left\{1 + \sum_{i=2}^{N} e_i \left(\partial e_j / \partial e_i\right)\left(e_i / e_j\right)\right\} \qquad \text{Eq. 5}$$

Thus η is an elasticity that measures the percentage response of total labor effort to a marginal change in the *i-th* worker's effort. This elasticity is comparable to what Chinn (1979) defines as a "cohesion coefficient" that captures the extent to which other workers emulate the actions of the *i-th* worker. It is also a "social" marginal

8. See, e.g., Kemp (1969) and Takayama (1972).

product because it takes into account the externality generated by the action of the *i-th* worker on total labor effort. Chinn (1979) argues that η varies from a lower bound of *1/N* when other workers choose not to emulate the response of an individual worker up to an upper bound value of *1* when other workers respond in an identical fashion to the *i-th* worker's change in effort. However, for labor-managed firms, it is possible that members may reduce their effort in response to an increase in the effort by other members.

The second production function we employ is similar to a conventional CD production function. The key differences are that we include the sum of each individual worker's effort,

$$\sum_{i=1}^{N} e_i$$

as the aggregate labor input and we incorporate Kremer's *B* parameter within the stock of capital as we did earlier. The CD production function is

$$Q^{CD} = \left(t^*\right)^{\alpha} \left(\sum_{i=1}^{N} e_i \right) \qquad \text{Eq. 6}$$

where *Q* is output, and, as before, α is capital's output share, *N* is the number of workers, and t^* is the output per worker with *K* units of capital if all tasks are performed perfectly:

$$t^* = K \Big/ \left(\sum_{i=1}^{N} e_i \right) = K / N$$

conditional on $e_i = 1$ for all $i = 1,\ldots,N$. Differentiating Q^{CD} with respect to a marginal increase in e_i, we obtain

$$\left(\partial Q^{CD} / \partial e_i\right) = \left(Q_E \sum_{i=1}^{N} e_i \right) \left(e_i\right)^{-1} N\eta_w \qquad \text{Eq. 7}$$

where $Q_E = (t^*)^{\alpha}$ captures the change in production in response to a change in *total* labor effort,

$$E = \sum_{i=1}^{N} e_i$$

and

$$\eta_w = \left(1/N\right) \left\{ \delta_1 + \sum_{i=2}^{N} \delta_j \left(\partial e_j / \partial e_i\right) \left(e_i / e_j\right) \right\} \qquad \text{Eq. 8}$$

is an elasticity comparable to η, except that each term of η_w is weighted by δ_i, individual *i*'s ($i = 1,\ldots,N$) share of total effort provided. Note that, if the δ_i's are identical, then $\eta_w = (1/N)\eta$ because

$$\delta = e / \sum_{i=1}^{N} e_i = e / Ne = 1/N$$

We use this result later.

B. Behavioral and Environmental Assumptions

We now set out several simplifying behavioral and environmental assumptions. First, like Berman (1977) and Conte (1980), we are concerned only with a time span in which labor-managed firms are not free to adjust membership but are free to adjust work effort. Second, like Conte (1980), we assume that workers care only about income and leisure but not about working conditions. For simplicity, individual workers are assumed to possess one unit of effort, which they allocate between effort at work, e_i, and leisure, $1\text{-}e_i$; thus, e_i ranges from 0 to 1, with higher numbers indicating greater worker supply of effort. Third, we assume that the capitalist firm and the labor-managed firm operate with the same capital stock.[9] Finally, the objective of a worker-managed firm is to maximize the utility of a typical worker where e_i is the choice variable. In contrast, the capitalist or private firm is assumed to operate in a competitive environment and to hire labor until the marginal revenue product is equated to the exogenously given market wage rate. In such an environment, changes in an individual's work effort have no effect on the market wage and workers act independently while focusing on their own income.[10]

The cooperative's maximization problem is expressed as:

$$Max\ U^i = U^i(y_i,\ 1\text{-}e_i)$$

where U^i is the utility of the i-th member, y_i is her income and $l=1\text{-}e_i$ is the leisure consumed. Ignoring the member superscript for U, we assume that U is quasi-concave, and that $U_y, U_l > 0$ and $U_{yy}, U_{ll}, U_{yl} < 0$, where U_i is the partial derivative with respect to the i-th variable.

We assume that V, the labor-managed firm's residual income computed as total revenue, PQ^j $(j = OR, CD)$, less R, the payment for capital, is distributed to the cooperative's workers in two payments.[11] First, a portion of net revenue, aV, is set aside for meeting basic needs, and each member receives an equal share of this por-

9. Theory predicts that the labor-managed firm would under-invest (Furubotn and Pejovich, 1970). In practice, Yugoslav self-managed firms tended to have high rates of investment (Estrin and Uvalic, forthcoming).

10. For more details, see the discussion in Ireland and Law (1981).

11. In the more general case, the labor-managed firm would subtract its payments for all non-labor inputs, but, because we develop our model of production in terms of two inputs only, we ignore intermediate inputs without any loss of generality.

tion of *V*.[12] Second, what remains of the residual income is paid out to each member in proportion to his or her share of total work effort, $\delta_i = e_i / \Sigma e_i$. Thus, a member's income is

$$y_{i,j} = s_i\, [PQ^j - R]\ (i = 1, \ldots, N, j = OR, CD) \qquad \text{Eq. 9}$$

where

$$s_i = [\delta_i(1-a) + (1/N)a] \qquad \text{Eq. 10}$$

C. Comparative Productivity

Our next step is to develop the first-order conditions (FOCs) for the private and labor-managed firm under both Cobb-Douglas and OR technologies. We do this explicitly to demonstrate that our main results regarding the incentive structure facing workers in the labor-managed firm are largely consistent with those developed in the extensive theoretical literature on labor-managed firms, although the introduction of the OR technology does modify them in an important way. We also develop these FOCs in order to obtain explicit expressions for the optimal effort levels in labor-managed firms or cooperatives using OR and CD production technology, denoted $(e_{or-c})^*$ and $(e_{cd-c})^*$, and for private firms, denoted $(e_{or-p})^*$ and $(e_{cd-p})^*$. These expressions for the optimal effort levels, once substituted into the appropriate production function, will then permit us to compare the optimal production level of a labor-managed firm to that of a private firm using the same technology and the same amount of capital or other inputs. These comparative-productivity ratios are denoted, respectively, by $(Q^{OR\text{-}C}/Q^{OR\text{-}P})^*$ and $(Q^{CD\text{-}C}/Q^{CD\text{-}P})^*$.

Beginning with the FOCs for those workers employed in labor-managed firms that use an OR production technology, we obtain

$$U_y\left\{s_j PQ^E\left(\prod_{i=1}^{N} e_i\right)\left(e_j\right)^{-1} N^2\eta + (1-a)(1-N\eta_w)V^{OR} / \sum e_j\right\} - U_l = 0 \qquad \text{Eq.11}$$

where P is the exogenously-given price of the output. Note that the above FOC is similar to equation 5 in Israelsen (1980), equations 5a and 5b in Ireland and Law (1981), and equation 11 in Lin (1988).

To solve for $(e_{or-c})^*$, we now make several additional simplifying assumptions. First, we assume that, at the initial point of differentiation, we can ignore capital costs

12. The tendency for older workers to seek higher distributions and younger workers to be more willing to use internal resources for investment was largely offset by the socialist nature of the Yugoslav economy (Estrin and Uvalic, 2008 forthcoming). Thus we do not pursue this area of difference between the two types of firms in this paper.

and that workers are identical. The former allows us to set $V = PQ_i$ $(i=OR, CD)$ and the latter implies that

$$\eta_w = (1/N)\eta,\ s = (1/N) \text{ and } \sum_{i=1}^{N} e = Ne$$

Second, like Ireland and Law (1981), we adopt a specific functional form for the member's utility function, $U = (y_i)^{1-\beta} (1-e_i)^{\beta}$, in order to simplify our computations. After making the appropriate substitutions, we obtain the optimal effort level for the worker in a labor-managed firm

$$(e_{or\text{-}c})^* = (1-\beta)[N\eta + (1-a)(1-\eta)] / \{(1-\beta)[N\eta + (1-a)(1-\eta)] + \beta\} \qquad \text{Eq. 12}$$

where $(e_{or\text{-}c})^*$ is bounded from 0 to 1. To obtain $(e_{or\text{-}p})^*$, we set both η and a equal to zero because workers of privately-owned firms are assumed not to influence each others' supply of effort and there are no needs payments. The result is identical to the result obtained by assuming that workers employed by the private firm are also only concerned with maximizing their utility, but, by assumption, their only source of income is wage income, $y_i = we_i$ where w is the exogenously given competitive wage.

Carrying out the same exercise for the labor-managed firm operating with a CD technology, the optimal level of effort is

$$(e_{cd\text{-}c})^* = (1-\beta)[\eta + (1-a)(1-\eta)] / \{(1-\beta)[\eta + (1-a)(1-\eta)] + \beta\} \qquad \text{Eq. 13}$$

which differs from $(e_{or\text{-}c})^*$ in that N does not appear in the numerator or denominator as a multiplier of η, the cohesion coefficient. In contrast, the worker's optimal effort level when private firms operate with a CD rather than an OR production function, $(e_{cd\text{-}p})^*$, remains unchanged.

To compute the ratio of production in the labor-managed firm versus that in a capitalist firm when both employ the optimal amount of labor and the same technology, $(Q^{OR\text{-}C}/Q^{OR\text{-}P})^*$ and $(Q^{CD\text{-}C}/Q^{CD\text{-}P})^*$, we substitute the expressions for $(e_{or\text{-}c})^*$, $(e_{cd\text{-}c})^*$, $(e_{or\text{-}p})^*$ and $(e_{cd\text{-}p})^*$ into their respective production functions. We obtain, respectively,

$$(Q^{OR\text{-}C}/Q^{OR\text{-}P})^* = [\{N\eta + (1-a)(1-\eta)\} / \{(1-\beta)(N\eta + (1-a)(1-\eta)) + \beta\}]^N \qquad \text{Eq. 14}$$

and

$$(Q^{CD\text{-}C}/Q^{CD\text{-}P})^* = \{\eta + (1-a)(1-\eta)\} / \{(1-\beta)(\eta + (1-a)(1-\eta)) + \beta\} \qquad \text{Eq. 15}$$

Note that, *a priori*, it is not possible to determine whether labor-managed production will be higher or lower than that of private firms, and this holds regardless of the technology. Such indeterminacy is consistent with the large body of inconclusive empirical work on the issue of which organizational form has higher productivity (Bonin, Jones and Putterman, 1993). Note also that parameter changes influence relative productivity in a manner consistent with our intuition. For instance, labor-managed firms exhibiting a degree of cohesion or enthusiasm among members, *i.e.*, those with a cohesion coefficient closer to one, are more likely to exhibit higher production than do private firms. Moreover, as theory suggests, increases in a, the share of output devoted to needs payments, increase the likelihood that labor-managed production will fall short of private production. Finally, notice from Equation 14 that an increase in *N*, which we would interpret as an increase in the number of stages in, or the complexity of, the production process, causes the difference in production between the two types of firms to increase. To be able to say more about the possible magnitude of these productivity differences, we calculate comparative productivity values for alternative levels of *a and* η. These calculations are presented in the next section.

D. Simulations of Comparative Productivity

Table 1 summarizes the results of computing values of our comparative productivity measure for each technology with $\beta = 0.4$, $N = 2$, and alternative values of a and η. We present values for OR production technology with only two stages because that is sufficient to demonstrate our main point that differences in the technology of production can lead to large differences in private firm and cooperative performance.

Panel A of Table 1 examines the effect of differences in η and a on the productivity of labor-managed firms relative to private firms when both employ the identical Cobb-Douglas technology. Generally, except for the topmost row and the first column, cooperatives are less productive than private firms but only marginally so for low values of a, the share of income distributed according to need. Differences in productivity of no more than 10 percent, which characterize the top-left portion of Panel A, are unlikely to be of material importance in actual practice, and, under such productivity differentials, labor-managed firms and private firms could coexist in a competitive market. As the share of cooperative revenue devoted to needs payments rises beyond 0.2, a movement along any row from left to right, the labor-managed firm becomes increasingly less productive in comparison to private firms. Finally, note that as we move up each column, productivity for the labor-managed firm rises relative to that of private firms; that is, the more sensitive other labor-managed firm members are to an increase in the *i*-th worker's effort, the more productive the labor-managed firm becomes.

Panel B of Table 1 presents values of comparative productivity when both firm types use the identical O-Ring production technology. The values are computed for the same set of parameters as in Panel A; the principal difference is that there are now two production stages, *i.e.,* $N = 2$. Productivity differences between private and labor-managed firms become much more striking. For a range of high cohesion and low sharing-parameter values, labor-managed firms can exceed private firm productivity by over 50%, and a productivity advantage of more than 20% is evident in over half the cells in Panel B. Such a productivity advantage requires a combination of high levels of cohesion and low levels of income-sharing. Conversely, for low levels of cohesion and high levels of sharing, labor-managed firms' productivity is much lower than that of private firms. In this section of the Table, for any given pair of values of a and η, productivity is dramatically larger or smaller in labor-managed firms in comparison to private firms. Thus, with the same monitoring technology and incentives, the differences in actual output are much greater than they are with the CD technology. The results in Panel B are thus consistent with the theory of output collapse put forward by Lin (1988), Carter (1987) and Carter *et al.* (1996) in that they demonstrate the possibility of large shortfalls in output even if shirking does not involve long and easy-to-observe periods of idleness by workers.

These computations thus demonstrate the ability of small differences in technology to create large differences in the productivity, and, in a market economy, in the economic viability of different ways of organizing production and in the ownership of productive assets. While the literature has largely focused on monitoring and incentives as the key determinants of differences in the performance of firms, our results show that, even when monitoring and incentives remain fixed, different characterizations of the technology can imply very large differences in firm performance. This suggests that private firms and labor-managed firms may not be able to coexist in many industries unless labor-managed firms are able to constrain their choices of a and η to a narrow range and, thus, that the coexistence of these two forms of organization may be tightly constrained by technology to a few industries. Finally, we note that, in our work, we have taken the form of the technology and the number of sequential steps as exogenous. The possibility that firms, aware of the effect of the number of sequential steps on productive efficiency, would choose technologies with either more or fewer steps so as to exploit the advantages or mitigate the inefficiencies created by their capitalist or labor-managed form of organization is an area for further research.

III. Conclusions

We have constructed a model of private and cooperative firms whose production function assigns a key role to the supply of effort. We have shown that in such firms, any differences in the supply of effort results in very large differences in productivity and costs, but the model does not provide *a priori* conclusions as to whether labor-managed or private firms are able to elicit greater effort. More broadly, our work serves to explain why some studies are able to observe very large shortfalls from potential production, even in organizations such as Chinese collective farms where there may be severe penalties for shirking. It is possible that relatively small deviations from maximum effort can cause large shortfalls in production. Moreover, our work underscores the importance of organizations' ability to elicit effort and shows how this ability to extract effort can play a very large role in determining which forms of organization are viable in a competitive environment. It may be that organizations do not differ much in their ability to elicit effort, implying that the explanatory role of incentive and monitoring issues in explaining the competitiveness of different ways of organizing production is less than commonly believed, while the effort intensity of the production technology utilized by firms plays a key role in explaining why different organizational forms may not be able to coexist in a competitive industry. Ironically, if the firms in the former Yugoslavia have retained some of the labor-managed characteristics but now operate in a less "socialist" environment they may now exhibit more of the liabilities of labor management than they did in the Yugoslav environment.

Table 1: Computations of Comparative Productivity: Optimal Cooperative Production Divided by Optimal Private Firm Production, $(Q^C/Q^P)^*$

Panel A: Cobb-Douglas Production Technology

Cohesion Coefficient (***η***)						$(Q^C/Q^P)^*$					
1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.9	1.000	0.996	0.992	0.988	0.984	0.979	0.975	0.971	0.966	0.962	0.957
0.8	1.000	0.992	0.984	0.975	0.966	0.957	0.948	0.939	0.929	0.919	0.909
0.7	1.000	0.988	0.975	0.962	0.948	0.934	0.919	0.904	0.888	0.871	0.854
0.6	1.000	0.984	0.966	0.948	0.929	0.909	0.888	0.865	0.842	0.816	0.789
0.5	1.000	0.979	0.957	0.934	0.909	0.882	0.854	0.823	0.789	0.753	0.714
0.4	1.000	0.975	0.948	0.919	0.888	0.854	0.816	0.775	0.730	0.680	0.625
0.3	1.000	0.971	0.939	0.904	0.865	0.823	0.775	0.722	0.663	0.595	0.517
0.2	1.000	0.966	0.929	0.888	0.842	0.789	0.730	0.663	0.584	0.493	0.385
0.1	1.000	0.962	0.919	0.871	0.816	0.753	0.680	0.595	0.493	0.370	0.217
0	1.000	0.957	0.909	0.854	0.789	0.714	0.625	0.517	0.385	0.217	0.000
Needs Parameter (***a***)	**0.0**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**

Panel B: O-Ring Production Technology *(N=2)*

Cohesion Coefficient (***η***)						$(Q^C/Q^P)^*$					
1.000	1.563	1.563	1.563	1.563	1.563	1.563	1.563	1.563	1.563	1.563	1.563
0.9	1.522	1.518	1.514	1.510	1.505	1.501	1.497	1.492	1.488	1.484	1.479
0.8	1.479	1.470	1.461	1.452	1.443	1.433	1.424	1.414	1.404	1.394	1.384
0.7	1.433	1.419	1.404	1.389	1.374	1.358	1.342	1.326	1.309	1.292	1.275
0.6	1.384	1.363	1.342	1.320	1.298	1.275	1.251	1.226	1.201	1.175	1.148
0.5	1.331	1.304	1.275	1.245	1.214	1.181	1.148	1.113	1.077	1.039	1.000
0.4	1.275	1.239	1.201	1.162	1.120	1.077	1.031	0.984	0.934	0.881	0.826
0.3	1.214	1.168	1.120	1.069	1.016	0.959	0.899	0.836	0.769	0.698	0.623
0.2	1.148	1.092	1.031	0.967	0.899	0.826	0.749	0.666	0.579	0.487	0.391
0.1	1.077	1.008	0.934	0.854	0.769	0.677	0.579	0.475	0.366	0.255	0.148
0	1.000	0.917	0.826	0.729	0.623	0.510	0.391	0.268	0.148	0.047	0.000
Needs Parameter (***a***)	**0.0**	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**

Note: All computations assume $\beta = 0.4$

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