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# To Innovate or Not To Innovate: Incentives and Innovation in Hierarchies

By JAMES DEARDEN, BARRY W. ICKES, AND LARRY SAMUELSON\*

*Hierarchical organizations often perform poorly in inducing the adoption of innovations. We examine a principal offering contracts to agents who make unobservable effort and adoption-of-innovation choices (yielding moral hazard), who occupy jobs of differing, unobserved productivities (yielding adverse selection), and who engage in a repeated relationship with the principal (causing a ratchet effect to arise). Increasing the rate of adoption of an innovation in such an organization causes the incentive costs of adoption to increase at an increasing rate. Relatively low rates of adoption may then be a response to the prohibitive incentive costs of higher adoption rates. (JEL 021, 110, 620)*

The Soviet Union has been chronically plagued by difficulties with the diffusion of innovation. In 1941, for example, Georgii Malenkov reported to the 18th Congress of the Communist Party that

... highly valuable inventions and product improvements often lie around for years in the scientific research institutes, laboratories and enterprises, and are not introduced into products.

[Joseph Berliner, 1987 p. 72]

More recently, Mikhail Gorbachev reported to the 27th Party Congress that

... many scientific discoveries and important inventions lie around for years, and sometimes decades, without being introduced into practical applications.

[Berliner, 1987 p. 72]

The technical achievements of the Soviet Union, including such inventions as the hydrogen bomb, Sputnik, and antisatellite and space technology, have been exemplary. As the quotations above attest, the problem lies not in the technical process of invention but in the adoption of the resulting innovations. Why does the Soviet system consistently produce potentially valuable innovations but consistently fail to induce the use of these innovations?

This paper examines innovation in hierarchical organizations, focusing particularly on process (rather than product) innovations. We draw our motivation and examples from the Soviet Union because they are the most striking, but the analysis can be applied to general hierarchical systems.<sup>1</sup>

Our basic finding is that a key obstacle to the adoption of innovations in hierarchical organizations is not the cost of inventing or developing an innovation but, rather, the

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<sup>1</sup>For example, F. M. Scherer (1984 part III) finds that the rate of innovation on the part of a firm increases as firm size increases but does so at a decreasing rate. He suggests that the relatively poor innovation performance of large firms "is in turn probably due to organizational problems ... although the precise mechanism of this phenomenon is not clear" (p. 191). We take the distinguishing feature of a hierarchical organization to be that the incentives to adopt innovations or take other actions must be explicitly constructed by a principal or planner rather than provided by the market. A similar characterization is adopted by Michael Riordan (1987).

cost of constructing incentives to induce agents to adopt the innovation once it is available. We show that increasing the rate of adoption of an innovation causes these incentive costs to increase at an increasing rate. Relatively low rates of adoption, such as seen in the Soviet Union, may then be a response to the prohibitive incentive costs of higher adoption rates. Moreover, achieving increased adoption rates without prohibitive cost may require not just a tinkering with the form of incentive contracts, but a modification of the hierarchical decision-making process.<sup>2</sup>

The first difficulty in constructing incentives to adopt an innovation is that the principal generally cannot observe whether an innovation has been adopted, being instead able to observe only the output of an agent. This is especially likely to be the case with process innovations. Furthermore, the level of output is generally affected not only by the innovation-adoption decision, but also by such factors as an agent's choice of effort, which usually cannot be observed by the principal, as well as unobserved exogenous factors such as the quality of the inputs, facilities, and organization with which an agent must work. We generally refer to these as simply the productivity of the job or enterprise that an agent fills or manages.

A principal desiring to induce the adoption of an innovation must then solve a principal-agent problem with moral hazard (on effort and innovation adoption) and adverse selection (on job productivity).<sup>3</sup> Un-

fortunately, a ratchet effect appears in repeated principal-agent relationships with moral hazard and adverse selection.<sup>4</sup> If the principal is uncertain concerning the productivity of an enterprise or job, the principal has an incentive to use current performance as a signal of that productivity. High current output is then followed by more stringent future remuneration schemes. The benefits from adopting an innovation thus tend to be "ratcheted" away.

In particular, suppose the economy contains high-productivity and low-productivity jobs which cannot be distinguished. The principal will generally seek to induce innovation adoption and high effort, at least from agents in high-productivity jobs. Doing so will require an "innovation-adoption bonus" for the resulting exceptionally high output (denoted  $y_1$ ) sufficient to induce the agents to bear the cost of adopting the innovation and high effort. Suppose now that agents in low-productivity jobs are also to be induced to adopt an innovation and to supply high effort, yielding an output  $y_2$  with  $y_2 < y_1$ . An innovation-adoption bonus to cover these costs must now be attached to  $y_2$ . The temptation then arises for agents in the high-productivity jobs to eschew innovation adoption and produce  $y_2$ . These agents can then claim to be occupants of low-productivity jobs who have adopted the innovation and thus collect the adoption bonus without bearing the cost of adopting the innovation. Even more seriously, the agents in high-productivity jobs may adopt the innovation but then mimic low-productivity jobs by supplying low effort. This provides these agents with an innovation-adoption bonus, savings on effort, and a cushion against the ratchet effect arising from having increased the productivity of the job without revealing this increase.

<sup>2</sup>A substantial literature considers microeconomic models of the diffusion of innovations. Our analysis departs from this literature in *assuming* that the innovation yields revenue increases that exceed direct adoption costs. The difficulty is that the hierarchical nature of the organizations forces a principal to construct costly incentives to induce agents to adopt innovations.

<sup>3</sup>See Oliver Hart and Bengt Holmström (1987) for a survey of the principal-agent literature. The principal can often come arbitrarily close to a first-best outcome if arbitrarily negative payoffs could be attached to some outcomes (J. Mirrlees, 1974; Holmström, 1979; Steven Shavell, 1979). If ever such a forcing contract could be written, the Soviet Union appears to be the natural place. Even in the Soviet Union, however, there are limits on the penalties that can be imposed. One notes that in the Stalinist period, such limits may

well have not arisen. Interestingly, innovation diffusion rates in the Soviet Union were highest in the 1930's (David Dyker, 1985 p. 28), though we do not wish to argue that the potentially extra severe sanctions were the cause.

<sup>4</sup>See, for example, Berliner (1957), A. Nove (1977), M. L. Weitzman (1980), Holmström (1982), M. Keren et al. (1983), and X. Freixas et al. (1985).

How is this pooling behavior to be deterred and how are the agents in high- as well as low-productivity jobs to be induced to supply high effort and adopt the innovation? The return to output  $y_1$  must be increased even further to make masquerading as a low-productivity job unprofitable. Inducing agents in low-productivity jobs to adopt an innovation thus carries an extra cost related to preserving the desired innovation-adoption incentives for agents in high-productivity jobs. This result readily generalizes to organizations with more than two job productivities. At each step down the scale of job productivities, the adoption of an innovation can be induced only if one pays the direct and incentive costs of adoption to the agents in question and also pays the *increase* in incentive cost to agents in all higher-productivity jobs. This causes the cost of inducing innovation adoption to increase at an increasing rate as one proceeds from high- to low-productivity jobs. The response to this cost-of-adoption schedule may be to induce innovation adoption only in jobs of relatively high productivity and, hence, to induce relatively little use of the innovation.

This result can be contrasted with the outcome of a decentralized or market economy. In the latter, the benefits of an innovation need only exceed the direct costs of adoption in order to induce the agent to innovate. The market will then induce adoption levels that are efficient and that tend to be higher than those of the hierarchical system.

Section I motivates the analysis by providing some evidence on the key features of the model for the case of the Soviet Union. Section II presents a two-period model. Section III presents an equilibrium existence and characterization result. In Section IV we examine potential equilibria and establish their properties. In the process, the workings of the ratchet effect are exposed. Our conclusions are presented in Section V.

### **I. Innovation and Diffusion in the Soviet Union**

Our analysis rests on three stylized facts: that hierarchical systems perform poorly in inducing the use of innovations; that job

productivities, effort levels, and innovation-adoption decisions are difficult to monitor in a hierarchical system; and that the principal's inability to commit gives rise to a ratchet effect. We can illustrate each of these for the case of the Soviet Union.

A growing body of research reveals that the Soviet system of bonus contracts is ineffective in providing innovation incentives (Phillip Hanson, 1981 p. 64; Berliner, 1976) and that differences in innovation are so important as to be a major cause of the technological gap between East and West (Ronald Amann and Julian Cooper, 1986 p. 12).<sup>5</sup> There is also evidence that the problem lies not with the technological process of invention but with the failure of innovations to diffuse in the Soviet Union. For example, Table 1 reports the date of the first introduction of various innovations in the Soviet Union and several Western economies. Table 2 reports data on the spread of these technologies.

Table 1 indicates that the Soviet Union's record in developing advanced technologies is quite good. The initial dates of commercial production of the various technologies generally lag only slightly behind those of the four Western economies. Table 2, however, reveals that the subsequent diffusion of these technologies into widespread use has proceeded at a much slower pace in the Soviet Union than in the West. In every case, a significantly higher fraction of 1982 output is produced by the new technology in the Western economies than in the Soviet Union. Given the Soviet tendency to concentrate innovation efforts in leading enterprises such as steel and nuclear power, the data in Tables 1 and 2, if anything, overstate the success of Soviet innovation attempts.<sup>6</sup>

<sup>5</sup>A striking illustration of the bonus-contract system's failure to induce adequate diffusion is provided by the fact that some innovations have so stubbornly resisted diffusion as to spread into general use only after direct intervention on the part of the highest political leadership. Inducing the use of natural gas, for example, required the personal efforts of Nikita Khrushchev (Nove, 1977 p. 187).

<sup>6</sup>See, for example, Amann and Cooper (1982 p. 24). Similar diffusion experiences characterize other planned economies. For example, Steven Popper (1988) studies the diffusion of numerically controlled machine

TABLE 1—ADOPTION OF NEW TECHNOLOGIES: DATES OF FIRST COMMERCIAL PRODUCTION

Technology	USSR	USA	Japan	FRG	UK
Oxygen steel	1956	1954	1957	1955	1960
Continuous cast steel	1955	1954	1960	1954	1958
Synthetic fiber (nylon)	1948	1938	1942	1941	1941
High-pressure polythene	1953	1941	1954	1944	1937
Nuclear power station	1954	1957	1966	1961	1956
Numerically controlled machine tools	1965	1957	1964	1963	1966

Source: Amann and Cooper (1986 p. 12).

TABLE 2—SUBSEQUENT DIFFUSION OF NEW TECHNOLOGIES: PROPORTIONS OF OUTPUT PRODUCED BY NEW TECHNOLOGIES IN 1982

Technology	USSR	USA	Japan	FRG	UK
Oxygen steel (as percentage of total steel)	29.6	62.1	73.4	80.9	66.1
Continuously cast steel (as percentage of total steel)	12.1	27.6	78.7	61.9	38.9
Synthetic fiber (as percentage of total man-made fiber)	51.2	91.2	83.8	83.1	78.6
Polymerized plastics (as percentage of total plastics)	46.4	87.5	80.0	73.0	79.3
Energy generated by nuclear power station (percentage of total)	7.1	12.4	17.6	17.3	16.7
NC machine tools (as percentage of total metal-cutting machine tools)	16.6	34.0	52.8	20.6	27.7

Source: Amann and Cooper (1986 p. 13).

Our analysis presumes that job productivity as well as effort and innovation-adoption levels cannot be observed by the principal (or at least cannot be observed without exorbitant cost). While it is natural to think of effort as unobservable, one might conjecture that it is easy to observe whether an enterprise manager has adopted an innovation. However, the evidence suggests otherwise. In order to fulfill innovation-adoption targets, for example, Soviet managers frequently either adopt artificial or "pseudoinnovations" that represent only superficial changes in the process of production

(Berliner, 1976 p. 375) or claim innovation adoptions that are actually nonexistent:

Where the [innovation] plans are fulfilled ... one would expect that the technological level would be satisfactory, but in fact this is not always the case.... This state of affairs was recognized by [Leonid] Brezhnev at the XXV Party Congress when he pointed out that "there are still products which in the reports appear as 'new' but in fact are new only by the date of production and not by their technical level." [M. J. Berry, 1982 p. 82]

tools in Hungary. He finds much longer diffusion lags in Hungary than in Western economies. Neil Leary and Judith Thornton (1989), in a study of the Soviet steel industry, find not only slower diffusion rates but utilization rates that peak at "much lower ceilings than those in the market economies" (p. 65).

We can also provide evidence that Soviet planners cannot observe effort or, more generally, input levels. In the late 1960's, for example, managers of the Shchekino Chemical Plant were allowed to keep any cost savings that could be achieved by employing labor more efficiently and releasing excess

labor for other uses. The response was an increase in labor productivity of 52 percent in the first year. This experience is revealing both because of the extent of the labor hoarding or inefficient input use that persisted under the conventional monitoring system and because the response to suspected labor hoarding was not increased monitoring but revised incentives. This presumably testifies to the difficulty of monitoring.<sup>7</sup>

If anything, it is not even clear that output can be observed. This is evident, for example, in the existence of the "second economy," where finished goods are often diverted from official channels by claims that they are "spoiled" (Gregory Grossman, 1981 p. 76). It is also indicated by the frequency with which output reports are inflated to make performance appear better than it is. These inflated reports go undetected by the conventional monitoring system but are occasionally exposed by extraordinary audits:

...spot checks of 48 enterprises belonging to the USSR Ministry of Construction Materials Industry revealed significant inflated reports at every other enterprise.... Inflated reports were found at 20 out of 24 plants and associations checked in the USSR Ministry of Petrochemical Industry.

[E. Manevich, 1987, pp. 84–85]

Recent Soviet discussions reveal that this problem of inflated performance reports is pervasive.<sup>8</sup>

<sup>7</sup>A somewhat unusual illustration of the difficulties in observing the productivity of an enterprise is provided by noting that Soviet athletes received bonuses for winning medals in the 1988 Olympics (*Time* magazine, October 3, 1988, Vol. 132, No. 14, p. 58). A basic scheme of descending payments for gold, silver, and bronze medals was established. However, an athlete's bonus for winning a particular medal was then adjusted upward if his finish was higher than expected and adjusted downward if the finish was lower than expected. Expected finish thus plays a role much like job productivity. It is imperfectly observed and is based on observations of previous performance.

<sup>8</sup>Increased Soviet attention has recently been focused on the ubiquity of inflated Soviet performance

Our final presumption is that the planner's inability to commit to future remuneration schemes gives rise to a ratchet effect. In the Shchekino experiment, the planning ministry committed to refrain from revising targets for five years. However, the initial gains to managers from the increased labor productivity were quickly dissipated as planners reneged on this "commitment." The Shchekino plant had its instructions rewritten seven times in ten years. A second enterprise operating on the same system suffered 17 changes in five years (Peter Rutland, 1984 p. 353). These are not isolated examples. A recognition of the costs of the ratchet motivated the reform decrees of 1979 and the Andropov Experiment of 1983, which stipulated that the five-year plan was to take precedence over the annual plan in order to lengthen the period of commitment. In practice, however, the planning ministries persisted in continually revising enterprise performance targets (Ed Hewett, 1988 pp. 252, 264–65). The Sibtiashmash Productive Association, for example, had its norm linking wage funds to performance revised four times in 1984 alone (Hewett, 1988 p. 265).

There is ample evidence that this inability to commit gives rise to a ratchet effect. For example:

The Kornevskii Silicate Brick Plant succeeded in 1954 in shortening the autoclave baking cycle to 9.8 hours, while the industry average was 12.4 hours. In 1955 they set its plan at 9.7 hours. Having run into trouble getting enough raw materials, the enterprise failed to fulfill its plan in the first quarter and fell among the lagging enterprises, even though it was producing more per unit of equipment

reports. Spurred by V. Selyunin and G. Khanin (1987), Soviet economists have recognized that inflated performance reports can yield significantly overstated growth rates and understated inflation rates. Khanin, for example, estimates that Soviet national income increased by a factor of 660 percent between 1928 and 1985 as compared to the official figure of 8,900 percent. The controversy generated by Selyunin and Khanin is discussed in R. E. Ericson (1988) and V. G. Trembl (1988).

than other silicate plants which had fulfilled their plans.

[Berliner, 1957 p. 78]

More generally, Yuri Andropov reported that

The business leader who has ... introduced in the enterprise a new technology ... not infrequently is a loser, while those who avoid that which is new lose nothing. [Hewett, 1987 p. 216]

## II. A Model of the Incentives to Innovate

### A. Extensive Form

We assume that a risk-neutral principal (or central planner) hires or writes a contract with two or more identical risk-neutral agents (or enterprise managers). For convenience, we assume that the relationship between the principal and agents lasts for two periods and the second period is not discounted.<sup>9</sup>

The jobs to be performed by the agents (or enterprises to be managed) can be one of two possible types, either high or low productivity. Agents observe their job's productivity. The principal cannot observe the productivity of a job and must act on the basis of prior beliefs. We can then let the parameter  $\beta$  denote the productivity of a job and let  $p_1$  be the prior probability of high productivity, so that

$$\beta = \bar{\beta} \text{ (high productivity)} \\ \text{with probability } p_1$$

$$\beta = \underline{\beta} \text{ (low productivity)} \\ \text{with probability } 1 - p_1.$$

We can think of nature originally independently choosing a value of  $\beta$  for each job with this value then characterizing the job for *both* periods.

In period one, and after observing  $\beta$ , the agents choose one of two possible effort levels and choose whether to adopt an innovation. Let  $a$  denote the choice of effort and  $\theta$  the innovation-adoption choice, with  $\bar{a}$  and  $\underline{a}$  denoting high and low effort, respectively, and with  $\bar{\theta}$  and  $\underline{\theta}$  denoting the choices to adopt and not to adopt the innovation, respectively. The period-one choice of effort level has implications only for period-one output. However, if the innovation is adopted, it makes the job more productive both in periods one and two. The principal and the agents both observe output, and the principal then makes payments to the agents. The principal cannot observe the agents' choices of  $(a, \theta)$ . The principal updates the principal's prior expectation concerning the productivity of each agent's job based upon the principal's observations of period-one outputs.

The principal now decides whether to have the agents occupy the same jobs in period two as in period one or to transfer them between jobs. If the agents perform the same period-two jobs as they performed in period one, then the accumulation of job-specific human capital causes period-two outputs to be  $\alpha$  times the corresponding period-one levels, where  $\alpha > 1$ . If the agents are transferred, the job-specific human capital is lost. In period two, each job is characterized by the same basic productivity it carried in period one. Agents recall this or observe the productivity of their new job if they have been transferred. If the innovation was adopted in the job in period one, that innovation adoption continues to boost the job's output. If no adoption occurred, no further opportunity arises. Agents then make effort choices, output is realized, and the principal makes a period-two payment to the agents. Table 3 summarizes the sequence of events.

The principal cannot commit to period-two remuneration schemes. Hence, any period-one announcement must include a period-two payment scheme that will be optimal for the principal once period two has arrived. Equivalently, we can think of the principal as announcing the period-two remuneration scheme at the beginning of pe-

<sup>9</sup>The role of the two-period limitation and possible extensions to longer horizons in models of this type are discussed briefly in Ickes and Samuelson (1987).

TABLE 3—SEQUENCE OF EVENTS

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Period one:
1) Nature chooses productivities of jobs ( $\beta = \underline{\beta}$ or $\bar{\beta}$ ); agents observe $\beta$
2) Principal announces remuneration scheme <sup>10</sup> for period one and announces whether job transfers will occur
3) Agents choose effort levels ( $a = \underline{a}$ or $\bar{a}$ ) and make innovation adoption choices ( $\theta = \underline{\theta}$ or $\bar{\theta}$ )
4) Outputs are realized and payments to agents made. Principal updates expectations concerning $\beta$
5) Job transfers occur ( $\alpha = 1$ ) if contract calls for transfers; otherwise, job transfers do not occur ( $\alpha > 1$ )
Period two:
6) Jobs retain values of $\beta$ and $\theta$ chosen in period one
7) Principal announces remuneration scheme for period two
8) Agents choose effort levels ( $a = \underline{a}$ or $\bar{a}$ )
9) Outputs are realized and payments to agents made

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riod two, as shown in Table 3. Given these assumptions about commitment possibilities, we examine a Bayesian subgame perfect equilibrium.<sup>10</sup>

The possibility that the agents may be transferred among jobs may appear novel. It has been shown previously (Ickes and Samuelson, 1987) that in the presence of the ratchet effect, optimal contracts may call for regularly transferring agents between jobs. This practice of job transfers removes the incentive for an agent in a high-productivity job to disguise the job's productivity in order to secure more favorable future remuneration schemes. It does so by ensuring that future schemes, applicable to the new job into which the agent has

been transferred, will not depend upon the productivity of the current job.<sup>11</sup>

Because agents and the jobs they occupy are *ex ante* identical, we can simplify the analysis by hereafter examining the relationship between the principal and a single agent, referred to as "the agent." Job transfers in the single-agent model are equivalent to presuming that job-specific human capital does not appear and that, in period one, the agent takes the principal's expectations concerning the job as exogenous and unaffected by the agent's actions (because they describe expectations in a new job to which the agent is transferred). We will also occasionally refer to the agent in a high-productivity job and the agent in a low-productivity job, but this refers to the two possible types of the job filled by the single agent.

B. Assumptions

A function  $y: \{\underline{\beta}, \bar{\beta}\} \times \{\underline{a}, \bar{a}\} \times \{\underline{\theta}, \bar{\theta}\} \rightarrow \mathbb{R}$  gives output levels. The function  $y$  is as-

<sup>10</sup>We assume that the principal can make a credible commitment to transferring agents between jobs. Because transfers are readily defined and verified, it is relatively easy to write and enforce an explicit contract or sustain an implicit contract to transfer employees from one job to another. In contrast, it is likely to be impossible to write and enforce contracts specifying future remuneration schemes. As noted in Ickes and Samuelson (1987), one readily finds examples in which employers commit to transferring employees between jobs, but one rarely finds explicitly specified criteria for evaluation of job performance and remuneration. For example, compare the number of academic departments that commit to times at which tenure reviews will be conducted with the number that explicitly state criteria for tenure.

<sup>11</sup>We assume that the principal cannot make the decision whether to transfer an agent to a new job contingent upon the agent's output in the current job and cannot contract to transfer an agent into a job of a particular productivity. It is then convenient (and sacrifices no generality) to assume a random-assignment rule. Allowing transfers to depend upon current output alters some of the details of the calculations and equi-



sumed to satisfy

$$(1) \quad y(\bar{\beta}, \bar{a}, \bar{\theta}) \equiv y_1$$

$$y(\bar{\beta}, \underline{a}, \bar{\theta}) = y(\bar{\beta}, \bar{a}, \underline{\theta}) = y(\underline{\beta}, \bar{a}, \bar{\theta}) \equiv y_2$$

$$y(\bar{\beta}, \underline{a}, \underline{\theta}) = y(\underline{\beta}, \bar{a}, \underline{\theta}) = y(\underline{\beta}, \underline{a}, \bar{\theta}) \equiv y_3$$

$$y(\underline{\beta}, \underline{a}, \underline{\theta}) \equiv y_4.$$

The intricacies of the problem arise because of the pooling possibilities manifest in (1). When  $y_2$  or  $y_3$  is produced, the principal cannot distinguish the effort level of the agent, the productivity of the job, or whether the innovation has been adopted.

The agent derives disutility both from supplying effort and adopting the innovation. We can take  $\underline{a}$ ,  $\bar{a}$ ,  $\underline{\theta}$ , and  $\bar{\theta}$  to be real numbers with  $\underline{a} < \bar{a}$  and  $0 = \underline{\theta} < \bar{\theta}$  and then let the agent's disutility be given by

Action	Disutility
$\bar{a}, \bar{\theta}$	$\bar{a} + \bar{\theta}$
$\underline{a}, \bar{\theta}$	$\bar{a} + \bar{\theta}$
$\bar{a}, \underline{\theta}$	$\bar{a}$
$\underline{a}, \underline{\theta}$	$\underline{a}$ .

We then assume that  $\bar{\theta} > \bar{a} - \underline{a}$ , so that  $\bar{a} + \bar{\theta} > \underline{a} + \bar{\theta} > \bar{a} > \underline{a}$ . This reveals that it is most costly (in utility terms) to supply high effort and adopt the innovation and least costly to do neither. Of the two possible intermediate choices, adopting the innovation with low effort is more costly than supplying high effort without adopting. The principal must provide the agent with nonnegative utility, since the agent retains the option of nonparticipation and receiving a utility which we normalize to zero. In the Soviet Union, for example, managers retain the option of becoming workers (though see footnote 3).

We assume that

$$(2) \quad y_1 > y_2 > y_3 > y_4 \geq \underline{a}.$$

The first three inequalities in condition (2) indicate that output is higher in a high-productivity job than in a low-productivity job and that output can be increased by exerting high rather than low effort and by innovation adoption. The final inequality in (2) ensures that it is always profitable to employ an agent, even if the job is low-productivity and low effort is supplied with no innovation adoption. We further assume that

$$(3) \quad \bar{\theta} > (y_i - y_{i+1}) > (\bar{a} - \underline{a}) \quad i = 1, 2, 3$$

$$(4) \quad \bar{\theta} < 2(\bar{a} - \underline{a}).$$

The first inequality in (3) indicates that the disutility of adopting the innovation exceeds the single-period gain in output. The second inequality indicates that it is profitable to induce the agents to supply high effort and ensures that high effort will be induced in at least some cases. Condition (4) implies that over the course of two periods it is less costly to raise output via innovation adoption than through high effort. Conditions (3) and (4) yield  $\bar{\theta} < 2(y_i - y_{i+1})$ , which ensures that innovation adoption is efficient in a two-period model.

### C. Strategies and Equilibrium

We can now describe formally the strategy spaces and payoffs of the principal and agent and state equilibrium conditions. Let  $P_2(\bar{\beta}, \bar{\theta})$  be the principal's period-two expectation that  $\beta = \bar{\beta}$  and  $\theta = \bar{\theta}$ , with  $P_2(\bar{\beta}, \underline{\theta})$ ,  $P_2(\underline{\beta}, \bar{\theta})$ , and  $P_2(\underline{\beta}, \underline{\theta})$  being similar. Let  $\bar{P}_2 \in \{P \in \mathbb{R}_+^4 : \sum P_i = 1\} \equiv S^4$  be a vector of such probabilities ( $S^4$  is the unit simplex in  $\mathbb{R}^4$ ). The principal provides a remuneration scheme in each period to the agent which specifies the payment, denoted  $h_{\cdot i}$ , to be made to the agent in the event that the commonly observed outcome in period  $\cdot$  is  $y_i$  ( $i = 1, 2, 3, 4$ ). The principal's pure strategy set thus consists of triples  $h \equiv (h_1, t, h_2)$  where  $h_1 \in \mathbb{R}_+^4$ ,  $t \in \{\text{Yes, No}\}$ , and  $h_2 : S^4 \rightarrow \mathbb{R}_+^4$ . The payment attached in period one to output  $y_i$  is specified as  $h_{1i}$ ;  $t$  identifies whether job transfers occur; and

librium strategies but leaves the basic character of the results unchanged.

$h_{2i}(P_2)$  identifies the period-two payment attached to output  $y_i$  given expectations  $P_2$ .

Let  $H_2$  be the set of functions  $h_2: S^4 \rightarrow \mathbb{R}_+^4$  and let  $H$  be the set of triples  $(h_1, t, h_2)$ . Then, an agent's strategy is a pair  $z_1: \{\underline{\beta}, \bar{\beta}\} \times H \rightarrow \{0, (\underline{a}, \underline{\theta}), (\underline{a}, \bar{\theta}), (\bar{a}, \underline{\theta}), (\bar{a}, \bar{\theta})\}$  and  $z_2: \{\underline{\beta}, \bar{\beta}\} \times \{\underline{\theta}, \bar{\theta}\} \times H_2 \times S^4 \rightarrow \{0, \underline{a}, \bar{a}\}$ :  $z_1(\beta, h)$  gives the agent's period-one choice of  $a$  [denoted  $z_{1a}(\beta, h)$ ] and  $\theta$  [denoted  $z_{1\theta}(\beta, h)$ ] as a function of the productivity of the job occupied by the agent and the remuneration scheme chosen by the principal;  $z_2(\beta, \theta, h_2, P_2)$  gives the agent's period-two choice of effort as a function of the productivity and innovation status of the job, the period-two remuneration scheme, and the principal's period-two expectation. A choice of zero is taken to denote nonparticipation, yielding a utility and an output of zero.

If output  $y_{ij}$  appears in period  $i$ , then the principal's payoff in that period is given by  $y_{ij} - h_{ij}$ . Let  $\alpha: \{\text{Yes}, \text{No}\} \rightarrow [1, \alpha]$ , denoted  $\alpha(t)$ , be a function with  $\alpha(\text{Yes}) = 1$  and  $\alpha(\text{No}) = \alpha$ , where  $\alpha > 1$  is the productivity parameter capturing the accumulation of job-specific human capital. Then the principal's objective for the game is<sup>12</sup>

(5) 
$$\max_{h \in H} E_{\beta} \{ y(\beta, z_1(\beta, h)) - h_1(y_1(\beta, z_1(\beta, h))) + \alpha(t) y(\beta, z_2(\beta, z_{1\theta}(\beta, h), h_2, P_2), z_{1\theta}(\beta, h)) - h_2(y(\beta, z_2(\beta, z_{1\theta}(\beta, h), h_2, P_2), z_{1\theta}(\beta, h)), P_2) \}.$$

In the second period, the principal solves

(6) 
$$\max_{h_2 \in H_2} E_{\beta} \{ \alpha(t) y(\beta, z_2(\beta, z_{1\theta}(\beta, h), h_2, P_2), z_{1\theta}(\beta, h)) - h_2(y(\beta, z_2(\beta, z_{1\theta}(\beta, h), h_2, P_2), z_{1\theta}(\beta, h)), P_2) \}.$$

<sup>12</sup>In keeping with our consideration of a single agent, payoffs or profits for the principal will always be taken to mean expected profits per agent.

TABLE 4—AGENT'S PERIOD-ONE UTILITY FROM VARYING CHOICES

Agent's action	Job	Outcome	Utility
$\bar{a}, \bar{\theta}$	$\bar{\beta}$	$y_1$	$h_{11} - (\bar{a} + \bar{\theta})$
$\bar{a}, \underline{\theta}$	$\bar{\beta}$	$y_2$	$h_{12} - \bar{a}$
$\underline{a}, \bar{\theta}$	$\bar{\beta}$	$y_2$	$h_{12} - (\underline{a} + \bar{\theta})$
$\underline{a}, \underline{\theta}$	$\bar{\beta}$	$y_3$	$h_{13} - \underline{a}$
$\bar{a}, \bar{\theta}$	$\underline{\beta}$	$y_2$	$h_{12} - (\bar{a} + \bar{\theta})$
$\bar{a}, \underline{\theta}$	$\underline{\beta}$	$y_3$	$h_{13} - \bar{a}$
$\underline{a}, \bar{\theta}$	$\underline{\beta}$	$y_3$	$h_{13} - (\underline{a} + \bar{\theta})$
$\underline{a}, \underline{\theta}$	$\underline{\beta}$	$y_4$	$h_{14} - \underline{a}$

The agent's payoff in period  $i$  is given by  $h_i(y_i)$  minus the disutility of the period- $i$  effort and innovation adoption choice. The agent's single-period utility levels from varying choices are given in Table 4. In the second period, the agent in a  $\beta$  job (for  $\beta = \underline{\beta}$  or  $\bar{\beta}$ ) thus solves

(7) 
$$\max_{z_2 \in \{\underline{a}, \bar{a}\}} \{ h_2(y(\beta, z_2, z_{1\theta}(\beta, h)), P_2) - z_2 \}.$$

In period one, the agent in a  $\beta (= \underline{\beta} \text{ or } \bar{\beta})$  job solves

(8) 
$$\max_{\substack{z_{1a} \in \{\underline{a}, \bar{a}\} \\ z_{1\theta} \in \{\underline{\theta}, \bar{\theta}\} \\ z_2 \in \{\underline{a}, \bar{a}\}}} \{ [ h_1(y(\beta, z_{1a}, z_{1\theta})) - z_{1a} - z_{1\theta} ] + [ h_2(y(\beta, z_2, z_{1\theta}), P_2) - z_2 ] \}.$$

A subgame perfect equilibrium is then a triple of strategies  $(h, z_1, z_2)$  such that the  $h_2$  component of  $h$  maximizes (6) given  $z_2$ ;  $h$  maximizes (5) given  $z_1$  and  $z_2$  and given that  $h_2$  must solve (6);  $z_2(\beta)$  and  $z_2(\bar{\beta})$  each maximizes (8) given  $h$ ;  $z_1(\beta)$  and  $z_1(\bar{\beta})$  each maximizes (7) given  $h$  and given that  $z_2(\beta)$  and  $z_2(\bar{\beta})$  solve (8); and period-two posterior expectations  $P_2$  are calculated according to Bayes' rule. This last requirement warrants some elaboration. If job transfers are not practiced, this requires that the  $P_2$  appearing in (5)–(8) be calculated by the principal according to

Bayes' rule and that both the principal and agent recognize that the agent's actions, through their effects on  $y_{1i}$ , affect  $P_2$ . If job transfers are practiced, then the principal again calculates  $P_2$  via Bayes' rule and recognizes that the actions the agent is induced to take in period one will affect  $P_2$ . The agent's maximization takes  $P_2$  to be equal to the equilibrium value calculated by the principal but to be exogenously fixed at that level (because  $P_2$  applies to a different period-two job than the one the agent now occupies).

### III. Equilibrium Existence and Characterization

This section presents a basic equilibrium existence and characterization result:

**PROPOSITION 1:** *A subgame perfect equilibrium exists. Generically,*

- 1) *the equilibrium is unique;*
- 2) *the equilibrium strategies are pure;*
- 3) *the period-one outcome is separating, in that period-one outputs reveal job productivities;*
- 4) *all agents are induced to supply high effort in period two;*
- 5) *the equilibrium may or may not involve job transfers, depending upon parameter values;*
- 6) *innovation and high effort are induced from agents in  $\beta$  jobs in period one;*
- 7) *depending upon parameter values, agents in  $\beta$  jobs may be induced to supply high effort and innovate (this may occur with or without job transfers), may be induced to supply high effort and not innovate (only with job transfers), or may be induced to supply low effort and not innovate (only without job transfers);*
- 8) *the equilibrium will consist of one (and only one) of four sets of strategies, each corresponding to one of the four possibilities identified in 7, depending upon parameter values. The four sets of strategies are given in Table 5.<sup>13</sup> The payoff to the princi-*

*pal from each potential equilibrium is given in Table 6.*

The characteristics of the four potential equilibria are listed in Table 6.

The Appendix proves this proposition. The intuition behind these results is readily provided. First, the existence and uniqueness of the equilibrium follows from a backward induction argument. Second, the equilibrium features pure strategies, because the principal is in general not indifferent over agents' actions. An equilibrium then cannot exhibit agent randomization, because the principal would respond by slightly increasing the payoff to the principal's preferred outcome and hence inducing pure strategies.<sup>14</sup> Third, the principal induces separating outcomes in period one, because the information gleaned from such outcomes allows the principal to reduce the cost of period-two contracts. Fourth, given such separation, there are no information-based obstacles to inducing effort choices in period two, and it is profitable for the principal to induce all agents to expend high effort in the second period. Fifth, the period-one separating outcome may or may not be achieved with the help of job transfers, depending upon the values of parameters that determine the rate at which transfers trade reduced period-one incentive costs for sacrifices of human capital accumulation. Sixth, agents in high-productivity jobs will always be induced to adopt and supply high effort, because the output gains from doing so exceed the utility costs (and

<sup>13</sup>In order to avoid clutter, Table 5 presents only the actions that agents' strategies yield along the equilibrium path. Out-of-equilibrium behavior is easily calculated from (7) and (8).

<sup>14</sup>We are assuming here and throughout the analysis that when an agent is indifferent between two actions, the agent chooses the action most preferred by the principal. This presumption is required for the existence of an equilibrium. If the agent does not choose the principal's most preferred action when the agent is indifferent, the principal could induce such a choice by adding an arbitrarily small  $\varepsilon$  to the payoff from the desired action. As there is no smallest such  $\varepsilon$  which will suffice, equilibrium requires  $\varepsilon = 0$  and a tie which is broken in the principal's favor. It is important to note that it is not entirely obvious that ties will be broken in the principal's favor, especially with multiple agents. Ching-to Ma (1987, 1988) and Ma et al. (1988) examine incentive schemes that do not invoke such an assumption.

TABLE 5—EQUILIBRIUM STRATEGIES

Equilibrium	Strategy	Period 1	Period 2		Transfer?
			$P_2 = 1$	$P_2 < 1$	
1	Principal:	$h_1$	$2\bar{\theta} + \bar{a}$	$\bar{a}$	yes
		$h_2$	$\bar{\theta} + \bar{a}$	$\underline{a}$	
		$h_3$	$\underline{a}$	$\underline{a}$	
		$h_4$	$\underline{a}$	$\underline{a}$	
	Agent:	$\bar{\beta}$	$\bar{a}, \bar{\theta}$	$\bar{a}$	
		$\underline{\beta}$	$\bar{a}, \bar{\theta}$	$\bar{a}$	
2	Principal:	$h_1$	$\bar{\theta} + 2\bar{a} - \underline{a}$	$\bar{a}$	yes
		$h_2$	$\bar{a}$	$\underline{a}$	
		$h_3$	$\bar{a}$	$\bar{a}$	
		$h_4$	$\underline{a}$	$\underline{a}$	
	Agent:	$\bar{\beta}$	$\bar{a}, \bar{\theta}$	$\bar{a}$	
		$\underline{\beta}$	$\bar{a}, \bar{\theta}$	$\bar{a}$	
3	Principal:	$h_1$	$\bar{\theta} + 3\bar{a} - 2\underline{a}$	$\bar{a}$	no
		$h_2$	$\bar{\theta} + \bar{a}$	$\underline{a}$	
		$h_3$	$\underline{a}$	$\underline{a}$	
		$h_4$	$\underline{a}$	$\underline{a}$	
	Agent:	$\bar{\beta}$	$\bar{a}, \bar{\theta}$	$\bar{a}$	
		$\underline{\beta}$	$\bar{a}, \bar{\theta}$	$\underline{a}$	
4	Principal:	$h_1$	$\bar{\theta} + \bar{a}$	$\bar{a}$	no
		$h_2$		$\underline{a}$	
		$h_3$		$\bar{a}$	
		$h_4$	$\underline{a}$	$\underline{a}$	
	Agent:	$\bar{\beta}$	$\bar{a}, \bar{\theta}$	$\bar{a}$	
		$\underline{\beta}$	$\underline{a}, \underline{\theta}$	$\underline{a}$	

Note:  $P_2$  is  $P_2(\bar{\beta}, \bar{\theta})$ .

TABLE 6—SUMMARY OF POTENTIAL EQUILIBRIUM OUTCOMES AND PRINCIPAL'S EXPECTED PROFITS

Equilibrium	Period-1 actions ( $a, \theta$ ) and outcome ( $y$ ) in $\bar{\beta}$ job	Period-1 actions ( $a, \theta$ ) and outcome ( $y$ ) in $\underline{\beta}$ job	Transfers practiced?	$\underline{\beta}$ adopt innovation?	$\underline{\beta}$ supply high effort?
1	$\bar{a} \bar{\theta} y_1$	$\bar{a} \bar{\theta} y_2$	yes	yes	yes
2	$\bar{a} \bar{\theta} y_1$	$\bar{a} \bar{\theta} y_3$	yes	no	yes
3	$\bar{a} \bar{\theta} y_1$	$\bar{a} \bar{\theta} y_2$	no	yes	yes
4	$\bar{a} \bar{\theta} y_1$	$\underline{a} \underline{\theta} y_4$	no	no	no

Principal's expected profits:

$$\begin{aligned}
 \pi_1 &= p_1[2y_1 - 2\bar{\theta} - 2\bar{a}] + (1 - p_1)[2y_2 - \bar{\theta} - 2\bar{a}] \\
 \pi_2 &= p_1[2y_1 - \bar{\theta} - 3\bar{a} + \underline{a}] + (1 - p_1)[2y_3 - 2\bar{a}] \\
 \pi_3 &= p_1[(1 + \alpha)y_1 - 4\bar{a} - \bar{\theta} + 2\underline{a}] + (1 - p_1)[(1 + \alpha)y_2 - 2\bar{a} - \bar{\theta}] \\
 \pi_4 &= p_1[(1 + \alpha)y_1 - 2\bar{a} - \bar{\theta}] + (1 - p_1)[y_4 + \alpha y_3 - \bar{a} - \underline{a}]
 \end{aligned}$$

inducing these agents to do so does not raise the incentive costs associated with other agents). Seventh, agents in low-productivity jobs may or may not be induced to innovate, depending upon the values of parameters that determine the relative magnitudes of the increased output and the increase in incentive costs associated with high-productivity agents. Finally, we then have four possible equilibria, differing according to whether transfers are practiced and whether low-productivity agents are induced to innovate.

#### IV. Incentives and Innovation

The four sets of strategies given in Table 5 represent four possible equilibria. Because the principal moves first in a sequential game, we can equivalently view these as four possible optimal remuneration schemes for the principal (with the associated induced-agent actions). We begin with the question of whether there exist parameter values for which it is optimal for the principal to offer each remuneration scheme.

**COROLLARY 1:** *There exist parameter values for which each of equilibria 1–4 is the unique equilibrium.*

#### PROOF:

We prove this by presenting four examples. In each example,

$$y_1 = 26 \quad p_1 = 0.3$$

$$y_2 = 16.5 \quad \bar{a} = 7.8$$

$$y_3 = 10.6 \quad \underline{a} = 2$$

$$y_4 = 2.$$

*Example 1*—Remuneration scheme 1 optimal:

Parameters	Payoffs	
$\bar{\theta} = 9.6$	$\pi_1 = 10.62$	$\pi_3 = 10.2135$
$\alpha = 1.01$	$\pi_2 = 10.22$	$\pi_4 = 10.1522.$

*Example 2*—Remuneration scheme 2 optimal:

Parameters	Payoffs	
$\bar{\theta} = 11.7$	$\pi_1 = 7.89$	$\pi_3 = 8.1135$
$\alpha = 1.01$	$\pi_2 = 9.59$	$\pi_4 = 9.522.$

*Example 3*—Remuneration scheme 3 optimal:

Parameters	Payoffs	
$\bar{\theta} = 9.6$	$\pi_1 = 10.62$	$\pi_3 = 11.955$
$\alpha = 1.1$	$\pi_2 = 10.22$	$\pi_4 = 11.522.$

*Example 4*—Remuneration scheme 4 optimal:

Parameters	Payoffs	
$\bar{\theta} = 11.7$	$\pi_1 = 7.89$	$\pi_3 = 9.855$
$\alpha = 1.1$	$\pi_2 = 9.59$	$\pi_4 = 10.892.$

The potential optimality of remuneration schemes 2 and 4 confirms the argument presented in the introduction that it may be unprofitable to induce the low-productivity agent to adopt the innovation, because of the increased incentive costs of inducing the high-productivity agent to innovate. Notice that transfers occur when  $\alpha$  is low (job-specific human capital is not important) and that innovation is induced from all agents when  $\bar{\theta}$  is low (innovation is inexpensive).

We can pursue the connection between parameter values and the optimal remuneration scheme further. First, we investigate the conditions under which the principal will find it optimal to induce innovation adoption from all agents. Comparing schemes 1 and 2, we find that the former entails an extra cost of  $\bar{\theta} - p_1(\bar{a} - \underline{a})$  in exchange for an expected output gain of  $2(1 - p_1)(y_2 - y_3)$ . Similarly, comparing schemes 3 and 4 reveals that the former entails an extra cost of  $(1 - p_1)\bar{\theta} + p_1[2(\bar{a} - \underline{a})] + (1 - p_1)(\bar{a} - \underline{a})$  in exchange for an extra output

gain of  $(1 - p_1)[(1 + \alpha)y_2 - \alpha y_3 - y_4]$ . We thus immediately have the following corollary (we can identify precise boundaries on the parameter values for which innovation adoption will occur, but the resulting expressions are cumbersome<sup>15</sup>).

**COROLLARY 2:** *Inducing all agents to adopt the innovation is more likely to be optimal as  $\bar{\theta}$  is small,  $y_2 - y_3$  large,  $\alpha$  large,  $y_2 - y_4$  large, and  $p_1$  small.*

These results are not surprising. They indicate that inducing innovation adoption from low-productivity agents is more likely to be optimal when the cost of innovation ( $\bar{\theta}$ ) is small, the output gains ( $\alpha[y_2 - y_3]$  and  $y_3 - y_4$ ) are large, and it is more likely that jobs are low-productivity ( $p_1$  is small).

The effect of variations in the marginal cost of inducing high effort,  $(\bar{a} - \underline{a})$ , on the optimality of inducing innovation adoption from low-productivity agents is ambiguous. If job transfers are not practiced, so that schemes 3 and 4 are relevant, increases in  $(\bar{a} - \underline{a})$  make it less likely that low-productivity-agent innovation adoption is optimal. This occurs because, without job transfers, agents in  $\beta$  jobs are induced to adopt the innovation if and only if they also are induced to supply high effort, so that an increase in the cost of the latter makes it less

likely that inducing innovation adoption is optimal. In contrast, if job transfers are practiced, so that remuneration schemes 1 and 2 are relevant, then increases in  $(\bar{a} - \underline{a})$  make it more likely that innovation adoption by agents in low-productivity jobs is optimal. This occurs because job transfers reduce the cost of inducing high effort. In the presence of job transfers, agents in the  $\beta$  job are then induced to supply high effort regardless of whether they adopt the innovation, and increases in the cost of inducing high effort are not inimical to inducing innovation adoption.

These findings direct attention to the role in the model played by the agents' effort choices. One might initially wonder why we do not strip the model of effort choices and concentrate on the choice of innovation adoption in jobs of varying productivity. Effort choices are essential to the analysis because the most profitable deviation for an agent from a recommendation of high effort and innovation adoption is to adopt the innovation but supply low effort. Adopting the innovation raises the productivity of the job while supplying low effort saves on effort disutility and (most importantly) disguises the job's productivity. This allows the agent to avoid more severe future remuneration schemes while making it easier to attain high payments from existing schemes. The highest incentive costs accordingly arise in deterring agents from adopting the innovation while supplying low effort, and an important facet of the incentive problem is not captured when effort choices are ignored.

Attention now turns to job transfers. Ickes and Samuelson (1987) demonstrate that job transfers may reduce the cost of effort incentives. This is again evident in the results of this paper. A comparison of remuneration schemes 1 and 3, for example, reveals that an extra ratchet price of  $2(\bar{a} - \underline{a}) - \bar{\theta}$  is required to induce high effort from agents in  $\beta$  jobs in scheme 3 (without job transfers), which is unnecessary in scheme 1 (with transfers). Because of this, job transfers are optimal in some circumstances. In addition, if an agent in a  $\beta$  job is not induced to adopt the innovation, as in schemes 2 and 4,

<sup>15</sup>For example, inducing innovation adoption from low-productivity agents is optimal if  $\pi_1 > \max\{\pi_2, \pi_4\}$  or  $\pi_3 > \max\{\pi_2, \pi_4\}$ . After manipulation, this is equivalent to

$$\begin{aligned} \theta &< \max\left[\min\left(p_1[\bar{a} - \underline{a}] + (1 - p_1)[2(y_2 - y_3)],\right.\right. \\ &\quad \left.p_1[(1 - \alpha)y_1] + (1 - p_1)\right. \\ &\quad \left.\times [2y_3 - y_4 - \alpha y_3 - (\bar{a} - \underline{a})]\right), \\ \min\left(\frac{p_1}{1 - p_1}[(\alpha - 1)y_1 - (\bar{a} - \underline{a})] + [(1 + \alpha)y_2 - 2y_3],\right. \\ &\quad \frac{p_1}{1 - p_1}[-2(\bar{a} - \underline{a})] \\ &\quad \left.+ [(1 + \alpha)y_2 - \alpha y_3 - y_4 - (\bar{a} - \underline{a})]\right). \end{aligned}$$

high effort is optimally induced from this agent only if job transfers are practiced. This occurs because the cost of such effort is prohibitive (given  $\underline{\beta}$  does not adopt) without job transfers.

We can identify conditions under which job transfers will occur as follows.

**COROLLARY 3:** *Job transfers are more likely to be optimal as  $\alpha$  is small,  $p_1$  is close to neither 0 nor 1, and  $y_2 - y_3$  and  $y_3 - y_4$  are large.*

This follows immediately from comparing profit expressions for job-transfer schemes 1 and 2 with those for remuneration schemes 3 and 4. The results are expected. First, job transfers sacrifice job-specific human capital and, thus, are most likely to be optimal when the effect of such capital, or  $\alpha$ , is small. Second, job transfers are designed to deter agents from concealing job productivities, a problem that is most serious when the principal entertains significant uncertainty concerning productivity, so that  $p_1$  is close to neither 0 nor 1. Finally, job transfers are most likely to be optimal when the effect of high effort, given by  $y_2 - y_3$  and  $y_3 - y_4$ , is large. Notice that the effect of effort costs is again ambiguous. As  $(\bar{a} - \underline{a})$  increases, transfers are more likely to be optimal if all agents are induced to adopt the innovation but less likely to be optimal if  $\underline{\beta}$  agents are not induced to adopt.

We can now make precise the statement that, in the hierarchical system, the cost of innovation adoption increases at an increasing rate. The principal in our model has the option of offering a remuneration scheme that induces the adoption of innovation from no agents, from agents in high-productivity jobs only, or from agents in all jobs. Let  $C_0$  be the cost of inducing innovation in no jobs,  $C_1$  the cost of inducing innovation in high-productivity jobs only, and  $C_2$  the cost of inducing innovation from all agents.

**PROPOSITION 2:** *Suppose job transfers are not practiced. Then for all  $p_1 \in [0, 1)$ ,*

$$(9) \quad C_2 - C_1 > C_1 - C_0.$$

*Alternatively, if job transfers are practiced, then (9) holds for all  $p_1 \in [0, \bar{\theta}/(\bar{\theta} + (\bar{a} - \underline{a}))]$ .*

**PROOF:**

Consider the case of job transfers. We have

$$C_0 = [p_1(2\bar{a} - \underline{a}) + (1 - p_1)\bar{a}] + \bar{a}$$

$$C_1 = [p_1(\bar{\theta} + 2\bar{a} - \underline{a}) + (1 - p_1)\bar{a}] + \bar{a}$$

$$C_2 = [p_1(2\bar{\theta} + \bar{a}) + (1 - p_1)(\bar{\theta} + \bar{a})] + \bar{a}.$$

The bracketed term in each case gives the period-one cost of inducing the outcome, which is the sum of the remunerations received by a  $\underline{\beta}$  and  $\bar{\beta}$  agent multiplied by  $p_1$  and  $1 - p_1$ , respectively. The second term is the period-two cost. Because these are separating outcomes, both agents receive  $\bar{a}$  in period two, and the period-two cost is thus  $p_1\bar{a} + (1 - p_1)\bar{a} = \bar{a}$ . The terms  $C_1$  and  $C_2$  follow directly from Table 6, while  $C_0$  follows from Ickes and Samuelson (1987). We then calculate  $C_2 - C_1 > C_1 - C_0$  if  $p_1 \in [0, \bar{\theta}/(\bar{\theta} + (\bar{a} - \underline{a}))]$ . The no-transfers case involves a similar calculation.

The result shows that the cost of inducing agents in both types of jobs to adopt the innovation is more than twice that of inducing agents in only one type of job to adopt the innovation. This is what we refer to as the cost of innovation adoption increasing at an increasing rate. A first expectation is that this result will hold only if  $p_1$  is not too large. If  $p_1$  is large, there are many more  $\bar{\beta}$  jobs than  $\underline{\beta}$  jobs, and the incremental cost of inducing the relatively few agents in  $\underline{\beta}$  jobs to adopt the innovation would appear unlikely to be larger than the incremental cost of inducing the relatively many agents in  $\bar{\beta}$  jobs to adopt. Without transfers, however, we find  $C_2 - C_1 > C_1 - C_0$  for all  $p_1 < 1$ . This result appears because agents in  $\bar{\beta}$  jobs can be induced to adopt only if incentive costs are also paid to agents in  $\underline{\beta}$  jobs. The incremental cost of inducing agents in  $\bar{\beta}$  jobs to adopt then exceeds the corresponding adoption cost for agents in  $\underline{\beta}$  jobs,

regardless of the relative numbers of each type of job. Because job transfers partially alleviate the incentive problem (though at the cost of sacrificing job-specific human capital), an upper bound on  $p_1$  (which always exceeds  $1/2$ ) is required for the comparison with job transfers.

### V. Conclusion

We have examined the incentives to adopt innovations in a hierarchical system such as the Soviet planned-enterprise sector. Because the principal in such a system is generally uncertain as to the productivity of the jobs filled by the agents, a ratchet effect appears. An agent's exemplary performance is taken as a signal that the agent fills a high-productivity job and is accordingly followed by more demanding remuneration schemes. Agents then have an incentive to disguise the productivity of their jobs.

The operation of the ratchet effect raises particularly severe problems in inducing the adoption of innovations. The principal will always induce innovation adoption from agents in high-productivity jobs and will do so by attaching a large payment to the relatively high output accompanying innovation. Suppose now that agents in lower-productivity jobs are to be induced to adopt an innovation. To do so, the payments attached to the outputs produced if these agents innovate must be increased. Unfortunately, this increases the return that agents in higher-productivity jobs can earn by deviating from recommended actions in order to disguise the productivities of their jobs. The payments made to these agents must then also be increased to deter such deviations. As a result, each decision by the principal to induce innovation adoption from agents in jobs of a given productivity level increases the incentive costs of inducing innovation adoption from all agents in jobs of higher productivity. The principal will thus begin by inducing innovation adoption in the highest-productivity jobs and proceed downward, finding that at each step the costs of inducing innovation adoption increase at an increasing rate. The response

to these incentive costs is likely to entail inducing a relatively low rate of innovation adoption.

We have derived these results in a highly stylized model, and we can comment on which features of the model are most important. Similar forces will appear if there are more than two levels of  $\theta$ ,  $a$ , and  $\alpha$ , though the analysis is more complicated (and completely separating contracts are unlikely to be optimal or even possible if the number of values is too large or forms a continuum). The basic forces also survive generalization to many or infinite periods, though this generalization appears to be most interesting if job productivities are continually subjected to random shocks so that there is always new information to be learned. The simplicity of the results, especially those pertaining to job transfers, is driven by the separation of the adverse selection and moral-hazard problems, with the former applying only to jobs and the latter only to agents' actions. The principal faces a much more difficult problem if agents also differ in types. In some cases, however, job transfers will still be a useful device to reduce the incentive to disguise job productivities, though transfers will be ineffective in eliminating incentives to disguise worker productivities.

We can use these results to illustrate the key difference in inducing innovation adoption between a centralized system and a decentralized or market economy. Suppose that output  $y$  sells at a fixed price (which we can normalize to equal unity). Then an innovation will be adopted whenever the increment to output, or  $2(y_1 - y_{i+1})$ , exceeds the direct cost of adopting, or  $\bar{\theta}$ . The market system would thus always induce the adoption of the innovations examined in our model. This yields an efficient level of investment and allows a Pareto efficient outcome to appear. Equivalently, we can say that the curve identifying the private cost of adopting an innovation in the various enterprises in the market economy is linear in the number of adoptions and has a constant slope or marginal cost equal to the technical cost of the innovation. Any innovation whose private benefits exceed this



technical cost is then adopted. In addition, the market economy eliminates the incentive-cost externalities examined above, so that private and social costs and benefits coincide, yielding an efficient innovation level.

In a hierarchical system, in contrast, the corresponding cost curve increases at an increasing rate. The marginal cost of adopting an innovation equals the technical cost of adoption only for initial adoptions. The marginal cost of subsequent adoptions includes increasingly large increases in incentive costs. Given this more sharply increasing cost curve, the optimal response is the inducement of fewer innovation adoptions than in the decentralized economy. In particular, cases will arise in which innovations exist whose benefits exceed the direct cost of adoption but which are not adopted. This yields an outcome with inefficiently low innovation adoption. It appears as if this difficulty is inherent in the hierarchical nature of the system. Mere adjustments in incentive schemes within the hierarchical system are unlikely to counter the problem.

Finally, we can return to the case of the Soviet Union. We have seen that the optimal response to the increasing cost-of-adoption schedule that arises in a hierarchical system is relatively little innovation. While the Soviet Union exhibits all of the characteristics of a hierarchical system required to yield the increasing cost-of-adoption curve and also exhibits relatively little innovation, it is clear that the Soviets do not consider their innovation adoption rates to be optimal. Comments such as those of Malenkov and Gorbachev, quoted in our introduction, suggest frustration with achieved performance. Reinforcing this, Gorbachev has designated "the acceleration of scientific and technical progress" to be "problem number one" for the USSR (see Amman and Cooper, 1986 p. 1). On the one hand, this perceived lack of optimality reflects the lack of coordination in Soviet planning and a resulting inability to extract the hierarchical system's best performance. In our view, however, these sentiments also represent a frustration with the constraints imposed by

the hierarchical system and a desire to be able to operate without such constraints. This is reflected in the comment by Abel Aganbegyan, one of Gorbachev's chief economic advisers, that current trends can be overcome only by "revolutionary changes" (Aganbegyan, 1988, p. 84) and by the reforms which form the heart of *perestroika*. Our findings suggest that achieving increased adoption rates without prohibitive cost may require not just a tinkering with the form of incentive contracts but a modification of the hierarchical decision-making process, so that *perestroika* faces a formidable task.

#### APPENDIX

This Appendix proves Proposition 1 via a series of lemmas. In many cases, the proofs are straightforward adaptations of previous proofs or arguments appearing in Ickes and Samuelson (1987) and are omitted. Full details are available in Dearden et al. (1989).

**LEMMA 1:** *In equilibrium, an agent in a  $\beta$  job earns a zero payoff in period two. If the period-one outcome is separating, so that one of  $P_2(\bar{\beta}, \bar{\theta})$ ,  $P_2(\bar{\beta}, \underline{\theta})$ ,  $P_2(\underline{\beta}, \bar{\theta})$ , or  $P_2(\underline{\beta}, \underline{\theta})$  equals unity, then the corresponding agent earns a zero payoff in period two.*

#### PROOF:

This follows directly from the period-two equilibrium conditions given by (6) and (7). In particular, the principal will find it optimal to reduce the payments  $h_{2i}$ ,  $i = 1, \dots, 4$ , until some agent earns a return of zero. The only question concerns what type of job that agent occupies. If one of  $P_2(\bar{\beta}, \bar{\theta})$ ,  $P_2(\bar{\beta}, \underline{\theta})$ ,  $P_2(\underline{\beta}, \bar{\theta})$ , or  $P_2(\underline{\beta}, \underline{\theta})$  equals unity, then the utility of an agent in the corresponding job will be reduced to zero, giving the second result of Lemma 1. Suppose there is positive probability of either a  $\bar{\beta}$  or a  $\underline{\beta}$  job. Because the agent in a  $\bar{\beta}$  job can always produce as much output and hence secure as much utility as an agent in a  $\underline{\beta}$  job, the latter's utility will then be the one reduced to zero, giving the first statement of Lemma 1.

LEMMA 2: *In equilibrium, the  $\bar{\beta}$  agent chooses  $(\bar{a}, \bar{\theta})$  in period one with probability one.*

PROOF:

Suppose not. We will show that  $h_1$  can be adjusted so as to increase the principal's profits. If  $(\bar{a}, \bar{\theta})$  is played with positive probability, say  $\rho$ , the principal can increase  $h_{11}$  to  $h_{11} + \varepsilon$  for small  $\varepsilon$ . This breaks the  $\bar{\beta}$  agent's indifference, causing the agent to play  $(\bar{a}, \bar{\theta})$  with unitary probability. This gives an output gain of at least  $p_1(1 - \rho)(y_1 - y_2)$  at a cost of  $\varepsilon$ , which is profit-increasing for the principal for sufficiently small  $\varepsilon$ . Suppose then that  $(\bar{a}, \bar{\theta})$  is played with zero probability and that  $(\underline{a}, \underline{\theta})$ ,  $(\bar{a}, \underline{\theta})$ , and  $(\underline{a}, \underline{\theta})$  are played with probabilities  $\rho_A$ ,  $\rho_B$ , and  $\rho_C$ , each of which is positive (the extension to the case in which one or more of these equals zero is immediate). Then the indifference needed to support this randomization requires  $h_{12} - \bar{a} - \bar{\theta} + x_A = h_{12} - \bar{a} + x_B = h_{13} - \bar{a} + x_C$ , where  $x_A$  is the expected period-two return to the  $\bar{\beta}$  agent given that  $(\underline{a}, \underline{\theta})$  is played in period one and  $x_B$  and  $x_C$  are analogous for  $(\bar{a}, \underline{\theta})$  and  $(\underline{a}, \underline{\theta})$ . Now set  $h_{11}$  so that the  $\bar{\beta}$  agent is indifferent between  $(\bar{a}, \bar{\theta})$  and  $(\underline{a}, \underline{\theta})$ ,  $(\bar{a}, \underline{\theta})$ , or  $(\underline{a}, \underline{\theta})$ . This requires  $h_{11} - \bar{a} - \bar{\theta} = h_{12} - \bar{a} - \bar{\theta} + x_A = h_{12} - \bar{a} + x_B = h_{13} - \bar{a} + x_C$  or

$$(A1) \quad h_{11} - h_{12} = \bar{a} - \underline{a} + x_A$$

$$h_{11} - h_{12} = \bar{\theta} + x_B$$

$$h_{11} - h_{13} = (\bar{a} - \underline{a}) + \bar{\theta} + x_C.$$

This choice of  $h_{11}$  induces the  $\bar{\beta}$  agent to choose  $(\bar{a}, \bar{\theta})$  with probability one (otherwise add  $\varepsilon$  to  $h_{11}$ ). The cost to the principal of setting this value of  $h_{11}$ , from (A1) is then at most

$$(A2) \quad p_1[\rho_A(\bar{a} - \underline{a} + x_A) + \rho_B(\bar{\theta} + x_B) + \rho_C(\bar{a} + \bar{\theta} - \underline{a} + x_C)]$$

where  $p_1$  is the probability of a  $\bar{\beta}$  agent.<sup>16</sup> The gain to the principal from setting this value of  $h_{11}$  is at least

$$(A3) \quad p_1\{\rho_A[y_1 - y_2 + x_A] + \rho_B[2(y_1 - y_2) + x_B] + \rho_C[y_1 - y_3 + y_1 - y_2 + x_C]\}.$$

From (3) and (4), we now see that (A3) exceeds (A2). This precludes the optimality of an outcome in which the  $\bar{\beta}$  agent mixes over any of  $(\underline{a}, \underline{\theta})$ ,  $(\bar{a}, \underline{\theta})$ , and  $(\underline{a}, \underline{\theta})$  and completes the proof.

LEMMA 3: *The  $\underline{\beta}$  agent does not play  $(\underline{a}, \bar{\theta})$  with positive probability in period one.*

PROOF:

The  $\underline{\beta}$  agent strictly prefers playing  $(\bar{a}, \bar{\theta})$  to  $(\underline{a}, \bar{\theta})$ , since  $(\bar{a}, \bar{\theta})$  provides an identical period-one payment of  $h_{13}$ , yields less disutility, and trivially allows the  $\underline{\beta}$  agent to still reap the equilibrium period-two utility of zero.

LEMMA 4: *The  $\underline{\beta}$  agent plays a pure strategy in period one.*

PROOF:

Analogous to Lemma 2.

LEMMA 5: *There are five possible equilibrium paths, described in Table A1 where the period-two equilibria are as given in Table A2.*

PROOF:

Lemmas 1–4 indicate that, in equilibrium, agents in  $\bar{\beta}$  jobs must play  $(\bar{a}, \bar{\theta})$  in period one while those in  $\underline{\beta}$  jobs must play a pure strategy of either  $(\bar{a}, \bar{\theta})$ ,  $(\bar{a}, \underline{\theta})$ , or  $(\underline{a}, \underline{\theta})$ .

<sup>16</sup>Since  $y_1$  is infeasible for an agent in a  $\underline{\beta}$  job, the only implications of this adjustment of  $h_{11}$  for an agent in a  $\underline{\beta}$  job is that it may affect  $P_2(\underline{\beta}, \bar{\theta})$  and hence the period-two remuneration scheme. Since the  $\underline{\beta}$  agent earns zero utility in any period-two remuneration scheme (Lemma 1), this adjustment cannot affect the actions of an agent in a  $\underline{\beta}$  job and hence does not affect the outcomes or costs that appear if the job is  $\underline{\beta}$ .

TABLE A1—SUMMARY OF POTENTIAL EQUILIBRIUM PATHS

Outcome path	Period-one actions ( $a, \theta$ ) and outcome ( $y$ ) in $\bar{\beta}$ job	Period-one outcome type: separating (S) or pooling (P)	Period-one actions ( $a, \theta$ ) and outcome ( $y$ ) in $\underline{\beta}$ job	Job transfers practiced?	Period-two equilibrium
1	$\bar{a} \bar{\theta} y_1$	S	$\bar{a} \bar{\theta} y_2$	yes	1A
2	$\bar{a} \bar{\theta} y_1$	S	$\bar{a} \underline{\theta} y_3$	yes	2A
3	$\bar{a} \bar{\theta} y_1$	S	$\bar{a} \bar{\theta} y_2$	no	1A
4	$\bar{a} \bar{\theta} y_1$	S	$\underline{a} \underline{\theta} y_4$	no	2A
5	$\bar{a} \bar{\theta} y_1$	S	$\bar{a} \underline{\theta} y_3$	no	2A

TABLE A2—PERIOD-TWO EQUILIBRIA

Strategy	Period-two equilibrium 1A <sup>a</sup>	
	$P_2(\bar{\beta}, \bar{\theta}) < p^*$	$P_2(\bar{\beta}, \bar{\theta}) \geq p^*$
Principal: $h_{21}$	$2\bar{a} - \underline{a}$	$\bar{a}$
$h_{22}$	$\bar{a}$	$\underline{a}$
$h_{23}$	$\underline{a}$	$\underline{a}$
$h_{24}$	—	—
Agent: <sup>b</sup> $z_2(\bar{\beta}, \cdot)$	$\bar{a}(y_1)$	$\bar{a}(y_1)$
$z_2(\underline{\beta}, \cdot)$	$\bar{a}(y_2)$	$\underline{a}(y_3)$
Strategy	Period-two equilibrium 2A	
Principal: $h_{21}$	$\bar{a}$	
$h_{22}$	$\underline{a}$	
$h_{23}$	$\bar{a}$	
$h_{24}$	$\underline{a}$	
Agent: <sup>b</sup> $z_2(\bar{\beta}, \cdot)$	$\bar{a}(y_1)$	
$z_2(\underline{\beta}, \cdot)$	$\underline{a}(y_4)$	

<sup>a</sup>Where  $p^* = 1 - \frac{\bar{a} - \underline{a}}{\alpha(t)(y_2 - y_3)}$ .

<sup>b</sup>Agent's output is given in parentheses.

Depending upon whether job transfers occur, this yields six period-one outcomes. However, it is suboptimal for the principal to induce  $(\bar{a}, \bar{\theta})$  from  $\bar{\beta}$  agents and  $(\underline{a}, \underline{\theta})$  from  $\underline{\beta}$  agents and to practice transfers. In particular, agents in  $\underline{\beta}$  jobs would then produce output  $y_4$ , and there would be no opportunity for agents in  $\bar{\beta}$  jobs to pool. Accordingly, there is no reason to sacrifice job-specific human capital by transferring, and this outcome path is suboptimal. This leaves the five paths listed in Table A1. It remains to show that a unique period-two equilibrium, given by 1A or 2A, can be

associated with each path. This follows the analysis of Ickes and Samuelson (1987).

**LEMMA 6:** *Only outcome paths 1–4 constitute potential equilibria. The equilibrium associated with each path and the principal's profits are as shown in Tables 5 and 6.*

#### PROOF:

We examine the first path. The others are analogous. In the first case, the first-period outcome reveals the productivity of a job, with an outcome of  $y_1$  ( $y_2$ ) indicating that the job has high (low) productivity. The period-two remuneration scheme will be 1A and for any job will induce high effort and yield the agent a period-two utility of zero. The complete remuneration scheme is shown in Table 5.<sup>17</sup> It remains to show that the principal's strategy is optimal (i.e., that it induces the desired outcome at minimum cost). Consider the choices of actions available to the agents in period one and the resulting utilities reported in Table A3. The optimal action for an agent in either a high- or low-productivity job is clearly  $(\bar{a}, \bar{\theta})$ , as desired. Given the payoffs to the alternative choices of  $(\underline{a}, \underline{\theta})$  for an agent in a  $\underline{\beta}$  job and  $(\bar{a}, \bar{\theta})$  for an agent in a  $\bar{\beta}$  job, the scheme also induces the desired outcomes at mini-

<sup>17</sup>A complete specification of a remuneration scheme must also identify the inferences drawn by the principal if an out-of-equilibrium first-period outcome of  $y_3$  or  $y_4$  appears. We assume here that the principal assumes that such an outcome reveals the job to be of low productivity. It is easily verified that this does not disrupt the equilibrium. Similar choices apply to subsequent remuneration schemes, and we omit the details.

TABLE A3—AGENT'S TWO-PERIOD UTILITIES FROM VARYING CHOICES GIVEN REMUNERATION SCHEME 1

Agent	Action	Period-one utility	Period-two utility	Total utility
$\underline{\beta}$	$(\bar{a}, \bar{\theta})$	0	0	0
	$(\underline{a}, \bar{\theta})$	$-\bar{\theta}$	0	$-\bar{\theta}$
	$(\bar{a}, \underline{\theta})$	$\underline{a} - \bar{a}$	0	$-(\bar{a} - \underline{a})$
	$(\underline{a}, \underline{\theta})$	0	0	0
$\bar{\beta}$	$(\bar{a}, \bar{\theta})$	$\bar{\theta}$	0	$\bar{\theta}$
	$(\underline{a}, \bar{\theta})$	$\bar{a} - \underline{a}$	0	$\bar{a} - \underline{a}$
	$(\bar{a}, \underline{\theta})$	$\bar{\theta}$	0	$\bar{\theta}$
	$(\underline{a}, \underline{\theta})$	0	0	0

mum cost. A key step in these calculations is the verification that an agent receives a zero payoff in period two. It is clear that this occurs along the equilibrium path, but why is an agent in a  $\bar{\beta}$  job unable to profit by choosing  $(\underline{a}, \bar{\theta})$ ? This would appear to yield an immediate extra payoff of  $\bar{a} - \underline{a}$  (at a cost of  $\bar{\theta}$ ) and also to convince the principal that the job is actually  $\underline{\beta}$ , allowing the agent to choose  $\underline{a}$  in the second period and produce  $y_2$  for an additional extra period-two payoff of  $\bar{a} - \underline{a}$ . The total extra payoff of  $2(\bar{a} - \underline{a})$  exceeds the extra cost of  $\bar{\theta}$  [cf. (4)], apparently making this optimal. However, job switching ensures that the agent will occupy a different job in the next period, with an equilibrium utility that depends upon information about the new job's productivity (which is revealed by the actions of the period-one agent in that job and is exogenous to this agent's calculation) and which is set equal to zero. There is then no period-two payoff from convincing the principal the job is actually a  $\underline{\beta}$  job.

The expected profits in this case are then

$$\pi_1 = p_1[(y_1 - 2\bar{\theta} - \bar{a}) + (y_1 - \bar{a})] + (1 - p_1) \times [(y_2 - \bar{a} - \bar{\theta}) + (y_2 - \bar{a})]$$

where the first bracketed expression gives profits if a job has high productivity (which is then weighted by the probability of such a job, or  $p_1$ ), while the second bracketed expression gives profits if a job has low productivity (weighted by  $1 - p_1$ ). Within each bracketed term, the parentheses indicate the net revenues for each period.

## REFERENCES

- Aganbegyan, Abel, *The Economic Challenge of Perestroika*, Bloomington, IN: Indiana University Press, 1988.
- Amann, Ronald and Cooper, Julian, eds., *Industrial Innovation in the Soviet Union*, New Haven, CT: Yale University Press, 1982.
- \_\_\_\_\_, and \_\_\_\_\_, eds., *Technical Progress and Soviet Economic Development*, New York: Blackwell, 1986.
- Berliner, Joseph, *Factory and Manager in the USSR*, Cambridge, MA: Harvard University Press, 1957.
- \_\_\_\_\_, *The Innovation Decision in Soviet Industry*, Cambridge, MA: MIT Press, 1976.
- \_\_\_\_\_, "Organizational Restructuring of the Soviet Economy," in U.S. Congress, Joint Economic Committee, eds., *Gorbachev's Economic Plans*, Vol. 1, Washington, DC: U.S. Government Printing Office, 1987.
- Berry, M. J., "Towards an Understanding of R and D Innovation in a Planned Economy: The Experience of the Machine Tool Industry," in R. Amman and J. Cooper, eds., *Industrial Innovation in the Soviet Union*, New Haven, CT: Yale University Press, 1982, 39-100.
- Dearden, James A., Ickes, Barry W. and Samuelson Larry, "To Innovate or Not to Innovate: Incentives and Innovation in Hierarchies," working paper, Department of Economics, Pennsylvania State University, 1989.
- Dyker, David, *The Future of the Soviet Eco-*

- nomic Planning System*, New York: Sharpe, 1985.
- Ericson, R. E.**, "The Soviet Statistical Debate: Khanin vs. TsSU," Harriman Institute Occasional Paper 1, Columbia University, 1988.
- Freixas, X., Guesnerie, R. and Tirole, J.**, "Planning Under Incomplete Information and the Ratchet Effect," *Review of Economic Studies*, April 1985, 52, 173-92.
- Grossman, Gregory**, "The 'Second Economy' of the USSR," in Morris Bornstein, ed., *The Soviet Economy: Continuity and Change*, Boulder, CO: Westview Press, 1981, 71-93.
- Hanson, Phillip**, *Trade and Technology in Soviet-Western Relations*, New York: Columbia University Press, 1981.
- Hart, Oliver and Holmström, Bengt**, "The Theory of Contracts," in Truman F. Bewley, ed., *Advances in Economic Theory*, Cambridge: Cambridge University Press, 1987, 71-156.
- Hewett, Ed**, *Reforming the Soviet Economy*, Washington: Brookings Institute, 1988.
- Holmström, Bengt**, "Moral Hazard and Observability," *Bell Journal of Economics*, Spring 1979, 10, 74-91.
- , "Design of Incentives and the New Soviet Incentive Model," *European Economic Review*, February 1982, 17, 127-48.
- Ickes, Barry W. and Samuelson, Larry**, "Job Transfers and Incentives in Complex Organizations: Thwarting the Ratchet Effect," *Rand Journal of Economics*, Summer 1987, 18, 275-86.
- Keren, M., Miller, J. and Thornton, J.**, "The Ratchet: A Dynamic Managerial Incentive Model of the Soviet Enterprise," *Journal of Comparative Economics*, December 1983, 7, 347-67.
- Leary, Neil A. and Thornton, Judith**, "Are Socialist Industries Insulated Against Innovation? A Case Study of Technological Change in Steelmaking," *Comparative Economic Studies*, January 1989, 31, 42-65.
- Ma, Ching-to**, "Unique Implementation of Incentive Contracts with Many Agents," STICERD working paper 87/146, London School of Economics, 1987.
- , "Implementation in Dynamic Job Transfers," *Economics Letters*, 1988, 24(4), 391-95.
- , **Moore, John and Turnbull, Stephen**, "Stopping Agents from 'Cheating,'" *Journal of Economic Theory*, December 1988, 46, 355-72.
- Manevich, E.**, "Means of Restructuring the Economic Mechanism," *Problems of Economics*, May 1987, 30, 81-97.
- Mirrlees, J.**, "Notes on Welfare Economics, Information, and Uncertainty," in M. Balch, D. McFadden, and S. Wu, eds., *Essays on Economic Behavior under Uncertainty*, Amsterdam: North-Holland, 1974, 243-57.
- Nove, A.**, *The Soviet Economic System*, London: Allen and Unwin, 1977.
- Popper, Steven W.**, "The Diffusion of Numerically Controlled Machine Tools in Hungary," in Josef Brada and Istvan Dobozi, eds., *The Hungarian Economy in the 1980's*, Greenwich, CT: JAI Press, 1988.
- Riordan, Michael H.**, "Hierarchical Control and Investment Incentives in Procurement," mimeo, Stanford University, 1987.
- Rutland, Peter**, "The Shchekino Method and the Struggle to Raise Labour Productivity in Soviet Industry," *Soviet Studies*, July 1984, 36, 345-65.
- Scherer, F. M.**, *Innovation and Growth*, Cambridge, MA: MIT Press, 1984.
- Selyunin, V. and Khanin, G.**, "Lukavaya tsifra" ("The Cunning Figure"), *Novy Mir*, February 1987, 2, 181-201.
- Shavell, Steven**, "Risk Sharing and Incentives in the Principal and Agent Relationship," *Bell Journal of Economics*, Spring 1979, 10, 55-73.
- Treml, V. G.**, "Perestroika and Soviet Statistics," *Soviet Economy*, January 1988, 4, 65-94.
- Weitzman, M. L.**, "The 'Ratchet Principle' and Performance Incentives," *Bell Journal of Economics*, Spring 1980, 11, 302-8.