The Controllability Principle in Responsibility Accounting

Rick Antle; Joel S. Demski


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The Controllability Principle in Responsibility Accounting

Rick Antle and Joel S. Demski

ABSTRACT: The purpose of this paper is to examine controllability: the notion a manager should be evaluated based on that which she or he controls. We embed the managerial evaluation problem in a principal-agent setting and ask whether the optimal agency solution bears any logical relation to a casual definition of controllability. It does not. More to the point, the agency framework compels us to look at information content. This information content perspective, upon reflection, agrees with our intuition, with our anecdotal impressions of practice, and with the dictates of the principal-agent model. Moreover, there is a well-defined relation between information content and a notion of control. Thus, the information content perspective may be thought of as offering a precise definition of controllability.

Should a manager be evaluated as the head of a cost center or a profit center? Our familiar and intuitive analysis of this perennial question focuses on whether the manager controls cost and revenue. If so, the manager should be evaluated as the head of a profit center. If the manager only controls cost, a cost center evaluation is appropriate. If the manager only controls revenue, a revenue center evaluation is appropriate.

Analyzing this wisdom requires two specifications. First, we must be precise about what it means for the manager to "control" cost or revenue. Second, we must be precise about what it means to evaluate the manager "correctly" or in the "best possible manner."

We use a principal-agent model to

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provide a coherent framework for the evaluation exercise. This gives a setting where a nontrivial control problem is present, where evaluation of the manager can be explicitly modeled, and where managerial evaluation can be endogenously specified. In this way a control problem is modeled as an exercise in motivating a particular behavior by the manager, and performance evaluation as producing information relevant to the question of whether the desired behavior was supplied. The focus is on control of inputs, not outputs. Managerial evaluation, then, becomes framed in terms of inferring this supply of input.

In turn, we specify what it means for the manager to "control" an evaluation statistic, such as cost or revenue, by asking whether his or her supply of inputs is able to affect the probability distribution of the output statistic. For example, if cost is characterized as a probability distribution, can the manager affect this distribution by altering her or his managerial inputs?

This particular definition is highly stylized, but expositionally convenient. A result is that the principal-agent analysis leads to a focus related to, but distinct from, this notion of controllability. In particular, the principal-agent analysis leads us to ask whether the manager can affect the probability distribution of the output statistic conditioned on whatever other information is present. The intuition for this conclusion is best developed by beginning with a stylized notion of controllability, and then refining it to match the principal-agent conclusion. In this way the principal-agent paradigm is used to infer a formal definition of controllability. For exposition purposes, we refer to the performance evaluation dictates of the principal-agent model as the information content approach and the casual controllability definition as the (traditional) controllability approach.¹

The paper is organized as follows: In Section I we present three numerical examples that explore the traditional controllability notion in a principal-agent setting. In Section II we introduce the information content perspective and use it to explain the anomalies in the earlier examples. In Section III we illustrate this perspective with a brief analysis of tournaments. Conclusions are offered in Section IV.

I. SOME EXAMPLES

Basic Model

Consider a setting where an individual, termed a principal, owns a production function that offers uncertain cash flow prospects. Three items of cash flow are identified: cash inflow from customers (revenue), cash outflow for materials and overhead (cost), and cash outflow to compensate the supplier of labor (wage). The revenue and cost amounts depend on which state of nature obtains as well as whether labor supply is "LOW" or "HIGH." There are three equally likely states of nature. The possibilities are described in Table 1 (000 omitted).

The principal faces two options, whether to input labor supply HIGH or LOW. She is risk neutral and, therefore, evaluates the options in terms of the expected value of the net profit they promise. To complete the analysis, we must specify the labor cost, or wage.

Labor is supplied by a second individual, termed an agent (or manager). Three characteristics of this second indi-

¹ We emphasize our particular controllability rhetoric is designed to build intuition. Earlier authors, such as Ferrara [1967], were not as narrow in their conception of controllability. On the other hand, we use the formality of the principal-agent paradigm to propose a precise notion of controllability.
vidual are important. First, he is strictly risk averse, and values his wage compensation according to the expected value of [wage]\(^1\). In this way, both individuals are important in the production process. The agent supplies labor, while the risk neutral principal supplies risk carrying capacity.\(^2\)

Second, labor supply by the agent is personally costly. He prefers LOW to HIGH. In fact, his preference for wage \((w)\) and labor supply \((l)\) is given by the additive function \([w]^{1/2} - V(l)\), with \(V(LOW) = 0\) and \(V(HIGH) = 50\). In this way the supplier of labor is not an indifferent automaton. He and the principal are in conflict. She prefers HIGH, while he prefers LOW, other things equal.\(^3\)

Third, the agent is not being held captive. He is free to work for the principal, or to work "elsewhere." Working elsewhere nets the agent an expected utility of 250 utiles. (For example, it offers a wage of \((250)^2\), and \(V(\ast) = 0\).) The principal must match this to secure the agent's employment.

With these details in place, we can calculate the cost of labor. If the agent is to supply \(l = LOW\), he must face a wage, denoted \(w_L\), such that \([w_L]^{1/2} - 0 \geq 250\). Otherwise, he does better by working elsewhere. This implies \(w_L \geq (250)^2\) = 62,500. Similarly, to provide \(l = HIGH\), the principal must offer a wage, denoted

\(^2\) Risk is noxious to the agent and a matter of indifference to the principal. Efficiency dictates the principal shoulder the risk. In this way we view the principal as a loose caricature of a capital market.

More specifically, contrast the agent's thoughts about receiving $500 for certain or flipping a fair coin where with probability 1/2 he "wins" 1000 and with probability 1/2 he "wins" nothing:

\[500]^{1/2} = 22.36 > 1/2[1000]^{1/2} + 1/2[0]^{1/2} = 15.81\]

Concavity of \([\ast]^{1/2}\) guarantees the agent will reject fair gambles. He considers risk noxious. The principal, however, is indifferent between the two options:

\[500 = 1/2[1000] + 1/2[0]\].

\(^3\) The idea is the two individuals face some conflict in the employment relationship. In a larger model this might arise over human capital concerns, over taste for a particular style of administration or set of products, or whatever. The most straightforward way is to assume some type of nonpecuniary cost befalls the agent. We further model this in a separable manner, so the conflict does not interact with the agent's wage. While unrealistic, this allows us to examine the controllability dictates in a transparent setting.
that \( \lbrack w_H \rbrack^{1/2} - 50 \geq 250 \). This implies \( w_H \geq (300)^2 = 90,000 \).

The principal, of course, will pay what the "market demands." Combining these labor cost calculations with the earlier (gross) profit data, we conclude with the following analysis of the principal's decision (000 omitted).

<table>
<thead>
<tr>
<th>Labor Supply</th>
<th>LOW</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E(\text{Revenue}) )</td>
<td>933.33</td>
<td>933.33</td>
</tr>
<tr>
<td>Less ( E(\text{Cost}) )</td>
<td>466.67</td>
<td>433.33</td>
</tr>
<tr>
<td>( E(\text{Gross profit}) )</td>
<td>466.67</td>
<td>500.00</td>
</tr>
<tr>
<td>Less Wage</td>
<td>62.50</td>
<td>90.00</td>
</tr>
<tr>
<td>( E(\text{Net profit}) )</td>
<td>404.17</td>
<td>410.00</td>
</tr>
</tbody>
</table>

**Evaluation Context**

To this point there is little interest in evaluating the agent. The principal prefers labor supply HIGH, while the agent prefers LOW. But we have implicitly assumed the agent, in exchange for appropriate compensation, supplies the agreed upon amount. If this assumption is accurate, there is no interest in verifying the agent's labor supply.

Now move to the opposite extreme and assume the agent operates in his self interest. Further assume only the realized cost (exclusive of labor payment) and revenue are jointly observable and verifiable. Thus, the contract with the agent can call for payment as a function of the gross profit, but not as a function of the labor input actually supplied. The actual labor input is not verifiable and, therefore, not available as a basis for contracting.

This final verifiability assumption is important because it allows the agent room to maneuver in exploiting the natural conflict between principal and agent. In particular, suppose the principal offers a guaranteed wage of \( w_H = 90,000 \) in exchange for supply of input HIGH. The agent can supply HIGH, with a resulting utility measure of \( [90,000]^{1/2} - 50 = 250 \) or supply LOW with a resulting utility measure of \( [90,000]^{1/2} - 0 = 300 > 250 \). In short, supply of HIGH under this compensation arrangement is not incentive compatible.

Our original analysis, in other words, does not provide a practicable resolution of the labor contracting problem in this setting of self interested behavior coupled with limited observability and verifiability. We seek labor input, but cannot verify its supply. Only labor output, cost and revenue here, is observable and verifiable. Thus, we use the output to infer the input. We evaluate the agent, so to speak, based on his output. In this way output serves two roles: it is a source of value in the production process and it is a source of information for the control problem of motivating the self interested manager. This gets to the basic question: how should we use the information provided by output; do we want to use cost, revenue, or cost and revenue to evaluate the manager? The question is interesting because the value and information components of the output are not coextensive. We cannot unambiguously infer the one from the other.

* It is efficient to compensate the agent with a constant wage. Otherwise, his payment is at risk while risk is noxious to him but not to the principal.

\[
\begin{align*}
(1/3)(800) + (2/3)(1000) &= 933.33 \\
(1/3)(400) + (2/3)(500) &= 466.67 \\
(2/3)(400) + (1/3)(500) &= 433.33
\end{align*}
\]

* We sketch the story in terms of cost, revenue, or cost and revenue to provide a caricature of an institutional setting. The typical cost center setting would, however, focus on cost and physical output, as with a flexible budget. So the available information is perhaps better framed in terms of cost, physical output, and revenue rather than cost and revenue. The addition of an explicit output descriptor, though, needlessly complicates our setting. Similar comments apply to variances.
**Controllability Answer**

Consider the controllability prescription. If an output statistic such as revenue is used in the agent's evaluation then the agent should be able to control that statistic. Return to the data in Table 1. The revenue depends on which state nature supplies, but not the labor input. Conversely, the cost depends on both the state and labor. The agent, through conscious behavior, can influence the cost probability or lottery. The revenue probability or lottery is totally independent of what the agent does. We conclude, using this notion of controllability, our particular agent is best evaluated as the head of a cost center. He controls cost, but not revenue.

**Model's Answer**

Now ask the agency model the same question. First, suppose we observe only the cost outcome. What is the best way to contract for supply of HIGH? The trick is to design the agent's decision tree so his self interested behavior mirrors the principal's wishes. Let \( w_a \) denote the agent's wage if cost = 400 is realized and \( w_s \) if cost = 500 is realized. The agent's decision tree is shown in Exhibit 1. Goal congruence demands the agent prefer HIGH to the other options. Thus, we must engineer the agent's decision tree so HIGH is preferred. This requires:

\[
\frac{2}{3}[w_a]^{1/2} + \frac{1}{3}[w_s]^{1/2} - 50 \geq 250,
\]

and

\[
\frac{2}{3}[w_a]^{1/2} + \frac{1}{3}[w_s]^{1/2} - 50 \geq \frac{1}{3}[w_a]^{1/2} + 2/3[w_s]^{1/2} - 0.
\]

The first inequality forces HIGH to be as good as "go elsewhere...." The second forces HIGH to be as good as LOW. In this way self interest on the agent's part leads to choice of HIGH. Goal congruence is a constraint in designing the control system. We design the system so the preferred behavior is in the agent's self interest.

But achieving goal congruence is only part of the principal's problem. Another concern is the cost of aligning the agent's behavior. Naturally, the principal will select the \( w_a \mid w_s \) combination that is least expensive. With the principal risk
neutral, least expensive means least expected payment to the agent when he is motivated to supply HIGH. The best combination is, therefore, located by the following program:

\[
\begin{align*}
\text{Min} & \quad 2/3 w_4 + 1/3 w_5 \\
\text{subject to} & \quad \frac{2}{3}[w_4]^{1/2} + \frac{1}{3}[w_5]^{1/2} - 50 \geq 250 \\
& \quad \frac{2}{3}[w_4]^{1/2} + \frac{1}{3}[w_5]^{1/2} - 50 \\
& \quad \geq 1/3 [w_4]^{1/2} + 2/3 [w_5]^{1/2} - 0 \\
& \quad w_4, w_5 \geq 0.
\end{align*}
\]

The solution is \( w_4 = 122,500 \) and \( w_5 = 40,000 \). The principal’s evaluation is now:

Contrast this with use of revenue and cost in the agent’s evaluation. Recalling

\[
(1/3)(122,500) + (1/3)(40,000) = 95,000.
\]
the data in Table 1, we see the possible (gross) profit realizations are 400, 500, and 600. Let \( \hat{w}_4 \) denote the agent’s compensation if a profit of 400 is realized, \( \hat{w}_5 \) if a profit of 500 is realized, and so on. The agent’s decision tree is shown in Exhibit 2. Engineering the agent’s tree requires

\[
\frac{1}{3}[\hat{w}_4]^{1/2} + \frac{1}{3}[\hat{w}_5]^{1/2} + \frac{1}{3}[\hat{w}_6]^{1/2} - 50 \\ 
\geq 250,
\]

and

\[
\frac{1}{3}[\hat{w}_4]^{1/2} + \frac{1}{3}[\hat{w}_5]^{1/2} + \frac{1}{3}[\hat{w}_6]^{1/2} - 50 \\ 
\geq 1/3[\hat{w}_4]^{1/2} + 2/3[\hat{w}_5]^{1/2} - 0.
\]

The principal’s program becomes

\[
\text{Min} \quad \frac{1}{3}\hat{w}_4 + \frac{1}{3}\hat{w}_5 + \frac{1}{3}\hat{w}_6
\]

subject to

\[
\frac{1}{3}[\hat{w}_4]^{1/2} + \frac{1}{3}[\hat{w}_5]^{1/2} + \frac{1}{3}[\hat{w}_6]^{1/2} - 50 \\ 
\geq 250
\]

and

\[
\frac{1}{3}[\hat{w}_4]^{1/2} + \frac{1}{3}[\hat{w}_5]^{1/2} + \frac{1}{3}[\hat{w}_6]^{1/2} - 50 \\ 
\geq 1/3[\hat{w}_4]^{1/2} + 2/3[\hat{w}_5]^{1/2} - 0
\]

\( \hat{w}_4, \hat{w}_5, \hat{w}_6 \geq 0. \)

The solution is \( \hat{w}_4 = 90,000, \hat{w}_5 = 50,625, \hat{w}_6 = 140,625. \) The principal’s evaluation is now:

<table>
<thead>
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<th>Labor Supply</th>
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</tr>
<tr>
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<td>93.75</td>
</tr>
<tr>
<td>( E(\text{Net profit}) )</td>
<td>404.17</td>
<td>406.25</td>
</tr>
</tbody>
</table>

The principal is strictly better off using cost and revenue, as opposed to just cost, in the agent’s evaluation. The agent, however, is indifferent. In either case his expected utility is 250. Revenue is a useful evaluation statistic, despite the uncontrollability-based conclusion it is not controllable and, therefore, useless in the evaluation exercise.\(^{14}\)

A Second Example

Now consider a slight variation on this example. Everything is identical except the revenue structure is altered in Table 2 (000 omitted).

This makes the revenue lottery dependent on the agent’s behavior. So a controllability approach would imply revenue is a useful evaluation statistic because the agent is able to influence which revenue result obtains. Further observe the revenue structure is constructed so a cost realization of 400 always is accompanied by a revenue realization of 1000; and a cost realization of 500 always is accompanied by a revenue realization of 800.\(^{15}\) Working through

---

\(^{12}\) Some may be troubled by the non-monotonicity of this contract, which calls for a higher payment to the manager for achieving a profit of 400 than a profit of 500. Before concluding this does not accord with schemes in practice, the following reinterpretation should be considered. The manager’s contract is equivalent to a salary of 50,625, with a bonus of 39,375 for holding costs to 400. If costs are “controlled” (i.e., held to 400) while revenue is “maintained” at 1000, the bonus is increased to 90,000.

\(^{13}\) \( (1/3)(90,000) + (1/3)(50,625) + (1/3)(140,625) = 93,750. \)

\(^{14}\) Two important assumptions should be recalled. First we carefully chose an illustration in which the relationship between revenue and cost and revenue less cost is one to one. Otherwise, the precise pair of realizations is important, not just their algebraic difference. Second, we assume the principal is risk neutral. The agent, therefore, has no comparative advantage at carrying risk. If this were not the case we would always prefer a profit center evaluation simply because efficient risk sharing would dictate the principal and agent each have income at risk. Here, however, we focus exclusively on control considerations in examining how best to evaluate the agent. This is accomplished by neutralizing the demand for risk sharing with the agent. See Demski [1976].

\(^{15}\) This extreme case of a one-to-one association between cost and revenue makes the analysis transparent, but is not necessary for the point to hold. As is discussed later, the important feature is that the distribution of revenue conditional on cost does not vary with the agent’s behavior. The distinction is one of equivalence in (conditional) distribution, not of “equality” in the guise of a one-to-one association. Of course, the latter implies the former.
the details of the agency framework will produce the following conclusions: (1) the principal prefers to implement a HIGH supply of labor; (2) the most efficient contracting arrangement is use of the cost outcome, accompanied by \( w_4 = 122,500 \) and \( w_5 = 40,000 \); and (3) revenue is of no use in evaluating the agent.\(^{16}\) Thus, we have a case where a controllability focus implies revenue is an important evaluation statistic while an agency analysis implies it is superfluous.

**A Third Example**

For a final example, change the revenue structure in our setting as described in Table 3 (000 omitted). As in the second example, revenue now depends on the agent's behavior and a controllability focus implies it is best to hold the agent responsible for the cost and revenue (or profit) outcomes. In turn, working through the details of the agency framework reveals: (1) the principal prefers to implement a HIGH supply of labor; and (2) the most efficient contracting arrangement is use of cost and revenue with payment to the agent of \( \hat{w} = 0 \) when a profit of 200 obtains and \( \hat{w} = 90,000 \) otherwise.

In this setting, a profit of 200 signals unmistakably the agent has supplied LOW. So the contract "penalizes" the maximal amount by paying 0 (dismissal?). This threat allows for an equilibrium payment of 90,000. We, thus, have an illustration where the controllability and agency analyses agree.

**II. SOME INTUITION**

These examples, taken together, give settings where a non-controllable item is useful, where a controllable item is useless, and where a controllable item is useful. The important question is what explains this schism between the common sense of the controllability notion and the deductive sense of the principal-agent exercise. The answer is to be found in the probabilities of the revenue and cost outcome.

\(^{16}\) More precisely, knowledge of cost implies knowledge of revenue and vice versa. So using only cost, using only revenue, or using cost and revenue are identical evaluation schemes. Also notice HIGH is preferred here because we have the same cost structure along with less revenue prospects under LOW.
To develop this point, notice the common structure in the above examples centers on two facts: First, there is inherent conflict because the principal wants to implement one labor supply (HIGH) while (other things equal) the agent wants to implement a different labor supply (LOW). Second, informational asymmetry is present since the cost and revenue outcomes do not necessarily reveal exactly what input the agent has supplied. Put differently, the principal seeks input from the agent, but cannot directly observe input. As a result, the parties contract on observable and verifiable output. In short, output is used as an imperfect indicator of input, and the information content of output becomes of concern.\footnote{As mentioned earlier, the productive output provides value (here in the sense of profit) and information. In an extended setting, we would then design the productive process to balance these two types of output. As a result, we do not model the setting as one of finding the least costly control system to implement the otherwise most efficient production arrangement. The design problem does not separate.}

Information Content

Information content is a subtle notion in this setting. We use the cost and revenue outcomes as indicators of what input was supplied. In particular, we use the statistical pattern of these outcomes. But since we are concerned about the agent's supply of input, we contrast the statistical pattern under the assumption he supplies the desired input with the statistical pattern under the assumption he supplies some other input.

To develop this theme, we contrast two probability statements: (1) the probability of revenue = R under inputs a = HIGH and a = LOW; and (2) the probability revenue = R under inputs a = HIGH and a = LOW conditioned on cost = C. Let \( f(R \mid a) \) denote the probability revenue = R when the agent supplies input = a. Also, let \( f(R \mid C, a) \) denote the probability revenue = R when cost = C has been observed and when the agent supplies input = a. These probabilities, for the three examples, are displayed in Table 4.\footnote{The easiest way to replicate these calculations is to construct the joint probabilities, \( f(R, C \mid a) \). These are displayed in the Appendix. By the laws of probability, we have \( f(C \mid a) = f(700, C \mid a) + f(800, C \mid a) + f(1000, C \mid a) \) and \( f(R \mid C, a) = f(R, C \mid a) / f(C \mid a) \).} Notice, in particular,
TABLE 4
MARGINAL AND CONDITIONAL PROBABILITIES

Example 1

\[ f(R|a) \]
\[ a=LOW \quad a=HIGH \]

\begin{array}{c|cc}
\text{Revenue} & 800 & 1/3 \\
& 1000 & 2/3 \\
\end{array}

\[ f(R|C,a) \]
\[ a=LOW \quad a=HIGH \]

\begin{array}{c|cc}
\text{Revenue} & 800 & 1/2 \\
& 1000 & 1/2 \\
\end{array}

Example 2

\[ f(R|a) \]
\[ a=LOW \quad a=HIGH \]

\begin{array}{c|cc}
\text{Revenue} & 800 & 2/3 \\
& 1000 & 1/3 \\
\end{array}

\[ f(R|C,a) \]
\[ a=LOW \quad a=HIGH \]

\begin{array}{c|cc}
\text{Revenue} & 800 & 0 \\
& 1000 & 1 \\
\end{array}

the following differences among the three examples:

event one:

\[ f(R|HIG\text{H}) = f(R|LO\text{W}) \] and
\[ f(R|C,HIG\text{H}) \neq f(R|C,LO\text{W}) \]

event two:

\[ f(R|HIG\text{H}) \neq f(R|LO\text{W}) \] and
\[ f(R|C,HIG\text{H}) = f(R|C,LO\text{W}) \]

example three:

\[ f(R|HIG\text{H}) \neq f(R|LO\text{W}) \] and
\[ f(R|C,HIG\text{H}) \neq f(R|C,LO\text{W}) \].

The following two points should be noted. First, an example where revenue is simply noise would provide a setting with \( f(R|HIG\text{H}) = f(R|LO\text{W}) \) and \( f(R|C,HIG\text{H}) = f(R|C,LO\text{W}) \). Second, there is nothing pathological about the examples. The data for event 2, for instance, exhibit perfect correlation between cost and revenue. But as mentioned in footnote 15, this is done to keep
Consider $f(R|a)$, the marginal probability revenue $= R$ under input supply $a$. $f(R|\text{HIGH}) = f(R|\text{LOW})$ in the first example, while $f(R|\text{HIGH}) \neq f(R|\text{LOW})$ in the second and third examples. By conscious choice of input, the agent controls the revenue probabilities (or revenue lottery) in the latter two examples, but not in the first. This is the basis on which we applied the controllability notion.

**definition:** The agent controls revenue if $f(R|a)$ is a nontrivial function of $a$.

That is, we say the agent controls revenue if he is able to affect the marginal probability of revenue through his behavior (i.e., his supply of labor input).

Now consider the use of revenue (or cost) in the compensation arrangement. We say the parties use the revenue measure if the agent’s compensation depends on the actual revenue realization. Let the agent’s compensation be denoted $w = I(R,C)$. If revenue of $R$ and cost of $C$ are realized the agent is paid amount $w = I(R,C)$. If for some value of $C$ different values of $R$ lead to different payment amounts, we then say the agent is held responsible for revenue.

**definition:** The agent is held responsible for revenue (cost) under $I(R,C)$ if $I(R,C)$ is a nontrivial function of revenue (cost).\(^{21}\)

---

Consider the illustration uncluttered. Consider a setting where revenue is either 1000 or 800. Let the revenue lottery depend only on cost, and be such that $R = 1000$ is more probable with one cost realization than another. This will ensure $f(R|\text{HIGH}) \neq f(R|\text{LOW})$ and $f(R|C,\text{HIGH}) = f(R|C,\text{LOW})$. See the extended example that begins in footnote 26.

\(^{20}\) A similar statement can be made about controlling cost and $f(C|a)$.

\(^{21}\) By nontrivial we mean for some value of $C$, say $\hat{C}$, we have distinct $R^1$ and $R^2$ such that $I(R^1,\hat{C}) \neq I(R^1,\hat{C})$. 

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### Table 4—Continued

<table>
<thead>
<tr>
<th>Example 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f(R</td>
</tr>
<tr>
<td>$a=\text{LOW}$</td>
</tr>
<tr>
<td>$a=\text{HIGH}$</td>
</tr>
<tr>
<td><strong>Revenue</strong></td>
</tr>
<tr>
<td>800</td>
</tr>
<tr>
<td>1000</td>
</tr>
</tbody>
</table>

| $f(R|C,a)$ |
| $a=\text{LOW}$ |
| **Cost** | 400 | 500 |
| **Revenue** | 700 | 0 | 1/2 |
| 800 | 1 | 0 |
| 1000 | 0 | 1/2 |

| $a=\text{HIGH}$ |
| **Cost** | 400 | 500 |
| **Revenue** | 700 | 0 | 0 |
| 800 | 1/2 | 0 |
| 1000 | 1/2 | 1 |
From here we articulate the controllability notion as saying the agent should be held responsible for revenue if he controls revenue, for cost if he controls cost, and for profit if he controls revenue and cost. By this principle, the agent should be held responsible for cost in each of the three examples, and for revenue (and, therefore, profit) in only the latter two.

Conditional Probabilities

The conclusion above does not agree with the principal-agent solutions, where we find revenue a useful evaluation measure in the first and third examples. This discrepancy arises because information content and controllability are not coextensive. In the second example, for instance, the agent controls revenue, but revenue tells us nothing about the agent’s input, provided we already are observing cost. In this case, \( f(R|C,a) \) depends only on cost; we may write \( f(R|C,a) = f(R|C) \). Given we are already using cost to evaluate the agent, the conditional probability of revenue, \( f(R|C,a) \), cannot be influenced by the agent.

In contrast, the agent does influence the conditional probability of revenue in the other two examples. \( f(R|C,a) \) is a nontrivial function of input \( a \) in these two cases. The explanation is, perhaps, more clear if we factor the probability construction:

\[
f(R,C|a) = f(R|C,a) f(C|a).
\]

If \( f(R|C,a) = f(R|C) \), we have a case where the random variation in revenue that is not explained by cost cannot be influenced in any way by the agent’s behavior. Stated differently, if \( f(R|C,a) = f(R|C) \) the random variation in revenue not explained by cost tells us nothing whatever about whether the agent supplied \( a=LOW \) or \( a=HIGH \). Given we know cost, revenue has no information content in terms of inferring what the agent supplied. If this is the case, holding the agent responsible for revenue and cost is inefficient. It merely “noises up” the evaluation. Revenue variations are, in the presence of cost, pure noise. This suggests the following:

**definition:** Revenue has information content in the presence of cost if \( f(R|C,a) \) is a non-trivial function of \( a \).

To understand this definition, suppose we already know cost and focus on the conditional distribution of revenue, \( f(R|C,a) \). If the agent cannot influence this conditional distribution, we say revenue has no information content in the presence of cost. But if the agent can influence this conditional distribution, we say revenue has information content in the presence of cost. Note well, information content is related to our concept of control over revenue. The difference is we now acknowledge the information content of cost. The focus is influence over the distribution of revenue given

---

22 Stated differently, the idea is the agent should be held accountable for revenue if he controls revenue. Held accountable, in turn, translates into \( I(R,C) \) is a non-trivial function of revenue in this setting.

23 Observe that the controllability principle can be applied sequentially. If we are considering three variables, say labor cost, raw material cost, and revenue, we can assess whether the manager controls each of these variables without reference to the others. In this way, one form of textbook exercise consists of the specification of the individual’s position within the organization and a list of potential performance measures. The student is then asked to proceed down the list and suggest whether each variable is controllable by the identified individual. In this way, the student supposedly identifies the best subset of variables for evaluating the individual in question.

24 More precisely, we are indifferent between use of revenue or cost in the second example, but strictly prefer use of both variables in the first and third examples. As noted, the second example has a one to one relation between revenue and cost. An expanded version of the example, as sketched in footnote 26, would have cost strictly preferred to revenue, along with revenue being useless in the presence of cost for evaluation purposes.
cost is known. The key is \( f(R | C, a) \), not \( f(R | a) \).

**Model Interrogation**

This shift in focus has intuitive appeal. Marginal and conditional distributions are not the same, and it seems we should focus on what we learn conditioned on what we are already observing. Moreover, the principal-agent analysis reinforces this intuition.\(^{25}\)

**Claim:** Suppose the agent is held responsible for revenue in the optimal solution to the principal-agent problem. Then revenue has information content.

The assertion is nontrivial use of revenue (given cost is being used to evaluate the manager) can only arise in the principal-agent solution if revenue has information content. To explore the formal reasoning, suppose, to the contrary, we have a case where the agent is held responsible for revenue even though \( f(R | C, a) \) does not depend on input \( a \). In our specialized setting, this means we have some \( f(R, C) \) compensation scheme that satisfies the following constraints: \(^{26}\)

\[
\Sigma_{R,C}[I(R,C)]^{1/2}f(R,C|HIGH) - V(HIGH) \geq \overline{U},
\]

and

\[
\Sigma_{R,C}[I(R,C)]^{1/2}f(R,C|HIGH) - V(HIGH) \geq \Sigma_{R,C}[I(R,C)]^{1/2}f(R,C|LOW) - V(LOW).
\]

The first constraint, recall, requires the agent weakly prefer accepting the contract terms and supplying HIGH to his other alternative, with a utility value of \( \overline{U} \). The second requires the agent weakly prefer accepting the contract terms and supplying HIGH to accepting the contract terms and supplying LOW. Now, since revenue does not have information content in the presence of cost, factoring the probability provides: \(^{27}\)

\[^{25}\] Holmstrom [1979] and Shavell [1979] developed the generic argument that use of a monitor in the principal-agent setting implies the monitor's conditional distribution is a nontrivial function of the agent's input. Subsequent studies, such as Baiman and Demski [1980], Baiman [1982], and Demski and Sappington [1986], have applied it to specific accounting questions. Baiman and Noel [1985] examine a multi-period setting where non-controllable capital cost is useful as a proxy for anticipated capacity choices by the principal when the agent is induced to alter his input as a function of this proxy.

Further recall we assume the principal is risk neutral. This means the agent is never used for risk sharing purposes. (By analogy, risk sharing is accomplished in the capital, not the labor, market.) If the principal were also risk averse here, simple risk sharing would dictate the agent always be held responsible for revenue and cost, since profit is at risk.

\[^{26}\] To illustrate, consider a setting identical to that in our earlier examples, except for the following relationship among states, acts, revenue, and cost (000 omitted):

<table>
<thead>
<tr>
<th>Probability</th>
<th>( s_1 )</th>
<th>( s_2 )</th>
<th>( s_3 )</th>
<th>( s_4 )</th>
<th>( s_5 )</th>
<th>( s_6 )</th>
<th>( s_7 )</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revenue</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>1000</td>
<td>1000</td>
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<td>500</td>
<td>400</td>
<td>400</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Gross Profit</td>
<td>400</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>600</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>HIGH labor supply:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revenue</td>
<td>800</td>
<td>800</td>
<td>800</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Cost</td>
<td>400</td>
<td>400</td>
<td>500</td>
<td>400</td>
<td>400</td>
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<tr>
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<td>300</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>500</td>
</tr>
</tbody>
</table>

Further assume the agent is held responsible for revenue and cost under the following \( I(R,C) \) payment arrangement:

\[
i(1000,400) = 1600,000, \\
i(1000,500) = 400,000, \\
i(800,400) = 400,000, \text{ and} \\
i(800,500) = 10,000.
\]

This payment arrangement meets the agent's required utility constraint (of 250 utiles). It also induces the agent to supply the HIGH labor input. Using the construction that follows in the text, however, we can show this is a wasteful arrangement because it ties the agent's pay to revenue, which has no information content in the presence of cost. Subsequent notes trace this construction.

\[^{27}\] In the example in the previous footnote we have:

\[
f(800,400 | LOW) = f(800 | 400, LOW)f(400 | LOW) = (.25)(.50) = .125, \\
f(800,400 | HIGH) = f(800 | 400, HIGH)f(400 | HIGH) = (.25)(.75) = .1875, \\
f(800,500 | LOW) = f(800 | 500, LOW)f(500 | LOW) = (.50)(.50) = .25, \text{ and} \\
f(800,500 | HIGH) = f(800 | 500, HIGH)f(500 | HIGH) = (.50)(.25) = .125.
\]

Note, \( f(800 | 400, LOW) = f(800 | 400, HIGH) = .25 \) and
\[ f(R, C | a) = f(R | C, a) f(C | a) = f(R | C) f(C | a). \]

With this factoring, we rewrite the constraints as follows:

\[
\Sigma_{R,C} [I(R,C)]^{\frac{1}{2}} f(R | C) f(C | \text{HIGH}) - V(\text{HIGH}) \geq \bar{U},
\]

and

\[
\Sigma_{R,C} [I(R,C)]^{\frac{1}{2}} f(R | C) f(C | \text{HIGH}) - V(\text{HIGH}) \geq \Sigma_{R,C} [I(R,C)]^{\frac{1}{2}} f(R | C)
\]

\[
f(C | \text{LOW}) - V(\text{LOW}).
\]

Each term enclosed within the \{\} brackets is identical. This allows us to express the constraints in the following fashion:\(^{28}\)

\[
\Sigma_c [\Sigma_R [I(R,C)]^{\frac{1}{2}} f(R | C) f(C | \text{HIGH}) - V(\text{HIGH}) \geq \bar{U},
\]

and

\[
\Sigma_c [\Sigma_R [I(R,C)]^{\frac{1}{2}} f(R | C) f(C | \text{HIGH}) - V(\text{HIGH}) \geq \Sigma_c [\Sigma_R [I(R,C)]^{\frac{1}{2}} f(R | C)]
\]

\[
f(C | \text{LOW}) - V(\text{LOW}).
\]

From here we replace the common term with a payment that depends only on cost:\(^{29}\)

\[
\Sigma_R [I(R,C)]^{\frac{1}{2}} f(R | C) = [\hat{I}(C)]^{\frac{1}{2}}.
\]

\(\hat{I}(C)\) is that payment the agent would gladly exchange for the \(I(R,C)\) lottery. Since the agent is held responsible for revenue, we know \(I(R,C)\) is a nontrivial function of \(R\). But \(\hat{I}(C)\) does not depend on \(R\). For each cost realization, the agent is indifferent between receiving \(\hat{I}(C)\) for certain or engaging in the nontrivial \(I(R,C)\) compensation lottery. But since the agent is strictly risk averse, he is willing to pay a premium to unburden himself of this revenue risk:

\[
\Sigma_R I(R,C) f(R | C) > \hat{I}(C).
\]

In this way, the principal is able to replace \(I(R,C)\) with \(\hat{I}(C)\). This replacement does not hold the agent responsible for revenue, has lower expected cost to the principal, delivers the same expected utility to the agent, and induces the agent to supply \text{HIGH}.\(^{30}\) Put another way, the \(\hat{I}(C)\) construction is possible because we are "filtering out" needless noise in the evaluation process.

\textit{From Controllability to Information Content}

Thus, any solution that holds the agent responsible for revenue when revenue has no information content in the presence of cost can be improved. The key

\[
f(800 | 500, \text{LOW}) = f(800 | 500, \text{HIGH}) = .50. \text{ We also have } f(1000 | \text{LOW}) = 10/16 \text{ and } f(1000 | \text{HIGH}) = 11/16.
\]

\(^{28}\) In the continuing example, these constraints become:

\[
\{400(3/4) + 200(1/2)(3/4) + [200(1/2) + 100(1/2)](1/4)\}
\]

\[
- 50 \geq 250,
\]

and

\[
\{400(3/4) + 200(1/2)(3/4) + [200(1/2) + 100(1/2)](1/4) + 100(1/2)(1/2) - 0.
\]

\(^{29}\) Continuing the example, we have the following constructions:

\[
\{400(3/4) + 200(1/2)\} = 350 = [\hat{I}(400)]^{\frac{1}{2}}
\]

\[
\text{or } \hat{I}(400) = 122,500;
\]

and

\[
\{200(1/2) + 100(1/2)\} = 150 = [\hat{I}(500)]^{\frac{1}{2}}
\]

\[
\text{or } \hat{I}(500) = 22,500.
\]

This is, in fact, the optimal payment schedule to motivate choice of \text{HIGH} in this example. It has an expected labor cost of 97,750. In contrast, the original \(I(R,C)\) arrangement has an expected labor cost of 103,750.

\(^{30}\) By construction we have:

\[
\Sigma_{R,C} [I(R,C)]^{\frac{1}{2}} f(R,C | \text{HIGH}) - V(\text{HIGH}) = \Sigma_c [\hat{I}(C)]^{\frac{1}{2}} f(C | \text{HIGH}) - V(\text{HIGH}) \geq \bar{U},
\]

and

\[
\Sigma_{R,C} [I(R,C)]^{\frac{1}{2}} f(R,C | \text{HIGH}) - V(\text{HIGH}) = \Sigma_c [\hat{I}(C)]^{\frac{1}{2}} f(C | \text{LOW}) - V(\text{LOW})
\]

\[
= \Sigma_c [\hat{I}(C)]^{\frac{1}{2}} f(C | \text{LOW}) - V(\text{LOW}).
\]
insight is we use the agent's output (revenue and cost here) to infer his input. This inferential exercise compares the statistical properties of the agent's input when he supplies the desired input with those that arise when he supplies some alternative input. Given cost is already observed, an informative revenue output means the (conditional) statistical properties differ according to the agent's behavior. But an uninformative revenue output means the (conditional) statistical properties are independent of the agent's behavior. Holding the agent responsible for revenue in such a case has no effect other than making his compensation subject to purely random noise. In other words, the information content of revenue is signaled by the conditional probability being controllable. Use of an uninformative output statistic merely subjects the agent to noise. The definition of information content tells us precisely when we would want to "filter out" this noise in the agent's evaluation.

In this manner we conclude from the principal-agent analysis that any use of revenue in the agent's evaluation implies revenue has information content in the presence of cost. Conversely, with additional regularity assumptions (as in Holmstrom [1982] or Demski and Sappington [1986]), we could provide a setting where information content of revenue necessarily implies the agent should be held responsible for revenue. The important message, though, is no use of revenue is called for by the model unless revenue has information content in the presence of cost.

The intuition for this conclusion parallels that for the original controllability notion. The single variation in the logic is to take account of what other information we already are observing. The key, in other words, is to define controllability in terms of the conditional probability of the output statistic, thereby taking account of the available information.

III. Application

Stepping back from the examples and analysis somewhat, we are focusing on a setting where a list of performance variables is present and asking which elements on the list should be used in evaluating the manager (or agent) in question. Applying the controllability notion, we are led to a focus on marginal probabilities. Can the manager, through action, control the probability distribution of the variable in question. If so, the manager should be held responsible for that variable. Control begets responsibility in this framework.

Adopting a more explicit information perspective, we ask what it is the manager is supposed to be doing and why we want to evaluate his performance. Moving to an agency setting, the answers are the manager is to supply personally costly labor inputs, the supply of this input is not observable, and we must use output (including the output of various performance statistics) as a noisy indicator of input. This allows us to be precise about the information content of an evaluation measure. The key principle turns out to be information content, a close cousin of controllability but one that adjusts for what other information is already being used. Controllability does not imply information content and information content does not imply controllability.

Going still further, we now ask whether this insight of distinguishing controllability and information content helps us solve or understand real problems as opposed to numerical examples. This is not an easy task, because the information perspective demands we think in terms of probabilities and take explicit
account of what other information is being processed.

A ready illustration is provided by tournaments. Familiar examples are sports bonus clauses (e.g., for achieving some type of all-star status) and sales contests (e.g., sales person of the year recognition).\textsuperscript{31} Grading on a curve is a common practice. Relative performance evaluation of high level executives, where compensation depends on performance relative to that of a peer (e.g., industry group), is another illustration. In each case a primary consideration in the agent's evaluation is performance of a peer agent. When viewed from a controllability perspective this is perplexing. The agent in question has no control over the performance of the peer. When viewed from an information content perspective, this practice is far from perplexing. It is easy to imagine performance of another agent in similar circumstances could possess information content.\textsuperscript{32} Each agent's performance is affected by the common environment. The peer's performance tells us something about that environment and, thus, indirectly something about the performance of the agent in question.

Suppose two students take a common examination. The second student's score tells us nothing about the first student's performance. But the second student's score in conjunction with the first student's score typically does, by indirectly telling us something about the common environment. For the sake of argument, suppose the score of student \( i \) is determined by

\[
\text{score}_i = \text{effort}_i + \text{noise}_i + \text{instrument}
\]

where \( \text{effort}_i \) is the effort of the student in question, \( \text{noise}_i \) is randomness in the examination environment that is idiosyncratic to our student, and \( \text{instrument} \) is randomness associated with the examination instrument. Clearly, student \( i=1 \) cannot control \( \text{score}_2 \). But \( \text{score}_1 - \text{score}_2 \) is an interesting statistic, because the instrument randomness has been factored out. In this way, \( \text{score}_2 \) becomes useful in the evaluation of student \( i=1 \), given we already know \( \text{score}_1 \).\textsuperscript{33}

As another illustration, suppose we have two agents, each working in the environment described by Table 1. One agent's output tells us something about the state and, therefore, something about the other's environment and, indirectly, something about the other's input. In fact, agents working in perfectly correlated environments, an admitted extreme, is a case where one agent's output is unusually informative about the other agent, given we know that agent's output.

\textbf{IV. Conclusions}

This paper offers a refined version of the controllability principle. The argument rests on the assumption managerial evaluation is aimed at producing information that reports on the managerial services or inputs supplied. If the manager can affect the statistical pattern of some particular variable, the manager controls that variable. If the manager can affect the statistical pattern condi-

\textsuperscript{31} Halberstam [1986] describes extensive use of sales contests in the domestic automobile industry.


\textsuperscript{33} This vignette hints that an extension of our argument would have the agent's labor supply more generally characterized in terms of quantity and quality. Alternatively, in this particular setting the student's performance would depend on effort, skill, and luck. We then proceed as before, but in a manner aimed at information content with respect to quantity and quality of input, as opposed to quantity of input.
tioned on whatever else we know, the variable carries information content about the manager’s behavior. The concept of information content falls out of a principal-agent analysis as being a central feature of valuable monitoring or evaluation information. In this sense, we offer the information content perspective as a refined version of the controllability principle. Whether the manager controls the variable in question is immaterial. Whether the manager controls (or influences) the variable in question, conditioned on whatever other information is present, is the key notion. That is, information content is a precisely defined controllability notion that accounts for other sources of information.

The darker side to this refined principle is the added demand it places on the identification of a control problem. With the traditional controllability notion, we need only ask whether the manager can control the variable in question. With the conditional or information content notion, we must first specify what other information is being used in the evaluation process. Once this source of information is accounted for, we ask whether any new information is produced by the variable in question. This manifests itself in the manager’s conditional control of the variable in question.

In short, we find the intuition of the information content perspective appealing, but we also recognize assessing information content is likely to be a difficult task.

Recent field studies by Merchant [1987] and Dent [1987] illustrate this difficulty. Each study reports violations of the controllability principle. This is accomplished by documentation of various uncontrollable phenomena that are used in the evaluation process. In contrast, the information content perspective is not so amenable to investigation. It demands assessing information content in light of all information being used in the evaluation process. The field investigator’s task is dramatically complicated by the importance of identifying the conditioning information.
## APPENDIX

### JOINT PROBABILITIES

\[ f(R,C|a) \]

### Example 1

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<tr>
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<td>( 400 )</td>
</tr>
<tr>
<td>( 500 )</td>
<td>( 500 )</td>
</tr>
<tr>
<td>Revenue</td>
<td>Revenue</td>
</tr>
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<td>800</td>
<td>1/3</td>
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### Example 2

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<td>Revenue</td>
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### Example 3

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</tr>
<tr>
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<td>( 500 )</td>
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</tr>
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<td>0</td>
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