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OBSERVABLE CONTRACTS AS COMMITMENTS: INTERDEPENDENT CONTRACTS AND MORAL HAZARD

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Abstract

A large literature examines the use of observable and unrenegotiable agency contracts as commitments. These analyses generally impose an ad hoc restriction that contracts cannot be contingent on one another. I relax this restriction and obtain a folk theorem. Unlike earlier folk theorems in this area, the present result applies to agency relationships that have hidden-action problems. By example, I also demonstrate that there are settings in which interdependent contracts support a strictly larger set of equilibrium outcomes than do independent contracts. The result highlights the critical need for careful thought about restrictions placed on the set of feasible contracts.

1. INTRODUCTION

In a pair of important papers, Spencer and Brander (1983) and Brander and Spencer (1985) argued that a country can use a tax or subsidy policy as a visible commitment to enable a domestic firm to obtain greater profits in export competition with firms of other nations. By setting an irreversible subsidy policy, a government can influence the choices made both by its domestic firm and by foreign firms. Brander and Spencer's trade policy analysis is an example of the strategic use of an agency contract, where each government is a principal and the corresponding domestic firm is its agent. What distinguishes this analysis from typical agency analyses is that each principal's agent is engaged in a strategic conflict with other players.

Brander and Spencer’s work has been very influential. However, it contains the implicit assumption that the policy of one principal cannot be made contingent on the policy of another. For example, they rule out a country’s having the following policy: if the other country does not subsidize output, then our country will not do so either, but if they do offer subsidies, then we will set a subsidy of X dollars per unit.

In the present paper, I show that allowing such contingent policies or agency contracts can fundamentally change the predicted outcome. Specifically, I obtain a folk theorem. Unlike earlier folk theorems in this area, the present result applies to settings in which agency relationships have hidden-action problems. I also demonstrate that there are settings in which interdependent contracts support a strictly larger set of equilibrium outcomes than do independent contracts.

A principal's use of an agent to play a game opens the possibility of the principal's setting a strategic compensation scheme that makes the agent a "tougher" player in the game following the signing of the agency agreement. It has long been well understood that if: (a) only one principal uses an agent; (b) the agency contract cannot be renegotiated once signed; and (c) the contract is observable to the other players in the game; then the contract can serve as a form of binding commitment that may give rise to first-mover (Stackelberg) advantages in the game against the other principals. Indeed, over forty years ago, Thomas Schelling (1960) suggested that parties might write such contracts *solely* for the purpose of serving as commitments.[1]

Brander and Spencer's important insight was to extend this analysis to the case of simultaneous contracting by multiple principal-agent pairs. In contrast with the single-agent case, when multiple principals hire agents there may be no clear first mover, and the principals' efforts may be largely offsetting. Under the assumption that subsidy/tax policies had to be linear in output, Brander and Spencer (1985) found that each government subsidizes output to make its firm more aggressive (*i.e.*, shifts its reaction curve outward), but the collective efforts are self-defeating (*e.g.*, neither firm gains market share in comparison with the no-subsidy equilibrium but the price paid by consumers in other nations falls).[2]

Many, if not most, interesting applications of either game theory or agency theory involve several principals' simultaneously choosing agents to represent them in games. Brander and Spencer started what is now a large literature on simultaneous contracting by multiple principal-agent pairs in settings in which contracts are observable and cannot be renegotiated.[3] For example, Brainard and Martimort (1996 and 1997), Zhou *et al.* (2002), and others further examined strategic trade policy. Fershtman and Judd (1986 and 1987), González-Maestre

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1 For more recent analyses of contracts as commitments in this setting, see Bolton and Scharfstein (1990) and Melumad and Mookherjee (1989).

2 Eaton and Grossman (1986) showed this conclusion is sensitive to the nature of oligopolistic interaction.

3 For an insightful survey of the issues raised by this literature, see Gal-Or (1997).

(2000), Sklivas (1987), and Vickers (1985) considered the strategic use of managerial compensation contracts in oligopoly settings. Saracho (2002) examined the interaction of strategic managerial contracts with technology licensing. Brander and Lewis (1986), Hughes *et al.* (1998), Jensen and Showwalter (2004), and Povel and Raith (2004) examined the effects of financial structure on the play of oligopoly games. Kühn (1997), Moner-Colonques *et al.* (2004), Rey and Stiglitz (1988), and Vickers and Bonanno (1988) analyzed how contracts between successive stages in the vertical production and distribution chain affect downstream competition. Baik and Kim (1997) endogenized the delegation decision in contests such as R&D races and rent seeking. Lastly, Vulkan (1999) noted that intelligent agent computer programs could serve as agents with observable instructions when representing principals in e-commerce transactions, such as bargaining games or auctions.

By and large, these analyses—like Brander and Spencer's—support the intuition that the benefits of commitment are reduced when multiple principals have agents; the competing parties' attempts to gain advantages through contract design tend to offset one another to the benefit of third parties, such as consumers. However, like Brander and Spencer, these authors generally impose *ad hoc* restrictions on the sets of feasible contracts that affect the analyses' findings.[4]

It is readily shown that, if non-linear tax and subsidy policies were allowed in the setting analyzed by Brander and Spencer (1985), then one could obtain different equilibrium outcomes.[5] Indeed, two papers show how strongly restrictions on the form of feasible contracts can

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[4] The more recent literature has relaxed some of the earlier *ad hoc* contract restrictions and has partially motivated the remaining contract restrictions through reference to the underlying information structure. Examples of this approach include Brainard and Martimort (1996 and 1997) and Kühn (1997).

[5] A policy or contract affects an agent's reaction function in the subsequent stage-game, which in turn affects the other agent's choice of action. Because both the level and the slope of the induced reaction functions matter even for satisfying local necessary conditions for equilibrium, linear transfer functions may be unable to induce reaction functions that other contracts can.

influence the results obtained. Fershtman *et al.* (1991) and Polo and Tedeschi (2000) allow for more general sets of contracts and establish folk theorems for particular classes of delegation games. These analyses suggest that, in a trade-policy game like Brander and Spencer's, one could well see zero subsidies or even output taxes in equilibrium. Indeed, standard equilibrium selection arguments suggest that Brander and Spencer's equilibrium is not the outcome we would expect to see—there are other equilibrium outcomes that both producing countries would prefer. These questions about the robustness of earlier results carry over to the analyses of tariff setting, managerial compensation, capital structure, and distribution arrangements in oligopolistic markets. Specifically, they call into question many early authors' findings that the use of agents will result in greater competition and lower profits.

Although insightful, the analyses of both Fershtman *et al.* (1991) and Polo and Tedeschi (2000) suffer from an important limitation. As Fershtman and his co-authors themselves note, their approach relies on making a flat payment to an agent for a wide range of outcomes and having the agent pick the action the principal favors. Consequently, this approach is not robust to the introduction of moral-hazard problems—the agent will choose the least-costly action of those that trigger the same payment. Similarly, Polo and Tedeschi (2000) assume that the agency relationship is one of symmetric information and, thus, contracts can be contingent on an agent's choice of action.[6] Given the prevalence of asymmetric information in agency relationships, this is a significant limitation.

The papers in the literature on game-playing agents generally consider a two-stage game with the following structure. In the first stage, the principals hire agents to play a second-stage

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[6] Indeed, Polo and Tedeschi assume that principal *i* can write a contract that is directly contingent on the action of principal *j*'s agent as well as on that of principal *i*'s own agent.

game on their behalf.[7] A principal and her agent sign a contract specifying the agent's reward as a function of the outcome of the second-stage game. After this contract has been signed, the agent is matched against other players in the second-stage game. The fundamental premise of the literature cited above is that an agency contract can serve as a commitment that influences the second-stage play of rival agents when the contract is non-renegotiable and becomes common knowledge among all agents before they play the second-stage game.[8]

Under those conditions, a principal could condition the contract with her agent on either her own observation of the rival principal's contract or—if she cannot observe the contract herself—on her agent's report of the rival contract. For instance, the New Hampshire legislature passed a law requiring that election officials hold New Hampshire's presidential primary at least one week before that of any other state. Despite the feasibility of writing contracts that are contingent on one another, however, almost all previous analyses of strategic agency with observable contracts simply assume-away contingent contracts of this form.[9]

There are two reasons to study such contracts. First, there is no basis for simply *assuming* that a principal will fail to make use of a contract form that often would benefit her. If one believes that such contracts are rare in practice, then one should analyze models that give

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7 I assume throughout that each principal hires her own agent. Bernheim and Whinston (1985 and 1986) analyze the use of a common agent. Alexander and Reiffen (1995) consider strategic vertical contracting where a single manufacturer (principal) hires two competing retailers (agents).

8 For analyses of settings in which these assumptions do not hold, see for example, Caillaud and Hermalin (1993), Caillaud, Jullien, and Picard (1995), Dewatripont (1988), Katz (1991), and Myerson (1982).

9 Unlike many other authors, Kühn (1997) rigorously defines information structures that support the assumption that the contracts cannot refer to one another. One of his cases assumes that the agents can observe one anothers' contracts, but the principals either cannot observe these contracts or else cannot verify them in court. As discussed in Section 3 below, however, this assumption often is insufficient to rule out interdependent contracts. For a discussion of the impact of observable but unverifiable variables on agency contracts more generally, see Hermalin and Katz (1991).

rise to this finding endogenously.[10] Second, one obtains significantly different results when one allows interdependent contracts, and it is useful to understand why.

Below, I give conditions under which a relatively simple contingent contract can be used to support essentially any individually rational second-stage outcome as an equilibrium of the two-stage game.[11] The contracts can be described as follows. Each principal instructs her agent to play his part in the candidate equilibrium as long as the other principal has honored the implicit agreement to do the same. If the agent reports that the other principal has violated the agreement by choosing a different contract, however, then the agent is induced to punish the rival principal by taking an action that is unfavorable to her. Unlike the results of Fershtman *et al.* (1991) and Polo and Tedeschi (2000), the resulting folk theorem is robust to hidden-action problems of the sort that often lie at the heart of agency.

Under strategic agency, a principal uses a contract to shape her agent's reaction function in the second-stage game.[12] Moral hazard in the agency relationship can weaken the principal's ability to implement various reaction functions. Under my approach, a principal uses the agency

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[10] A potential objection is that interpretation problems can arise when agency contracts are contingent on one another. To see why, consider trade policy and suppose each government announces a policy of setting its subsidy $1 per unit higher than any other government's subsidy. How could the policies be interpreted? More generally, interpretation problems can arise whenever the contract chosen by a principal takes the realized value of the transfer paid under a rival contract, rather than the entire (actual or reported) contract itself, as an argument. In effect, what is needed is a language for describing contracts in their entirety. These issues are addressed briefly in an earlier version of the present paper (available from the author) and in a much more sophisticated fashion by Epstein and Peters (1999) in the context of principals that offer competing mechanisms to attract agents, where those mechanisms can be contingent on one another. The type of contract in Theorem 1 below does not give rise to coherency problems because it takes the entire contract of a rival principal-agent pair as an argument.

[11] I say "essentially" because some individually rational outcomes may not be attainable because of moral hazard in the individual agency relationships.

[12] To the extent that principals are picking reaction functions, the problem is similar to supply-function competition (see, *e.g.,* Klemperer and Meyer, 1989), and to auctions in which bidders submit demand functions (see, *e.g.,* Wilson , 1979). The similarity with supply-function equilibria has been noted by others, including Kühn (1997) and Polo and Tedeschi (2000), and Klemperer and Meyer noted that firms

contract to induce a reaction function that is contingent on the instructions given to the other agent. A principal thus can have considerably more power to shape her agent's behavior in the second-stage game. I show by example that the assumption that agency contracts cannot refer to one another can significantly restrict the set of equilibria in the presence of moral hazard.

The paper is organized as follows. The next section lays out a two-stage game with observable agency contracts. A folk theorem is presented in Section 3. Section 4 examines how moral hazard influences the equilibria of delegation games through its effects on a principal's ability to implement various reaction functions and her cost of doing so. I show that improved information about an agent's actions, which reduces the moral-hazard problem, can nevertheless harm a principal. Section 5 presents an example in which interdependent contracts support a strictly larger set of equilibrium outcomes in the second-stage game than can independent contracts. The Conclusion briefly discusses some implications of these findings.

2. A MODEL

Consider the following two-stage delegation game, which is general enough to include several leading applications of the use of observable contracts as commitments. There are two principal-agent pairs, $i = 1,2$. In the first stage, each principal offers her agent a contract, which the agent then accepts or rejects. Contract negotiations take place simultaneously. Before the start of the second stage, each agent observes whether the rival agent has accepted his principal's contract offer and, if so, what that contract is. In the second stage, agents 1 and 2 simultaneously choose actions, a_1 and a_2, respectively, from finite sets of possible actions, A_1 and A_2.

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might commit to supply functions through contracts with their workers. Kühn (1997), however, showed that there can be important differences between delegation games and supply-function competition.

Agent i can be thought of as devoting effort to a project that (stochastically) generates a capability, k_i, for firm i in competition with firm j, $j \neq i$. There is a finite set of possible values, K_i, for k_i. Denote the probability mass vector for k_i conditional on a_i as $h(\cdot;a_i)$. In a slight abuse of terminology, I will refer to $h(\cdot;a_i)$ as a conditional density. Except in Section 5, this conditional density is assumed to be independent of a_j and k_j, $j \neq i$.

The product-market payoff, measured in monetary units, is denoted $\pi_i(k_1,k_2)$. Define

$$\psi_i(a_1,a_2) \equiv \sum_{k_1 \in K_1} \sum_{k_2 \in K_2} \pi_i(k_1,k_2) h_1(k_1;a_1) h_2(k_2;a_2).$$

For convenience, I assume that the principals are risk neutral. Principal i's expected payoff conditional on the agents' actions is $\psi_i(a_1,a_2) - \delta E[T_i]$, where $E[T_i]$ is the expected transfer to the agent and δ is a non-negative constant which allows for the possibility that the principal is a governmental agency with distributional preferences that do not count transfers as one-for-one losses. If the principal fails to hire an agent, her payoff is 0.

Agent i's payoff is $E[u_i(T_i)] - e_i(a_i)$, where $u_i(\cdot)$ is the utility of income and $e_i(a_i)$ is the cost of effort. This formulation allows for risk aversion, but assumes that the cost of effort is additively separable from the utility of income. $u_i(\cdot)$ is assumed to be invertible, with inverse $u_i^{-1}(\cdot)$. Note that there is no direct link between the effort cost of an action taken by one agent and the action taken by the other agent. Normalize the agent's outside opportunity utility to 0.

The structure of the game is assumed to be common knowledge, and the equilibrium concept is perfect Bayesian equilibrium.

The outcome of project i, k_i, is a sufficient statistic for agent i's action relative to the outcome of the other firm's project or the resulting level of profits. Hence, as shown by

Holmstrom (1979), the expected cost to principal i of inducing action a_i would not be reduced by making her agency contract depend on $\pi_i(k_1, k_2)$ or k_j, $j \neq i$.[13] If the agency contract is contingent solely on k_i, then agent i chooses his action to

$$\max_{a_i \in A_i} \sum_{k_i \in K_i} u_i[T_i(k_i)]h_i(k_i; a_i) - e_i(a_i),$$

the solution to which is independent of the other agent's action (*i.e.*, the contract induces a point reaction function in the second-stage game).[14]

Let A_i^I denote the set of actions implementable at finite cost to principal i. By Hermalin and Katz (Proposition 2, 1991), a is implementable if and only if there is no strategy for agent i that induces the same conditional density for k_i but which costs less in terms of the agent's expected disutility of effort.[15] For $a \in A_i^I$, let $\hat{T}_i(\cdot; a)$ be the least-cost contract that induces agent i to choose action a, and define $c_i(a) \equiv \sum_{k_i \in K_i} \hat{T}_i(k_i; a)h_i(k_i; a)$.[16] When k_i is an invertible function of a_i, the principal can effectively order the agent to choose a specific a and there exists a contract that implements action a at the first-best cost to the principal: $c_i(a) = u_i^{-1}[e_i(a)]$ for all $a \in A_i$. In other cases, k_i serves as a noisy signal of a_i and $c_i(a)$ will typically be strictly greater

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13 When agency contracts cannot be contingent on one another, allowing contract i to depend on k_j as well as k_i can have powerful effects. Compare, for example, Theorem 2 of Polo and Tedeschi (2000) with Proposition 1 below. Similarly, an independent contract based on $\pi_i(k_1, k_2)$ could create a potentially valuable linkage between agent i's compensation and the actions of agent j that would substitute for contractual interdependence. Under the conditions of Theorem 1 below, these effects do not arise when contracts can be contingent on one another.

14 Although the notation is in terms of pure strategies, the analysis readily extends to mixed strategies.

15 A sufficient condition for implementability of a^0 is that $h_i(\cdot,a^0) \notin$ convex hull of $\{h_i(\cdot,a) \mid a \neq a^0\}$.

16 See Grossman and Hart (Proposition 1, 1983) for a proof that such a contract and associated implementation cost exist.

than $u_i^{-1}[e_i(a)]$. In any event, the contract that implements a given action and the associated cost to the principal are independent of the actions of the other principal-agent pair.

Before analyzing the general model, it is helpful to describe two applications that are special cases. The first is strategic trade policy. The assumption of contract observability seems most reasonable when the "contract" takes the form of public policy. And, as noted in the introduction, Brander and Spencer pioneered this literature with a trade policy example. In this application, the principals are two governments and the agents are two respective domestic firms that compete to sell to consumers in a third nation. In the first stage, the governments simultaneously choose tax or subsidy policies to influence the behavior of their domestic firms and, indirectly, the behavior of the foreign firms. It is convenient to think of a_i as the output level chosen by firm *i*, but it could be some other action such as the level of R&D activity or investment in plant and equipment. In some versions of this application, each government's objective is to maximize its domestic firm's profits net of the subsidy or tax: $\delta = 0$ and $\psi_i(a_1, a_2)$ is the domestic firm's expected product-market profits. In other cases, there are other distributional preferences or costs of raising public funds, so that $\delta > 0$. Each firm's objective is to maximize its expected profits, including any subsidy or netting out any tax. An agent's contract acceptance decision can be interpreted as a firm's decision whether to shut down given its government's policy.

Another early application of strategic agency was the use of strategic managerial compensation schemes for the managers of oligopolistic competitors.[17] In this application, principal *i*'s payoff is equal to the firm's product-market profits minus its agent-manager's

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[17] The financial structure of an oligopolistic competitor is a closely related application.

compensation; $\delta = 1$. A manager acts to maximize his expected utility from transfer payments minus the costs of managerial effort.

3. INTERDEPENDENT CONTRACTS

Suppose the payment made to one agent depends upon the contract signed by the other agent. That is, if principal *j* sets policy T_j, then agent *i* is paid $T_i(k_i;T_j)$. In the trade policy context, for instance, the subsidy paid by country *i* to its domestic producer might depend upon the subsidy policy chosen by country *j*. In effect, this dependence allows a principal to condition the instructions to her agent on the instructions given by the other principal to her agent. Observe, however, that agent *i*'s reaction curve in the second-stage game remains a single point conditional on T_j.

The following result shows that a simple pair of interdependent contracts can be used to support a vast range of second-stage outcomes.

Theorem 1: *Suppose that agency contracts are allowed to be contingent on one another. Given any pair of actions, (a_1^c, a_2^c), such that each principal's net payoff is at least as large as its maximin level, there is a pair of contracts that support those actions as a perfect Bayesian equilibrium.*

Proof: Define the "punishment" level $a_1^p \in A_1^I$ as the value of a_1 that minimizes

$$\max_{a \in A_2^I} \psi_2(a_1, a) - c_2(a).$$

Define a_2^p similarly. Let r_i denote the report made by agent *i* about his observation of T_j, and define

$$T_i^c(\cdot, r_i) \equiv \left\langle \begin{array}{l} \widehat{T}_i(\cdot; a_i^c) \text{ if } r_i = T_j^c \\ \\ \widehat{T}_i(\cdot; a_i^p) \text{ if } r_i \neq T_j^c \end{array} \right.$$

for i = 1,2 and $j \neq i$. Under the assumption that k_i is independent of k_j, the agent has no incentive to submit a false report because he earns his reservation utility in any event. Given truthful reporting by both agents, these contracts are mutual best responses and support the candidate second-stage outcome as an equilibrium in the two-stage game. To see that they are best responses, observe that deviation by principal 1 would trigger agent 2's choosing a_2^p. Principal 1 thus determines whether to deviate by comparing $\pi_1(a_1^c, a_2^c) - c_1(a_i^c)$ with $\max_{a \in A_1^I} \pi_1(a, a_2^p) - c_1(a)$. Principal 2 makes a similar determination. By construction, neither principal finds it profitable to deviate. **Q.E.D.**

Intuitively, the strategies can be described as follows. Each principal "instructs" her agent to play his part in the candidate second-stage equilibrium as long as the other principal has honored the implicit agreement to do the same. If the other principal is reported to have violated the agreement, however, then the initial agent is induced to punish the rival principal by taking an action that is unfavorable to her.

The proof relies on the fact that, under the assumption that k_i is independent of k_j, the agent has no incentive to submit a false report because he earns his reservation utility no matter what report he submits.[18] Two comments are in order. First, observe that, whether or not k_i is independent of a_j and k_j, this logic also applies to any situation in which a_i is observable to principal i and verifiable in court. Second, one could object that, although an agent has no

[18] Grossman and Hart (Proposition 2, 1983).

incentive to submit a false report, neither does he have a strict incentive to submit a true report. The lack of a strictly positive incentive arises because the proof allows for situations in which the principal and the court responsible for enforcing the contract have absolutely no information about the rival agency contract. If principal *i* can observe *T*j and verify it in court, for example, then agent *i* can be punished for providing a false report, and there is a strictly positive incentive for agent *i* to report truthfully.

One might conjecture that perfection arguments relying on the possibility of mistakes or trembles by the players would rule out the use of these contracts, which punish both intentional deviations and mistakes in a way that may be very costly to all parties. Such arguments do not hold force. Neither principal would alter her policy in response to a small probability of mistakes by other players because to do so would invite almost certain punishment by the other principal-agent pair. As long as the punishment outcome is strictly worse than (a_1^c, a_2^c), it will be optimal to play T_i^c in response to T_j^c for sufficiently low probabilities of trembles.

One might also try to rule out this type of equilibrium based on claims of excessive complexity. In many contexts, however, the transfer policies would be quite simple. In oligopoly games, for example, it is often the case that actions can be indexed such that actions with a higher index are more costly to the agent undertaking the action and less desirable to the competing principal-agent pair (*e.g.,* output or R&D investment in settings where the agents manage competing firms). In such contexts, the punishment part of the contract involves providing strong incentives to take the highest action. In the case of trade policy, for instance, a government would announce that it will induce its firm to flood the market with output unless the other country plays its part of the candidate equilibrium. Even if a government were restricted to offering a subsidy or tax that was linear in its firm's output level, a sufficiently large subsidy rate would allow the government to induce its domestic firm to produce a high output level regardless of what the other firm does. Thus, there would be no difficulty inducing a_i^p. If the cost and demand functions in the product market were sufficiently well behaved (*e.g.,* the firms were Cournot dupolists with constant marginal costs facing linear industry demand for a homogeneous product), then, given any (a_1^c, a_2^c) that is individually rational, one could readily calculate affine taxes/subsidies supporting that pair of actions as an equilibrium second-stage outcome. Moreover, in the trade policy context, the principals could explicitly communicate with each other to coordinate on a pair of cross-referential policies.

4. THE EQUILIBRIUM EFFECTS OF HIDDEN ACTIONS

As noted in the Introduction, Theorem 1 is robust to the presence of moral hazard, while earlier folk theorems are not. In the present section, I examine how moral harzard affects the set of second-stage outcomes that can be supported as equilibria of the larger game. I compare two situations. In both, principal *i* cannot write a contract contingent on k_j either directly or, through $\pi_i(k_1, k_2)$, indirectly. In one situation, only k_i is observable and verifiable, $i = 1,2$. In the other, a_i is itself observable and verifiable, so there is no hidden-action problem in either agency relationship.[19] If there were a single principal-agent pair, then clearly the principal would (weakly) benefit from improved information about a_i. In a strategic agency setting, however, this result need not hold.

First, suppose that agency contracts are not allowed to be contingent on one another. The following example illustrates that there can exist an outcome that is supportable as a perfect Bayesian equilibrium when each agent's actions are neither observable nor verifiable but not when each agent's actions are observable by its principal and verifiable in court. Each agent has only two possible actions, a_L and a_H. The costs of effort and the product-market profit functions are the same for both firms. Specifically, the common values of effort costs are $u^{-1}[e(a_L)] = 12$ and $u^{-1}[e(a_H)] = 20$. Expected product-market profits are $\psi_i(a_L, a_L) = 25$, $\psi_1(a_H, a_L) = 34 = \psi_2(a_L, a_H)$, $\psi_1(a_L, a_H) = 18 = \psi_2(a_H, a_L)$, and $\psi_i(a_H, a_H) = 32$.

An agency contract contingent only on a_i or k_i induces a point reaction function. Hence, the two principals can be thought of as simultaneously choosing a_1 and a_2. The payoff matrix is illustrated in Figure 1. χ represents the amount by which the principal's cost of inducing her agent to play a_H exceeds $u^{-1}[e(a_H)]$. Observe that, because $e(a_L) < e(a_H)$, the principal can induce a_L by offering a flat payment of $u^{-1}[e(a_L)] = 12$.

When a_i is observable and verifiable, $\chi = 0$ and, thus, the principals are engaged in a standard Prisoners' Dilemma game in which a_H is a dominant strategy but (a_H, a_H) is Pareto inferior to (a_L, a_L). When a_i is unobservable to principal *i*, she has to rely on a contract that is contingent only on k_i, which is a noisy signal of a_i. If the agent is risk averse, then $\chi > 0$ because the contract must force the agent to bear risk in order to generate incentives to take the more costly action. For $\chi \geq 1$, (a_L, a_L) is an equilibrium outcome of the second stage of the delegation game. And for $\chi > 6$, it is the unique equilibrium outcome. Both principals benefit from the increase in agency costs because it allows them to avoid the Prisoners' Dilemma.

In this first example, each principal benefits from degradation of the *rival* principal's information. In the example illustrated in Figure 2, however, the principal choosing the column

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[19] Alternatively, k_i is an invertible function of a_i.

benefits from degradation of her *own* information. When $\chi = 0$, (a_H, a_H) is the unique second-stage equilibrium outcome. When $\chi > 6$, (a_L, a_L) is the unique equilibrium outcome. Intuitively, a large value of χ has the effect of making credible an implicit promise by the principal choosing the column to induce a_L, and the principal choosing the row has incentives to match. Of course, in other examples, a principal benefits from improved information, both because it lowers her cost of implementing a given outcome and because new outcomes may be implementable.

Now, suppose that interdependent contracts are feasible. In this case, too, an improvement in information can make the set of second-stage outcomes supportable as perfect Bayesian equilibria either smaller or larger. The reason for the ambiguity is that there are three opposing effects. The first two effects arise from the fact that every action is implementable when a_i is observable and verifiable, but may not be otherwise. Thus, assuming for the moment that the principals could agree to do so, there is potentially wider range of outcomes that the principals could implement as equilibrium outcomes. Turning to whether the principals will "agree," writing contracts contingent on a_i instead of k_i may make the harshest credible punishment weaker or stronger. The punishment may be stronger because principal *i* can choose a_i^p from a potentially larger feasible set. It may be weaker because the principal being punished has a potentially larger set of responses and because the cost of inducing a given action may fall. Formally, although principal 1 can potentially choose a_1^p from a larger set, it is also the case that, for any given value of a_1^p, $\max_{a \in A_2} \psi_2(a_1^p, a) - u_2^{-1}[e_2(a)] \geq \max_{a \in A_2^I} \psi_2(a_1^p, a) - c_2(a)$, sometimes with strict inequality.[20]

The next result is useful for analyzing the effects of allowing agency contracts to be interdependent and applies to situations in which there is no moral hazard:

Proposition 1: *Suppose that contracts are not allowed to be contigent on one another and that* a_i *is observable by principal i and verifiable in court, i* = 1,2. *Any pair of actions,* (a_1^c, a_2^c), *that can be supported as a perfect Bayesian equilibrium of the delegation game must also constitute an equilibrium in the game where players 1 and 2 simultaneously choose* a_1 *and* a_2, *and player i has payoff function* $\psi_i(a_1, a_2) - u_i^{-1}[e_i(a_i)]$.

This result is an immediate consquence of the fact that contracts based solely on a_i or k_i induce a point reaction function for agent *i* in the second stage game. Thus, as in the examples above, the game of simultaneously choosing a_1 and a_2 is effectively moved up from the second stage to the first. Comparing Proposition 1 and the Theorem 1, one can readily see that there are situations in which interdependent contracts give rise to a strictly larger set of second-stage equilibrium outcomes than do independent contracts. The next section presents a specific example that makes this point concretely.

5. AN EXAMPLE WITH INTERDEPENDENT PROJECT OUTCOMES

This section presents an example that makes two points. First, it demonstrates that there are situations in which interdependent contracts can support a strictly larger set of equilibrium

20 In the inequality, A_2^I refers to the set of implementable actions when a_2 is not observable and verifiable, and $c_2(\cdot)$ refers to the corresponding cost function.

outcomes in the second-stage game than can independent contracts. Second, it illustrates the fact that the techniques used to establish Theorem 1 can be extended to settings in which the distribution of k_i is not independent of a_j. Specifically, it is shown that it can still be possible to implement a contract that instructs an agent to cooperate with or punish the other principal-agent pair depending on the contract to which that pair agrees.

Two firms compete in a patent race in which a firm earns product-market profits of W if it wins the race and 0 if it doesn't. In terms of earlier notation, $k_i = 1$ if the firm wins and 0 otherwise, with $\pi_1(1,0) = W$ and $\pi_1(0,1) = 0 = \pi_1(0,0)$. $\pi_2(k_1, k_2)$ has the analogous form. Because it is a race, the probability that $k_i = 1$ depends on both a_1 and a_2, and the earlier independence assumption is not satisfied. Let $h(k_1, k_2; a_1, a_2)$ denote the joint density of k_1 and k_2 conditional on a_1 and a_2, and let $p_1(a_1, a_2) \equiv h_1(1,0; a_1, a_2)$ denote the probability that firm 1 wins the race given the R&D investment levels. Define $p_2(a_1, a_2)$ analogously. Principal i earns expected payoff $p_i(a_1,a_2)W - E[T_i]$. The agents are risk neutral, with $u_i(T) = T$. An agent's effort or R&D cost function is $e(\cdot)$, which is assumed to be the same for both agents. The possible effort levels are $A_i = \{0,1,2,\ldots,n\}$. If agent i rejects the contract, then $a_i = 0$ in the second-stage game.

The probability-of-success function, $p_i(\cdot,\cdot)$, and the R&D effort cost function, $e(\cdot)$, are assumed to be well behaved and, for convenience, symmetrical. Specifically:

Assumption A1: For all $a, b \in \{0,1,2,...,n\}$: (a) $p_1(a,b) = p_2(b,a)$; (b) $p_1(a+1,b) > p_1(a,b)$; (c) $p_1(a,b+1) < p_1(a,b)$; (d) $p_1(0,b) = 0$; (e) $p_1(a+2,b) - p_1(a+1,b) < p_1(a+1,b) - p_1(a,b)$; and

(f) $p_1(a+1,b) - p_1(a,b) > p_1(a+1,b+1) - p_1(a,b+1)$.[21]

Assumption (f) implies that R&D efforts are strategic substitutes.

Assumption A2: For all $a \in A_i$, $i = 1,2$, $e_i(a) = \gamma a$, γ a positive constant.

A1(e) and A2 together imply that there are diminishing returns to R&D expenditures measured in terms of monetary equivalent units of effort. Coupled with A1 and A2, the next assumption implies: (a) if $a_2 = n$, then principal-agent pair 1 cannot earn a positive payoff, and (b) the best response to $a_2 \leq 1$ is $a_1 \geq 1$:

Assumption A3: $p_1(1,n) < \gamma / W < p_1(1,1)$.

The information structure is as follows. An agent's effort level, a_i, is unobservable to either principal, but whether agent *i* wins the race is both observable to principal *i* and verifiable in court. Principal *i* cannot observe k_j (but can infer $k_j = 0$ when $k_i = 1$).[22] Hence, the contract between principal *i* and her agent can be made contingent only on the value of k_i (*i.e.*, whether agent *i* wins the R&D race).

As a baseline for comparison, suppose that the agency contracts cannot be contingent on one another either directly or through agents' reports. Given the information structure, the most general agency contract consists of two payment levels contingent on whether agent *i* wins the race or not.[23] Because the agent is risk neutral, only the difference between these two levels, Δ_i,

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21 It should be understood that certain properties do not hold for extreme values of *a* and *b*. For example, A1(b) holds only for $a < n$.

22 The assumption that a principal cannot observe whether the other firm has won the patent race may seem unnatural, but it greatly simplifies the analysis and allows me to make the main point of the example as cleanly as possible. An alternative interpretation of the model is that the two firms are competing to win a contract to supply a third firm, and the results of the competition are not made public.

23 As shown by Holmstrom (1979), there is no value to paying an agent with a lottery in this setting.

is relevant for the choice of a_i. Of course, the principal has to set the absolute levels of the payments to insure that the agent's individual rationality constraint is satisfied.

If he has accepted the contract, then agent 1 chooses

$$a_1 \in \arg\max_{a \in A_1} p_1(a, a_2)\Delta_1 - e(a) .$$

Agent 2 makes a similar decision. Given A1 and A2, the following conditions are necessary and sufficient for the agents to take actions (a_1, a_2) in equilibrium given that both have accepted contracts (with suitable dropping of conditions for corner solutions):

$$p_1(a_1+1, a_2) - p_1(a_1, a_2) \le \gamma/\Delta_1 \le p_1(a_1, a_2) - p_1(a_1-1, a_2)$$

and

$$p_2(a_1, a_2+1) - p_2(a_1, a_2) \le \gamma/\Delta_2 \le p_2(a_1, a_2) - p_2(a_1, a_2-1).$$

Hence, when $\Delta_1 = W = \Delta_2$, the condition for a symmetric equilibrium is

$$p_1(a+1, a) - p_1(a, a) \le \gamma/W \le p_1(a, a) - p_1(a-1, a) . \qquad (1)$$

Assumption A4: There exists at least one $a \in \{0,1,2,...,n\}$ satisfying (1), again with appropriate dropping of conditions for corner solutions.

Assumptions A1 through A3 imply that there is at most one solution to (1) and that this solution, if it exists, is strictly greater than 0 and less than n.[24] Label this solution $\hat{a}$.

Lemma 1: *If the agency contracts are not allowed to be contingent on one another and* (a^e, a^e) *is a pair of actions taken in a symmetric, perfect Bayesian equilibrium, then* $a^e \ge \hat{a}$.

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[24] To prove uniqueness, suppose counterfactually that a and b are two solutions, with $b > a$. Then $p_1(b, b) - p_1(b-1, b) < p_1(b, a) - p_1(b-1, a) \le p_1(a+1, a) - p_1(a-a) \le \gamma/W$, a contradiction.

Proof: Suppose that (a^e, a^e) is an equilibrium outcome. Let (Δ^e, Δ^e) denote a pair of non-interdependent agency contracts that support this outcome. If $a^e < \hat{a}$, then it must be the case that $\Delta^e < W$. Suppose principal i deviated from the candidate equilibrium by setting $\Delta_i = W$. Given A1-A3, there exists a new second-stage equilibrium in which $a_j \leq a^e < \hat{a} \leq a_i$. Using A1(c) and the fact that agent i is now a residual claimant, firm i's expected profits net of effort costs, $p_i(a_1, a_2)W - e(a_i)$, would rise. Principal i could appropriate the increase by lowering her agent's base payment. Hence, if $a^e < \hat{a}$, it would be profitable for a principal to deviate.

Q.E.D.

Now, consider the effects of allowing agency contracts to refer to each other.

Proposition 2: *Suppose that agency contracts are allowed to be contingent on one another. Given any pair of actions,* (a_1^c, a_2^c)*, such that* $p_i(a_1^c, a_2^c)W - e(a_i^c) \geq 0$*, there is a pair of contracts that support those actions as a perfect Bayesian equilibrium.*

Proof: Define

$$\Delta^c \equiv \frac{\gamma}{p_1(a_1^c, a_2^c) - p_1(a_1^c - 1, a_2^c)}.$$

and

$$\Delta^p \equiv \frac{\gamma}{p_1(n, n) - p_1(n-1, n)} + \varepsilon,$$

where ε is a positive constant. Lastly, define contract T_i^c, i = 1,2, $j \neq i$, as follows:

$$T_i^c(k_i; T_j) = \begin{cases} k_i\Delta^c \text{ if } T_j = T_j^c \\ k_i\Delta^p \text{ otherwise} \end{cases}.$$

To satisfy the agent's individual rationality constraint, the absolute levels of the payments have to be set so that the expected payment given (a_1^c, a_2^c) is equal to $e(a_i^c) = \gamma a_i^c$.

By construction, if the principals sign contracts T_1^c and T_2^c with their agents, then (a_1^c, a_2^c) will be an equilibrium of the second-stage game and principal *i* will earn expected profits $p_i(a_1^c, a_2^c)W - e(a_i) \geq 0$. Suppose principal *i* and her agent agree to T_i^c and principal *j* and her agent agree to any contract other than T_j^c. Given that agent *i*'s incentives would then be based on Δ^p, any second-stage equilibrium must entail $a_i = n$, which implies that principal-agent pair *j* would have a non-positive joint payoff. Therefore, T_j^c is a best response to T_i^c. **Q.E.D.**

Clearly, Proposition 2 identifies the maximal set of second-stage outcomes supportable as equilibria given the principal and agent's individual rationality constraints. Moreover, this example establishes that the assumption that contracts cannot be contingent one on another can significantly restrict the set of equilibria. As shown by Lemma 1, there are no "clever" non-interdependent contracts that could support the full set of second-stage equilibria that interdependent contracts can support.

Up to this point, the analysis of this example has assumed that contract T_i can be made directly contingent on contract T_j. Now, suppose that the principal *i* cannot observe T_j. The contracts used in Section 3, which were based on the agent *i*'s reported value of T_j, may fail to work in the present setting because the payments necessary to induce a given a_i may depend on T_j through its effects on k_j. Hence, agent *i* may have incentives to distort his report in order to induce a contract with more favorable compensation.

When the agent is risk neutral, however, a second approach can be applied as long as courts have even a minimal ability to discern the truth about rival contracts. In particular, let

$\rho(r,T)$ denote the probability that the court responsible for enforcing the agency contract will determine that the agent is telling the truth when he asserts that the contract is *r* and it actually is *T*. Suppose that there is exists a constant, $\eta > 0$, such that, for all *T*, $\rho(r,T) < \frac{1}{2} < \frac{1}{2} + \eta \leq \rho(T,T)$ for any $r \neq T$. Suppose that the agency contract calls for the agent to make a report, *r*, which is then audited with probabilty α. If the court finds that the agent has told the truth, then the principal pays the agent $\beta\{1 - \rho(r,r)\}$, in addition to any payments based on k_i. If the court does not find that the agent has told the truth, then the transfer is $-\beta\rho(r,r)$ (*i.e.*, the agent pays the principal, again in addition to any payments based on k_i). The agent's expected payoff from reporting *r* is thus $\alpha\beta\{\rho(r,T) - \rho(r,r)\}$ which equals 0 for $r = T$ and is less than $-\alpha\beta\eta < 0$ for $r \neq T$. By making β large enough, the principal can induce the agent to make a truthful report about T_j even if doing so affects the compensation paid to induce a particular value of a_i. Note that this approach may fail to be optimal when the agent is risk averse because it may entail the agent's bearing a large amount of risk.

6. CONCLUSION

I have used a simple model to examine the strategic use of observable and unrenegotiable agency contracts. I argued that, if one accepts the assumptions that contracts are observable and unrenegotiable, then one should allow the contracts to be contingent on one another. I showed that, if one allows a very simple type of contract in the feasible set, then a wide range of second-stage outcomes can be supported as equilibria of the delegation game. Moreover, I showed by example that independent contracts sometimes can support only a strictly smaller set of second-stage outcomes as equilibria.

Having established that the results of many earlier analyses critically depend on the assumption that contracts cannot be interdependent, it is natural to ask whether this is a reasonable assumption. On what basis might one rule out interdependent contracts? In my view, the analysis above demonstrates that—at least for many settings in which the contracts are observable—one cannot appeal to arguments that interdependent contracts are too complex or impose informational requirements that are too great in comparison with contracts that do not refer to one another.

Some readers have argued that interdependent contracts need not be analyzed because they would be found to be illegal. But that approach leaves unanswered the question of what sort of contractual interdependence *ought* to be allowed by policy makers. Presumably such legal prohibitions are derived from the hypothesized effects of the contracts. Antitrust policy, for example, might block managerial compensation schemes that referred to one another in the manner identified above on the grounds that they were attempts to restrain competition. But the use of contracts that refer to one another also could be used to support extremely competitive outcomes. One of the uses of economic analysis should be to determine whether the restrictions imposed by public policy are sensible ones. Moreover, one cannot appeal to antitrust policy to rule out interdependent trade policies.

To my mind, a greater problem with the use of interdependent contracts is whether agency contracts truly are observable. Elsewhere (Katz, 1991), I have argued that informational conditions will limit the use of contracts as commitments in many situations. For instance, managerial contracts often are not observable, at least ex ante. With unobservable contracts (or contracts subject to renegotiation), the equilibrium set may be considerably smaller.[25]

As noted earlier, the observability assumption may be most reasonable when the "contract" is a public policy. Is there an information structure in which policies could serve as commitments but could not be explicitly interdependent? In theory, yes, but the empirical importance of these conditions is questionable. One would have to have a situation in which: (a) each agent knew the policies of all other governments, but no government knew the policy of any other government; (b) a policy could not be made contingent directly on the agent's action nor were project outcomes independent; and (c) agents were risk averse. Condition (a) strikes me, at least, as implausible.

If one does allow for interdependent contracts or policies, the equilibrium set may be very large. Clearly, a result of the form "anything is possible" does not shed a great deal of light on actual markets. Perhaps the main contribution of this analysis is that it properly focuses attention on the sets of feasible contracts that are included in the analysis of any given application. The modeling of these restrictions is central to the results obtained. To date, far too little justification has been given for the simplifying assumptions that have been made in the literature.[26] Fortunately, in many applications, there are natural restrictions on the sets of feasible contracts, and by imposing these restrictions it should be possible to narrow the equilibrium set and thus generate sharper, and hence testable, predictions.

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[25] For insightful analyses of unobservable contracts see Bolton and Scharfstein (1990), Caillaud and Hermalin (1993), Caillaud, Jullien, and Picard (1995), Dewatripont (1988), Myerson (1982), and Schelling (1960).

[26] Notable exceptions include, Brainard and Martimort (1996), Fershtman and Judd (1986), and Kühn (1997), although only Kühn provides a justification for ruling out contractual interdependence.

Contract restrictions may arise for a variety of reasons, including: (i) legal restraints; (ii) asymmetric information in the underlying agency relationships; (iii) costs of contractual complexity; and (iv) industry custom. The study of industry custom is perhaps the most interesting direction of the four. In many applications, there is a particular contract form that is used by principals to reward their agents. For example, lawyers for the plaintiffs in tort cases typically are reimbursed on a contingency basis. Such industry customs may be optimal responses to the conditions of that market. Or, a custom may be more of an historical accident that has become locked-in because an alternative arrangement would be viewed with suspicion by one side of the principal-agent pair. Suppose, for example, that a lawyer demanded to be paid a flat fee in advance. Even if there were no problem of moral hazard, the client might fear an adverse selection problem—what does the lawyer know that leads him to demand a fixed fee? For whatever reason that they exist, contracts that are an industry custom are worthy of examination in the study of agency and may serve to limit the set of equilibria.[27]

[27] See Hermalin (1988) and Spier (1992) for analyses of some of these issues.

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Figure 1

	H	L
H	$12 - \chi$ $12 - \chi$	6 $14 - \chi$
L	$14 - \chi$ 6	13 13

Figure 2

	H	L
H	$12 - \chi$ 12	6 0
L	$14 - \chi$ 0	13 13