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Contract Renegotiation and Organizational Design*

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Abstract / Résumé

This paper studies the implications of non-commitment for organizational design. An organizational form must trade-off between the coordination benefits associated with the centralization of information and its associated costs in terms of renegotiation. This analysis makes precise what these benefits and costs are. First, I characterize renegotiation-proof allocations for organizational forms that differ in the amount of decentralization that they support. Second, I compare these different organizational forms. The analysis shows that a complete decentralization of decision-making is always weakly dominated by more centralized structures when information is dispersed in the organization. Decision-making should always be in the hand of the player with the most important or relevant information.

Ce papier étudie les implications pour la structure organisationnelle des problèmes de non-engagement. Une structure organisationnelle adéquate permet l'arbitrage entre les bénéfices et les coûts associés à la centralisation de la prise de décision. Parmi les bénéfices, on retrouve une meilleure coordination des informations des membres de l'organisation; parmi les coûts, on retrouve les inefficacités reliées aux difficultés d'engagement et à la renégociation. L'analyse démontre qu'une décentralisation complète est toujours faiblement dominée par une structure plus centralisée. Finalement, la prise de décision doit être conférée aux agents ayant l'information la plus cruciale pour la performance de l'organisation.

Mots-clés : Information asymétrique, renégociation de contrats, structure organisationnelle, décentralisation

Key Words: Asymmetric information, contract renegotiation, organizational form, decentralization

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1 Introduction

It is an ongoing preoccupation of business managers to find the optimal decision-making structure for their firm. For example, suppose a new project comes up in a firm. The first important decision that must be made regarding the management of this project is how to design the relations between the firm and the manager of this new project. One aspect of this important decision is how much authority should be given to the project's manager as opposed to the firm's owners or managers, namely, should decision-making for this project be centralized to the firm's top decision-makers, or should it be decentralized to the manager of the relevant project.

Milgrom and Roberts (1992) provide some examples in which the internal organization of the firm has played a central role in achieving success and high profitability. One striking example is that of General Motors. The internal reorganization of General Motors undertaken by Alfred Sloane in the early 1920s was motivated by a much needed change in its marketing strategy which in turn had to be implemented by a modification of its decision-making structure. Of concern was the feeling that some decisions had to be decentralized to the different divisions of the company, but at the same time, some coordination of decisions had to be maintained to ensure that the different divisions would not compete against each other. This reorganization was critical to the fact that within the next twenty years General Motors became the clear leader of the industry surpassing Ford and its highly centralized organization. Milgrom and Roberts also give the example of the early rivalry between the North West company and the Hudson's Bay company to capture the North American market for animal furs. Again, in this example, organizational design was a clear determinant of the success or failure of these rivals.

Although the problem of organizational design is central to business managers, economists still do not understand all facets of the problem. With a complete set of contingent markets and no market imperfections, the First Theorem of Welfare states that the Walrasian equilibrium is Pareto optimal. Organizational design then plays no role. For organizational design to matter there must be some sort of market incompleteness. The presence of asymmetric information is one factor of such incompleteness because there cannot exist markets contingent on the private information detained by one or a group of agents. An organization can then arise as a substitute to some missing markets by allowing agents to write possibly complex contingent contracts that replicate partially (subject to private information) the

missing markets. Private information would then be a sufficient condition for the emergence of firms.

Even if one admits that asymmetric information is a sufficient condition for the existence of organizations, economists do not know much about how such organizations should be internally structured, namely, should decision making be centralized or decentralized. In fact, the Revelation Principle (Myerson, 1979) states that any allocation attained by a complex decentralized organization can always be replicated by a simple centralized organization in which all agents report (truthfully) their private information to some central authority which then recommends, based on these reports, actions to be undertaken by the agents. This principle states that centralization is always (weakly) preferred to decentralization. This seems to be at odds with casual empirical observation. In most organizations, be they public or private, players seem to recognize the benefits of decentralization of decision making. It is therefore a challenge for economists to understand rigorously the relative benefits and costs of decentralization.

An important aspect of the Revelation Principle is that it holds in environments in which the players involved in the organization are committed not to renegotiate the initial contract once their private information has been reported. A centralized organization is based on an extensive communication network between the agents that allows the optimal decision to be the result of a complete coordination of the available information. Such centralized organization may not be feasible if agents can renegotiate the initial contract following communication of their private information (see Holmström and Myerson (1983) for a discussion of this basic point).

The approach taken in this paper is to suppose that organizations act as substitute for incomplete markets because of the presence of asymmetric information. Within the organization I assume the players cannot commit not to renegotiate past agreements every time communication occurs. This assumption effectively invalidates the application of the Revelation Principle. For example, a contract signed between two players in the presence of asymmetric information may trade off between the efficiency of the allocation and the costs of providing the players with incentives for revealing their private information. This trade-off generally involves incorporating in the contract some distortions (ex post inefficiencies) to elicit the players to reveal their private information. The problem is that, in general, these distortions are time-inconsistent, that is, once the players have reported their private information there is no reason to maintain allocative distortions. Thus, if players are not

committed not to renegotiate the contract they will effectively renegotiate it. In this context, the Revelation Principle generally does not hold.

These observations have lead economists to study "renegotiation-proof" contracts in environments where agents have commitment problems. There is a fairly abundant literature on renegotiation now (for example, Fudenberg and Tirole, 1990, Laffont and Tirole, 1990, Dewatripont, 1988 and 1989, Hart and Tirole, 1988, Beaudry and Poitevin, 1993 and 1994, Maskin and Tirole, 1992, all study the effect of renegotiation on contracts with asymmetric information). Renegotiation arises because agents have an opportunity to communicate after the contract has been signed. Since renegotiation generally reduces their ex ante welfare, players of the organization may seek ways to commit not to renegotiate. Organizational design defines the communication channels that will govern the relationships between the agents. It is therefore natural to think that an organization will be designed to prevent harmful renegotiation. The organizational design then becomes a credible commitment towards the prevention of renegotiation.

Consider the following simple example. Two players form an organization. Player 1 is the principal and player 2, the agent. Suppose the two players sign a contract (setup the organization) at date 0. At date 1, the agent receives some private information that is payoff relevant to the two players. For example, the agent may be the production manager who learns about a new technology. The state of technology affects the agent's utility cost of effort as well as the principal's monetary profit from production. Production occurs at date 2 after which payoffs for the two players are realized. It turns out that, even in this fairly simple setting, organizational design can have a significant impact on the efficiency of the organization.

Consider a centralized organization. In this case, the contract linking the two players specifies that the agent must (verifiably) report to the principal his private information (the state of the technology) following date 1. The principal then orders a production level to the agent and pays him the associated compensating wage as specified in the contract. The contract is then a whole menu of production–wage pairs that are contingent on the agent's report. The equilibrium contract is incentive compatible and induces the agent in revealing his private information. Such a contract is associated with a centralized organization because the principal centralizes information from the agent, and then gives production orders.

A centralized organization is quite vulnerable to renegotiation. The governance of a cen-

tralized organization is based on a contract which requires the agent to send a verifiable message to the principal on which production and transfer payments depend. Communication, in the form of a verifiable message sent by the agent, modifies the set of alternatives that the two players can renegotiate, that is, once the agent has sent his verifiable message, the contract specifies which production–wage pair should be chosen among all those specified in the menu of the contract. The two players then have a fairly precise idea of the payoff they will earn if they do not renegotiate the contract. Consequently, if renegotiation occurs following the verifiable message it may be quite easy for the two players to agree to some new contract that improves on the chosen production–wage pair, and this even if such renegotiation potentially arises under asymmetric information. In this case, renegotiation may undo some of the incentives built in the contract, thus reducing the ex ante efficiency of the organization.

Consider now a decentralized organization. The contract governing a decentralized organization is a mapping from production levels to transfer payments. It requires the agent to produce at a level of his choice, and his remuneration is then contingent on the chosen production level as specified by the contracted mapping. No verifiable communication between the principal and the agent is necessary in a decentralized organization. The equilibrium contracted mapping between production and wage is designed such that the agent's production choice reveals his private information (the state of the technology). Such a contract is associated with a decentralized organization because it effectively decentralizes the production decision to the agent without any communication between the principal and the agent.

A decentralized organization is not as vulnerable to renegotiation as is a centralized one. Communication may still occur in a decentralized organization, but it is not verifiable as the contract specifies that the wage depends on the production level, not on the content of communication between the two players. This difference in the type of communication under the two structures has a significant impact on the success or failure of renegotiation. In a decentralized organization, communication does not change the beliefs of the principal with regards to the agent's private information, and more importantly it does not change the set of alternatives that can occur if renegotiation is rejected. It is therefore almost impossible for the two players to agree on a Pareto improving contract, and renegotiation cannot be successful. Furthermore, renegotiation cannot succeed once the agent has produced since then only the wage needs to be paid, and the players cannot agree on whether to reduce it

or increase it. In a decentralized organization, renegotiation has very little effects on its ex ante efficiency and this type of organization therefore dominates a centralized organization.

The assumption that players cannot commit not to renegotiate ex post has important consequences for our understanding of internal organizational design. If full commitment is possible, the two types of organizations are equivalent in many cases (see Melumad and Reichelstein, 1987, for a characterization of these cases); however, when full commitment is not possible, organizational design may be an optimal response to commit not to renegotiate. A decentralized organization limits the scope for ex post opportunism by limiting verifiable communication, and therefore is optimal ex ante. A centralized organization cannot achieve such commitment, and is thus vulnerable to renegotiation. Ex ante players should choose a decentralized organizational form.

The simple setting of one-sided private information leads to an interesting result linking the efficiency of an organization to the extent of decentralization it supports. This result, however, may not be robust to the presence of bilateral private information. Suppose both the principal and the agent possess some private information. For example, the principal may have some information about demand, while the agent knows better the state of technology. Optimal coordination requires that the production decision be based on the two players' information. The organizational form must be setup to coordinate the private information of the two players, while at the same time avoid costly (in terms of renegotiation) communication channels. There is a trade-off here between coordination and limited communication. The optimal organizational design is then represented by a contract which achieves optimally this trade-off.

With bilateral private information many different contracts are possible. A completely *centralized* organization is governed by a contract that specifies a menu (matrix) of production–wage pairs contingent on the verifiable reports of the two players. After learning their private information, both players report it, and the executed production–wage pair depends on these reports. Such organization allows full communication, and hence maximal coordination of the available information; however, it also allows for strong renegotiation possibilities since full communication reduces the set of implementable alternatives if renegotiation is rejected. It is then easy for the two players to agree to some Pareto improving contract.

A completely *decentralized* organization is governed by a contract that specifies a mapping from production levels into wages. After learning his private information the agent decides

on a production level based on the contracted mapping between output and wage. No communication occurs in such an organization, and therefore coordination is minimal. The agent makes his production decision based on his own information but not on that of the principal. A completely decentralized organization eliminates communication, and hence reduces the problem of renegotiation at the expense, however, of minimal coordination of information. The efficiency of the organization is then reduced because the production decision is based on very limited information.

With one-sided private information, only these two types of organization exist, that is, those with full communication (centralized) and those with no communication (decentralized); however, with bilateral private information, there exist hybrid types with partial communication. One player may communicate its information to the other player who then makes the production decision based on this report and its own private information. I call these hybrid organizations *hierarchical* organizations. They are governed by a contract which specifies a menu of different mappings of production levels into wages where the specific choice of a mapping is contingent on one player's report of its private information. For example, suppose the principal must report her private information to the agent who then makes the production decision. The principal's report determines the choice of the production–wage mapping that, in turn, conditions the agent's choice of production. Partial communication occurs, namely, one player communicates its information. This leaves some scope for renegotiation, but not as much as in a centralized organization since, following one-way communication, the set of implementable alternatives is still fairly large (a whole production–wage mapping). It may then be hard for the players to agree on what constitutes a Pareto improving allocation. A hierarchical organization allows some coordination through partial communication, but it also opens the door to some renegotiation which affects its ex ante efficiency.

With bilateral private information, three types of organization emerge. Centralized organizations are characterized by full communication and coordination of the information, but also by a high potential for successful renegotiation. Decentralized organizations are characterized by no communication and coordination of information, but also no potential for renegotiation. Hierarchical organizations are in middle grounds: some coordination is achieved at the expense of some renegotiation.

The first objective of this paper is to characterize implemented allocations for all three types of organization forms. The second objective is to compare these allocations to study

the determinants of decentralization in an organization, and those of the flow of information inside the organization.

There is a recent literature that studies the determinants of organizational form. Laffont and Martimort (1994) show how organizational form becomes a credible commitment against collusion. In a model with two regulators they show that separation of powers between these two regulators reduces their potential for discretionary behaviour. The separation of powers limits the information each regulator can extract from the firm, which is shown to limit collusive behaviour. This literature on collusion (see the citations in Laffont and Martimort) focuses on collusive behaviour to invalidate the Revelation Principle and to explain decentralization. It shall be seen as complementary to this paper which focuses on commitment problems.

The basic idea that organizational form can resolve commitment problems has been proposed by Milgrom (1988) in a model of moral hazard. Milgrom shows that decentralization of certain decisions to players that care about them may be an optimal response against the presence of wasteful influence activities. These activities reflect the presence of ex post opportunism, and therefore Milgrom's work is related to this paper.

Melumad, Mookherjee, and Reichelstein (1990, 1991) compare the relative efficiency of different hierarchical structures when communication costs are exogenously imposed. For example, they show that decision-making should be decentralized to a better informed agent if that agent cannot communicate all of his information to the principal. In this paper, I endogenize or make precise what is the nature of these communication costs when commitment is an organizational problem.

The next section describes the economic environment. Section 3 presents the analysis for the one-sided private-information case. Section 4 provides a characterization of the implemented allocations for the different organization forms in the bilateral private-information case. Section 5 compares the different types of organizations. A conclusion follows.

2 The model

Two players form an organization to produce two actions a_1 and a_2. Player i has control over action a_i. I denote by $a = (a_1, a_2)$ the vector of action-pairs. I assume that $a \in \mathcal{A}$ where $\mathcal{A}$ is a compact set. The environment in which the organization evolves is stochastic. The

variables θ_1 and θ_2 parameterize the uncertainty. Each realization of the variable θ_i is drawn from a finite set $\Theta_i = \left\{\theta_i^L, \ldots, \theta_i^H\right\}$. The probability of θ_1^x is $\pi_x > 0$, and the probability of θ_2^y is $p_y > 0$.

Player 1, the principal, has state-contingent preferences over an action-pair a defined by $U(\theta_1, \theta_2, a)$. The function U is monotonic, continuously differentiable, and concave in a for all θ_1 and θ_2. Player 2, called the agent, has state-contingent preferences over an action-pair a defined by $V(\theta_2, a)$. The function V is monotonic, continuously differentiable, and concave in a for all θ_2. Note that the agent's preferences do not depend on θ_1. Even though this facilitates the derivation of the results, it is also economically relevant in many different circumstances. Finally, I assume that the principal and the agent have opposite preferences over a_1 and a_2, that is, $\text{sign}U_{a_i} = \text{sign}{-}V_{a_i}$ for $i = 1, 2$. The principal and the agent have reservation utility of $\bar{u}$ and $\bar{v}$ respectively. These assumptions assure that the contractual problem is well behaved.

An allocation is a matrix of action-pairs where each entry is associated with a possible realization of the states of nature. Denote an allocation by $\mu = \{a^{xy}\}_{x,y=L}^{x,y=H}$, where a^{xy} is the executed action-pair in states θ_1^x and θ_2^y.

Consider the following example. Suppose the agent is in charge of production, and the principal is the residual claimant. The variable θ_2 represents the productivity of the technology used to produce the units of output, and θ_1, the level of demand. The action a_2 represents the amount of units produced, while a_1 is a transfer from the principal to the agent (the agent's wage). The agent's preferences are $V(\theta_2, a) = v(a_1) - e(a_2, \theta_2)$ where $e(a_2, \theta_2)$ represents the agent's personal cost of producing a_2 units with the technology θ_2. The principal's preferences are $U(\theta_1, \theta_2, a) = P(\theta_1)a_2 - c(a_2, \theta_2) - a_1$ where $P(\theta_1)$ represents the price at which the units are sold, and $c(a_2, \theta_2)$, the financial cost of producing a_2 units with technology θ_2. With an appropriate choice of the functions v, e, P, and c, this example would satisfy all above assumptions. Although this is a good example of the type of situations I would like to model, I will still stick with the more general formulation.

The basic structure of the economic environment is the following. Before the states of nature are revealed the two players get together and agree to some organizational form. An organization is a commitment to some form of communication between the two players. Once the organization is in place, nature chooses states θ_1 and θ_2. Some communication

occurs, thus inducing the execution of an action-pair a. Finally, payoffs are realized.[1]

The organizational form is implemented by a contract that the two players sign before the states of nature are realized. The form of the contract dictates the communication channels through which players coordinate on an action-pair, and thus the allocation that is implemented. This allocation depends on the type of contract that can be written and on the process by which the contract is chosen and carried out. A contract has the following general structure.

Definition 1 *A contract c (or mechanism) is defined by*

1. *A menu of actions $m(c) = \{a^{n_1,n_2}\}_{n_1,n_2=1}^{N_1,N_2}$ where $a^{n_1,n_2} \in \mathcal{A}$ for all n_1, n_2;*
2. *A communication structure through which the two players coordinate on an element of the menu.*

A contract is therefore a game form to be played by the two players. The game form has some important features. First, it allows for mechanisms other than direct revelation mechanisms since it is precisely the nature of the communication channels that is under investigation here. Second, the coordination on a given action-pair is achieved through the communication stage. The form of communication is derived endogenously and typically depends on the informational environment as well as on the commitment possibilities. Third, attention is restricted to contracts that only specify choices over deterministic outcomes. Finally, I assume that the contract is enforceable.

The purpose of the paper is first to characterize the constraints that renegotiation imposes on implemented allocations and how different contractual arrangements can alter these constraints; and second, to characterize the contracts (or organizational forms) that will emerge in different informational environments.

The approach is to first construct a finite (renegotiation) game in which the players have already signed a (status quo) contract. The players then observe their private information; communicate; possibly renegotiate; and finally execute the agreed-upon action-pair. This

[1] This framework is one of hidden information as the two players contract before the states of nature are realized.

game is used to derive conditions for an allocation to be robust to the possibility of renegotiation. Such allocations are supported by a status quo contract that is not renegotiated in the renegotiation subgame.[2]

The second step is to compare the welfare of the two players under different organizational forms. For each organizational forms, there are typically many allocations that are robust to renegotiation. I therefore focus on the (constrained) efficient allocation that maximizes the ex ante expected utility of the principal subject to a participation constraint for the agent, and to conditions for it to be renegotiation-proof. The comparison is then made on the basis of these allocations.[3]

Before proceeding with the analysis with private information, I will characterize the optimal allocation under symmetric information. Suppose first that the states of nature become common knowledge and verifiable after they are revealed. Consider the following game.

1. The principal offers a contract c_0.
2. The agent can accept or reject it. If he rejects it, the game ends, and both players receive their reservation utility.
3. In the third stage (if reached), the players publicly observe the states θ_1 and θ_2.
4. Both players choose their actions as prescribed by the element of the menu $m(c_0)$ corresponding to the observed states.

This game has a simple structure and the communication channels are trivial. The contract specifies a menu of action-pairs to be selected contingently on the realization of the states of nature. The players publicly observe the realized states of nature, and simply execute the action-pair from the contracted menu corresponding to the realized states.

[2] This same approach has been used by Maskin and Tirole (1992).

[3] One reason why the renegotiation game is not extended to include an initial contract proposal stage that would endogenize the status quo contract is that an equilibrium renegotiation-proof allocation may fail to exist in such a game; however, this nonexistence result is only caused by the fact that the game is finite. In a finite game players can use the last stage of the game to commit to distortions which would be renegotiated away had the game one more renegotiation stage. The last stage may then allow players to implement the optimal full-commitment allocation. This approach is not satisfactory and is therefore discarded in favor of the one above.

For this game, the principal's strategy is to make a contract offer at the initial stage. The agent's strategy is to accept or reject any offer the principal may make. Throughout the paper, the equilibrium concept used is that of Perfect Bayesian Equilibrium (PBE) as defined in Fudenberg and Tirole (1991).

It is easy to show that any equilibrium allocation μ^{si} is a solution to the following maximization problem.[4]

$$\begin{array}{rl} \max_{\{a^{xy}\}} & \sum_x \pi_x \sum_y p_y U(\theta_1^x, \theta_2^y, a^{xy}) \\ \text{s.t.} & \sum_x \pi_x \sum_y p_y V(\theta_2^y, a^{xy}) \geq \bar{v} \end{array} \tag{1}$$

The equilibrium strategies are the following: the principal offers the contract c^{si} with associated menu $m(c^{si}) = \mu^{si}$; the agent accepts all contracts yielding an expected utility of at least $\bar{v}$.

The equilibrium allocation specifies an action-pair for each possible realization of θ_1 and θ_2. The contract helps players coordinate on an action-pair as well as providing them with some risk sharing. The organizational form is quite simple in this framework. The states of nature are verifiable and no communication is necessary. The players simply execute the action-pair corresponding to the realized states.

The equilibrium allocation is ex ante as well as ex post efficient. Ex post efficiency arises because the two players agree on which action-pair to execute following the realization of the states of nature. There is therefore no room for successful renegotiation. Such unanimity over which action-pair should be executed may be lost if the states of nature were privately observed. In the next section we study the case in which θ_1 is single-valued and the realization of θ_2 is observed privately by the agent. Section 4 looks at the bilateral private-information case in which player i privately observes the realization of θ_i.

3 The one-sided private-information case

This section provides results for the one-sided private information case which carries some intuition about the effect of renegotiation (or non-commitment) on optimal organization design. Suppose that θ_1 is single-valued and $\theta_2 \in \Theta_2$.

[4]Note that it is implicit in this formulation that the two players must stay in the organization following the realization of the states of nature. This is a reasonable assumption when studying ongoing organizations.

Organizational forms differ in the way players can communicate. Communication channels affect the incentives to reveal private information, and also the possibility for renegotiation at different stages. Two means of communication are considered. First, the players can communicate *verbally* and verifiably. The contract specifies that, once the agent has observed θ_2, he must report to the principal his private information. This report is verifiable and it conditions which element of the contracted menu is to be implemented by the principal. Second, the agent can communicate *physically.* In this case the contract specifies that the agent executes a specific action level a_2 among all those specified by the different elements of the contracted menu. The principal then undertakes her own action a_1 based on the action selected by the agent and the contracted menu. Although these two types of communication appear quite similar in the way they coordinate the two players, they have quite different implications for the possibility of renegotiation. With verbal and verifiable communication, there may be some scope for renegotiation after the agent's report; however, with physical communication, the scope for renegotiation is greatly reduced given that the action a_2 has already been executed.

I now present the characterization of the renegotiation-proof allocations under these alternative communication structures when the two players cannot commit not to renegotiate; however, before proceeding, I characterize equilibrium allocations when there is full commitment. The two players then play the following commitment game.

1. The principal proposes a contract c_0 to the agent.
2. The agent accepts or rejects the contract offer. If it is rejected, the game ends and both players receive their reservation utility.
3. In the third stage (if reached), the agent observes the state θ_2.
4. The agent selects an element $s_0 \in m(c_0)$.
5. Both players execute their action as prescribed by the element s_0.

For this game, the principal's strategy is to offer a contract in stage 1. The agent's strategy is to accept or reject the principal's contract offer, and to select an element of the contracted menu contingently on the observed state of nature.

Proposition 1 *An allocation μ_1^{fc} is an equilibrium allocation of the commitment game if and only if it is a solution to the following maximization problem.*

$$\begin{array}{rl} \max_{\{a^y\}} & \sum_y p_y U(\theta_1, \theta_2^y, a^y) \\ s.t.\ (i) & \sum_y p_y V(\theta_2^y, a^y) \geq \bar{v} \\ (ii) & V(\theta_2^y, a^y) \geq V(\theta_2^y, a^{y'}) \quad \forall\, y, y' \end{array} \tag{2}$$

The proof of this proposition is presented in Beaudry and Poitevin (forthcoming), and is therefore omitted. The equilibrium allocation μ_1^{fc} yields the highest expected utility to the principal subject to the agent's participation and incentive-compatibility constraints. Incentive constraints ensure that the agent selects the appropriate element in the contracted menu.

The allocation μ_1^{fc} is supported by the following strategies. The principal offers a contract c_1^{fc} with $m\left(c_1^{fc}\right) = \mu_1^{fc}$. The agent accepts all contracts whose incentive-compatible menu yields at least expected utility of $\bar{v}$; he selects his most preferred element in the menu of the accepted contract contingent on his private information θ_2.

The presence of incentive constraints generally introduces ex post distortions in the equilibrium allocation. With full commitment, these distortions can be sustained in equilibrium since no renegotiation is allowed; however, if the players cannot commit not to renegotiate, they may try to use renegotiation to eliminate such distortions. Renegotiation can occur at two instances. First, players can renegotiate after the agent has learned his private information, but before he selects an element of the menu. This is referred to as interim renegotiation. Second, renegotiation can occur after the agent has selected an element of the menu. This is ex post renegotiation. Beaudry and Poitevin (forthcoming) show that interim renegotiation has no effect on the set of equilibrium allocations attainable under full commitment.[5] I therefore do not consider this type of renegotiation and only focus on ex post renegotiation.

Ex post renegotiation is introduced by allowing one renegotiation round after the agent has communicated his private information to the principal. Consider the following renegotiation game in which players start out with an arbitrary status quo contract c_0.[6]

1. The agent observes the state of nature θ_2.

[5] This result is reminiscent of the "Groucho Marx" theorem proved in Milgrom and Stokey (1982).

[6] In this game, only the principal is allowed to make renegotiation offers. This is meant as a simplifying feature which has no bearing on the qualitative results.

2. The agent selects an element $s_0 \in m(c_0)$.

2.1 The principal can offer a new contract c_1 to the agent.

2.2 The agent can then accept or reject this new offer.

2.3 If it is accepted, the agent selects an element $s_1 \in m(c_1)$.

3. Both players execute their action as prescribed by the element s of the outstanding contract c.

For this game, a strategy for the principal consists in offering a renegotiation in stage 2.1 for every element $s_0 \in m(c_0)$ that the agent may have selected. The agent must communicate with the principal for every possible states of nature he might have observed by selecting an element in the menu of the status quo contract c_0; accept or reject the renegotiation offer after any history so far; and if he accepts the renegotiation c_1, he must communicate again with the principal by selecting an element in the menu of the accepted contract c_1.

The approach used here is to characterize those allocations that are supported by a status quo contract which is not renegotiated along the equilibrium path even though it is possible to do so. Allocations satisfying this property are called renegotiation-proof. I now define more formally renegotiation-proof allocations for the renegotiation game.

Definition 2 *A renegotiation-proof allocation for the renegotiation game is an equilibrium allocation of the renegotiation game which is supported by a status quo contract that is not renegotiated in stage 2.1 along the equilibrium path.*

The characterization of renegotiation-proof allocations depends on whether communication from the agent to the principal is verbal or physical. Suppose the organizational form is such that all communication is verbal. The agent selects (verifiably) an element of the menu $m(c_0)$. This may communicate some information to the principal who may then try to renegotiate the contract. The following proposition provides a characterization of renegotiation-proof allocations when communication is verbal.[7]

[7] This proposition corresponds to Beaudry and Poitevin's (forthcoming) Proposition 5 and is therefore stated without proof.

Proposition 2 *Suppose communication is verbal. An allocation is renegotiation-proof if and only if it satisfies the following conditions.*

(i) $V(\theta_2^y, a^y) \geq V(\theta_2^y, a^{y'}) \quad \forall\, y, y'$

(ii) *For all* y', $\sum_{y \in \mathcal{Y}(a^{y'})} p^y U(\theta_1, \theta_2^y, a^y) \geq$

$$\left\{ \max_{\{\alpha^y\}_{y \in \mathcal{Y}(a^{y'})}} \sum_{y \in \mathcal{Y}(a^{y'})} p^y U(\theta_1, \theta_2^y, \alpha^y) \ s.t. \begin{array}{l} V(\theta_2^z, \alpha^z) \geq V(\theta_2^z, a^z) \,\forall\, z \in \mathcal{Y}\left(a^{y'}\right) \\ V(\theta_2^z, \alpha^z) \geq V(\theta_2^z, \alpha^{z'}) \,\forall\, z, z' \in \mathcal{Y}\left(a^{y'}\right) \end{array} \right\}$$

where $\mathcal{Y}(a^{y'}) = \left\{ y \text{ such that } \theta_2^y \in \Theta_2 \text{ and } a^y = a^{y'} \right\}$.

This proposition provides a characterization of renegotiation-proof allocations when communication is verbal. These allocations must satisfy standard incentive-compatibility constraints and a set of constraints imposed by the requirement of renegotiation-proofness. The conditions (ii) state that the equilibrium allocation must be such that, conditional on her updated information following the agent's selection in the menu $m(c_0)$, the principal cannot find it profitable to offer a new incentive-compatible contract to the agent. For example, if the equilibrium allocation is separating, the set $\mathcal{Y}(a^{y'})$ is a singleton, and therefore these constraints impose ex post efficiency.

Suppose now that communication is physical. The players then play the renegotiation game described above. The only difference with verbal communication is that the contract specifies that the action a_1 taken by the principal depends on the action a_2 chosen by the agent and the menu $m(c_0)$, and not on the agent's report. The agent therefore selects in stage 2 an element in $m(c_0)$ by executing its associated action a_2 in the set of those specified in the menu. This implies that the principal's renegotiation offer consists of a contract for which every element of its associated menu includes the action a_2 chosen by the agent. This effectively corresponds to the principal renegotiating only over action a_1. The following proposition characterizes the renegotiation-proof allocations.[8]

Proposition 3 *Suppose communication is physical. An allocation is renegotiation-proof if and only if it satisfies the following conditions.*

$$(i) \quad V(\theta_2^y, a^y) \geq V(\theta_2^y, a^{y'}) \quad \forall\, y, y'$$

With physical communication, renegotiation-proofness does not impose any additional constraints on allocations beyond incentive-compatibility.

[8] All proofs are relegated to the Appendix.

We now compare the two means of communication. Many allocations may satisfy the renegotiation-proofness criterion. The comparison is then established on the basis of the renegotiation-proof allocations that maximize the ex ante expected utility of the principal subject to a participation constraint for the agent that his expected utility is at least $\bar{v}$. This analysis yields the following results. First, the comparison of the constraints in problem (2) and Proposition 2 indicates that, in general, verbal communication and renegotiation reduces the set of attainable equilibrium allocations. For example, any separating renegotiation-proof allocation must be ex post efficient while this may not be the case for a separating allocation solving problem (2).

Second, the comparison of the constraints in problem (2) and Proposition 3 shows that physical communication does not reduce the set of allocations attainable under full commitment. Physical communication is a strong commitment to an action level which removes all scope for renegotiation. Once the action a_2 is physically communicated to the principal (executed), she can only renegotiate over the action a_1. Such renegotiation is never successful since the two players have opposite preferences over this action.

In the one-sided private-information case, physical communication is preferred to verbal communication since it eliminates all scope for renegotiating. This result can be given the following interpretation. Verbal communication can be associated with a centralized organization where the principal collects all information, and then makes her decision based on the reported information and the initial agreement the players have. Alternatively, physical communication can be associated with a decentralized organization in which the principal collects no information, and delegates decision-making to the informed agent. The result then implies that decentralization of decision making is a credible means of avoiding the inefficiencies associated with renegotiation in environments where players cannot commit not to renegotiate. In one-sided private-information environments, a decentralized organization is always preferred since only one player possesses private information. The organizational form then serves the only purpose of avoiding renegotiation. This is optimally achieved through decentralization.

With bilateral private information, the organizational form must not only limit the scope for renegotiation, but also coordinate the actions on the information of the two players. There is a trade-off between decentralization and centralization.

4 The bilateral private-information case

In this section, I assume that $\theta_1 \in \Theta_1$ and $\theta_2 \in \Theta_2$, where the probabilities of θ_1^x and θ_2^y are $\pi_x > 0$ and $p_y > 0$ respectively.

As before, the organizational form defines the communication channels through which the two players can coordinate. With bilateral private information, there are many possible organizational forms. Three classes are considered. In the first class, all communication is verbal. The two players report their private information simultaneously. Based on these reports, the contract prescribes an action-pair to be undertaken. In the second class, one player first communicates its information verbally, the second then communicates its information physically, and finally the first player executes its action based on the communicated information. I will consider in turn the two cases in which the principal or the agent first communicates verbally. In the third class, the two players communicate their information sequentially and physically. The two cases in which the principal or the agent communicates first are considered in turn.[9]

Renegotiation can have very different effects on the set of equilibrium allocations depending on the type of communication allowed by the organizational form. Before proceeding with the analysis, I will present the benchmark case in which there is complete verbal communication and full commitment. The commitment game of the preceding section is slightly modified to take into account bilateral private information.

1. The principal proposes a contract c_0 to the agent.

2. The agent accepts or rejects the contract offer. If it is rejected, the game ends and both players receive their reservation utility.

3. In the third stage (if reached), the principal observes the state θ_1, and the agent observes the state θ_2.

4. The principal selects a row $r_0 \in m(c_0)$, and the agent selects a column $n_0 \in m(c_0)$.

[9] These three classes exhaust all interesting organizational forms. Or, players communicate simultaneously, or they do it sequentially. In the latter case, the second stage of communication is always physical to avoid renegotiation (see Section 3). The first stage may be verbal or physical, corresponding respectively to the second and third classes. In the former case, simultaneous communication must be verbal. It is easy to show that simultaneous physical communication is (weakly) dominated by sequential physical communication.

5. Both players execute their action as prescribed by the intersection of the row r_0 and the column n_0.

For this commitment game, the principal's strategy is to offer a contract in stage 1; and to select a row of the menu of the accepted contract contingently on the state θ_1. The agent's strategy is to accept or reject the principal's offer; and to select a column of the menu of the accepted contract contingently on the state θ_2.

There are some differences between the one-sided private-information case and the bilateral-information case. First, in the latter, a menu is a matrix that associates an action-pair with each possible combination of realizations of θ_1 and θ_2. Therefore, by reporting its state of nature a player selects a row (the principal) or a column (the agent) of the matrix. The executed action-pair is that at the intersection of the selected row and column. Second, I assume that the two players report their information simultaneously. It can be shown that simultaneous reports (weakly) dominate sequential reports since, in the former case, each player's incentive constraints only have to hold in expectation over the other player's types, while in the latter case, for one player they have to hold for every type of the other player.

Proposition 4 *An allocation μ_2^{fc} is an equilibrium allocation of the commitment game if it is a solution to the following maximization problem.*

$$\begin{array}{rl} \max_{\{a^{xy}\}} & \sum_x \pi_x \sum_y p_y U(\theta_1^x, \theta_2^y, a^{xy}) \\ s.t.\ (i) & \sum_x \pi_x \sum_y p_y V(\theta_2^y, a^{xy}) \geq \bar{v} \\ (ii) & \sum_x \pi_x V(\theta_2^y, a^{xy}) \geq \sum_x \pi_x V(\theta_2^y, a^{xy'}) \quad \forall\, y, y' \\ (iii) & \sum_y p_y U(\theta_1^x, \theta_2^y, a^{xy}) \geq \sum_y p_y U(\theta_1^x, \theta_2^y, a^{x'y}) \quad \forall\, x, x' \end{array} \tag{3}$$

An equilibrium allocation μ_2^{fc} of the full-commitment game with bilateral private information yields the highest expected utility to the principal subject to the agent's participation constraint and the two players' incentive-compatibility constraints. Note that these constraints are in expected terms over the other player's state since both players communicate simultaneously. The proof of this proposition is trivial and is therefore omitted.[10]

[10] The reason why an equilibrium allocation of the commitment game is not necessarily a solution to problem (3) is that there may be multiple equilibrium reporting strategies for the two players at stage 4. For example, truth-telling can be part of an equilibrium if the allocation is incentive compatible. Each player tells the truth expecting the other to do so. However, lying may also be part of an equilibrium, that is, each may have an incentive to lie if the other player is also expected to lie. This multiplicity can then be used to support allocations that are not solution to problem (3).

An allocation μ_2^{fc} is supported by the following strategies and beliefs. The principal offers a contract c_2^{fc} with $m\left(c_2^{fc}\right) = \mu_2^{fc}$; and she selects her preferred row in the menu of the accepted contract contingent on her private information θ_1, her prior beliefs about θ_2, and her expectation that the agent reports truthfully. The agent accepts all contracts whose associated incentive-compatible menu yields at least expected utility of $\bar{v}$; and he selects his most preferred column in the menu of the accepted contract contingent on his private information θ_2, his prior beliefs about θ_1, and his expectation that the principal reports truthfully.

As with one-sided private information, the presence of incentive-compatibility constraints usually prevents the players from achieving optimal allocative efficiency and risk sharing. With full commitment not to renegotiate the contract, such distortions can be sustained in equilibrium; however, if players cannot commit not to renegotiate, they have incentives to eliminate such distortions once they learn their private information. Again renegotiation can occur after the information has been learned, but before players communicate, or it can occur after the players have communicated. Renegotiation after communication has occurred is unlikely to have any effect on allocations as in the one-sided private-information case for reasons cited therein. I therefore focus on renegotiation following communication.

The following subsections characterize the set of renegotiation-proof allocations for different communication structures or organizational forms. In each case, a renegotiation game is defined. For a given renegotiation game , , the following statement defines the set of renegotiation-proof allocations.

Definition 3 *A renegotiation-proof allocation for the , game is an equilibrium allocation of the , game which is supported by a status quo contract that is not renegotiated in stage 2.1 along the equilibrium path.*

This general definition is used throughout the analysis. Note that I delay the comparison of the different organizational structures to Section 5.

4.1 Centralized organization

I first examine the case in which the two players communicate simultaneously their information verbally, and cannot commit not to renegotiate the initial contract. All information is

centralized, and actions are dictated by the contract on the basis of the reported information. Such organizational form can be associated with a centralized structure.

For any outstanding contract c_0, the players play the following renegotiation game, referred to as the C game (for centralized communication).

1. The principal observes the state θ_1, and the agent observes the state θ_2.

2. The principal selects a row $r_0 \in m(c_0)$, and the agent selects a column $n_0 \in m(c_0)$.

2.1 The principal can offer a new contract c_1 to the agent.

2.2 The agent can then accept or reject this new offer.

2.3 If the contract c_1 is accepted, the agent selects a column $n_1 \in m(c_1)$.

3. Both players execute their action as prescribed by the intersection of the row r and n of the outstanding contract c.

For the C game, the principal's strategy is to select a row of the menu of the status quo contract contingently on the state θ_1; and to offer a new contract c_1 to the agent contingently on the history of the game.[11] The agent's strategy is to select a column of the menu of the status quo contract contingently on the state θ_2; to accept or reject the renegotiation offer contingently on the history of the game; and to select a column in the menu of the contract c_1 (if it has been accepted) contingently on the history of the game.

The following proposition provides a characterization of renegotiation-proof allocations for the C game.

Proposition 5 *An allocation is renegotiation-proof for the C game if and only if it satisfies*

[11] Note that, without loss of generality, the principal can be constrained to offer a contract c_1 whose menu has only one row since the agent's preferences and the status quo outcome do not depend on θ_1.

the following constraints.

$$(i)\quad \textstyle\sum_x \pi_x V(\theta_2^y, a^{xy}) \geq \sum_x \pi_x V(\theta_2^y, a^{xy'}) \quad \forall\, y, y'$$

$$(ii)\quad \textstyle\sum_y p_y U(\theta_1^x, \theta_2^y, a^{xy}) \geq \sum_{y'} \left\{ \begin{array}{l} \max_{\{\alpha^y\}_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)}} \sum_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^x, \theta_2^y, \alpha^y) \\ \quad s.t. \\ V(\theta_2^y, \alpha^y) \geq V(\theta_2^y, a^{x'y'}) \quad \forall\, y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right) \\ V(\theta_2^z, \alpha^z) \geq V(\theta_2^z, \alpha^{z'}) \quad \forall\, z, z' \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right) \end{array} \right\} \quad \forall\, x, x'$$

$$(iii)\quad \textstyle\sum_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^x, \theta_2^y, a^{xy'}) \geq \left\{ \begin{array}{l} \max_{\{\alpha^y\}_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)}} \sum_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^x, \theta_2^y, \alpha^y) \\ \quad s.t. \\ V(\theta_2^y, \alpha^y) \geq V(\theta_2^y, a^{xy'}) \quad \forall\, y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right) \\ V(\theta_2^z, \alpha^z) \geq V(\theta_2^z, \alpha^{z'}) \quad \forall\, z, z' \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right) \end{array} \right\} \forall\, x, y'$$

where $\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right) = \left\{y \text{ such that } \theta_2^y \in \Theta_2 \text{ and } \{a^{xy}\}_x = \left\{a^{xy'}\right\}_x\right\}$.

This proposition describes conditions that must be satisfied by any renegotiation-proof allocation of the C game. Condition (i) represents the agent's incentive-compatibility constraints. The set $\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$ contains agent types for which the equilibrium allocation is $a^{xy'}$ when the principal's type is x. If the allocation is separating, this set reduces to a singleton. The third condition then states that, given that the principal and the agent have reported truthfully their private information, it is not possible for the principal to increase her expected utility (computed with her revised beliefs) by renegotiating to a surely acceptable contract by the agent, that is, an incentive-compatible contract that increases the agent's payoff regardless of his beliefs about the principal's type. For example, if the allocation is separating for a subset of types, condition (iii) implies that it must be ex post efficient in those states. Condition (ii) requires that, given the expected renegotiation possibilities by the principal after reports are in, she reports her type truthfully. The set of conditions (ii) are more stringent than standard incentive-compatibility constraints because the prospect of renegotiation may increase the desirability of reporting falsely.[12]

The constraints in Proposition 5 are generally more stringent than those in the full-commitment problem (3). Renegotiation allows the players to undo ex post some of the distortions included ex ante to induce truth-telling. The principal's incentive constraints then become more stringent since she accounts for the possibility of renegotiating when

[12]Note that condition (ii) for $x' = x$ implies condition (iii). The latter are included for expositional purposes.

evaluating different reports. The possibility of renegotiation therefore reduces the expected utility of the principal compared with the full-commitment case.

Renegotiation has some effect because the organizational form specifies a contract that remunerates the players according to the verbal (and verifiable) report they make. The loss in expected utility that the principal suffers may be partially avoided by having one of the players communicating verbally and the other physically. This is the object of the next subsection.

4.2 Hierarchical organization

To avoid (at least partially) the adverse effects of renegotiation, the organizational form can specify contracts that require one player to actually undertake its action as a means of communicating with the other player. This is referred to as physical communication in the sense that communication occurs by the very fact that one player is undertaking an observable and verifiable action. In this section, I consider the case in which one player first communicates verbally its information to the other player and then the other player, on the basis of this report and its own information, undertakes its action. Finally, the first player undertakes its action. This organizational form is a mixed structure in that some information is centralized through verbal communication, but not all information is. We can associate this organizational form with a hierarchical structure. Such an organizational form is vulnerable to renegotiation after the first player verbally reports its information. No action has yet been undertaken, and renegotiation can have some effect; however, once one of the actions has been undertaken there is no room for further renegotiation.

There are two forms of hierarchical structure. First, the principal can communicate verbally with the agent who then executes his action, followed by that of the principal. Information is flowing down the hierarchy, from the principal to the agent. Second, the agent can communicate verbally with the principal, who then executes her action followed by that of the agent. Information is flowing up the hierarchy, from the agent to the principal. I will consider these two cases in turn.

4.2.1 Verbal communication by the principal

For any status quo contract c_0, the players play the following renegotiation game referred to as the HP game (for hierarchical communication initiated by the principal).

1. The principal observes the state θ_1, and the agent observes the state θ_2.

2. The principal selects a row $r_0 \in m(c_0)$.

2.1 The principal can offer a new contract c_1 to the agent.

2.2 The agent can then accept or reject this new offer.

3.1 The agent executes his action a_2 among all those available in the menu of the outstanding contract.

3.2 The principal executes her action a_1 associated with the choice of a_2 and the menu of the outstanding contract.

For the HP game, the principal's strategy is to select a row of the menu of the status quo contract contingently on the state θ_1, and to offer a new contract c_1 to the agent contingently on the history of the game. The agent's strategy is to accept or reject the renegotiation offer contingently on the history of the game, and to execute an action a_2 in the menu of the outstanding contract.

The HP game differs from the C game in that the agent can physically communicate his information to the principal after she has communicated verbally. Renegotiation can arise after the principal has verbally communicated. At this point the players have not yet physically committed to one action-pair. Following the agent's physical communication, no renegotiation can arise since only the principal's action can be changed.

Proposition 6 *An allocation is renegotiation-proof for the HP game if and only if it satisfies the following constraints.*

$$(i) \quad \left\{ V(\theta_2^y, a^{xy}) \geq V(\theta_2^y, a^{xy'}) \quad \forall\, y, y' \right\} \quad \forall\, x$$

$$(ii) \quad \sum_y p_y U(\theta_1^x, \theta_2^y, a^{xy}) \geq \left\{ \begin{array}{ccc} \max_{\{\alpha^y\}} & \sum_y p_y U(\theta_1^x, \theta_2^y, \alpha^y) & \\ s.t. & V(\theta_2^y, \alpha^y) \geq V(\theta_2^y, a^{x'y}) & \forall\, y \\ & V(\theta_2^y, \alpha^y) \geq V(\theta_2^y, \alpha^{y'}) & \forall\, y, y' \end{array} \right\} \quad \forall\, x, x'$$

This set of conditions has to be satisfied for an allocation to be renegotiation-proof in the HP game. The first constraints are simply the agent's incentive-compatibility constraints. These constraints are conditional on the principal's information. Since the agent communicates after the principal has communicated her information. The second constraints represent the principal's incentive-compatibility constraints taking into account the possibility for renegotiation. The right-hand-side of the equation states that, from any allocation $\left\{a^{x'y}\right\}_y$, the principal can always successfully renegotiate to another allocation $\{\alpha^y\}$ that is incentive compatible for the agent (second set of constraints), and that is weakly preferred by the agent regardless of his private information and beliefs (first set of constraints). Any such offer is surely acceptable by the agent since it increases his payoffs regardless of his beliefs. Note that the renegotiated offer need not depend on θ_1 since the agent executes his action a_2 before the principal can communicate, and his preferences are independent of θ_1. Conditions (ii) then say that the principal must weakly prefer truthfully reporting her information to misreporting and renegotiating to a surely-acceptable offer. The principal's incentive constraints hold in expected terms over the agent's information since the principal reports before the agent communicates.

There are two differences between the constraints in Proposition 6 and those in the full-commitment problem (3). First, renegotiation constrains the expected utility that the principal can achieve compared with the full-commitment case. The principal takes into account the possibility of renegotiating before reporting, and this may affect the relative value of different reports. Second, the sequentiality of communication implies that the agent's incentive-compatibility constraints must hold contingently on the principal's private information.

4.2.2 Verbal communication by the agent

I now consider the case in which the agent first communicates verbally his information to the principal, and then the principal physically communicates by executing her action.

Given a status quo contract c_0, the players play the following renegotiation game referred to as the HA game (for verbal by the agent).

1. The principal observes the state θ_1, and the agent observes the state θ_2.

2. The agent selects a column $n_0 \in m(c_0)$.

2.1 The principal can offer a new contract c_1 to the agent.

2.2 The agent can then accept or reject this new offer.

3.1 The principal executes her action a_1 among all those available in the menu of the outstanding contract.

3.2 The agent executes his action a_2 associated with the choice of a_1 and the menu of the outstanding contract.

For the HA game, the principal's strategy is to offer a new contract c_1 to the agent contingently on the state θ_1 and the agent's choice of a column in the menu of the status quo contract, and to execute the action a_1 prescribed by the menu of the appropriate outstanding contract. The agent's strategy is to select a column in the menu of the initial contract contingently on his private information, and to accept or reject the renegotiation offer contingently on the history of the game.

Proposition 7 *An allocation is renegotiation-proof for the HA game if and only if it satisfies the following constraints.*

$$(i) \quad \sum_x \pi_x V(\theta_2^y, a^{xy}) \geq \sum_x \pi_x V(\theta_2^y, a^{xy'}) \quad \forall\, y, y'$$

$$(ii) \quad \sum_{y \in \mathcal{Y}(\{a^{xy'}\}_x)} p_y U(\theta_1^x, \theta_2^y, a^{xy}) \geq$$
$$\left\{ \begin{array}{ll} \max_{\{\alpha^z\}} & \sum_{y \in \mathcal{Y}(\{a^{xy'}\}_x)} p_y U(\theta_1^x, \theta_2^y, \alpha^x) \\ s.t. & V(\theta_2^y, \alpha^z) \geq V(\theta_2^y, a^{zy'}) \quad \forall\, z, \forall\, y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right) \\ & \sum_{y \in \mathcal{Y}(\{a^{xy'}\}_x)} p_y U(\theta_1^z, \theta_2^y, \alpha^z) \geq \sum_{y \in \mathcal{Y}(\{a^{xy'}\}_x)} p_y U(\theta_1^z, \theta_2^y, \alpha^{z'}) \quad \forall\, z, z' \end{array} \right\} \forall\, x, y'$$

$$(iii) \quad \left\{ \sum_{y \in \mathcal{Y}(\{a^{xy'}\}_x)} p_y U(\theta_1^x, \theta_2^y, a^{xy}) \geq \sum_{y \in \mathcal{Y}(\{a^{xy'}\}_x)} p_y U(\theta_1^x, \theta_2^y, a^{x'y}) \quad \forall\, x, x' \right\} \forall\, y'$$

where $\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right) = \left\{y \text{ such that } \theta_2^y \in \Theta_2 \text{ and } \{a^{xy}\}_x = \left\{a^{xy'}\right\}_x\right\}$.

The conditions imposed by the communication scheme here are different from those in the HP game because the two players move in reverse order and thus face different information structure before playing. The first conditions are the agent's usual incentive-compatibility constraints which hold in expected terms over the principal's information given that the agent reports before the principal communicates. The second conditions represent the principal's incentive-compatibility constraints. The principal executes her action after the agent has reported his information. The right-hand side of the inequality states that, from any

allocation $\left\{a^{xy'}\right\}_x$ the principal can always successfully renegotiate to an allocation $\{\alpha^x\}$ that is incentive compatible for the principal and weakly preferred by the agent regardless of his private information and beliefs. Note that the renegotiated offer depends on θ_1 as the agent's perception of the status quo is contingent on it. It does not, however, depend on θ_2 as the principal will select a_1 before the agent can communicate again. The conditions (ii) then say that, conditional on his revised beliefs about the agent's type, the principal must weakly prefer to truthfully report her information and not renegotiate rather than renegotiate to a surely-acceptable offer. The conditions (iii) represent standard incentive-compatibility constraints for the principal where the principal evaluates each action-pair using her revised beliefs following the agent's report. In particular, if the allocation is separating for the agent types, these constraints reduce to standard ex post incentive-compatibility constraints.

Again, a simple examination of the constraints in Proposition 7 and those of problem (3) reveals that one-sided verbal communication can be harmful and thus can reduce the ex ante expected utility of the principal compared to that in the full-commitment case.

4.3 Decentralized organization

Section 3 illustrates how physical communication becomes a means of avoiding ex post opportunism associated with renegotiation in the one-sided private-information case. I now investigate whether an organizational form in which communication is only physical and sequential can be helpful in reducing the losses associated with non-commitment and renegotiation in the bilateral private-information case. Such organization is called decentralized. It is most interesting to look at the case in which the two players take their action sequentially. The first player executes its action without any information from the other player. The second player then undertakes its own action thus coordinating somewhat on the information conveyed by the first player's choice of action. Clearly, such structure dominates a structure in which the two players would choose their respective action simultaneously, and thus would have no opportunity to communicate with each other. A decentralized organizational form is not vulnerable to renegotiation since after the first player has taken its action and is committed to it, there is no room for renegotiating over the action of the second player.[13]

There are two possible organizational forms. First, the principal can communicate phys-

[13]This is the same argument as that of Section 3.

ically by executing her action, and the agent then undertakes his action. Information is (physically) flowing down the hierarchy, from the principal to the agent. Second, the agent can communicate physically by executing his action, and the principal then undertakes her action. Information is flowing up the hierarchy, from the agent to the principal. I will consider these two cases in turn.

4.3.1 Physical communication by the principal

Given a status quo contract c_0, the players play the following renegotiation game referred to as the DP game (decentralized communication initiated by the principal).

1. The principal observes the state θ_1, and the agent observes the state θ_2.
2. The principal executes her action a_1 associated with her preferred action-pair in the menu $m(c_0)$.
3. The agent executes his action a_2 associated with the choice of a_1 and the menu $m(c_0)$.

For the DP game, the principal's strategy is to select an action a_1 contingently on the state θ_1. The agent has no strategy since the contract is assumed to be enforceable, that is, the agent has no choice but to execute the action a_2 associated with the action a_1 in the menu of the outstanding contract.

The DP game differs from the previous games in that no verbal communication is required by the contract. The two players simply execute their respective action in turn. The implemented allocation can only depend on the principal's information, and therefore the menu of its associated contract only consists of a single column. The allocation must then be incentive compatible for the principal in expected terms over the agent's type. Since renegotiation cannot arise after the principal has physically communicated, the offered contract will be renegotiation-proof. It is then clear that renegotiation-proof allocations satisfy the following conditions.

$$(i) \quad \sum_y p_y U(\theta_1^x, \theta_2^y, a^x) \geq \sum_y p_y U(\theta_1^x, \theta_2^y, a^{x'}) \quad \forall\, x, x'$$

The avoidance of renegotiation through physical communication is achieved, however, at the expense of lower coordination of the information of the two players. The equilibrium

allocation can only depend on the principal's private information and not on that of the agent. Note that the conditions for renegotiation-proofness do not conflict with the constraints in the full-commitment problem (3). Consequently, renegotiation-proof allocations are always feasible in the full-commitment problem. In general, however, the lack of coordination has some ex ante efficiency costs as players can do better if they can commit not to renegotiate.

4.3.2 Physical communication by the agent

I now consider the case in which the agent communicates physically with the principal by selecting his action first.

Given a status quo contract c_0, the players play the following renegotiation game referred to as the DA game (for decentralized communication initiated by the agent).

1. The principal observes the state θ_1, and the agent observes the state θ_2.
2. The agent executes his action a_2 associated with his preferred action-pair in the menu $m(c_0)$.
3. The principal executes his action a_1 associated with the choice of a_2 and the menu $m(c_0)$.

For the DA game, the agent's strategy is to select an action a_2 contingently on his information θ_2. For the same reasons as in the preceding section, the principal has no explicit strategy.

The implemented allocation can only depend on the agent's information since he selects his action before the principal has any opportunity to communicate. The menu of the contract consists of a single line, and must be incentive compatible for the agent in expected terms over the principal's information. Again, renegotiation cannot arise after the agent has physically communicated, and the offered contract is then renegotiation-proof. It is then clear that renegotiation-proof allocations satisfy the following conditions.

$$(i) \quad \sum_x \pi_x V(\theta_2^y, a^y) \geq \sum_x \pi_x V(\theta_2^y, a^{y'}) \quad \forall\, y, y'$$

Note that these conditions are equivalent to standard ex post incentive constraints since the allocation and the agent's preferences are independent of the principal's information. As before, renegotiation is avoided at the expense of lower coordination of the information of the two players, which has some ex ante efficiency costs.

The last two subsections characterize the decentralized organizational forms. A complete decentralization avoids the adverse effects of renegotiation but coordinates poorly the different sources of information. With one-sided private information, such coordination is not relevant, and decentralization is therefore the most preferred organizational form. With bilateral private information, coordination of information may be important. The next section compares the various organizational forms.

5 Comparisons of the different organizational forms

For each organizational form there may be many renegotiation-proof allocations. The comparison of these different organizational forms is then made on the basis of that renegotiation-proof allocation which maximizes the ex ante expected utility of the principal subject to the agent's participation constraint. For the , game, this maximizing allocation is defined as follows.

$$\begin{array}{rl} \mu^{\Gamma} = \arg\max_{\{a^{xy}\}\in RP(\Gamma)} & \sum_x \pi_x \sum_y p_y U(\theta_1^x, \theta_2^y, a^{xy}) \\ \text{s.t.} & \sum_x \pi_x \sum_y p_y V(\theta_2^y, a^{xy}) \geq \bar{v} \end{array} \tag{4}$$

where $RP(,)$ represents the set of renegotiation-proof allocations for the , game. Finally, define $\mathcal{U}^{\Gamma} := \sum_x \pi_x \sum_y p_y U(\theta_1^x, \theta_2^y, \mu_{xy}^{\Gamma})$.

Before comparing the different organizational forms, I shall mention that existence of renegotiation-proof allocations is not a problem in well-behaved environments. In general, the sets $RP(,)$ are closed; they are nonempty in single-crossing environments. In these environments, the agent's preferences satisfy the single-crossing property if $-V_{a_1}/V_{a_2}$ is monotone in θ_2. The principal's preferences satisfies the single-crossing property if $-U_{a_1}/U_{a_2}$ is monotone in θ_i for each value of θ_j. Hence, for appropriate values of $\bar{v}$ there exists a solution to (4) in these environments.

First, I study the extent of decentralization in organizations.

Consider the optimal allocation under complete decentralization to the agent (DA renegotiation game) μ^{DA}. This allocation is independent of the principal's private information θ_1. Consider now the hierarchical organization in which the principal first communicates verbally (HP renegotiation game). In that game, the principal can always refrain from communicating any information about θ_1 by offering a contract consisting of a menu with identical rows. Her verbal communication is then uninformative to the agent, and the result-

ing allocation is independent of θ_1. There are two cases. First, suppose that the allocation μ^{DA} is renegotiation-proof under the HP organizational form. In this case, it may or may not be optimal. Second, suppose that the allocation μ^{DA} is not renegotiation-proof under the HP organizational form. It is then possible to show that an allocation μ^{HP} dominates μ^{DA}. Therefore, decentralization to the agent is weakly dominated by the hierarchical organization in which the principal communicates verbally.

A similar argument shows that the optimal allocation under complete decentralization to the principal (DP renegotiation game) is weakly dominated by that of the hierarchical form in which the agent first communicates verbally (HA renegotiation game). We can therefore state the following proposition.

Proposition 8 *A decentralized organization is always weakly dominated by an appropriate hierarchical organizational form.*

The intuition behind this proposition is that if it is optimal for the principal to condition the allocation on only one player's private information, then this may be achieved equally well by a hierarchical organizational form as by a decentralized structure. If, to the contrary, it is not optimal to do so, then a hierarchical organizational form performs strictly better than a decentralized structure since it allows such conditioning on the two players' private information.

This proposition shows that complete decentralization is generally not optimal in environments in which there is bilateral private information. Some coordination, even if it induces costs associated with renegotiation, is optimal. This result shows that the solution of the one-sided private-information case is not robust to the introduction of bilateral private information. The trade-off between coordination and decentralization generally requires some coordination. Verbal communication is then an essential ingredient of an optimal organization. Such communication and coordination can be achieved by a properly designed organization in which communication channels allow information to be transmitted to the decision maker. It then remains to compare the relative efficiency of the different communication channels characterized in the previous section.

Suppose that there are only two types of principal and two types of agent, that is, $\Theta_i = \left\{\theta_i^L, \theta_i^H\right\}$ for $i = 1, 2$. The case with one-sided private information can then be parameterized by $\theta_i^H = \theta_i^L$ for $i = 1$ or 2.

When $\theta_1^H = \theta_1^L$, any communication by the principal becomes irrelevant. In this case, it is easy to show that the following relationships hold.

$$\mathcal{U}^C = \mathcal{U}^{HA} \leq \mathcal{U}^{HP}$$

In the renegotiation game HP, the (privately informed) agent communicates physically which prevents any type of renegotiation. This is therefore the most preferred organizational form. In the games C and HA, the agent communicates verbally, and thus there is scope for renegotiation. These organizational forms are therefore inferior to the one in which the agent communicates physically. Similarly, it is easy to show that the following relationships hold when only the principal has some private information ($\theta_2^H = \theta_2^L$).

$$\mathcal{U}^C = \mathcal{U}^{HP} \leq \mathcal{U}^{HA}$$

These relationships bear the same interpretation as above.

The intuition learned in the one-sided private-information case should then hold when θ_i^H is close to θ_i^L given the continuity in θ_i^H of the various maximization problems. This intuition implies that, in a hierarchy, it is always better to have the player who has low variance in its private information to send the verbal message. Information should then be flowing from the player who has the "least important" information to the other player to minimize the costs associated with renegotiation. The optimal hierarchy is characterized by some information communication, and then decentralization of decision making to the player with the "most important" private information, where the information is important if it influences significantly the action to be taken. For example, if θ_i^H is significantly different from θ_i^L, presumably that the optimal action-pair a is influenced significantly by the value of θ_i.

Another conclusion that may be drawn from this exercise is that a centralized organization is always dominated by an appropriate hierarchical organization when θ_i^H is close to θ_i^L for some i. A centralized organization should then arise when all dimensions of private information are important to the efficiency of the organization.

6 Conclusion

This paper offers a framework to study the trade-off between centralization and decentralization. Typically, one associates with centralization a better coordination of all relevant

information in decision-making. It is also generally thought that centralization bears some costs. This paper makes precise what the costs and the benefits of centralization are. The costs of centralization come from the renegotiation of contracted allocation, while the benefits stem from the coordination of the decision on all available information.

An optimal organization must setup formal communication channels through which information flows to the decision-maker. These channels offer the opportunity to renegotiate contracts, and such renegotiation has some ex ante efficiency costs. Organizational form then becomes a credible commitment to some communication channels that trade-off between coordination of information and its associated renegotiation costs.

Finally, this analysis suggests that it may be hard to derive a general approach to asymmetric-information problems with non-commitment. In effect, the results of this paper show that renegotiation-proof constraints depend on the details of the organizational form, and are likely to grow in complexity as the dimensions of the private information (and/or the size of the organization) increase. A "Renegotiation-Proof Revelation Principle" thus appears unreachable. The Revelation Principle is possible in a world with commitment because all organizational forms require the common property of incentive-compatibility. Such common property in renegotiation-proof environments has not been characterized yet. This explains why this paper must proceed with a case-by-case analysis.

References

[1] Beaudry, P. and M. Poitevin (1994) "The Commitment Value of Contracts under Dynamic Renegotiation," *Rand Journal of Economics* **25**, 501–517.

[2] Beaudry, P. and M. Poitevin (forthcoming) "Contract Renegotiation: A Simple Framework and Implications for Organization Theory," *Canadian Journal of Economics.*

[3] Beaudry, P. and M. Poitevin (1993) "Signalling and Renegotiation in Contractual Relationships," *Econometrica* **61**, 745–782.

[4] Dewatripont, M. (1988) "Commitment through Renegotiation-Proof Contracts with Third Parties," *Review of Economic Studies* **45**, 377–390.

[5] Dewatripont, M. (1989) "Renegotiation and Information Revelation over Time: The Case of Optimal Labor Contracts," *Quarterly Journal of Economics* **104**, 589–619.

[6] Fudenberg, D. and J. Tirole (1991) *Game Theory.* Cambridge: M.I.T. Press.

[7] Fudenberg, D. and J. Tirole (1990) "Moral Hazard and Renegotiation in Agency Contracts," *Econometrica* **58**, 1279–1319.

[8] Hart, O. and J. Tirole (1988) "Contract Renegotiation and Coasian Dynamics," *Review of Economic Studies* **55**, 509–540.

[9] Holmström, B. and R.B. Myerson (1983) "Efficient and Durable Decision Rules with Incomplete Information," *Econometrica* **51**, 1799–1819.

[10] Laffont, J.J. and D. Martimort (1994) "Separation of Regulators Against Collusive Behaviour," Mimeo, I.D.E.I.

[11] Laffont, J.J. and J. Tirole (1990) "Adverse Selection and Renegotiation in Procurement," *Review of Economic Studies* **57**, 597–625.

[12] Maskin, E. and J. Tirole (1992) "The Principal-Agent Relationship with an Informed Principal, II: Common Values," *Econometrica* **60**, 1–42.

[13] Melumad, N., D. Mookherjee, and S. Reichelstein (1990) "Hierarchical Decentralization of Incentive Contracts," Mimeo, Stanford University.

[14] Melumad, N., D. Mookherjee, and S. Reichelstein (1991) "A Theory of Responsability Centers," Mimeo, Stanford University.

[15] Melumad, N. and S. Reichelstein (1987) "Centralization versus Delegation and the Value of Communication," *Journal of Accounting Research* **25**, 1–21.

[16] Milgrom, P. and J. Roberts (1992) *Economics, Organization, and Management.* New Jersey: Prentice Hall.

[17] Milgrom, P. and N. Stokey (1982) "Information, Trade and Common Knowledge," *Journal of Economic Theory* **26**, 17–27.

[18] Milgrom, P.R. (1988) "Employment Contracts, Influence Acitivities, and Efficient Organization Design," *Journal of Political Economy* **96**, 42–60.

[19] Myerson, R.B. (1979) "Incentive-Compatibility and the Bargaining Problem," *Econometrica* **47**, 61–73.

APPENDIX

Proof of Proposition 3 The necessity part of the proposition is trivial: all renegotiation-proof allocations must be incentive-compatible.

The proof of the sufficiency part consists in constructing strategies and beliefs that support any incentive-compatible allocation as an equilibrium allocation that is not renegotiated along the equilibrium path of the renegotiation game. Consider the following strategies and beliefs.

Stage 2: The agent of type y selects his preferred action-pair in the menu $a^y \in m(c_0)$, and execute the associated action a_2^y.

Stage 2.1: Regardless of her beliefs, the principal makes no contract offer. At this stage, her beliefs are simply the Bayesian revision of her prior concentrated on the set $\mathcal{Y}\left(a^{y'}\right)$, where $a^{y'}$ is the selected pair by the agent.

Stage 2.2: The agent of type y accepts all contract offers which are weakly preferred to the allocation $a^{y'}$, and rejects all other offers.

Stage 2.3: The agent of type y selects his preferred allocation in the menu $m(c_1)$.

It is clear that these strategies and beliefs form a PBE of the renegotiation game. In stage 2, the agent anticipates no renegotiation, and therefore he chooses his favored element in the menu of the outstanding contract by executing its associated action a_2. In state 2.1, the principal can do no better than not making any offer, since she knows that the agent accepts only those contracts that are weakly worse off for her. Finally, in stages 2.2 and 2.3, the agent accepts all contracts that he weakly prefers to the status quo, and then selects his preferred element in the menu of the outstanding contract. *Q.E.D.*

Proof of Proposition 5 The first part of the proof shows that conditions (i)–(iii) must be satisfied by any renegotiation-proof allocation for the C game.
Conditions (i) are standard incentive-compatibility constraints for the agent which must naturally be satisfied by any renegotiation-proof allocation.
Consider now the conditions (iii). Suppose one is not satisfied for a value of x and y' in a renegotiation-proof allocation. Renegotiation-proofness implies that, along the equilibrium path, following the reports x (the principal) and y' (the agent), the action-pair $a^{xy'}$ must be

executed without being renegotiated. Consider the principal's beliefs following the reports. The principal must (Bayesian) revise her prior in the set $\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$. Since the action-pair $a^{xy'}$ does not satisfy condition (iii), there must exist a vector of incentive-compatible action-pairs $\{\alpha^y\}$ for $y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$ such that

$$\sum_{y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^x, \theta_2^y, \alpha^y) > \sum_{y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^x, \theta_2^y, a^{xy'}),$$

and $V(\theta_2^z, \alpha^z) > V(\theta_2^z, a^{xy'})$ for all $z \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$. Suppose that, in stage 2.1, the principal offers to the agent a contract c_1 with $m(c_1) = \{\alpha^y\}$ for $y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$. By construction, the agent should accept this contract regardless of his beliefs regarding the principal's type since rejection would implement the action-pair $a^{xy'}$ which is strictly worse than an appropriately chosen element of $\{\alpha^y\}$. Acceptance of c_1 by the agent effectively induces the principal in offering this contract, thus upsetting the equilibrium. Conditions (iii) must then be satisfied by a renegotiation-proof allocation.

Consider now the conditions (ii). Suppose that one is not satisfied for a value of x and x' in a renegotiation-proof allocation, and that the principal of type x reports x'. The interior of the bracket on the right-hand-side of the inequality of condition (ii) represents the maximum the principal of type x can get by reporting x' when the agent reports y'. The principal can achieve it by renegotiating to an allocation that will surely be accepted by the agent regardless of his beliefs. (This is easily shown by the same argument as above.) Summing these terms over y' gives the expected utility the principal gets by reporting x' before she knows what the agent will report. If the condition (ii) is not satisfied, the principal has an incentive to report x', and then renegotiate to an allocation that will surely be accepted by the agent. Hence, any renegotiation-proof allocation must satisfy the conditions (ii).

The next step in the proposition is to construct strategies and beliefs for the C game that support any allocation satisfying conditions (i)–(iii) as a renegotiation-proof allocation. Consider the following strategies and beliefs.

Stage 2: The principal of type x reports truthfully. The agent of type y reports truthfully. Each player reports truthfully by choosing the row or column that it prefers in the menu $m(c_0)$.

Stage 2.1: Regardless of the reports made in stage 2, the principal makes no contract offer. At this stage, her beliefs are simply the Bayesian revision of her prior concentrated on the set $\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$.

Stage 2.2: Following the reports x' and y', the agent of type y accepts all contract offers which are weakly preferred to the allocation $a^{x'y'}$, and rejects all other offers.

Stage 2.3: The agent of type y selects his preferred allocation in the menu $m(c_1)$.

It is clear that these strategies and beliefs constitute a PBE of the C game. If the contract c_1 is accepted, the agent selects his preferred element in its associated menu. Given this selection strategy, it is rational for the agent to accept those contracts that he weakly prefers to the status quo action-pair $a^{x'y'}$. Given this acceptance strategy, the principal can do no better than make no offer since the status quo allocation satisfies conditions (iii). Finally, given the ensuing resolution of the game and given that the status quo allocation satisfies conditions (i) and (ii), it is optimal for the two players to report truthfully. *Q.E.D.*

Proof of Proposition 6 The first part of the proof shows that conditions (i)–(ii) must be satisfied by any renegotiation-proof allocation for the HP game.
Conditions (i) are standard incentive-compatibility constraints for the agent which reflect the sequentiality of decisions in the game. These constraints must naturally be satisfied by any renegotiation-proof allocation.
Consider now the conditions (ii). Suppose one is not satisfied for a value of x and x' in a renegotiation-proof allocation. Renegotiation-proofness implies that, along the equilibrium path, upon reporting x (the principal), every executed action-pair in the vector $\{a^{xy}\}_y$ is not renegotiated. Since condition (ii) is not satisfied for x and x', there exists an incentive-compatible vector of action-pairs $\{\alpha^y\}_y$ such that $\sum_y p_y U(\theta_1^x, \theta_2^y, \alpha^y) > \sum_y p_y U(\theta_1^x, \theta_2^y, a^{xy})$, and $V(\theta_2^y, \alpha^y) > V(\theta_2^y, a^{x'y})$ for all y. Suppose that the principal reports x' in the stage 2, and offers in stage 2.1 a contract $\hat{c}$ with $m(\hat{c}) = \{\alpha^y\}_y$ which is accepted in stage 2.2 by the agent. Since $\hat{c}$ is incentive compatible, the agent selects his preferred element in the menu $m(\hat{c})$ at stage 3.1. In stage 2.2, it is then a dominant strategy for the agent to accept the contract $\hat{c}$ if offered by the principal because, by construction, this contract yields a strictly better allocation for the agent regardless of his beliefs about the principal's type. In stage 2.1, the principal then offers the contract $\hat{c}$, which is preferred to the status quo contract, given that she has reported x' in stage 2. In stage 2, the principal then has an incentive to report x' and renegotiate since, by construction, this yields her a strictly higher expected utility than reporting x. Hence, all conditions (ii) must be satisfied by a renegotiation-proof allocation for the HP game.

The next step in the proposition is to construct strategies and beliefs for the HP game

that support any allocation satisfying conditions (i)–(ii) as a renegotiation-proof allocation. Consider the following strategies and beliefs.

Stage 2: Conditional on her type, the principal selects her preferred row in the menu $m(c_0)$.

Stage 2.1: Regardless of her type, the principal makes no contract offer.

Stage 2.2 Conditional on his type y and the principal's report x, the agent accepts all contract offers that are weakly preferred to a^{xy} and rejects all other offers.

Stage 3.1: The agent selects his preferred action-pair in the menu of the outstanding contract, and execute the associated action a_2.

It is clear that, if an allocation satisfies the conditions (i)–(ii), these strategies and beliefs form a PBE of the HP game. *Q.E.D.*

Proof of Proposition 7 The first part of the proof shows that conditions (i)–(ii) must be satisfied by any renegotiation-proof allocation for the HA game.
Condition (i) represent the agent's incentive-compatibility constraints in expected terms over the principal's type since the agent selects a column of the menu before the principal has any chance of communicating her information to the agent. It is clear that these constraints must be satisfied by any renegotiation-proof allocation for the HA game.
Consider now conditions (ii). Suppose one is not satisfied for a value of x and x' in a renegotiation-proof allocation. Renegotiation-proofness implies that, along the equilibrium path, following the agent's report y', every executed action-pair in the vector $\left\{a^{xy'}\right\}_x$ is not renegotiated. In stage 2.1, the principal Bayesian updates her prior over the support $\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$. Since condition (ii) is not satisfied for x and y', there exists a vector of action-pairs $\{\alpha^x\}_x$ such that

$$\sum_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^x, \theta_2^y, \alpha^x) > \sum_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^x, \theta_2^y, a^{xy}),$$

and $V(\theta_2^y, \alpha^x) > V(\theta_2^y, a^{xy'})$ for all x and $y \in \mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)$. Furthermore, this vector is incentive compatible for the principal conditional on her revised beliefs, that is,

$$\sum_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^z, \theta_2^y, \alpha^z) > \sum_{y\in\mathcal{Y}\left(\left\{a^{xy'}\right\}_x\right)} p_y U(\theta_1^z, \theta_2^y, \alpha^{z'})$$

for all z, z'. Suppose that the principal offers a contract $\hat{c}$ with $m(\hat{c}) = \{\alpha^x\}_x$ in stage 2.1, and that the agent accepts it in stage 2.2. Since this contract is incentive compatible, the principal selects her preferred element in the menu $m(\hat{c})$ in stage 3.1. By construction, this new contract strictly dominates the outstanding contract for the agent, and he must then accept it regardless of his beliefs at stage 2.2. Given this resolution of the game following the offer $\hat{c}$, the principal indeed offers the contract $\hat{c}$, which is preferred to the status quo contract given that she has reported x at stage 2. Hence, all conditions (ii) must be satisfied by a renegotiation-proof allocation for the HA game.
I now consider the conditions (iii). These constraints state that, conditional on the principal's Bayesian updating of her prior following the agent's report, the principal has an incentive to report truthfully at stage 3.1. These constraints must be satisfied by any renegotiation-proof allocation.

The next step in the proposition is to construct strategies and beliefs for the HA game that support any allocation satisfying constraints (i)–(iii) as a renegotiation-proof allocation. Consider the following strategies and beliefs.

Stage 2: Conditional on his type, the agent selects his preferred column in the menu $m(c_0)$.

Stage 2.1: Regardless of her own type and the agent's selection, the principal makes no contract offer.

Stage 2.2 Conditional on his type y and his report y', the agent accepts all contract offers that are weakly preferred to $\left\{a^{xy'}\right\}_x$ for all x, and rejects all other offers.

Stage 3.1: The principal selects her preferred action-pair in the column of the outstanding contract and execute the associated action a_1.

It is clear that, if an allocation satisfies the constraints (i)–(iii), these strategies and beliefs form a PBE of the HA game. *Q.E.D.*

Proof of Proposition 8 We first show that the allocation μ^{DA} is weakly dominated by the allocation μ^{HP} of the HP game. Since μ^{DA} is independent of θ_1, the conditions (i) for renegotiation-proofness are equivalent to conditions (i) in Proposition 6. Suppose first that μ^{DA} satisfies conditions (ii) of Proposition 6. It would then be renegotiation-proof for the HP game, and the result would be proven. Now, suppose that μ^{DA} does not satisfy conditions (ii) of Proposition 6. This implies that at least one type of principal can increase its expected

utility without decreasing that of the agent (and without violating the agent's incentive constraints). For each principal type, compute the solution to the maximization problem of the right-hand-side of constraints (ii) in Proposition 6 with $a^{x'y} = \mu_y^{DA}$. Since the constraints of that maximization are independent of θ_1, these solutions themselves satisfy the principal's incentive compatibility constraints (ii) in Proposition 6. Furthermore, they satisfy the agent's incentive-compatibility constraints. This means that these solutions are renegotiation-proof for the HP game. Since this allocation is strictly better than μ^{DA}, the result is proven.

A similar argument shows that the allocation μ^{DP} of the DP game is weakly dominated by the allocation μ^{HA} of the HA game. *Q.E.D.*