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Contributions of Oliver Hart and Bengt Holmström to Contract Theory*

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Abstract

Oliver Hart and Bengt Holmström were awarded the 2016 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel for their fundamental contributions to contract theory. This article offers a short summary and discussion of their path-breaking work.

Keywords: Contract theory; incomplete contracts; Nobel prize; optimal incentive schemes

JEL classification: *B*21; *D*23; *D*82; *L*20

I. Introduction

The 2016 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel was awarded to Oliver Hart and Bengt Holmström for their fundamental contributions to contract theory. Oliver Hart was born in 1948 in London. He studied mathematics at King's College in Cambridge and economics at Warwick University, and he did his PhD at Princeton University in 1974. He worked at the University of Essex, Cambridge University, the London School of Economics (LSE) and the Massachusetts Institute of Technology (MIT) before going to Harvard University in 1993. Bengt Holmström was born in Finland in 1949. He studied mathematics at Helsinki University and Operations Research at Stanford University, where he also did his PhD at the Graduate School of Business. He worked at Northwestern University and Yale University before moving to MIT in 1994.

Contract theory analyzes the optimal design of incentive schemes ("contracts") that induce the involved parties to behave more efficiently. It is closely related to mechanism design theory, for which Leonid Hurwicz, Eric Maskin, and Roger Myerson received the 2007 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel. While mechanism design theory is mostly interested in allocation mechanisms that involve many agents (such as markets, auctions, tax systems, etc.),

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contract theory focuses on situations in which only a few parties interact with each other (often just two).

Contract theory deals with a fundamental problem of economic co-operation. Two (or more) parties can jointly generate a surplus in addition to what each of them can generate on their own. The amount of the surplus depends on the actions that each of the parties take. The problem is that each party has an incentive to behave opportunistically (i.e., to maximize its own pay-off rather than the joint surplus). If the parties could write a complete contingent contract that specifies the actions that each of them has to take in every possible state of the world and if this contract could be enforced by the courts, then the solution to this problem would be trivial. The parties would write a contract that obligates them to take exactly those actions that maximize the joint surplus in each possible state of the world, and then they would share this surplus in some way between them. If a party deviates from the prescribed behavior, then it has to pay a penalty that is sufficiently high to guarantee that everybody honors the terms of the contract.

Unfortunately, in the real world, it is often impossible to write complete contingent contracts, for example, because the actions of some parties are not observable (moral hazard) or because the actions or the different states of the world cannot be described and verified to a third party, such as the courts (incomplete contracts). In these situations, it is still possible to write contracts, but these contracts cannot enforce the desired behavior directly; rather, they have to offer incentives that induce the parties indirectly to behave more efficiently. This could be financial incentives, career concerns, or incentives that are provided by the allocation of control and property rights.

Hart and Holmström developed canonical models for the analysis of the optimal design of incentive mechanisms. Because of their contributions, we now have a much better understanding of the incentive effects of contracts and of how optimal incentive mechanisms should be designed. There is a broad range of possible applications of these models. They include the optimal design of incentive schemes for managers and workers, the optimal financial structure of a firm, the optimal design of hierarchies and decision structures in organizations, and the optimal allocation of property rights. A large body of literature on contract theory grew out of their work, which cannot possibly be summarized in this short review. A good overview of this literature is provided by the textbook of Bolton and Dewatripont (2005) and the anthology edited by Aghion *et al.* (2016).

In this short paper, I first discuss Bengt Holmström's work on optimal incentive schemes with moral hazard. I then move on to Oliver Hart's work on incomplete contracts and the optimal allocation of property rights. They were awarded the 2016 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel for these contributions. Both authors have made many more important contributions that I can mention only briefly at the end of this review.

The work of Bengt Holmström and that of Oliver Hart are conceptually quite different. However, they both start out from the same problem. This problem was raised by the famous Informativeness Principle, first established by Holmström (1979), and refined and stated more rigorously by Grossman and Hart (1983a). This principle (which is discussed in more detail below) implies that the shape of the optimal incentive scheme in a standard moral hazard problem is incredibly complex and highly sensitive to small changes in the (unobservable) beliefs of the contracting parties about the probabilities of the possible states of the world. The theory yields no robust predictions on the shape of the optimal incentive scheme. This problem is clearly pointed out in a joint survey article that Hart and Holmström (1987, p. 74) presented at the World Congress of the Econometric Society in 1985.

> Indeed, the economic credibility of the contractual approach may be called into question when, as often happens, optimal contracts become monstrous state-contingent prescriptions.
> (Hart and Holmström, 1987, p. 74)

> The main [problem] is its sensitivity to distributional assumptions. It manifests itself in an optimal sharing rule that is complex, responding to the slightest changes in the information content of the outcome x. Such "finetuning" appears unrealistic. In the real world incentive schemes do show variety, but not the degree produced by the basic theory.
> (Hart and Holmström, 1987, p. 90)

Hart and Holmström went on to solve this problem in different ways. Hart limits contractual complexity by introducing additional enforcement constraints that are exogenously given. He assumes that the parties cannot enforce complex contingencies because these contingencies cannot be described in a contract or they cannot be verified to a court. Furthermore, the parties cannot commit not to renegotiate their initial contract. This is the incomplete contracts approach of Grossman and Hart (1986) and Hart and Moore (1990). Holmström went in the opposite direction. He derives simple and more realistic contracts endogenously as the solution to a highly complex dynamic programming problem. Holmström and Milgrom (1987) show that if the agent has a very rich action space, then the optimal contract must be linear in an aggregate measure of the agent's performance.

II. Optimal Incentive Schemes with Moral Hazard

In the 1960s and 1970s, a body of literature on moral hazard in insurance and labor markets developed, dealing with the inefficiencies that arise if the insurance company cannot observe the effort spent by the insuree, or if a firm cannot observe the effort of a worker.[1] In this body of literature, it is assumed that the types of contracts that are traded are exogenously given. In contrast, Holmström (1979) asked how to optimally design an incentive contract if there is moral hazard.[2]

He studied this fundamental problem in a principal–agent model in which the principal cannot observe the actions taken by the agent but only some noisy signal. The principal wants to maximize her profits while the agent is instead interested in maximizing his own utility. As a leading example, consider the case where the principal is the owner of a firm and the agent is her manager. The manager has to exert non-observable effort to increase profits. The principal only observes a noisy signal of the manager's effort, such as the firm's profit, which depends on the manager's effort but also on other factors that are often stochastic. This model is known today as a standard principal–agent problem with hidden action.[3] If both parties are risk neutral, then there is a simple solution to this problem. The principal offers a contract to the agent that makes the agent a residual claimant on the margin of the firm's profits; that is, she sells the store to the agent (a management buyout). In this case, the agent fully internalizes all the costs and benefits of his actions and chooses an effort level that maximizes total surplus. However, in the real world, the parties are not risk neutral.[4] The agent, in particular, is risk averse because he cannot diversify his human

[1] See Arrow (1963, 1968) and Pauly (1968). Laffont and Martimort (2002) provide a short survey on the history of the theory of incentives.

[2] The term "moral hazard" has been used in the insurance industry for more than a century. It refers to the problem that a person who bought insurance against an accident is less inclined to invest proper care into preventing the accident. Thus, the probability of the accident is not exogenous but depends on the amount of insurance that was bought. Hart and Holmström (1987) define moral hazard as a contractual situation in which an asymmetry of information arises after the contract has been signed. In contrast, there is "adverse selection" if there is already an informational asymmetry at the contracting stage. Thus, with moral hazard, the parties are symmetrically informed when they write the contract and have the common interest to maximize the joint surplus, no matter how the bargaining power is allocated. A typical example of moral hazard is a situation where the agent has to take an action after signing the contract. The action affects the principal's pay-off, but the principal cannot observe it directly – she only observes a noisy signal ("hidden action"). Another moral hazard problem arises if the agent receives some private information, after signing the contract, that determines which action he should take. The principal observes the action but she does not know the information on which the choice of the action is based ("hidden information").

[3] A similar model was developed independently by Shavell (1979). Mirrlees (1975) worked on the principal–agent problem with hidden action in the early 1970s. He points to some important technical problems that are discussed later.

[4] Another problem with this solution is that the agent might be unable to buy the firm because he is cash-constrained and cannot finance a management buyout because of limited liability. Innes (1990) considers a model in which the agent is risk neutral but wealth-constrained. In this model, there is a trade-off between offering better incentives and reducing the rent

capital that has to be invested in one firm only.[5] For this reason, the agent wants to be insured against fluctuations of his wage. His most preferred contract would be a fixed wage contract. However, if he receives a fixed wage, he has no incentive to spend any effort. Thus, there is a trade-off between incentives and insurance. The (second-best) optimal contract has to find a balance between offering incentives and insuring the agent against wage fluctuations.

The Informativeness Principle

Holmström (1979) shows that the optimal solution to this problem must satisfy the Informativeness Principle, which requires that the wage of the agent should be conditional on all observable signals that contain statistical information about the agent's effort. The following example illustrates this principle. Suppose that the profit of a firm depends not only on the effort of its manager but also on other factors, such as the business cycle, the exchange rate, or the prices of raw materials and other input goods. In this case, the manager should be rewarded for high profits only if these profits are due to his effort, but not if they are due to favorable business conditions. This implies that the principal should use relative performance evaluation (Holmström, 1982a). If all firms in the same industry make high profits, then it is less likely that the high profits of the firm under consideration are due to the efforts of the manager, compared to a situation in which his firm is the only one with high profits while all other firms are making low profits. In the first case, it is more likely that the firm's success is due to favorable business conditions, so the manager should be rewarded less than in the second case, where it is more likely that the firm's success is due to the manager's effort.

At first glance, it might seem counterintuitive that the manager is rewarded or punished for events that he cannot control, such as the success of other firms or movements in the exchange rate. However, this is necessary in order to better insure the manager against these risks and, at the same time, to offer better incentives for those dimensions of profits that he does control. Some of the bonus schemes that are observed in the financial and other industries violate the Informativeness Principle in multiple ways. They reward managers for profits that are due to luck (e.g., profits due to a booming stock market or to rising house prices), and they

that has to be paid to the agent because the agent shares only in the gains but not in the losses that the firm might make. If the slope of the optimal incentives scheme can be neither negative nor steeper than 1, then the optimal contract is a debt contract.

[5] The assumption of risk neutrality is less problematic for the principal. If the firm is a joint stock company owned by shareholders with optimally diversified portfolios, then each shareholder owns a very small share of the firm and is risk neutral at the margin.

do not punish managers for losses that they are responsible for (e.g., legal liabilities due to the violation of financial regulations).

Holmström (1979) derived the optimal contract by using the so-called first-order approach, which replaces the agent's incentive compatibility condition with the first-order condition of the agent's utility maximization problem. This approach is problematic because the first-order condition is only a necessary but not a sufficient condition for the optimal action of the agent. Whether the agent's maximization problem is globally concave depends on the incentive scheme that is determined endogenously and is unknown until the problem has been solved. Rogerson (1985) and Jewitt (1988) have shown that fairly strong assumptions are required to guarantee that the first-order approach always characterizes the optimal contract. Furthermore, there is the so-called Mirrlees problem. Mirrlees (1975) has shown that a solution to the moral hazard problem need not exist if the agent chooses the mean of an unbounded probability distribution (such as the normal distribution). Furthermore, he shows in a simple example that the principal can approximate the first-best by offering a contract that pays the agent a fixed wage for almost all realizations of profit, but penalizes him heavily if the firm's profit falls below a very low threshold.

Grossman and Hart (1983a) offer a discrete model with finitely many actions and outcomes that avoids these technical problems. It proposes a two-step solution algorithm. First, for every possible action that the agent might take, the cost-minimizing incentive scheme is computed that implements this action at the lowest possible cost to the principal. Each of these problems has a solution that can be found using a standard Kuhn–Tucker approach. In a second step, the action that maximizes the principal's profit (given the cost to implement it) is selected. This discrete model is more rigorous but arguably less elegant and less intuitive than the original model by Holmström (1979).

Grossman and Hart (1983a) show that the optimal contract has very few general properties. It need not even be the case that the optimal contract is monotonically increasing in the profit of the firm. If a higher profit level is associated with a lower hazard rate, indicating that it is less likely that this profit level was generated by the desired action, then the wage of the agent should decrease. This property points to another striking implication of the Informativeness Principle. It requires that the principal rewards the agent *as if* she solves a statistical inference problem. She pays a higher wage if an outcome suggests that is more likely that the agent took the desired action. However, in equilibrium, the agent chooses the desired action with probability one. Thus, the principal knows with certainty the action taken by the agent.

The Informativeness Principle predicts that contracts are very complex because they should be contingent on all observable signals that are informative about the agent's effort, such as the profits of other firms in the same industry, the exchange rate, the prices of input goods, weather conditions, and other factors affecting profits. Furthermore, the functional form of the optimal contract depends delicately on the underlying probability distributions of these signals. In the real world, however, many contracts are fairly simple. They depend on very few variables and they have a simple functional form. For example, the wage of a production worker often depends linearly on the output he produces, a sharecropper has to pay a fixed share of his harvest to the landlord, and a salesman receives a commission that is linear in the number of contracts he sells. As pointed out by the quotes of Hart and Holmström (1987) in the introduction, this failure to accurately predict real-world incentive schemes calls the contractual approach into question.

Linear Incentive Schemes and Multiple Tasks

Holmström and Milgrom (1987) deal with this problem by arguing that contracts need to be robust to a richer action space of the agent. The standard principal–agent model considers a static situation in which the agent takes an action only once. In contrast, Holmström and Milgrom introduce a dynamic principal–agent model in which the agent has a much richer action space. First, the agent can move in any direction of an N-dimensional probability space. Second, the agent does not choose one action once and for all, but rather a time path of actions. Thus, the agent can change and adjust his action in reaction to his past performance. In the limit, as the length of each time period goes to zero, the agent controls the drift rate of an N-dimensional Brownian motion in continuous time.

This model is far more complex and more difficult to analyze than the standard principal–agent model, but the optimal solution is strikingly simple. Holmström and Milgrom (1987) show that the optimal incentive scheme in the continuous model is a contract that is linear in aggregates (e.g., linear in total profits). The intuition for this result is that any nonlinear incentive scheme would be exploited by the agent. The richer the agent's action space, the more degrees of freedom he has to adjust his actions in such a way that his own utility is increased at the detriment of the principal. The advantage of a linear incentive scheme is that it provides a constant incentive pressure that cannot be exploited.[6]

[6] In Holmström and Milgrom (1987), there is a discontinuity in the limit. In the discrete model, no matter how small each time period is, the optimal incentive scheme is still very complex because it is a linear function of N different "accounts", where N could be very large. Only in the limit, as the length of each time period shrinks to zero, is the optimal

This is a very important result that calls into question the widespread use of discontinuous bonus payments (e.g., the payment of a fixed bonus if a certain performance threshold is reached). These bonus contracts are prone to manipulation. For example, a salesman who receives a fixed bonus if his sales exceed a certain threshold at the end of the year will be inclined to work less hard if the threshold has already been reached in November. However, if he is close to the threshold but unlikely to pass it without extraordinary measures, he might try to induce additional sales by using expensive rebates at the detriment of his firm. A linear bonus scheme discourages this behavior because it offers the same incentive pressure at each point in time.

It is important to note that the model of Holmström and Milgrom (1987) considers an agent working in a stationary environment. Thus, it is not suitable for the analysis of the optimal contract for a top manager, but rather applies to workers and mid-level employees, and also to suppliers, salespeople, and independent contractors who are engaged in a stationary production process. The model predicts that the incentive intensity (the slope of the incentive scheme) is higher, the lower the agent's risk aversion, the smaller the noise term, and the higher the agent's impact on profits. Furthermore, it predicts that these parameters enter the optimal contract in a very simple and intuitive functional form.

One empirically testable prediction of the model is that the more risky the outcome of the agent's efforts, the lower the slope of his incentive scheme should be. However, it is difficult to identify this relationship in empirical data. Some studies find stronger incentives when performance measurement is easier (e.g., Aggarwal and Samwick, 1999), while other studies find a positive relationship or no correlation at all (e.g., Allen and Lueck, 1992; Lafontaine, 1992; Core *et al.*, 2003). There are two possible explanations for this. First, there could be a selection bias. If less-risk-averse managers self-select into more risky occupations, then the riskiness of an occupation might be positively correlated with incentive intensity (Chiappori and Salanié, 2003). Second, if the environment is more risky, it might be more difficult for the principal to tell the agent what to do. Therefore, the principal might give more discretion to the agent, which also requires her to give him more powerful incentives (Prendergast, 2002).

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contract linear in one aggregate of these N different accounts (such as total profits). Hellwig and Schmidt (2002) show how this discontinuity arises, and they offer an alternative model in which the limit is approached continuously. In their model, a contract that is linear in one account is approximately optimal, both in the discrete model with time periods of finite length and in the continuous model.

Holmström and Milgrom (1991) extend their model to situations in which the agent is engaged in multiple tasks that interact with each other. Tasks can be substitutes or complements in the agent's cost function. Tasks are substitutes if engaging in one task becomes more costly the more the agent engages in the other task, and tasks are complements if engaging in one task makes the other task easier to carry out. Thus, incentives that are given for one task affect the agent's effort in another task. For example, if a production worker has to produce output (task 1) and maintain his machine (task 2), and if producing output and maintaining the machine are substitutes in the agent's cost function, then offering a high piece-rate induces the worker to care less for his machinery. This problem is aggravated if it is easy to measure output but difficult to measure maintenance. If there was only one task (producing output), the agent should be offered high-powered incentives; however, with two tasks, the piece-rate should be lower. High-powered incentives for producing output would induce the agent to neglect his second task and not to take proper care of the machinery he is working with.

In some situations, it might even be optimal to pay a fixed wage and to offer no explicit incentives at all. For example, consider the question whether a teacher should be paid depending on the performance of his students in standardized tests. These tests measure certain skills such as reading, writing, or performance in mathematics, and they do provide a signal about the teacher's effort in teaching these skills. Thus, the Informativeness Principle suggests that the teacher's salary should be made contingent on his student's test scores. However, a teacher has to engage in multiple tasks. In addition to teaching basic skills, he also has to develop the creativity and the social skills of his students, which are much more difficult to measure by standardized tests. Thus, if the teacher's wage were to depend on his students' test scores for basic skills, then he would focus too much on teaching to the test and would neglect developing other important skills of his students. However, if the teacher is offered a fixed wage (and if there is some intrinsic motivation), he might work less hard altogether, but he would allocate his efforts more efficiently across tasks. Thus, if teaching creativity and social skills is sufficiently important, then it is better to pay a fixed wage to the teacher.

Holmström and Milgrom (1991, 1994) extend the multi-task model to show why some incentive instruments complement each other and should be used together. For example, workers who own (some of) the assets they work with should be offered high-powered incentives and should be given more discretion in how to do their jobs. Thus, these instruments should co-vary positively in cross-sectional data. This has been confirmed empirically by the literature on high-performance work places (Ichniowski and Shaw, 2003).

Moral Hazard in Teams

Agents often work in teams. In another classical paper, Holmström (1982a) discusses the incentive problems that arise from team production. There are two main issues. First, if the principal does not observe signals on individual performance but only a signal on the performance of the team, a public good problem arises. Each agent has an incentive to free-ride on the efforts of the other team members. Consider the case of a partnership where the partners want to set up an incentive scheme to mitigate the free-rider problem. If the sum of the payments that can be made to all partners must equal the total profit of the partnership, then it is impossible to overcome the free-rider problem, even if all partners are risk neutral. Efficiency requires that each partner is a full residual claimant on the margin, but without an external "budget breaker", it is impossible to make all partners full residual claimants at the same time. With a budget breaker, however, the problem can be solved by a Groves mechanism that pays the full profit minus an appropriately chosen lump-sum payment to each team member. Holmström suggests that the need for a budget breaker might be the reason why many capitalist firms have outside owners (shareholders) who do not spend effort but whose main function is to absorb fluctuations of net profits with their wealth.

A second issue with team production arises if the principal observes signals on the individual performance of each team member, and if these signals are correlated. In this case, the principal can improve the incentive contract for each team member by using the information provided by the other signals (i.e., she can use relative performance evaluation). This is common practice in many firms. However, many firms use very specific forms of relative performance evaluation, such as rank-order tournaments. For example, in a tournament for promotion, the agent with the best performance moves up the career ladder to a better job while the other agents are not promoted. The problem with rank-order tournaments is that they do not make efficient use of the available information. The Informativeness Principle requires that the principal should use all information that is informative about the agent's performance, not just the fact that he performed better than all other agents. Lazear and Rosen (1981) argue that it might be difficult for the principal to credibly commit to a complicated reward structure while it is much simpler to commit to a policy that promotes exactly one (or n) agent(s).

Career Concerns

Employees are not only motivated by direct monetary incentives, they also care about their career prospects. Fama (1980) argues that the moral hazard problem can be solved by career concerns and that performance-based wage contracts are therefore unnecessary. Holmström (1982b) offers the first formal model of career concerns. In his model, the output produced by an agent in each period depends on the agent's exogenously given ability, the agent's effort, and a noise term. In each period, the agent is paid a fixed wage that is determined by a perfectly competitive labor market so that firms offer the agent a fixed wage that equals his expected productivity in the coming period. All firms observe the agent's past output but they do not know which part of the output is due to the agent's ability, due to the agent's effort, and due to the noise term. Thus, firms have to form beliefs about the agent's ability based on the agent's past performance, and about the effort that the agent is going to choose in the coming period. The agent does not know his ability either, but he observes the effort level that he chooses in each period.[7]

In the last period, the agent receives a fixed wage and the world ends, so he has no incentive to spend any effort. Thus, in the last period, his expected output is determined by his ability alone. In the second to last period, the agent anticipates that his wage in the last period depends on the labor market's expectation of his ability. Thus, he has an incentive to choose some positive effort level in order to affect the market's expectation about his ability. However, in equilibrium, the market perfectly anticipates what the agent is going to do. In the third to last period (and all previous periods), the same logic applies. The agent works harder to affect the market's expectations in all future periods, but the market rationally anticipates his behavior and cannot be fooled. As a result, the agent works very hard at the beginning of his career, possibly spending an effort level that is far higher than the first-best level of effort. Over time, his effort level falls because there are fewer and fewer periods left that can be affected. The model nicely captures a "rat race" effect. At the beginning of his career, the agent works very hard in order to impress the market about his ability, but because the market expects him to work so hard, it attributes the agent's output to his high effort and not to high ability. Nevertheless the agent cannot reduce his efforts. If he were to do so (off the equilibrium path), the market would still believe that he worked very hard and therefore it would attribute the lower output to lower ability, resulting in a lower wage in all coming periods.

[7] Holmström (1982b) assumes that the agent is equally well informed about his own ability as is the labor market. For example, a PhD student on the job market might be equally well informed about his ability to write good papers in the future as are his more senior colleagues who evaluate him. Thus, there is symmetric information about the agent's ability, which simplifies the model considerably. Without this assumption, the model would turn into a signaling model that is much more complicated.

Gibbons and Murphy (1992) relax the assumption of fixed wages and they assume that wages might depend linearly on performance. In their model, career concerns and performance pay interact. They show that, on the one hand, a manager at the end of his career is no longer motivated by career concerns, so he should receive more high-powered performance pay. On the other hand, managers at the beginning of their careers should receive low-powered incentives because they will work hard anyway due to career concerns.[8]

III. Incomplete Contracts and Control Rights

In principal–agent theory, the parties write contracts that are contingent on all relevant information that is observable and verifiable to the courts. Such a contract is not a complete contingent contract (because it is not contingent on the agent's effort), but it is "comprehensive" in the sense that it specifies for each contractible state of the world which payments have to be made. Such a contract never has to be renegotiated or completed by the courts because all possible contingencies (that can be contracted upon) have been taken care of in the original contract. The Informativeness Principle implies that the optimal contract is highly complex and depends on the fine details of the underlying probability distributions.

Real-world contracts are far more simple and often incomplete. They are not contingent on all possible states of the world but have missing provisions and gaps that have to be completed over time (as the state of the world materializes) either through renegotiation or by the ruling of a court. Grossman and Hart (1986) model incomplete contracts by assuming that long-term contingent contracts are not feasible, for example, because some states of the world are observable by the contracting parties but cannot be verified to the courts. If contracts are incomplete, then it is of crucial importance who has the control right to decide what to do in a contingency not covered by the contract.

Grossman and Hart (1986) distinguish between specific control rights and residual control rights. Specific control rights can be contracted upon and can be assigned to one party or the other. If, however, a contingency has not been dealt with by the contract, then the party with the residual rights of control decides what is to be done. Residual control rights are often property rights. The owner of a physical asset (e.g., a machine, a building, or a patent) can decide what to do with the asset in all contingencies that have not been dealt with explicitly in the contract. In particular, the owner

[8] There are many other important extensions of Holmström's career concerns model, including Holmström and Ricart I Costa (1986), Stein (1989), Dewatripont *et al.* (1999a, 1999b), and Persson and Tabellini (2000).

of an asset can exclude other parties from using the asset. Grossman and Hart define a "firm" as the set of physical assets that the firm controls. This gives rise to the following fundamental questions. Which physical assets should be controlled by a firm, who should own this firm, and under what circumstances should a set of assets be divided between two firms rather than be controlled by one firm?

These questions are at the heart of the theory of the firm. Coase (1937) argued informally that some transactions are carried out more efficiently within a firm than between firms on a market. Williamson (1975, 1979, 1985) pointed out that if contracts are incomplete, then there are significant transaction costs in using markets. These transaction costs include inefficient bargaining and the hold-up problem (Klein *et al.*, 1978). The hold-up problem arises if parties have to make non-contractible, relationship-specific investments. These investments are more valuable within a relationship than with an external trading partner. Each party has an incentive to invest too little because it anticipates correctly that, after the investment cost is sunk, it will be "held up" by the other party and not receive the full return of its investment. A possible solution to this problem is vertical integration. If two firms merge, then the owner of the integrated firm will internalize all costs and benefits of the investments and will invest efficiently. However, this raises the question of the boundaries of the firm. Why shouldn't two firms always merge? Williamson argues informally that there are also transaction costs within firms (e.g., bureaucracy costs that increase as firms become bigger). However, this argument does not solve the famous Williamson puzzle. Williamson (1985) showed that a merger must always (weakly) increase efficiency if the involved parties can engage in selective intervention (i.e., if they can leave the two original firms as they were before the merger, and intervene selectively only if the intervention increases total surplus).

Grossman and Hart (1986) offer a formal model that solves this puzzle. The basic idea can be illustrated in a simple example with two parties and two physical assets. Both parties can make investments that increase the joint surplus. The investments are relationship-specific in the sense that they are more valuable within the relationship than if the two parties split up and trade with some third parties. The problem is that the parties cannot write contracts on the investments or on how to divide the surplus that is generated by the investments. The only contracts that are feasible *ex ante* (i.e., before the investments can be made) are contracts on the allocation of ownership rights.

After both parties have made their relationship-specific investments, they have to bargain on how to generate and split the surplus that can be generated with the investments. Bargaining is assumed to be efficient and to result in the Nash bargaining solution. If both assets are owned by one party, then this party has a strong bargaining position because it can exclude the other party from using the assets. That is, the threat-point of the owner in the Nash bargaining game becomes stronger while the threat-point of the non-owner becomes weaker. Hence, the owner will receive a larger share of the surplus, and thus has a stronger incentive to invest. The other party, which does not own any asset, is in a weak bargaining position, giving rise to lower investment incentives. Hence, if the relationship-specific investments of one party are very important while the investments of the other party are not, then the first party should own the assets (integration). If, however, the investments of both parties are of similar importance, then it is better that each party owns one of the assets (non-integration), so that both parties have at least some investment incentives.

This model derives the benefits and the costs of integration endogenously out of one general principle. The benefit of integration is that the owner of the firm has a stronger incentive to invest. The cost is that the investment incentives of the non-owner are reduced. This model not only explains under what circumstances integration outperforms non-integration, but it also shows who should be the owner of which assets. Furthermore, the model does not need to assume any *ex post* inefficiencies caused by bargaining frictions or bureaucratic decision-making.

The model of Grossman and Hart (1986) is restricted to two parties and it does not directly apply to large companies with many owners, investors, and employees. Hart and Moore (1990) have generalized and extended the model in several directions. They consider a model with N parties, K assets, and a rich set of possible ownership structures, including partnerships, joint-stock companies, supermajority rules, and veto power. They assume that *ex post* bargaining is always efficient (as in Grossman and Hart, 1986) and that it results in a division of the *ex post* surplus that is given by the Shapley value. This model gives rise to a rich set of predictions. For example, it shows that complementary assets should be owned together, that no more than one party should have veto power over an asset, that if an agent is indispensable for an asset, then this agent should own the asset, and that if a group of agents is indispensable for a set of assets, then these agents should control these assets by simple majority vote.

The incomplete contracts approach of Grossman, Hart, and Moore has proven to be very powerful in explaining the allocation of ownership and control rights in many applications. It plays an important role in corporate finance, industrial organization, organizational economics, and political economy.[9] Here, I briefly discuss only two important applications to which Oliver Hart made major contributions.

[9] The conference volume edited by Aghion *et al.* (2016) offers an excellent survey on the impact of the incomplete contracts approach on many different fields.

Corporate Finance

The incomplete contracts approach of Grossman, Hart, and Moore was particularly important in the field of corporate finance. Before Grossman and Hart (1986), different financial claims, such as equity, debt, or convertible securities, were mainly seen as instruments for minimizing taxes and bankruptcy costs. The classical irrelevance theorem of Modigliani and Miller (1958) shows that, in the absence of taxes and bankruptcy costs, the value of a firm is independent of how the firm is financed. However, because of the preferential tax treatment of debt and the existence of bankruptcy costs, the optimal debt–equity ratio is determined by equating the marginal tax benefits of debt and the marginal increase in expected bankruptcy costs (Miller, 1977).

This theory ignores the fact that financial claims also differ in how they allocate control rights in different states of the world. For example, as long as a firm honors its obligations and repays its debt, equity holders are in control and decide what to do with the firm. However, if the firm is in financial distress, debt holders can seize collateral and can force the firm into bankruptcy. In this case, equity holders lose control and debt holders take over.

Hart and Moore (1998) consider a model of entrepreneurial finance that explains many real-world properties of debt contracts, including bankruptcy and inefficient liquidation of assets. An entrepreneur needs funds from an investor to finance a positive net present value project. The problem is that the returns of the project are not verifiable. The entrepreneur can divert project returns into his own pocket, but he cannot divert the firm's physical assets. In the optimal contract, the entrepreneur promises to make a fixed stream of payments to the investor. As long as he does so, he runs the project, but if he defaults, then the investor has the right to seize and liquidate the project's assets, which is inefficient. At that stage, the parties can renegotiate the initial contract, but they might be unable to avoid liquidation if the investor cannot commit to return a sufficiently high share of future profits to the investor. Hart and Moore (1994) develop a closely related model in which the manager cannot commit not to leave the firm and withdraw his human capital. This gives rise to a hold-up problem that limits the total indebtedness of the entrepreneur to the investor at any point in time. Again, the second-best optimal contract closely resembles typical real-world debt contracts.

Hart and Moore (1995) consider the financial structure of a publicly held firm that is run by a manager who has only a small financial stake in the company but has large private benefits from control. In particular, the manager is assumed to be an empire builder who will undertake a new investment opportunity, even if the investment has a negative net present value. In this situation, senior (long-term) debt plays a crucial role in constraining the manager to raise new funds. If the company has too little long-term debt, the manager can easily raise money to fund new projects, even if they are not profitable. In this case, there will be overinvestment. However, if there is too much outstanding long-term debt, the manager is unable to finance a project, even if it has a positive net present value; this is the debt overhang problem of Myers (1977). This trade-off determines the optimal level of long-term debt. Furthermore, it is shown under what conditions multiple classes of debt, with different seniorities and covenants allowing limited dilution, can be optimal.

There is a large body of literature on corporate finance building on the incomplete contracts approach, including Aghion and Bolton (1992), Dewatripont and Tirole (1994), Bolton and Scharfstein (1990, 1996), and many others. An excellent synthesis of the early literature is given by Hart (1995).

The incomplete contracts approach focuses on the control and decision rights of different parties in different states of the world. Thus, the legal environment that defines the rights and obligations of the parties if the firm goes bankrupt is very important. Hart has made several suggestions on how to reform bankruptcy procedures and other legal financial institutions (see Aghion *et al.*, 1992; Hart *et al.*, 1997b).

Privatization

If comprehensive contracts could be written, there would be no difference between a nationalized firm and privatized firm that is regulated by the government. Any incentive scheme for the manager (and the workers) of a nationalized firm could be replicated by a comprehensive contract in the regulated private firm, and vice versa. Thus, to understand the costs and benefits of privatization, it has to be recognized that contracts are incomplete. Hart *et al.* (1997a) consider a firm that can invest in quality improvements and cost reductions. Quality improvements give rise to higher costs, and cost reductions give rise to lower quality. The problem is that neither quality improvements nor cost reductions are *ex ante* contractible. The owner-manager of a privatized firm does not need the permission of the government to implement a cost reduction, but he does have to negotiate with the government to implement quality improvements. Thus, he receives all the benefits from a cost reduction (without internalizing the negative externality due to lower quality) but only some fraction of the benefits from quality improvements. Therefore, he will invest too much in cost reduction and too little in quality improvement. The manager of a nationalized company, however, needs government approval for both types of investment. Furthermore, the government can threaten to replace him, which weakens his bargaining position. Thus, he will invest too little both in quality improvements and in cost reductions. The model predicts that privately owned companies will produce at lower cost, but they will sometimes also offer lower quality than nationalized firms. Thus, if quality improvements are not an issue while cost control is very important, a company should be privately owned. If, however, non-contractible quality is a major concern (as in schools, law enforcement, prisons, and perhaps some parts of public infrastructure) then it might be better to have public ownership.[10]

Foundations of Incomplete Contracts

The incomplete contracts approach has been criticized because it relies on the strong assumption that the only long-term contracts that can be written are contracts on the allocation of property rights. Why is it not possible to write a long-term contract (e.g., a contract on trade) that is non-contingent? Such a contract might have to be renegotiated with a high probability after the realization of the state of the world, but it could be useful to induce the parties to invest more efficiently. Hart and Moore (1988) propose a model that allows for such contracts. This model does not have ownership rights, but it does have relationship-specific investments and *ex post* efficient renegotiation. Hart and Moore show that this model gives rise to similar effects as the model of Grossman and Hart (1986). In particular, it is impossible to induce both parties to invest efficiently. However, Nöldeke and Schmidt (1995) show that this model crucially depends on the assumption that if trade fails, the courts cannot distinguish whether the seller refused to deliver or the buyer refused to take delivery. Without this assumption, simple option contracts can be used to implement efficient investments. Aghion *et al.* (1994) also show that the first-best can be achieved if it is possible *ex ante* to allocate all the bargaining power to one party. However, Che and Hausch (1999) show that it is impossible to achieve efficient investments if the investments are co-operative (i.e., if the seller's investment increases the buyer's benefit of the good and the buyer's investment reduces the seller's cost of producing it).

[10] Schmidt (1996) offers a different incomplete contracts model on the costs and benefits of privatization that is based on the idea that residual rights of control give privileged access to information inside the firm. In his model, the government is better informed about the cost of a publicly owned company than of a privatized company. This gives rise to a soft budget constraint: if a publicly owned firm fails to reduce its cost, then the government observes the firm's cost and chooses the *ex post* efficient production level, but this reduces the incentives for cost reduction. If the firm is privately owned, then the government does not observe the firm's cost. Thus, it will reduce the production level in order to reduce the firm's information rent. This hard budget constraint is *ex post* inefficient, but it gives stronger cost-saving incentives *ex ante*.

Maskin and Tirole (1999) raise an even more fundamental issue. In Grossman and Hart (1986), all parties are symmetrically informed and share the same expectations about future states of the world, but they are unable to specify all possible contingencies in a contract (e.g., because the contingencies cannot be described or verified to the courts). However, if the parties correctly anticipate their pay-offs in the different states of the world, then it is possible to construct a revelation mechanism that induces them to announce the state of the world truthfully. Such a mechanism can be used to implement the first-best efficient allocation independently of the allocation of ownership rights.

Hart and Moore (1999) argue that the Maskin–Tirole mechanism requires that the parties can commit to not renegotiating the outcome of the mechanism. They offer an example (based on Segal, 1999) in which the efficient allocation cannot be implemented if renegotiation cannot be excluded.

The debate on the theoretical foundations of incomplete contracts is not yet settled. Sophisticated revelation mechanisms, such as the one proposed by Maskin and Tirole (1999), are not observed in the real world, but we do not yet understand why. One possible answer is that these mechanisms are very sensitive to small changes in the informational structure. For example, Aghion *et al.* (2012) show that subgame perfect implementation (Moore and Repullo, 1988) relies on a very strong common knowledge assumption. Small information perturbations are sufficient to induce non-truthful revelation and undesirable outcomes. An alternative explanation is offered by behavioral economics. In fact, Oliver Hart contributed to this literature as well.

Contracts as Reference Points

Hart and Moore (2008) and Hart (2009) develop a behavioral model of incomplete contracts that is not prone to the critique of Maskin and Tirole (1999). Furthermore, this model introduces *ex post* inefficient outcomes. Hart and Moore (2008) argue that the traditional incomplete contracts approach, which assumes that the parties always reach an *ex post* efficient outcome, is ill suited to studying the internal organization of firms. The traditional model can explain inefficient relationship-specific investments. However, if the parties always end up on the *ex post* efficiency frontier, "it is hard to see why authority, hierarchy, delegation, or indeed anything apart from asset ownership matters" (Hart and Moore, 2008, p. 3).

Hart and Moore (2008) posit that contracts form reference points that shape the feelings of entitlement of the involved parties. They assume that each party feels entitled to the best possible outcome that is consistent with the contract. If a party does not get what it feels entitled to, it is aggrieved and shades in non-contractible ways. Shading reduces the pay-off of the other party but is costless for the shader. Hart and Moore compare a rigid contract to a flexible contract. The benefit of flexibility is that the contract can be better adjusted to the realization of the state of the world, but the cost is that it yields aggrievement and shading. This trade-off explains the optimal degree of contractual flexibility.[11] Hart (2009) extends this model to allow for asset ownership. Hart and Holmström (2010) use it to explain the allocation of decision rights and firm scope. Fehr *et al.* (2009, 2011, 2015) and Bartling and Schmidt (2015) offer some experimental evidence showing that contracts form reference points that affect behavior.

IV. Other Contributions

The Royal Swedish Academy of Sciences awarded the 2016 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel to Hart and Holmström for their contributions to contract theory, but Hart and Holmström have also made many other important contributions. In his dissertation, Hart (1974, 1975) provided the foundation for the theory of incomplete markets, which plays an important role in general equilibrium theory. There is a large body of literature on incomplete markets that is based on his early work. Furthermore, he wrote influential papers on monopolistic competition (Hart, 1979, 1982), on adverse selection in labor markets (Grossman and Hart, 1983b), on the market for corporate control (Grossman and Hart, 1980), and on the incentive effects of competition (Hart, 1983b). Holmström wrote extensively on liquidity in financial markets and the implications for regulation (Holmström and Tirole, 1993, 1997, 1998, 2001, 2011). In his most recent work, he studies the impact of market transparency on liquidity (Dang *et al.*, 2015).

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[11] Herweg and Schmidt (2015) develop a related model of inefficient renegotiations, which also assumes that contracts form reference points but it is based on loss aversion, a behavioral bias that is well established in the literature.

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