Optimal Time-Contingent Contract Design[1]

Bo Chen[2] and Zaifu Yang[3]

Abstract: This paper studies a contract design problem in a setting where time clauses are important. A principal hires an agent to complete a project within a fixed time horizon and prefers to have the project done as early as possible. The agent whose effort is not contractible has a tendency to shirk and to delay exerting effort. We show that in the principal's optimal contract, deadlines and payment schemes can be used jointly as effective instruments to motivate the agent to exert effort and to avoid delay so that a better outcome can be achieved for the principal. Specifically, if an early successful completion time is not verifiable and thus a time-contingent wage scheme is infeasible, then a stochastic deadline can be strictly optimal for the principal. On the other hand, if an early successful completion time is verifiable so that the principal can adopt a time-contingent wage scheme, then the principal's optimal deadline is deterministic and the optimal wage scheme features bonus for early completion.

JEL classification: D82; J31; M52

Keywords: Strategic deadline, moral hazard, contract design.

1 Introduction

Deadlines are important and pervasive in real-world contracts.[4] For many projects, the completion of the work might take prolonged periods of time and yet it is important that work be done early so that the owner or business can return to normal operations. In optimal contracting for such projects, the current study identifies an important interplay between an endogenously determined deadline and different payment schemes. Such an interplay highlights the trade-off between deadlines and the flexibility of payment schemes, and has important implications for the optimal contract design concerning deadlines and payment schemes so as to effectively motivate an in-time project completion and to achieve a higher payoff.

[1] This version: *March 26, 2009.* We are grateful to Yongmin Chen, Michel Le Breton and Santanu Roy for constructive discussions and encourgement. Remaining errors are ours.

[2] Department of Economics, Southern Methodist University (bochen@smu.edu).

[3] Faculty of Business Administration, Yokohama National University (yang@ynu.ac.jp).

[4] This is especially true for construction contracts. Clough (2000, p.265) points out: "Most construction contracts have a specified completion date. This date is determined by the owner and based on the owner's criteria." As another example, American Institute of Architects General Conditions A201-1997 (8.2.1) states that "Time limits stated in the Contract Documents are of the essence of the Contract."

To assess how deadlines and payment schemes interact, we develop a simple dynamic principal-agent model where a principal hires a risk-neutral and cash-limited agent to complete a project within a fixed period of time.[5] We analyze a scenario where on top of pure moral hazard, there is another dimension of conflict between the parties on how to allocate effort intertemporally: Both parties discount future payoffs. As a result, the principal prefers to have the project done as early as possible, but the agent incurs an immediate effort cost and hence has an incentive to delay exerting effort as much as possible, ceteris paribus.[6] In this setting, we investigate the optimal dynamic contracts where the principal employs a wage scheme and a strategic deadline *jointly* to cope with the moral hazard and the effort allocation issues.

We explore two different (time-independent and time-contingent) payment schemes in our analysis. This is motivated by the issue of verifiability of early successful completion times, or more directly, the feasibility of time-contingent wage schemes. In some real-world contracts, verification of project completion is highly technical or costly, making a time-contingent payment scheme difficult. For example, the most contentious issue of all between the owner and the contractor in construction contracts is the determination of project completion, which is resolved afterwards by a fair determination of an architect according to the AIA General Conditions; see O'Leary (2002). In some other situations, certain policies or regulations simply prohibit time-contingent payment schemes. For instance, this was the case for the Federal Highway Administration (FHWA) policy.[7] However, since 1984, FHWA has adopted an effective and more flexible bonus payments (for projects whose construction severely disrupt highway traffic/services) to motivate the contractor to complete projects early.[8] Such time-contingent payment schemes have been used in various

[5]Liquidated damages have also been used extensively in real contracts. However, there are also scenarios where such contract clause may not always be effective. As reported in Cyna (1992) on highway projects in the World Bank, "Most road agencies deal with this (delay) issue by including severe delay penalties (or liquidated damages) in the maintenance contracts. However, such penalties are not often enforced for various reasons and thus they don't succeed in creating a real pressure for on-time completion."

[6]For the principal, an earlier completion, for example, implies a shorter project financing period, or enables the principal to begin operating the (completed) facility earlier and obtain early revenues. The agent's preference for a less stringent deadline may also reflect that a more flexible schedule is better when the agent has multiple projects at hand.

[7]This policy goes back to a 1927 interpretation of a statute that limited the Government's share of project costs to the value of labor and materials. In the 1970's, the policy was based on the belief that FHWA should not have to pay "extra" just to have a project completed early. See T 5080.10 of FHWA on February 8, 1989 for more details.

[8]A well-documented example for this is *the 2007 Oakland project* where the California Department of Transportation successfully implemented a time-contingent payment scheme to have a busy and burnt ramp fixed promptly. See the New York Times (June 2, 2007): "A Miracle-Worker Highway Man Rides the Bonus Train". Such time-contingent payment schemes can be often found in various project contracts.

real-world contracts but received little attention in the literature. One of our purposes is to fill this theoretical gap.

We first examine the situation where an early completion time is unverifiable. In this case, although a *time-contingent* wage scheme is infeasible, we show that the principal can optimally employ a stochastic deadline to stimulate the agent to exert effort and to avoid delay. To be specific, our result is that if the cost of exerting effort is large, making inducing repeated efforts too costly, a premature deadline poses an effective threat in reducing the expected wage payment and is thus optimal. On the other hand, if effort cost is reasonably small compared to the project value and the agent is not extremely impatient, then a stochastic deadline is strictly better than any deterministic one. Such a result reflects the principal's joint consideration of imposing a premature deadline as a threat to resolve the agent's procrastination, as well as minimizing the efficiency loss from a premature deadline.

We next investigate the case where the successful completion time is verifiable. We show that the principal can more effectively use deadlines and time-contingent wage schemes to stimulate the agent to exert effort, and that only deterministic deadlines are optimal. More specifically, a premature deadline is again optimal for the large effort cost case. If the effort cost is small, it is then always optimal for the principal to allow the agent maximal time on the project. In particular, the corresponding optimal wage scheme features a bonus for early completion, the size of which being closely related to how fierce the two conflicts between the two parties are. This is consistent with the evaluation of National Experimental and Evaluation Program (NEEP) Project #24 on bonuses for early completion being a valuable cost-effective construction tool. Furthermore, we find that the optimal contract under a time-contingent wage scheme outperforms that under a time-independent wage scheme as a result of eliminating efficiency loss from a stochastic deadline. This provides a useful theoretical justification on the rescindment (on July 13, 1984) of the FHWA policy which prohibited the government from offering bonus payments for early completion.[9]

The current paper closely relates to two strands of the literature. First, it connects with a number of works on dynamic moral hazard models, which seek to explore the benefits of conditioning the agent's intertemporal performance in contracts for the principal. See, for example, Rogerson (1985), Malcomson and Spinnewyn (1988), Fudenberg, Holmström, and Milgrom (1990), Laffont and Martimort (2002), Salanie (2002), Mukoyama and Şahin (2005), Bolton and Dewatripont (2005) among others. In contrast, our focus here is on time-contingent issues, deadlines and time-dependent payments in contract design for in-time project completion.

Second, the current article links more intimately with several recent papers which ex-

[9] For this and the NEEP, we refer to Report T 5080.10 of the Federal Highway Administration on February 8, 1989.

plicitly incorporate the time variable into contract theory. In this new development, time is recognized as a natural and commonly used clause in real-world contracts. O'Donoghue and Rabin (1999) are the first to investigate how strategic (premature) deadlines can alleviate project delays in principal-agent models. In a setting with risk-neutral parties *without* the limited liability constraint, they demonstrate that premature deadlines can only be optimal if the agent has present-biased preferences, as a result of resolving the agent's self-control problem, while for time-consistent agents, premature deadlines are never optimal. Fischer (2001) proposes a time-consistent procrastination model to show that procrastination can be a result of utility maximization. Guriev and Kvasov (2005) introduce a continuous-time contract model to analyze how time clauses can be used as a compelling solution to overcome the holdup problem.

More recently, Toxvaerd (2006) studies project delays and optimal contract where the project takes time to build in a moral hazard agency problem. A comparison between a sequence of optimal spot contracts and an optimal long-term contract shows that a long-term contract facilitates intertemporal smoothing of the risk-averse agent's wages, making it easier and cheaper to address the agent's incentive problem. Toxvaerd (2007) further examines a continuous-time model on optimal deadline contracts under adverse selection and finds that deadlines can be used as effective screening devices on different types of agent efficiency and consequently, an optimal contract features inefficient delays for all but the most efficient type. Saez-Marti and Sjögren (2008) develop a principal-agent model where an agent, who faces private shocks to her cost of time and is thus occasionally distracted, exerts unobservable effort to complete a project before a natural deadline. They prove that a more frequently distracted agent may outperform a less likely distracted one. They further show that imposing a stochastic deadline can achieve a higher expected payoff for the principal and increase the chance of finishing the task.[10]

The current paper differs from the above studies in three aspects. First, the current model has a quite different motivation as explained previously. Second, we show that in our model, optimal deadlines and optimal wage schemes can be jointly determined and the interplay between these two important contractual clauses can be fruitfully explored. Third, we examine and highlight the role of time-contingent wage schemes.

The paper proceeds as follows. Section 2 introduces the basic dynamic agency model. Section 3 presents our main results. Section 4 extends the basic model by allowing the principal and the agent to have different discount factors. Finally, Section 5 concludes. All technical proofs are relegated to the Appendix.

[10] In Saez-Marti and Sjögren (2008), a stochastic deadline is defined as a tight deadline with a possible extension for one more period (with positive but less than unit probability). In addition, the payment to the agent is assumed to be exogenously given and therefore cannot be made contingent on the successful completion time.

2 The Model

Suppose a principal hires an agent to work on a project that must be completed within a commonly known T natural deadline. For simplicity of exposition and instructive purpose, we concentrate on the case of $T = 2$.[11] We assume that the project, once successfully completed, brings a (normalized) value of $R = 1$ to the principal *at the period of completion*. The agent's effort $e \in \{0, 1\}$, representing shirk and work respectively, is important for the successful completion of the project, in the sense that if the agent exerts effort in any given period, the probability of project failure is p, while if the agent shirks, the probability of failure is q, where $1 > q > p > 0$.

To motivate the agent to exert effort, the principal provides an incentive scheme which consists of *a deadline of completion* and *a wage scheme* $\mathbf{w}$.[12] We assume that the agent has no wealth and is protected limited liability and the principal cannot observe the agent's effort level in any period so as to incorporate moral hazard. Consequently, any contract between the two parties has to specify a non-negative wage scheme w only in terms of verifiable information that is available to both parties, namely, (possibly) the completion time and the final outcome of the project (success or failure). As our main focus is on how the principal can optimally design an incentive scheme using both completion deadlines and wage schemes, we will assume that (1) both the principal and the agent are risk-neutral, so risk-sharing is not an issue, making the dynamic incentives much clearer, and (2) the principal can fully commit to the deadline specified in the contract.[13]

Both the principal and the agent discount future with discount factor $\delta \in (0, 1)$. As a result, the principal prefers to have the project successfully completed as early as possible. On the other hand, for the agent, exerting effort in any given period incurs an immediate opportunity cost of u, $u \in (0, 1)$, which can be regarded as the (leisure) utility the agent has to give up for working in that period. Hence, to achieve a given probability of project success, the agent prefers to postpone working as much as possible so as to minimize the (discounted) cost of working. Finally, to ensure that hiring the agent to work on the project yields a non-negative payoff for the principal under moral hazard, we impose the following mild restriction on the opportunity cost u for the rest of the paper:

$$0 < u < R\,(q - p) = (q - p)\,. \tag{2.1}$$

[11] Similar insights can be carried over to cases with longer project durations $T \geq 3$, but the analysis and formulation will become much more lengthy and involved.

[12] As we shall see, if the agent's successful completion time is verifiable, the principal can pay the agent at the end of period 1 or at the end of period 2. If, however, the successful completion time is unverifiable, the principal can only pay the agent at the end of period 2.

[13] Models similar to this have been a building block of many recent studies on moral hazard. See, e.g., Innes (1990), Baliga and Sjöström (1998), Tirole (2001), Che and Yoo (2001), Schmitz (2005), and Mylovanov and Schmitz (2008).

3 Main Results

3.1 Observable and Verifiable Effort

As a useful benchmark, we first consider a simple case in which the agent's effort is perfectly observable and verifiable. In this case, the principal's optimal contract needs only to provide the agent his reservation utility, which is the agent's (discounted) utility level when he is not working. Together with the optimal wage scheme $\mathbf{w} = (w_1, w_2)$, the principal can also specify a time-limit $D = 1 + k$, $k \in [0, 1]$, which can be interpreted as follows: The agent works on the project for the first period. If the project is not successful after the first trial, the project deadline is extended to the second period with probability k.[14] Notice that when $k = 0$ (resp., $k = 1$), it is equivalent that the principal sets a firm deadline $D = 1$ (resp., $D = 2$), after which the contract relationship between the two parties is terminated.

The principal's optimal contract is determined by:[15]

$$\max_{\{k,\ \mathbf{w}\}} \ (1-p) - w_1 + k\delta p\left((1-p) - w_2\right)$$
$$s.t. \quad \begin{array}{l} \mathbf{w} \geq 0, \\ w_1 + (1-p)\,\delta u + p\delta\left(kw_2 + (1-k)\,u\right) \geq u + \delta u, \end{array}$$

where the objective function is the principal's payoff, the first constraint $\mathbf{w} \geq 0$ is the agent's limited liability constraint and the second is the agent's participation constraint: the agent's expected payoff of exerting effort in both periods under wage scheme $\mathbf{w}$ is no less than his discounted sum of leisure utility from not working.

By evaluating the principal's expected payoffs from different deadlines, we easily obtain:

Lemma 1 *If the agent's effort is observable (and verifiable), then the principal's optimal deadline and wage scheme are, respectively,*

$$\hat{D} = 2 \text{ (i.e., } \hat{k} = 1 \text{) and } \hat{w}_1 + p\hat{k}\delta\hat{w}_2 = u + p\delta u.$$

Lemma 1 summarizes the principal's optimal contract: when the agent's effort is contractible, the principal should always allow maximal time for the agent to work. Hence, setting no tight deadline ($D^* = 2$) is optimal.

[14] This interpretation on deadline extension is adopted from Saez-Marti and Sjögren (2008). However, our formulation of deadlines enables us to represent all (tight, stochastic, and natural) deadlines compactly using a single variable $k \in [0, 1]$.

[15] As the principal pays the agent only on the successful completion of the project and a successful outcome is more likely when the agent exerts effort, it is never optimal for the principal to offer a positive wage when the output is not successful. Hereafter, wages are interpreted as the payments on a successful completion (similar arguments apply to problems ($\mathcal{P}$) and ($\mathcal{P}'$)).

3.2 Unobservable Effort and Time-Independent Wages

Now we turn to the more natural setting where the agent's effort is not observable. We first consider a rigid wage scheme which is independent of the agent's successful completion time. Such wage schemes naturally arise in scenarios where the successful completion time is difficult to verify before the final natural delivery deadline, making a time-contingent wage payment infeasible.

As the principal has two instruments to motivate the agent to work, she offers a contract that specifies a wage scheme w and a deadline $D = 1 + k$. The principal's optimal contract can be derived from the following constrained optimization problem $(\mathcal{P})$:[16]

$$(\mathcal{P}) \quad \begin{array}{ll} \max_{\{k,\ w\}} & (1-p)(1-\delta w) + kp\delta(1-p)(1-w) \\ & w \geq 0, \\ s.t. & U(1,1;k,w) \geq U(0,0;k,w) \quad (IC_1) \\ & U(1,1;k,w) \geq U(1,0;k,w) \quad (IC_2) \\ & U(1,1;k,w) \geq U(0,1;k,w) \quad (IC_3) \end{array},$$

where the principal maximizes her expected payoff under the limited liability constraint and the agent's incentive constraints (for example, (IC_1) implies that the agent does not prefer to "shirking in the first period and also shirking in the second period, if the deadlines is extended (with probability k)"). Function $U(e_1, e_2; k, w)$ is the agent's expected utility given an effort choice (e_1, e_2), a deadline $D = 1 + k$ and a time-independent wage scheme w. For instance, $U(1,1;k,w)$ is given by:

$$U(1,1;k,w) = (1-p)(w + \delta u) + p\delta[k(1-p)w + (1-k)u].$$

Notice that as the successful completion time is not verifiable, the wage payment is only delivered at the end of period 2.

Lemma 2 summarizes some useful observations of the agent's incentive constrains:

Lemma 2 *In the principal's maximization problem* $(\mathcal{P})$, (IC_3) *is the only incentive constraint that is binding, which implies that the minimum wage to induce effort from the agent in both periods* (*i.e.*, $e_1 = e_2 = 1$) *given deadline* $D = 1 + k$ *is:*

$$w^* = \frac{u - (q-p)k\delta u}{\delta(q-p)(1-k+pk)}. \tag{3.2}$$

In addition, given w^*, *if the project is failed after his first-period effort, the agent is still willing to work if the deadline is extended.*

[16] Technically speaking, the principal can also have the agent shirk in the first period and work in the second period. As our focus is on motivating an in-time completion without delay, such an arrangement is less natural and less important. We discuss this possibility in more detail at the end of Section 3.3.

Lemma 2 implies that given a fixed wage scheme w, the most profitable deviation for the agent is to shirk in the first period and work in the second period (if the deadline is extended) and this is true for any $k \in [0,1]$. Lemma 2 captures the essence of our casual observation that *the incentive to procrastinate is the most salient and deserves the most attention in designing a successful dynamic contract that involves only one project.* The main driving force of this result is that the agent is impatient and working makes the project more likely to be successful. In particular, "shirking in the first period and working in the second period (if the deadline is extended)" is better than "shirking in both periods" as viewed at the start of period 1, the expected benefit of working outweighs the cost of working. On the other hand, "shirking in the first period and working in the second" is better than "working in the first period and then shirking if the deadline is extended" as the cost of working in period one is disproportionally high because of discounting.

Given Lemma 2, the principal's maximum expected payoff by setting a deadline $D = 1 + k$ can be compactly written as:

$$E\pi(k) = (1-p) + pk(1-p)\delta - \frac{(1-p)(1+pk)(u - k(q-p)\delta u)}{(q-p)(1-k+pk)}. \tag{3.3}$$

From expression (3.3), we can easily calculate the principal's expected payoffs from setting (deterministic) deadlines $D = 1$ and $D = 2$ as, respectively,

$$\begin{array}{l} E\pi(k=0) = (1-p)\left(1 - \frac{u}{q-p}\right) \\ E\pi(k=1) = (1-p) + p(1-p)\delta - (1-p^2)\frac{u-(q-p)\delta u}{p(q-p)} \end{array}. \tag{3.4}$$

We are now ready to present our first main result:

Proposition 1 *If the principal offers a time-independent wage scheme at the end of period 2, then there exists* $\underline{u} = \frac{p(q-p)}{1-(q-p)}$ *such that*

1. *for all* $u < \underline{u}$*, there exist* $\underline{\delta}$*,* $\overline{\delta}$ *and a unique* k^* $(\underline{\delta}, k^* \in (0,1))$ *such that*

   (a) *the stochastic deadline* $D^* = 1 + k^*$ *is strictly optimal for the principal if and only if* $\delta \in (\underline{\delta}, \overline{\delta})$*;*

   (b) *the deterministic deadline* $D^* = 1$ *is strictly optimal for the principal if and only if* $\delta \in (0, \underline{\delta})$*;*

   (c) *the deterministic deadline* $D^* = 2$ *is strictly optimal for the principal if and only if* $\delta \in (\overline{\delta}, 1)$*;*

2. *For all* $u \in \left(\frac{p(q-p)}{1-(q-p)}, (q-p)\right)$*, the deterministic deadline* $D^* = 1$ *is strictly optimal for the principal for all* δ*.*

Proposition 1 shows that a stochastic deadline can outperform deterministic deadlines when the cost of effort is small and the two parties are somewhat patient. As one will see from the proof, result 1 (a) can be made stronger. In particular, any stochastic deadline with $k \in (0,1)$ is strictly better than any deterministic deadline for the principal when $u < \underline{u}$ and $\delta \in \left(\underline{\delta}, \overline{\delta}\right)$.

We have mainly chosen the criteria on δ as our focus in the proposition because δ reflects the main conflict between the two parties in allocating effort intertemporally: given that both parties discount future payoffs, the principal prefers the project to be done as early as possible, but the agent wants to postpone effort on the project. The following table presents some numerical illustrations of Proposition 1:

δ	q	p	u	$\underline{u}$	$\underline{\delta}$	$\overline{\delta}$	k^*
0.95	0.9	0.2	0.455	0.467	0.99	1.14	0
0.95	0.9	0.2	0.35	0.467	0.91	1.13	0.14
0.95	0.9	0.2	0.21	0.467	0.73	1.12	0.5
0.95	0.7	0.4	0.21	0.171	1.15	1.79	0
0.95	0.7	0.4	0.15	0.171	0.91	1.68	0.07
0.95	0.7	0.4	0.06	0.171	0.43	1.27	0.74
0.5	0.9	0.2	0.14	0.467	0.59	1.10	0
0.5	0.9	0.2	0.07	0.467	0.37	1.05	0.27
0.5	0.9	0.2	0.035	0.467	0.21	0.97	0.57
0.5	0.7	0.4	0.09	0.171	0.61	1.47	0
0.5	0.7	0.4	0.06	0.171	0.43	1.27	0.15
0.5	0.7	0.4	0.03	0.171	0.23	0.90	0.62

A direct observation from the table is that if the two parties' conflict on intertemporal effort allocation is fierce (δ small), the principal should in general choose a smaller k (for a fixed effort cost u), or viewed from an outsider, the principal should more frequently adopt tighter deadlines if an early completion of the project is more important for her.[17]

Proposition 1 is intuitive: When the successful completion time is not verifiable and hence a time-contingent wage scheme is not feasible, the principal has to resort to a strategic choice of deadlines in motivating the agent to work at a minimum wage payment.

If the discount factor is small, the conflict between the principal and the agent in allocating effort intertemporally is fierce. To induce the agent to exert effort in the first period, the principal uses the harshest threat of terminating the agent's choices in the future so as to bring down the wage payment to the agent. Technically, this is equivalent

[17] We present specific comparative statics results in Corollary 1.

to reducing the options the agent has, hence eliminating some incentive constraints the principal has to face in her maximization problem ($\mathcal{P}$).

On the other hand, if the parties are patient, the above-mentioned conflict between the principal and the agent is mild. In this case, setting a (premature) deterministic deadline is no longer optimal as the efficiency loss from not allowing the agent to work in the second period outweighs the benefit of reducing the wage payment to the agent. This being said, a stochastic deadline can surprisingly be better than the natural deadline (or $D = 2$). Intuitively, a stochastic deadline can have two effects: First, creating a threat to the agent so that it is "cheaper" to induce a first-period effort from the agent; Second, mitigating the efficiency loss from terminating the agent's opportunity of working further. These two effects work interactively, making a stochastic deadline be optimal.

Although the optimal value k^* is implicitly determined, a standard application of the implicit function theorem enables us to obtain the following corollary on some comparative statics on k^* when a stochastic deadline is strictly optimal:[18]

Corollary 1 *Consider the optimal stochastic deadline* $D^* = 1 + k^*$, $k^* \in (0, 1)$*, in Proposition 1. The probability* k^* *increases as* δ *increases, increases as* q *increases, but decreases as* u *increases, or* $\frac{\partial k^*}{\partial u} < 0$, $\frac{\partial k^*}{\partial \delta} > 0$ *and* $\frac{\partial k^*}{\partial q} > 0$.

3.3 Unobservable Effort and Time-Contingent Wages

In the previous section an optimal contract is derived for the principal in the situation where the successful completion time is not verifiable. In this case, the wage scheme is independent of the agent's successful completion time. Now we will consider another natural setting where the principal can instead offer a more flexible *time-contingent* wage scheme to motivate efforts from the agent. Such a wage scheme is natural in scenarios where the successful completion time is verifiable.

At first sight, such a more flexible wage scheme does not necessarily help the principal since after all, the principal only cares about the outcome of the project and a wage rate offered at the first period and that at the second period seem to only differ by a discount factor. We show in the following that such a more flexible wage scheme is, however, beneficial for the principal. Intuitively, depending on the importance of the successful completion time to the principal, the principal can now arrange the two wage payments (the wage contingent on successful completion in period 1 and the wage contingent on successful completion in time 2) such that the agent's incentive constraints can be tailored so that a threat from a premature deadline becomes less important.

[18] As the moral hazard issue is only reflected by the difference between p and q, it is enough to fix p and only focus on q.

More specifically, the principal now faces the following problem after adopting a time-contingent wage scheme:

$$
(\mathcal{P}') \quad \begin{array}{ll} \max_{\{k,\ w_1,w_2\}} & (1-p)(1-w_1) + pk(1-p)\delta(1-w_2) \\ & \mathbf{w} \geq 0, \\ s.t. & U(1,1;k,\mathbf{w}) \geq U(0,0;k,\mathbf{w}) \quad (IC_1) \\ & U(1,1;k,\mathbf{w}) \geq U(1,0;k,\mathbf{w}) \quad (IC_2) \\ & U(1,1;k,\mathbf{w}) \geq U(0,1;k,\mathbf{w}) \quad (IC_3) \end{array},
$$

where the objective function is the principal's expected payoff, $U(e_1, e_2; k, \mathbf{w})$ is again the agent's expected utility given a two-period effort choice (e_1, e_2), a wage scheme $\mathbf{w}$, and a (possibly) stochastic deadline $D = 1 + k$. For example, $U(1,1;k,\mathbf{w})$ can be now calculated as (if $k = 0$, then only e_1 and w_1 are relevant):

$$
U(1,1;k,\mathbf{w}) = (1-p)(w_1 + \delta u) + p\delta[k(1-p)w_2 + (1-k)u].
$$

The three incentive constraints ((IC_1), (IC_2), and (IC_3)) represent that effort choice $(1,1)$ is preferred to all possible deviations the agent might have.

We now present our second major result: An optimal deadline for the principal is always deterministic given a time-contingent wage scheme.

Proposition 2 *When the principal adopts a time-contingent wage scheme, then*

1. *for all* $u \leq \underline{u} = \frac{p(q-p)}{1-(q-p)}$, *the optimal deadline for the principal is* $\check{D} = 2$ $(or\ \check{k} = 1)$ *and the optimal wage scheme* $\check{\mathbf{w}}$ *is defined as:*

$$
\check{w}_1 = \frac{u + (1-q)\delta u}{q-p}, \text{ and } \check{w}_2 = \frac{u}{q-p}.
$$

2. *for all* $u \in \left(\frac{p(q-p)}{1-(q-p)}, (q-p)\right)$, *the deterministic deadline* $\check{D} = 1$ $(or\ \check{k} = 0)$ *is strictly optimal for the principal for all* δ *and the principal's optimal wage scheme is*

$$
\check{w}_1(y) = \frac{u}{q-p}.
$$

Proposition 2 extends a familiar result for one-shot moral hazard problems with risk-neutral parties and limited liability to a dynamic setting where in addition to moral hazard, the two parties also have conflicts on how to allocate the agent's effort intertemporally. Our result is that if the agent's cost of exerting effort is reasonably small, then the principal should allow maximal time for the agent to work, and at the same time, offer a higher first-period wage so as to induce a more difficult first-period effort. On the other hand, if the agent's opportunity cost is large, a firm premature deadline should always adopted as a threat to induce the first-period effort from the agent at a minimum wage payment.

Specifically, the intuition of Proposition 2 is as follows:

If the opportunity cost of exerting effort u is small, then it is relatively easy to induce the agent to work in the first period. When a time-contingent wage scheme is feasible, the principal can adjust the wage payments in different periods so as to effectively induce a (more difficult) first-period effort and at the same time, eliminate the efficiency loss from a premature deadline. Consequently, such a more flexible wage scheme enables the principal to employ maximal time for the agent to complete the project.

On the other hand, if the opportunity cost u is large, it is then very costly for the principal to induce effort for two periods from the agent. At the same time, as inducing the first-period effort is important for the principal, the principal should impose a firm deadline so as to offer the lowest possible wage.

Finally, the principal's optimal wage scheme features that the wage rate conditional on a first-period success is higher than that conditional on a second-period success: As the agent is impatient and thus has an incentive to postpone exerting effort, the principal has to offer a higher wage to motivate a first-period effort. Such an arrangement also benefits the principal as she prefers to have the project done as early as possible. This result is consistent with bonus clauses commonly seen in construction contracts. Notice that the size of "the bonus for early completion", defined as $(\breve{w}_1 - \breve{w}_2) = \frac{(1-q)\delta u}{q-p}$, crucially hinges on the two conflicts between the principal and the agent: the moral hazard conflict $\frac{(1-q)u}{q-p}$ and the intertemporal effort allocation conflict δ. If it is more difficult to detect shirking and/or the principal values an early completion more while the agent is more prone to delay, then the principal has to offer a higher bonus to encourage an early completion.

Our last result is on a comparison between the two optimal contracts under time-contingent and time-independent wage schemes.

Proposition 3 *The principal's expected payoff under the optimal contract with time-contingent wages is always larger than that from the optimal contract with time-independent wages.*

The driving force of Proposition 3 is that the rigid time-independent wage scheme provides the principal a binding constraint, without which, the efficiency loss from a strategic stochastic deadline can be eliminated. As mentioned before, this result theoretically justifies the rescindment of the FHWA policy which prohibited the government from participating bonus payments for early completion.

Finally, notice that in deriving the optimal deadline for the principal, we have only considered the deadline choice $D = 1 + k$, $k \in [0, 1]$ in optimal dynamic contracts with time-independent and time-contingent wage schemes. Rigorously speaking, the principal also has the option of having the agent only working in the second period, in which case, the principal's optimal wages and expected payoff are, respectively, $\tilde{w}_1 = 0$, $\tilde{w}_2 = \frac{u}{q-p}$ and

$$E\tilde{\pi} = (1-q) + q(1-p)\delta - (1-pq)\frac{u\delta}{q-p}.$$

Our implicit definition of k^* prevents us from obtaining an explicit parameter threshold where such an arrangement is optimal. However, we argue that such an option is of little interest. After all, such an arrangement is seldom seen, especially with the consideration of, e.g., project financing decision of the principal, making an early completion essential. Secondly, extensive simulations (available upon request) show that such an option is only optimal for the principal when the opportunity cost of working u is close to the principal's value of the project and/or the failure probability of not working q is small. Such cases are less interesting. A more problematic issue is that the first term in expression $E\tilde{\pi}$ represents the principal's expected payoff in the first period when the agent shirks. Notice that probability q is introduced only to capture moral hazard. Such a first-period benefit to the principal makes little sense in reality.

4 The Effect of Heterogenous Discounting

In the previous sections we have assumed that both the principal and the agent have the same discount factor. In this section we consider a natural extension of our basic model by allowing the principal and the agent to have different discount factors. Specifically, we assume that the principal (resp., the agent) has a discount factor δ_P (resp., δ_I). As will be seen, all major insights obtained for the identical discounting case still hold for this general case but some additional insights can also be obtained. As the analysis is rather similar to the equal discounting case, our discussion will be brief and less formal.

We first analyze the case of time-independent wage schemes. The principal's optimal contract problem under different discounting is then:

$$\begin{array}{ll} \max_{\{k,\ w\}} & (1-p)(1-\delta_P w) + kp\delta_P(1-p)(1-w) \\ & w \geq 0, \\ & U(1,1;k,w,\delta_I) \geq U(0,0;k,w,\delta_I) \quad (IC_1) \\ s.t. & U(1,1;k,w,\delta_I) \geq U(1,0;k,w,\delta_I) \quad (IC_2) \\ & U(1,1;k,w,\delta_I) \geq U(0,1;k,w,\delta_I) \quad (IC_3) \end{array}.$$

The principal's expected payoff can be written as:

$$E\pi(k;\delta_P,\delta_I) = (1-p) + pk(1-p)\delta_P - \frac{(1-p)(1+pk)(u-k(q-p)\delta_I u)\delta_P}{(q-p)(1-k+pk)\delta_I}.$$

As $E\pi(k;\delta_P,\delta_I)$ is again strictly concave in k, a sufficient condition for the existence of an interior maximizer $k^* \in (0,1)$ is:

$$\left.\frac{dE\pi(k)}{dk}\right|_{k=0} > 0 \, and \, \left.\frac{dE\pi(k)}{dk}\right|_{k=1} < 0,$$

which implies that:

$$\frac{u}{(p+u)(q-p)} < \delta_I < \frac{u}{(p^3+u(1+p+p^2))(q-p)}.$$

Hence, with different discounting for the two parties, the optimal deadline and the optimal wage scheme are very similar to the identical discounting case. An additional insight here is that the principal's discount factor plays no role in the optimal dynamic contract when the principal can only offer a time-independent wage scheme.

Next we turn to the case where the principal can offer a time-contingent wage scheme. Then the principal's optimization problem can be written as:

$$\begin{array}{ll} \max_{\{k,\ w_1,w_2\}} & (1-p)-(1-p)w_1+pk(1-p)\delta_P-p(1-p)k\delta_P w_2 \\ & \mathbf{w}\geq 0, \\ s.t. & U(1,1;k,\mathbf{w},\delta_I)\geq U(0,0;k,\mathbf{w},\delta_I) \quad (IC_1) \\ & U(1,1;k,\mathbf{w},\delta_I)\geq U(1,0;k,\mathbf{w},\delta_I) \quad (IC_2) \\ & U(1,1;k,\mathbf{w},\delta_I)\geq U(0,1;k,\mathbf{w},\delta_I) \quad (IC_3) \end{array}.$$

Adopting a similar proof as in Proposition 2, we immediately obtain the optimal time-contingent wage scheme as:

$$w_1^* = \frac{u+(1-q)ku\delta_I}{q-p},\ w_2^* = \frac{u}{q-p}.$$

The principal's expected payoff under the optimal wage scheme can thus be defined as:

$$E\check{\pi}(k) = (1-p)\left(1-\frac{u+(1-q)k\delta_I u}{q-p}+pk\delta_P\left(1-\frac{u}{q-p}\right)\right).$$

Hence the principal's optimal deadline $\check{k}$ can be obtained as follows:[19]

$$\text{If } u \geq \frac{p\delta_P(q-p)}{(p\delta_P+(1-q)\delta_I)} = \frac{p(q-p)}{\left(p+(1-q)\frac{\delta_I}{\delta_P}\right)}, \text{ then } \check{k}=0;$$

$$\text{If } u < \frac{p\delta_P(q-p)}{(p\delta_P+(1-q)\delta_I)} = \frac{p(q-p)}{\left(p+(1-q)\frac{\delta_I}{\delta_P}\right)}, \text{ then } \check{k}=1.$$

[19]This is calculated using $\frac{dE\check{\pi}(k)}{dk} = \frac{1-p}{q-p}(p\delta_P(q-p)-(p\delta_P+(1-q)\delta_I)u)$.

The difference between this result with the identical discounting case is that the threshold on the opportunity cost of working u now depends on the ratio $\frac{\delta_I}{\delta_P}$. A possible implication of such a dependence is that if the agent is more patient (resp., less patient) than the principal, then the range of opportunity cost where allowing maximal time for completion is optimal is smaller (resp larger). Viewed to an outsider, this implies that the principal should set a tight deadline $D = 1$ more frequently if the agent is more patient than the principal, compared to the identical discounting case.

Summarizing, the above results indicate that nothing essential depends on our assumption of identical discounting. However, an additional insight derived from the above exercise is that

- if compared to the agent, an early completion is extremely important for the principal, then setting a tight deadline is most likely an optimal option for the principal — consider the limiting case where $\frac{\delta_I}{\delta_P} \to +\infty$, then setting a tight deadline $D = 1$ is always optimal for the principal;
- if compared to the agent, the principal is arbitrarily more patient, then allowing the maximal time for the agent to complete the project is optimal — consider the limiting case where $\frac{\delta_I}{\delta_P} \to 0$, then setting a deadline $D = 2$ is always optimal for the principal.

5 Concluding Remarks

We have studied dynamic optimal contracts for a principal under moral hazard and a conflict between a time-consistent agent on how to allocate effort intertemporally. Our analysis highlights the interplay of deadlines and different wage schemes in this dynamic moral hazard setting. In particular, we have identified a trade-off between the strategic value of deadlines and the flexibility of wage schemes: facing a rigid time-independent wage scheme, the principal may have to resort to a stochastic deadline so as to both induce an early completion and minimize the efficiency loss from a premature deadline. We have also examined the role of time-contingent wage schemes and explored their implications. Our theoretical findings are quite consistent with some of the common practices in real contracts. We have also discussed the different discount factors case and found that all essential results for the identical discount factor case hold true for this more general case but some additional insights can be obtained for the general case.

It is important to point out that as O'Donoghue and Rabin (1999), Fischer (2001), Toxvaerd (2006, 2007), Saez-Marti and Sjögren (2008), our results hold when the principal can commit to stochastic and premature deadlines. If it is perfectly clear that at the contracting stage, the principal would always renegotiate the contract ex post, then no premature deadline can be credible, rendering the threat of terminating the contracting relationship early moot. However, in our first result, a stochastic deadline being optimal can alternatively be interpreted as that uncertainty about such commitment can be beneficial for the principal to resolve the procrastination issue, as well as to reduce the agent's expected wage payment. Such uncertainty can come from that, for example, the principal has imperfect commitment and/or the agent has imperfect information about the principal's (commitment) type and is thus uncertain on whether or not a deadline extension will be guaranteed in the end.

To abstract away the risk-sharing issue, we have also assumed that both parties are risk-neutral and the agent faces limited liability. However, it is well-known that risk-aversion and liquidated damages are also important factors to consider in real-world dynamic contracts. This extension is left for future research.

Appendix

Proof of Lemma 1. The participation constraint implies that the optimal wage scheme $\hat{\mathbf{w}} = (\hat{w}_1, \hat{w}_2)$ under $D = 1 + k$ satisfies $\hat{w}_1 + pk\delta\hat{w}_2 = u + pk\delta u$. The principal's expected payoff under deadline $D = 1 + k$ is $\hat{\pi}_k = (1 + pk\delta)(1 - p - u)$, which is strictly increasing in k. Hence, the optimal deadline is $\hat{k} = 1$ or $\hat{D} = 2$, and the optimal wage scheme $\hat{\mathbf{w}} = (\hat{w}_1, \hat{w}_2) \geq 0$ satisfies $\hat{w}_1 + p\delta\hat{w}_2 = u + p\delta u$. ■

Proof of Lemma 2. First, the agent's incentive constraints can be written as:

$$\begin{aligned}
&U(1,1;k,\mathbf{w}) \geq (1-q)\delta w + qk(1-q)\delta w + u + \delta u && (IC_1)\\
&U(1,1;k,\mathbf{w}) \geq (1-p)\delta w + pk(1-q)\delta w + \delta u && (IC_2)\\
&U(1,1;k,\mathbf{w}) \geq u + (1-q)\delta w + qk(1-p)\delta w + (1-qk)\delta u && (IC_3)\\
&U(1,1;k,\mathbf{w}) = (1-p+kp(1-p))\delta w + (1-pk)\delta u
\end{aligned}$$

It can be calculated that from the three incentive constraints (IC_1), (IC_2) and (IC_3), the minimum wages are respectively:[20]

$$\begin{aligned}
w^1 &= \frac{u + pk\delta u}{\delta\left[(q-p)(1-k) + (q^2-p^2)k\right]};\\
w^2 &= \frac{u}{q-p};\\
w^3 &= \frac{u - (q-p)k\delta u}{\delta(q-p)(1-k+pk)}.
\end{aligned}$$

[20] Denote $w^i(y)$ to be the minimum wage to sustain incentive constraint (IC_i), $i \in \{1, 2, 3\}$.

One can verify that given $0 < p < q < 1$, $\delta \in (0,1)$ and $k \in [0,1]$, we have[21]

$$w^3 \geq w^1 \geq w^2,$$

implying that given a fixed wage scheme w, the most profitable deviation for the agent is to shirk and then work in the second period if the deadline is extended.

Next, given the wage scheme w^3, the following inequality holds:

$$(1-p)\,\delta w^3 \geq (1-q)\,\delta w^3 + u,$$

which is equivalent to $(1-p) \geq (q-p)\,\delta$. This implies that given w^3, the agent is willing to exert effort if the project is failed in period 1 and the deadline is extended (if $k \in (0,1]$). ■

Proof of Proposition 1. As the principal's expected payoff under deadline $D = 1 + k$ is a smooth function of k, we have

$$\frac{d^2 E\pi(k)}{dk^2} = \frac{-2u(1-p)}{(q-p)(kp-k+1)^3}\left((1-p)+(q-p)\,\delta\right) < 0,$$

implying that $E\pi(k)$ is a *strictly* concave function of k.

Sufficiency: A sufficient condition for the existence of an interior maximizer $k^* \in (0,1)$ is

$$\left.\frac{dE\pi(k)}{dk}\right|_{k=0} > 0 \text{ and } \left.\frac{dE\pi(k)}{dk}\right|_{k=1} < 0, \tag{5.5}$$

which reduces to

$$\frac{\lambda}{p+\lambda(q-p)} < \delta < \frac{\lambda}{p^3+\lambda(q-p)(1+p+p^2)}, \tag{5.6}$$

where $\lambda = \frac{u}{q-p}$ is the minimum wage to induce the first-period effort from the agent (see (3.4)). Next, define $\underline{\delta}$ and $\overline{\delta}$ as respectively $\underline{\delta} = \frac{\lambda}{p+\lambda(q-p)}$ and $\overline{\delta} = \frac{\lambda}{p^3+\lambda(q-p)(1+p+p^2)}$. It is easily verified that $\overline{\delta} > \underline{\delta}$. In addition, we have that if $u < \underline{u} = \frac{p(q-p)}{1-(q-p)}$, $\underline{\delta} \in (0,1)$.[22]

Necessity: It is easy to see that condition (5.5) is also necessary for the existence of an interior maximizer k^* as $E\pi(k)$ is strictly concave.

Part 1 (b), (c) and part 2 of the proposition can be shown similarly and the proof is thus omitted. ■

[21] For example, $w^3 \geq w^1$ is equivalent to $\frac{(1+pk\delta)-qk\delta}{(1-k+pk)} \geq \frac{(1+pk\delta)}{(1-k+pk)+qk}$, which reduces to $1 \geq \delta - \delta k + \delta qk$. On the other hand, $w^1 \geq w^2$ also reduces to the same inequality $1 \geq \delta - \delta k + \delta qk$, which holds as $\delta, k, q \in [0,1]$.

[22] Notice that if $u < \underline{u}$, the expected payoff $E\pi(k=0)$ is also strictly positive.

Proof of Corollary 1. The optimal deadline k^* is implicitly determined by the first order condition

$$0 = \frac{dE\pi(k)}{dk} \equiv -\frac{1-p}{(q-p)} \frac{1}{(kp-k+1)^2} F(k;p,q,u,\delta). \tag{5.7}$$

Hence, k^* is implicitly defined by $F(k^*;p,q,u,\delta) = 0$. It is then easy to obtain

$$F_{k^*} = \frac{\partial F(k^*;q,p,u,\delta)}{\partial k^*} = 2p\delta(q-p)(k^*p-k^*+1)(1-p-u) > 0,$$

which according to the implicit function theorem, implies that equation $F(k^*;p,q,u,\delta) = 0$ implicitly defines a unique C^1 function $k^* = f(u,\delta,q,p)$. To derive the partial derivatives of the implicit function $k^* = f(p,q,u,\delta)$, we apply the implicit function theorem again to have:

$$\frac{\partial k^*}{\partial u} = -\frac{F_u}{F_{k^*}}; \frac{\partial k^*}{\partial \delta} = -\frac{F_\delta}{F_{k^*}}; \frac{\partial k^*}{\partial q} = -\frac{F_q}{F_{k^*}},$$

where F_q, F_u, F_δ and F_{k^*} are partial derivatives. Next, it is easily verified that[23]

$$\begin{aligned} F_u &= 1-(q-p)\delta\left(1+2k^*p+k^{*2}p^2-k^{*2}p\right) > 1-\frac{\lambda(q-p)(1+p+p^2)}{p^3+\lambda(q-p)(1+p+p^2)} > 0, \\ F_\delta &< F_\delta|_{k^*=1} = -(q-p)\left(u+pu+p^2u+p^3\right) < 0, \\ F_q &< F_q|_{k^*=1} = -\delta\left(u+pu+p^2u+p^3\right) < 0. \end{aligned}$$

We therefore conclude that $\frac{\partial k^*}{\partial u} < 0$, $\frac{\partial k^*}{\partial \delta} > 0$ and $\frac{\partial k^*}{\partial q} > 0$. ■

Proof of Proposition 2. Firstly, the agent's incentive constraints can be more explicitly written as:

$$\begin{aligned} &U(1,1;k,\mathbf{w}) \geq (1-q)w_1 + qk(1-q)\delta w_2 + u + \delta u && (IC_1) \\ &U(1,1;k,\mathbf{w}) \geq (1-p)w_1 + pk(1-q)\delta w_2 + \delta u && (IC_2) \\ &U(1,1;k,\mathbf{w}) \geq (1-q)w_1 + qk(1-p)\delta w_2 + u + (1-qk)\delta u && (IC_3) \\ &U(1,1;k,\mathbf{w}) = (1-p)w_1 + p(1-p)k\delta w_2 + (1-pk)\delta u. \end{aligned}$$

Notice that the incentive constraint (IC_1) can be derived using (IC_2) and (IC_3) and thus can be omitted in solving the problem $(\mathcal{P})$: Using (IC_2), we have $w_2 \geq \frac{u}{q-p}$. It is easily verified that this inequality, together with (IC_3), implies that (IC_1) holds.

Given the above argument, we can set up a Lagrangian function with α, β, x and y being the Lagrange multiplies associated with constraints $w_1 \geq 0$, $w_2 \geq 0$, (IC_2) and (IC_3), respectively. The first-order necessary conditions can be derived as:

$$\begin{aligned} -(1-p)+\alpha+y(q-p) &= 0, \\ -p(1-p)k\delta+\beta+(q-p)kx-k\delta(1-p)(q-p)y &= 0. \end{aligned}$$

[23] Notice that $F_u > 0$ is derived using $k^* \in (0,1)$ and inequality (5.6), while $F_\delta < F_\delta|_{k^*=1}$ and $F_q < F_q|_{k^*=1}$ are obtained by $F_{\delta k^*} = 2p(k^*p-k^*+1)(1-p-u) > 0$ and $F_{qk^*} = 2p\delta(k^*p-k^*+1)(1-p-u) > 0$, respectively.

Next, by the complementary slackness conditions $\alpha w_1 = \beta w_2 = 0$, (IC_2) and (IC_3), we can verify that the only possible case where (IC_2) and (IC_3) are not violated is $\alpha = \beta = 0$, implying that $y = \frac{1-p}{q-p} > 0$ and $x = \frac{\delta(1-p)}{(q-p)} > 0$, or (IC_2) and (IC_3) are both binding.[24] Using (IC_2) and (IC_3), the optimal wage rates can then be solved as:

$$\check{w}_1 = \frac{u + (1-q)\,k\delta u}{q-p}, \quad \check{w}_2 = \frac{u}{q-p}. \tag{5.8}$$

Hence, the principal's optimal expected payoff given a deadline $D = 1 + k$ is:

$$E\check{\pi}\,(k) = (1-p)\left(1 - \frac{u + (1-q)\,k\delta u}{q-p} + pk\delta\left(1 - \frac{u}{q-p}\right)\right), \tag{5.9}$$

from which we obtain

$$\frac{dE\check{\pi}\,(k)}{dk} = \frac{\delta\,(1-p)}{q-p}\left(p\,(q-p) - u\,(1-q+p)\right).$$

Therefore, we can identify a threshold $\underline{u}= \frac{p(q-p)}{(1-q+p)}$ such that if $u <\underline{u}$, $E\check{\pi}\,(k)$ is strictly increasing in k and the optimal deadline is $\check{D} = 2$ (or $\check{k} = 1$), while if $u \in (\underline{u}, (q-p))$, $E\check{\pi}\,(k)$ is strictly decreasing in k and the optimal deadline is $\check{D} = 1$ (or $\check{k} = 0$), independently of the discount factor δ. ■

Proof of Proposition 3. Notice that compared with $E\check{\pi}\left(\check{k}\right)$, the principal's optimal payoff $E\pi\,(k^*)$ defined in (3.3) can be derived as the outcome from the maximization $(\mathcal{P}')$ with an additional constraint $w_1 = \delta w_2$, which is always binding according to (5.8). We thus conclude that $E\check{\pi}\left(\check{k}\right) \geq E\pi\,(k^*)$ for all u, p, q and δ. ■

References

[1] S. Baliga and T. Sjöström, 1998, "Decentralization and Collusion", *Journal of Economic Theory*, **83**, 196-232.

[2] P. Bolton and M. Dewatripont, 2005, Contract Theory. Princeton, N.J.: *Princeton University Press.*

[3] Y.K. Che and S.W. Yoo, 2001, "Optimal Incentives for Teams", *American Economic Review*, **91**, 525-541.

[4] R.H. Clough, 2000, "Construction project management", *Publisher: John Wiley and Sons.*

[24] If $k = 0$, then constraint (IC_2) is trivially binding.

[5] M. Cyna, 1992, "Lane Rental: Creating Incentives for Early Completion of Road Work", *Transportation, Water and Urban Development Department, The World Bank, Transport No. RD-12.*

[6] C. Fischer, 2001, "Read This Paper Later: Procrastination with Time-Consistent Preferences", *Journal of Economic Behavior and Organization*, **46**, 249-269.

[7] D. Fudenberg, B. Holmström, and P. Milgrom, 1990, "Short-Term Contracts and Long-Term Agency Relationships", *Journal of Economic Theory*, **51**: 1-31.

[8] S. Guriev and D. Kvasov, 2005, "Contracting on Time", *American Economic Review*, **95** (5), 1369-1385.

[9] R.D. Innes, 1990, "Limited Liability and Incentive Contracting with Ex-ante Action Choices", *Journal of Economic Theory*, **52**, 45-67.

[10] J.-J. Laffont and D. Martimort, 2002, The Theory of Incentives: The Principal-Agent Model. Princeton, N.J.: *Princeton University Press.*

[11] J.M. Malcomson and F. Spinnewyn, 1988, "The Multiperiod Principal-Agent Problem", *Review of Economic Studies*, **55**: 391-407.

[12] T. Mukoyama and A. Şahin, 2005, "Repeated Moral Hazard with Persistence", *Economic Theory*, **25**: 831-854.

[13] T. Mylovanov and P. Schmitz, 2008, "Task Scheduling and Moral Hazard", *Economic Theory*, forthcoming.

[14] T. ODonoghue and M. Rabin, 1999, "Incentives for Procrastinators", *Quarterly Journal of Economics*, **114** (3): 769-816.

[15] A. OLeary, 2002, "Consequences of Late Completion", *Design Cost Data (DCD) Archives.*

[16] W.P. Rogerson, 1985, "Repeated Moral Hazard", *Econometrica*, **53**: 69-76.

[17] M. Saez-Marti and A. Sjögren, 2008, "Deadlines and Distractions", *Journal of Economic Theory*, **143**: 153-176.

[18] B. Salanie, 2002, The Economics of Contracts. London, England.: *The MIT Press.*

[19] P.W. Schmitz, 2005, "Allocating Control in Agency Problems with Limited Liability and Sequential Hidden Actions", *RAND Journal of Economics*, **36**, 318-336.

[20] J. Tirole, 2001, “Corporate Governance”, *Econometrica*, **69**, 1-35.

[21] F. Toxvaerd, 2006, “Time of the Essence”, *Journal of Economic Theory*, **129**: 252-272.

[22] F. Toxvaerd, 2007, “A Theory of Optimal Deadlines”, *Journal of Economic Dynamics and Control*, **31**, 493-513.