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INCOMPLETE CONTRACTS AND THE USE OF OPTIONS TO PREVENT HOLD-UP IN INVESTMENTS UNDER UNCERTAINTY

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Abstract

I consider the unilateral investment problem, in which a principal makes an asset specific investment not knowing the quality of the asset at the time of investing, and not knowing if the asset will end up being most productive if owned by the principal or not. The paper shows that unconditional ownership cannot provide first-best incentives for investment. A striking result is that giving the principal ownership leads to overinvestment, even without the investment affecting his outside option. In some cases first-best incentives for investment can be provided using an option contract where the principal after observing the quality of the asset is given the option to buy it at a pre-negotiated price.

1 Introduction

There is a literature on the scale and motives of direct investments by foreign firms (FDI) in the manufacturing sector of the Central and Eastern European Countries (CEECs). Some of the empirical literature[1] points to the importance of firm specific information in the investment decision. Møllgaard, Overgaard (1998) describes case studies of Siemens investing in Slovenia:

> Based on interviews with Siemens officials ... the main issue or difficulty for Siemens when entering into an FDI in the CEECs is the *availability of information*; next comes infrastructure, quality of the privatisation program/administration, macro economic conditions, and the exchange rate regime, in that order.

Typically a major investment decision by Siemens will be preceded by an initial licensing agreement. This initial agreement provides Siemens with a minority

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[1] Møllgaard, Schröder (1998) and Møllgaard, Overgaard (1998)

share ownership and an future option on a majority share. Møllgaard, Overgaard (1998):

> During the licensing period Siemens engages in training of a local staff and places its own staff at the partner "plant". By Siemens this is considered both as a means to increase productivity, but also as a tool to "get to know" each other.

Møllgaard, Overgaard (199) points to the specific case where, in 1993, Bosch-Siemens Hausgeräte GmbH (BSGH) bought Slovenian manufacturer Mali Gospodinjski Aparati (MGA):

> In March, 1993, Bosch-Siemens Hausgeräte GmbH (BSGH) bought Slovenian small appliances manufacturer Mali Gospodinjski Aparati (MGA). Prior to this, MGA was producing BSGH products under license and the BSGH brand names, as well at its own products under the brand name Gorenje. During this period, BSGH had transferred technology and know-how to the Slovenian partner. According to senior BSGH officials, the decision to fully take over MGA was made after all the relevant knowledge about the quality of the firm had been acquired through the cooperation (the partnership) in the period prior to 1993.

In this paper I develop an incomplete contracting model to explain this observed use of option contracts in foreign investments. I use a principal-agent model with the principal making an initial investment to improve productivity and learn the quality of the asset. It is shown that unconditional ownership cannot provide first-best incentives for the principal's investment. Giving the agent ownership will put the principal in a hold-up, ex-post; and giving the principal ownership will lead him to overinvest to improve his bargaining position ex-post. Casual intuition suggests that an option contract can serve as insurance for the principal once his investment is sunk. When the quality of the asset is high, and the return to investment is greatest, the bargaining power of the agent will be high, and the option will serve to protect the investment. Should the quality turn out to low, the principal can ignore the option and expect a lower price to be negotiated ex-post. The use of option contracts to resolve problems arising from incomplete contracts is not novel. Most notable Demski and Sappington (1991) show that an option contract can provide an agent with incentives to undertake the optimal investment in a moral hazard context absent renegotiations. In equilibrium the principal will subsequently always exercise his option to buy out the agent, and the agent will thus be perfectly insured. This implements the first-best investment. Edlin and Hermalin (1998) show that this solution is not renegotiation proof, and that options can implement the first-best in the moral hazard framework, only in cases where the principal has to be prevented from overinvesting.

This paper consists of two parts. The first half shows that with this kind uncertainty even a unilateral investment cannot be implemented at the first-best level under very general conditions. To state it differently; considering taking over a firm of uncertain value, requiring a large up-front specific investment, unconditionally buying a majority share will not provide the optimal incentives for investing. The second half shows that an option contract can remedy some of the hold-up problems present in the current framework, and thus provides an explanation for the observed use of these contractual agreements.

2 Model

In the model there are two risk-neutral parties. An agent, who owns an asset initially, and a principal. The quality of the asset is initially unknown to both parties, and is represented by the random variable $\theta \sim F(\theta), \theta \in [\underline{\theta}; \overline{\theta}]$. The distribution is common knowledge, but initially the realization of θ is unknown to the parties. Before learning the quality of the asset the parties sign a contract. The principal then undertakes a specific investment, $i \in [\underline{i}; \overline{i}]$, and the parties learns the quality of the asset. The expected utility for the principal is, $U_P = \Pi - p_0$. Here p_0 represents the payments made according to the initial contract, and Π is the expected realized net-revenue from the use of the asset and payments made or received through bargaining with the agent and then finally subtracting the cost of investing. Whoever holds title to the firm receives the net-revenues generated by the use of the asset.

The principal's investment and the revenues generated by using the asset are assumed unverifiable, and cannot be included in a contract between the two parties. Also assume that there is no third party to break the budget, and that the parties cannot commit not to renegotiate the terms of the contract. I assume that only direct payments between the parties and ownership of the asset are verifiable, can be included in a contract, and be expected to be enforced. These restrictions limit the choice of contractual agreement to giving one of the parties either unconditional ownership or the option to buy or sell the asset at a prespecified price.

One can think of the principal as an established firm that will use the asset together with its other assets. Although this part is not explicitly modelled, the 'quality' then captures the complementarities arising from the joint use of the assets and the success of the investment. The net-revenue generated by the asset, is denoted; $R(i;\theta)$ when the principal owns the asset, and $r(i;\theta)$ when the agent owns it. I make the following general assumptions about these functions:

Assumption 1 *:*

- $R(i;\theta), r(i;\theta)$ *differentiable in* i *and* θ
- $R'_i(i;\theta) > r'_i(i;\theta) \geq 0$ *and* $R'_\theta(i;\theta) > r'_\theta(i;\theta) \geq 0, \ \forall \theta, i$

This second point in this assumption captures the specificity of the investment to the principal. The asset is specific to the principal in the sense that given the investment level, if the asset is more profitable for the principal, so are all assets of a greater quality. Formally this can be expressed by the implied single-crossing property:

$$R(i,\hat{\theta}) \geq r(i,\hat{\theta}) \Rightarrow R(i,\theta) > r(i,\theta),\ \forall \theta > \ \hat{\theta} \tag{1}$$

Think of the space of qualities as larger than the space of investments. No matter what the level of investment is, there is a chance that the asset is of a so high quality that the principal wants it, or so low quality, that the agent wants it.

Assumption 2 $P[R(i^*,\theta) > r(i^*,\theta)] > 0$ *and* $P[r(i^*,\theta) > R(i^*,\theta)] > 0,\ \forall i$

The above assumptions implies that given the investment, a quality level that leaves the principal and agent with equal net-revenues, when they own the asset, is uniquely defined. This quality level is denoted $\tilde{\theta}(i)$, and it specifies the pivotal level determining the optimal allocation of the asset ex-post. The implicit function theorem together with the above assumptions ensures that $\tilde{\theta}'(i) < 0$. The intuition is straight forward; the more the principal has invested, the lower is the lowest quality of the asset that he will still want to acquire.

Definition 1 *Define* $\tilde{\theta}(i)$ *by,* $R(i,\tilde{\theta}(i)) - r(i,\tilde{\theta}(i)) = 0$

The timing of the model is as follows. First an initial contract is specified. Second the principal undertakes his investment i, which is observed by both parties. Third the quality θ is revealed. Fourth the ownership and payment specified by the initial contract is enforced. Fifth the ownership is renegotiated, the asset is placed where it yields the greatest payoff, and the surplus from renegotiation is divided according to the rules specified below. Sixth the revenue is realized to the party owning the asset.

Since θ is revealed to both parties, the renegotiation in step five takes place under symmetric information. Following the Coase Theorem leads us to assume that renegotiations will place the asset where it yields the greatest net-revenue. The parties will divide the surplus from renegotiation in some way, and will furthermore expect all this and take it into account, when they sign the initial contract and make the investment. The payment, p_0, associated with the initial contract will thus serve as a division of the expected surplus generated by the whole mechanism. This leads to the belief that the parties will use a contract that maximizes total surplus, incentive constraints taken into consideration, since this will maximize the individual utility of both parties.

Following Edlin and Reichelstein (1996), I remain agnostic about the extensive form of the bargaining game played in the renegotiations. Rather, like them, I assume that the parties follow a sharing rule, with none of the parties making take-it-or-leave-it offers. The principal and agent split the renegotiation surplus according to the differentiable rules, $\sigma_P : \Re \rightarrow \Re_+$ and $\sigma_A : \Re \rightarrow \Re_+$, respectively, satisfying:

Assumption 3 *:*

- $\sigma_A(S) + \sigma_P(S) = S$, *(efficiency).*
- $0 < \sigma'_A < 1,\ 0 < \sigma'_P < 1$, *(strict monotonicity).*
- $\sigma_A(0) = \sigma_P(0) = 0$.

Following Meza and Lockwood (1998), think of the revenues as the net-present value of a stream of payments prevailing during negotiations. This represents an inside option, and imply that in case the principal owns the asset, but $R(i;\theta) < r(i;\theta)$, and the asset ownership is thus renegotiated to the agent, and the net-revenue to the principal will be $R(i;\theta) + \sigma_P(S(i,\theta))$. With $S(i,\theta) = r(i,\theta) - R(i,\theta)$ being the surplus generated from renegotiation. So generally speaking the parties get their inside option plus their share of the surplus generated by the bargaining. Similarly, if the agent owns the asset, but $R(i,\theta) > r(i,\theta)$, the principal will buy the asset at a price, negotiated such that his net-revenue is $\sigma(R(i,\theta) - r(i,\theta))$. The principal's inside option during renegotiation is now zero.

Also note that it is without loss of generality to assume, that the contract specifies ownership at the time when θ is revealed, and that although θ is known at this time, the contract cannot be contingent on θ. But given an option to buy the asset the principal will let his decision on whether to exercise his option or not, depend on the observed realization of θ.

2.1 First-best

The total expected surplus generated with an investment level of i is : $\mathrm{TS}(i) = E[\max(R(i;\theta), r(i;\theta))] - i$. From the definition of $\tilde{\theta}(i)$ it follows that it can be written as:

$$\mathrm{TS}(i) = \int_{\underline{\theta}}^{\tilde{\theta}(i)} r(i;\theta)\ dF(\theta)\ + \int_{\tilde{\theta}(i)}^{\overline{\theta}} R(i;\theta)\ dF(\theta) - i \tag{2}$$

The first term integrates over the quality levels where the asset is most profitable to the agent, and the second, where it is most profitable to the principal. The first-best investment levels maximize total expected surplus: $i^*_{FB} = \operatorname{argmax}_i \mathrm{TS}(i)$. If the set i^*_{FB} does not contain any of the endpoints I will call it interior, and then the first-order condition satisfied by all elements in i^*_{FB} is[2]:

$$\mathrm{TS}'_i(i^*_{FB}) = \int_{\underline{\theta}}^{\tilde{\theta}(i^*_{FB})} r'_i(i^*_{FB};\theta)\ dF(\theta)\ + \int_{\tilde{\theta}(i^*_{FB})}^{\overline{\theta}} R'_i(i^*_{FB};\theta)\ dF(\theta) - 1 = 0 \tag{3}$$

[2] Using Leibniz' rule to get this expression, the additional term $r((i,\tilde{\theta}(i)) - R(i,\tilde{\theta}(i)))\tilde{\theta}'(i)$ equals zero from the definition of $\tilde{\theta}(i)$

3 Findings

As a benchmark assume that a contract is signed that just gives one of the parties unconditional ownership. That means either the agent keeps the asset, or it is sold to the principal.

Theorem 1 *If i^*_{FB} is interior and the initial contract gives the principal ownership of the asset then the optimal investment for the principal will be strictly greater than the first-best level.*

This theorem contrasts the standard theory of unilateral investments. Usually the optimal investment can be implemented by giving the investing party ownership[3]. These results relies on the asset always generating the most revenue when owned by the investing party. In the presence of uncertainty about this, ownership will lead the principal to overinvest. The marginal return of investments to the principal is greater than the marginal social return, because not only does investment improve the revenue when the principal ends up with the asset, but it also improves his bargaining position when the asset is renegotiated back to the agent.

Lemma 1 *If i^*_{FB} is interior and the initial contract lets the agent keep the asset, the principal's investment will be strictly lower than the first-best level.*

This is the standard hold-up scenario, the principal expects the agent to hold him up ex-post. When the asset is transferred to the principal through renegotiations, the agent will extract part of the surplus, leaving the principal with less that first-best incentives. When the agent keeps the asset, the principal does not benefit from the investment at all, leaving him with even weaker incentives.

4 Option Contracts

Consider what happens when the principal and the agent sign a contract giving the principal the option to buy the asset at a fixed price C, at some specified time after he has undertaken the investment and observed the quality of the asset. Having exercised the option, the principal will either keep the asset or, if $r(i;\theta) > R(i;\theta)$, sell it back to the agent. For tractability I will restrict attention to a special case of the sharing rules considered in the first part of the paper

Assumption 4 $\sigma_P(S) = \lambda \cdot S,\ \lambda \in (0;1)$.

Denote the net-gain to the principal from exercising his option $V(i,\theta)$ (excluding the exercise price). When the principal keeps the asset, his net-gain is the obtained revenue subtracting the surplus he would have obtained, had he instead acquired the asset through renegotiation. If he exercises his option and

[3] e.g. Demski, Sappington (1991) and Edlin, Hermalin (1998)

subsequently sells the asset, the net-gain is the expected surplus from the renegotiations.

$$V(i;\theta) = \begin{cases} R(i;\theta) - \sigma_P(R(i,\theta) - r(i,\theta)) & \tilde{\theta}(i) \leq \theta \leq \overline{\theta} \\ R(i;\theta) + \sigma_P(r(i;\theta) - R(i;\theta)) & \underline{\theta} \leq \theta \leq \tilde{\theta}(i) \end{cases}$$

Since the sharing rules are linear, this expression equals:

$$V(i,\theta) = (1-\lambda)R(i,\theta) + \lambda r(i,\theta) \tag{4}$$

The principal will choose to exercise the option when $V(i,\theta) \geq C$. Consider the quality-level that, given i and C, leaves the principal indifferent between exercising and not; $\theta^E(i,C)$. Since $V(i,\theta)$ is increasing in θ, the principal will exercise the option whenever the quality is greater than $\theta^E(i,C)$. The derivatives of $\theta^E(i,C)$ are, ${\theta^E}'_C = 1/V'_\theta(i,\theta) > 0$ and ${\theta^E}'_i = -V'_i/V'_\theta < 0$. This confirms the intuition that, the higher the exercise price, the higher a quality is required for the principal to exercise, and the higher the investment, the lower a quality is necessary to cover the cost of exercising.

Definition 2 $\theta^E(i,C)$ *is defined by* $V(i,\theta^E(i,C)) - C = 0$.

When $\tilde{\theta}(i) < \theta^E(i;C)$ there are quality levels where the principal will choose to ignore his option being able to subsequently negotiate a lower price. His expected net-revenue in these cases are:

$$\int_{\tilde{\theta}(i)}^{\theta^E(i;C)} \lambda(R(i;\theta) - r(i;\theta))\, dF(\theta) + \int_{\theta^E(i;C)}^{\overline{\theta}} R(i;\theta) - C\, dF(\theta)$$

When $\tilde{\theta}(i) > \theta^E(i;C)$, the principal will sometimes choose to exercise his option and subsequently sell the asset back to the agent. His expected net-revenue becomes:

$$\int_{\theta^E(i;C)}^{\tilde{\theta}(i)} R(i;\theta) + \lambda(r(i;\theta) - R(i;\theta)) - C\, dF(\theta) + \int_{\tilde{\theta}(i)}^{\overline{\theta}} R(i;\theta) - C\, dF(\theta)$$

Note that the two above expressions for net-revenue are equal, and that the expression for net-revenue is actually continuously differentiable, even in the presence of an option. This is a bit surprising at first, but is a consequence of the renegotiations that irons out the discontinuities.

Casual intuition suggests that the higher the exercise price, the less the principal will benefit from his investment, and the less inclined he will be to invest. The following theorem supports this intuition, under general assumptions.

Lemma 2 *The investment level maximizing the principal's net-revenue is non-increasing in the exercise price.*

By lowering C sufficiently the option contract imitates ownership by the principal, and by raising C it can imitate ownership by the agent. So it follows that an option can provides incentives we for both overinvestment and underinvestment, and that the optimal option contract will always do as least as well as unconditional ownership. An immediate consequence of this is the following lemma:

Lemma 3 *If i^*_{FB} is not interior, it can be implemented by either an unconditional ownership contract or an option contract.*

For the following analysis assume that i^*_{FB} is interior. The above arguments also show that if the optimal investment level varies continuously in C, it is possible to implement the first-best with an option. To be more specific, the following lemma shows that if the optimal investment is fully characterized by the first-order condition, the first-best can be implemented by an option contract. The theorem is an immediate consequence.

Lemma 4 *There exist a C^* such that $\Pi'_i(i^*_{FB}, C^*) = 0$*

Theorem 2 *If $\Pi(i, C)$ is concave the first-best investment level can be implemented by an option contract.*

Generally $\Pi(i, C)$ cannot be assumed concave, due to some inherent convexities it the expression. The convexities arises because when the principal invests, not only does he receive the marginal investment when he gets the asset, but he also increases the likelihood that he will actually get it, and thus increase the marginal benefit from all his previous investments. If this effect is sufficiently small it will be offset when $R(i, \theta)$ and $r(i, \theta)$ are sufficiently concave.

4.1 The Siemens Case

Recall the Siemens case described in the introduction. To recast the case in the current framework, let Siemens be the principal and MGA be the agent. The θ parameter represents the degree of compatibility of MGA's assets (human and non-human), with the assets of Siemens. The investment represents a transfer of technology and know-how to MGA. It seems reasonable to expect this transfer and training to enable Siemens to learn θ. The compatibility of MGA's asset to Siemens' does not in itself represent any value to MGA, and thus r is assumed to not depend on θ. Although extreme, it is further assumed that the investment, to the extent that it represents technology and know-how specific to Siemens, does not increase the value of the asset to MGA. $r(i, \theta)$ is thus assumed constant over i and θ and is normalized to zero. The last two additional assumptions are purely technical.

Assumption 5

- $r(i, \theta) = 0$

- *$TS(i)$ and $R(i,\theta)$ concave in i.*
- *$f(\theta)\frac{R_i'^2(i,\theta)}{R_\theta'(i,\theta)}$ non-decreasing in θ (monotonicity).*

The following theorem is the main result of the paper, and it shows that the present model may provide an explanation for the observed use of option contracts in Siemens' take-over of MGA.

Theorem 3 *Under the above assumptions, the first-best investment level can be implemented by the use of an option contract.*

5 Conclusions

In the presence of a fairly general adverse selection problem, it is shown that option contracts will be able to implement the first-best investment. The analysis supports the intuition that the option is used mainly to protect the investment against hold-up, ex-post, when the quality is high and the hold-up problem is most severe. Even when the first-best is not obtainable by option contracts, the analysis still provides arguments to explain the use of options. First it is shown that an option can always do as least as well as unconditional ownership, and will in many cases do strictly better. Second more elaborate contracts may not be feasible, either due to a less developed legal system, that may not enforce more complex contracts, or it may be that additional signals are simply not available to be contracted upon. Option contracts are efficient under these circumstances in the sense that they only require direct payments and ownership to be included in the contract and subsequently enforced.

There are a some additional comments to be made about the incomplete contracts approach. First the model by focussing on asset ownership ignores the internal structure of the firms and the external forces (like market position and structure) under which the firms operate. These are important factors. The model examines the investment decision only with respect to generated revenues, and these factors are implicitly assumed to be part of this revenue. Second if the principal is able to make sequential investments it is reasonable to expect him to initially invest just enough to learn the quality of the asset and later make additional investment based on the observed quality of the asset[4]. The one time investment can be explained by thinking of the quality as not being fully determined until after the investment is sunk. The quality will then to some degree capture the success of the investment.

[4] Nöldeke, Schmidt (1998) considers option contracts with sequential investments.

6 Appendix

Throughout the appendix, I will define $S(i;\theta) = r(i;\theta) - R(i;\theta)$, also note that:

$$\mathrm{TS}'(i) = \int_{\underline{\theta}}^{\tilde{\theta}(i)} r_i'(i;\theta)\ dF(\theta)\ + \int_{\tilde{\theta}(i)}^{\overline{\theta}} R_i'(i;\theta)\ dF(\theta) - 1 \tag{5}$$

6.1 Proof of Theorem 1

The expected payoff to the principal from owning the asset is :

$$\Pi(i) = \int_{\underline{\theta}}^{\tilde{\theta}(i)} R(i;\theta) + \sigma_P(S(i;\theta))\ dF(\theta) + \int_{\tilde{\theta}(i)}^{\overline{\theta}} R(i;\theta)\ dF(\theta) - i$$

Denote the set of maximisers i^*. The marginal return to investment is:

$$\Pi'(i) = \int_{\underline{\theta}}^{\tilde{\theta}(i)} (1 - \sigma_P'(S))R_i'(i;\theta) + \sigma_P'(S)r_i'(i;\theta)\ dF(\theta) + \int_{\tilde{\theta}(i)}^{\overline{\theta}} R_i'(i;\theta)\ dF(\theta) - 1$$

Assumption 2 implies that $\underline{\theta} < \tilde{\theta}(i)$, and by comparing the expressions, it is observed that $\mathrm{TS}'(i) < \Pi'(i)\ \forall i$. Define the function:

$$F(i,k) = \begin{cases} \mathrm{TS}(i) & \text{if } k = 0 \\ \Pi(i) & \text{if } k = 1 \end{cases}$$

The above relation between the marginals implies that $F(i,k)$ satisfies the single crossing property in $(i;k)$. From Theorem 4 in Milgrom and Shannon (1994) it follows that $i^* \geq_s i^*_{FB}$ in the strong set-order. The strict result follows from i^*_{FB} being interior and $\Pi'(i^*_{FB}) > \mathrm{TS}'(i^*_{FB})$, which implies that $i^* \cap i^*_{FB} = \emptyset$.

6.2 Proof of Lemma 1

Since the principals inside option equals zero, the expected payoff to the principal when the agent owns the asset is:

$$\Pi(i) = \int_{\underline{\theta}}^{\tilde{\theta}(i)} 0\ dF(\theta) + \int_{\tilde{\theta}(i)}^{\overline{\theta}} \sigma_P(R(i;\theta) - r(i;\theta))\ dF(\theta) - i$$

The marginal is :

$$\Pi'(i) = \int_{\tilde{\theta}(i)}^{\overline{\theta}} \sigma_P'(R(i;\theta) - r(i;\theta))(R_i'(i;\theta) - r_i'(i;\theta))\ dF(\theta) - 1$$

Comparing this expression to $\mathrm{TS}'(i)$, it is observed that $\mathrm{TS}'(i) > \Pi'(i)$. By arguments similar to those used in the preceding proof, it follows that the maximisers of $\Pi(i)$ are strictly less than i^*_{FB}.

6.3 Proof of Lemma 2

The principal's return from investment, when given an option is:

$$\Pi(i, C) = \int_{\tilde{\theta}(i)}^{\theta^E(i;C)} \lambda(R(i;\theta) - r(i;\theta))\ dF(\theta) + \int_{\theta^E(i;C)}^{\overline{\theta}} R(i;\theta) - C\ dF(\theta) - i$$

Remembering that by definition $R(i, \tilde{\theta}) - r(i, \tilde{\theta}) = 0$ and $(1 - \lambda)R(i, \theta^E) + \lambda r(i, \theta^E) = C$, it follows that:

$$\Pi_i'(i, C) = \int_{\tilde{\theta}(i)}^{\theta^E(i;C)} \lambda(R_i'(i;\theta) - r_i'(i;\theta))\ dF(\theta) + \int_{\theta^E(i;C)}^{\overline{\theta}} R_i'(i;\theta)\ dF(\theta) - 1$$

$$\Pi_{iC}''(i, C) = -\theta^{E\prime}_C(i, C) f(\theta^E)((1 - \lambda)R_i'(i, \theta^E) + \lambda r_i'(i, \theta^E)) < 0$$

$\Pi_{iC} < 0$ shows that i and C are substitutes. From Milgrom and Shannon (1994), and the logic from the preceding proofs it follows that the set of maximisers is non-increasing in C in the strong set order.

6.4 Proof of Lemma 3

Define $\overline{C}$ and $\underline{C}$ by $\theta^E(i_{FB}^*, \overline{C}) = \tilde{\theta}(i_{FB}^*)$ and $\theta^E(i_{FB}^*, \underline{C}) = \underline{\theta}$. By evaluating the function if follows that:

$$\Pi_i'(i_{FB}^*, \overline{C}) \ \square\ \mathrm{TS}_i'(i_{FB}^*) = 0$$

$$\Pi_i'(i_{FB}^*, \underline{C}) > \mathrm{TS}_i'(i_{FB}^*) = 0$$

Since $\Pi_i'(i, C)$ changes continuously in C the result follows.

6.5 Proof of Theorem 3

Notice that if i_{FB}^* is the optimal choice under an option contract, we must have $\theta^E(i_{FB}^*, C^*) < \tilde{\theta}(i_{FB}^*)$, and with $r(i, \theta) = 0$ we get:

$$\Pi_{ii}''(i, C) = \int_{\theta^E(i,C)}^{\tilde{\theta}(i)} (1 - \lambda)R_{ii}''(i;\theta)\ dF(\theta) + \int_{\tilde{\theta}(i)}^{\overline{\theta}} R_{ii}''(i;\theta)\ dF(\theta) + ... \qquad (6)$$

$$... + f(\theta^E)(1 - \lambda)\frac{R_i'^2(i, \theta^E)}{R_\theta'(i, \theta^E)} + f(\tilde{\theta}(i))\lambda\frac{R_i'^2(i, \tilde{\theta}(i))}{R_\theta'(i, \tilde{\theta}(i))}$$

From the monotonicity condition it follows that this can be bounded by:

$$\Pi''_{ii}(i,C) \,\square\, \int_{\theta^E(i,C)}^{\tilde{\theta}(i)} (1-\lambda) R''_{ii}(i;\theta)\ dF(\theta) + \int_{\tilde{\theta}(i)}^{\overline{\theta}} R''_{ii}(i;\theta)\ dF(\theta) + ... \tag{7}$$

$$... + f(\tilde{\theta}(i)) \frac{R_i'^2(i,\tilde{\theta}(i))}{R'_\theta(i,\tilde{\theta}(i))}$$

TS(i) concave implies:

$$\mathrm{TS}''(i) = \int_{\tilde{\theta}(i)}^{\overline{\theta}} R''_i(i;\theta)\ dF(\theta) + f(\tilde{\theta}(i)) \frac{R_i'^2(i,\tilde{\theta}(i))}{R'_\theta(i,\tilde{\theta}(i))} \,\square\, 0 \tag{8}$$

Subtracting this from the expression for $\Pi''_{ii}(i)$ one gets:

$$\Pi''_{ii}(i,C) \,\square\, \int_{\theta^E(i,C)}^{\tilde{\theta}(i)} (1-\lambda) R''_{ii}(i;\theta)\ dF(\theta) \,\square\, 0 \tag{9}$$

This shows that $\Pi(i,C)$ is concave in i, and the result follows from Theorem 2.

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