Research Article

Pierre Dubois and Tomislav Vukina*

Incentives to Invest in Short-Term vs Long-Term Contracts: Theory and Evidence

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Abstract: We study the effects of the change in contract length on the agents' incentives to invest and exert effort. We present an agent's dynamic decision model that explicitly deals with two types of investments and directly allows for contract regime switching by varying the probability of contract renewal. The fact that the unobservable investment in human capital is complementary with the agent's effort produces a result that increasing the probability of contract renewal increases investment and effort, with the consequent increase in production. We also show that there exists a specific level of investment in human capital, for which the investment in physical capital is profitable. We test these theoretical predictions using contract settlement data for the production of hatching eggs which covers the period when the contract changed from short-term to long-term. The obtained empirical results are largely supportive of the developed theory.

Keywords: contract duration, dynamic incentives, relationship-specific investments

1 Introduction

Theories of contractual structure typically study contract choice in a principal-agent framework where the principal chooses the terms of the contract to maximize her payoff for given characteristics of the agent and the production technology. The terms of the contract have two dimensions: contract type (e. g., salary vs piece rate) and contract duration (e. g., short-term vs long-term). In this paper we focus on contract length and study how the agent's incentives change as contract duration changes.

***Corresponding author: Tomislav Vukina**, Department of Agricultural and Resource Economics, North Carolina State University, Raleigh, North Carolina 27695-8109, United States, E-mail: tom_vukina@ncsu.edu

Pierre Dubois, Toulouse School of Economics, UT 1 Capitole, Toulouse, France, E-mail: pierre.dubois@tse-fr.eu

Long-term contracts have several advantages over short-term contracts. First, when agent works with long-lived assets, contract duration determines her stake in future outcomes and hence provides incentives for specific investments. Such investments often take an intangible form (e. g. human capital) and hence are not contractible. As a result, the distribution of gains from the relationship cannot be achieved via explicit ex-ante contracting but through ex-post negotiations in which the investing party typically does not appropriate the full marginal returns on the investment. The diluted incentives are the crux of the hold-up problem. Following influential work of Hart and Moore (1988), various solutions to the hold-up problem have been proposed such as the allocation of property rights (Hart 1995), allocation of bargaining power (Aghion, Dewatripont, and Rey 1994); option contracts (Noldeke and Schmidt 1995), breach remedies such as specific performance (Edlin and Reichelstein 1996) and, in continuous time, renegotiation-proof perpetual contract that allows unilateral termination with advance notice (Guriev and Kvasov 2005).

Second, long-term contracts can be used to smooth consumption and reduce risk when the agents have no access to credit markets. This result follows from the repeated moral hazard models where the optimal long-term contract generally exhibits *memory*, i. e., payments in each period are a function of past performance (Chiappori et al. 1994). In cases when the agent has access to credit markets, the outcome of the long-term contract can be replicated by a sequence of short-term contracts and the rationale for long-term contracting disappears, see Fudenberg, Holmstrom, and Milgrom (1990).

Finally, long-term contracts involve lower transaction costs because they need to be agreed upon less frequently. An implication is that long-term contracts should be more common when the opportunity cost of time of the involved parties is high (Bandiera 2007).

One of the main disadvantage of the long-term contracts stems from the fact that the principal's commitment to continuing the relationship removes the threat of contract termination which otherwise could serve the purpose of providing the agent with incentives to exert effort. In addition to eliciting effort, the threat of contract termination could provide incentives to invest as investments increase output in the next period and hence the probability of contract renewal (Banerjee and Ghatak 2004).¹

¹ Another disadvantage of long-terms contracts is due to their rigidity which could prevent efficient matching of workers and firms due to asymmetric information problems, see e.g. Terviö (2009) or Anderson and Smith (2010). In our case, however, the contract duration change creates only an incentive effect, i. e., we are not studying the possible effects that contract duration change could have on hiring and consequently on the composition of agents under contract.

The empirical literature on contract duration is rather thin, with some notable exceptions. Joskow (1987) showed that contracts between coal suppliers and electric utilities are longer when relationship-specific investments are important. Crocker and Masten (1988) showed that natural gas contracts are shorter when flexibility becomes more important. Brickley, Misra, and Van Horn (2006) found that the duration of franchise agreements increases as the non-contractible investments become more important and decreases when the need for flexibility increases. Bandiera (2007) found that the choice of tenancy contract length is driven by the need to provide incentives for non-observable investments taking into account transactions costs and imperfections in the credit market that makes incentives provision costly. Finally, based on the contracts between carriers and truck drivers, Masten (2009) showed that the use of long-term contracts can be justified, even when trade involves no relationship-specific investments and termination is the only remedy, as a device for minimizing the cost of determining prices in a series of heterogeneous transactions.

The main objective of this paper is not to explain the determinants of contract length but to study the change in incentives associated with contract duration switch. As we do not model the principal's side of the problem, consequently, we make no claims about the optimality of the underlying contract. Our theoretical approach is unique in two respects. First, it provides a complex but analytically tractable dynamic decision model that explicitly deals with two types of investments and directly allows for contract regime switching by varying the probability of contract renewal parameter. The fact that the unobservable investment in human capital (specific knowledge) is complementary with the agent's effort produces a result that increasing the probability of contract renewal increases investment and effort, with the consequent increase in production. Regarding the second type of investment, the theory shows that there exists a specific level of investment in human capital, for which the investment in physical capital (technology adoption) is profitable. Unlike in Rey and Salanié (1990) our model does not allow the renegotiation of contract parameters based on the agent's performance and hence we cannot assume that the long-term optimal contract can be implemented with short-term contracts.

The above theoretical predictions are tested against the contract settlement data for the production of hatching eggs. This unique data set comes from one integrated poultry company that contracts the production of eggs with independent growers (farmers). Most of the contracts observed in the poultry industry used to be short-term (one flock at the time). However, in the middle of the period covered by our data, the poultry company has changed its contract from short-term to long term (15 years). We hypothesize that replacing a short-term

contract with a long-term one affects agents' incentives to carry out observable and unobservable investments with a measurable impact on agents' performance across various productivity margins.

The incentives effects are easier to assess when they stem from some exogenous change in incentives structure. In such a case there is no selection bias due to endogenous contract duration choice because the same people successively face different contracts and hence any resulting change in behavior can safely be attributed to the variation in incentives. A potential limitation of this kind of analysis is that the change in the incentive structure may fail to be truly exogenous. This is especially the case under the assumption that firms are supposed to adopt optimal contracts. If the switch from short-term to long-term contracts indicates that for some reason short-term contracts were optimal before the change but ceased to be optimal by the time the change has been implemented, then a direct regression will provide biased estimates, at least to the extent that the factors affecting the efficiency of short-term contracts had an impact on growers' investments and productivity (Chiappori and Salanié, 2003).

Acknowledging the reality that in actual business environments inefficient contracts could exist, our identification strategy hinges on the argument that the observed contract change from short-term to long-term happened in response to an exogenous change in regulatory environment. Our argument is based on two observations. First, the frequent contract changes in its short-term period strongly suggest that the observed contract was never fully optimal but rather the result of a trial-and-error search for what works best. Second, the timing of the introduction of the new breed of birds that could be construed as prompting the contract switch clearly indicates that the change in contract duration from short-term to long-term preceded the introduction of the new breed by more than a year.

Our results show that switching from a short-term to a long-term contract resulted in faster adoption of both observable and unobservable productivity enhancing technologies and practices and increased effort that initially improved performance across various performance margins. After technological change has been fully absorbed, the performance across all margins decreased which could be attributable to the reduction in the steady-state level of effort.

To the best of our knowledge, our analytically tractable dynamic decision model that explicitly deals with two types of investments and directly allows for contract regime switch by varying the probability of contract renewal is unique. The technological relationships where physical investment raises the productivity of effort and investments in human capital reduce the cost of effort are so pervasive in real-life situations that they make this model easily adaptable to

many different types of contracting situations such as share-cropping, franchising and equipment leasing, to name only a few.

2 The Model

A dynamic optimization model developed in this paper deals only with the agent's side of the principal-agent problem where the principal (firm) contracts the production of certain output with an independent agent (producer). Contract is one-sided, i. e. offered by the principal to the agents on a *take-it-or-leave-it* basis. Contract parameters that solve the principal's intertemporal optimization problem are treated as exogenous and fixed in the agent's decision problem. We also implicitly assume that the agent's participation constraint is *ex ante* satisfied such that the contract is accepted and continue to be accepted after the contract switches from the short-term to the long-term format.

The central feature of the model is its emphasis on the incentives to invest in relationship-specific assets and the related exertion of effort, both of which could be altered when the contract regime switches from short-term to long-term. The agent can make two types of investments: in physical capital φ which is deemed observable and in human capital or skills k which is deemed unobservable. The investment in physical capital (production technology) φ is discrete, i. e. the agent either buys and installs a certain piece of machinery or equipment in which case $\varphi = 1$ or does not in which case $\varphi = 0$. This investment incurs a fixed cost normalized to 1 and paid when acquired. The unobservable investment i in specific knowledge (skills) increases the stock of specific knowledge k and costs $C(i)$. We assume that the stock of knowledge depreciates at rate $\mu \in (0, 1)$ but increases additively with investment i such that $k = \mu k_0 + i$, where k_0 is the previous period stock of knowledge. Notice that we prefer to model the agent's decision making in terms of choosing k rather than i which is the same as long as the implicit constraint $i \geq 0$ is satisfied.

In addition to these two types of investments, the agent also supplies an unobservable productive effort e whose cost depends on accumulated knowledge k as given by $G(e, k) = \frac{e^2}{2k}$. Thus, the unobservable investment i increases specific knowledge k which reduces the marginal cost of effort.² Physical investment φ raises the productivity of effort such that the production function is given by

² Since in the existing model we do not explicitly model the principal's side of the problem, the fact that effort and the investment in human capital are unobservable is immaterial but it is important for understanding the origins of many empirically observed contracts.

$$q(e, \varphi) = \pi(\varphi) e \varepsilon$$

where ε is a production shock unknown at the time when effort is exerted, with $\pi(1) > \pi(0) > 0$. Finally, the payment function $w(q)$ is assumed to be linear such that $w(q) = \alpha q + \beta$, with α denoting the piece rate (bonus) and β denoting the fixed salary.

The salient feature of our model is the assumption that agents are behaving in a dynamically optimal fashion by maximizing the expected discounted sum of their individual per period utilities. Within this context we treat the probability of contract renewal p at each period as well as the contract parameters α and β as principal's ex ante commitments. Also $p \in [0, 1]$ can be treated as the agent's belief about the likelihood of contract renewal. Committing to a renewal probability p encompasses the full commitment case where $p = 1$ and the no-commitment case where $p < 1$. The limiting case where $p = 0$ corresponds to the situation where the agent, knowing that the contract will not be renewed, behaves myopically by ignoring the future benefits of investing. Contract parameters α, β, p are chosen by the principal.³

Concretely, at each period t , an agent makes a decision that maximizes the current period utility plus the discounted sum of all next period utilities weighted by the probability that the contract will be renewed. The instantaneous utility of the agent who invests k_t and exerts effort e_t is $U(w(q_t)) - G(e_t, k_t) - C(k_t - \mu k_{t-1})$ where $U(\cdot)$ is an increasing concave function. Then, the expected discounted utility of the agent who has initial knowledge k_0 if he decides to invest in physical capital φ will be

$$V(k_0, 1) = \max_{\{e_t, k_t | \varphi_t = 1\}_{t \geq 1}} \sum_{t=1}^{\infty} (p\phi)^{t-1} [EU(w(q_t)) - G(e_t, k_t) - C(k_t - \mu k_{t-1})] - 1 \quad [1]$$

where 1 is the fixed cost and $\phi \in [0, 1]$ is the per period discount factor. The expected discounted utility of the agent who has initial knowledge k_0 if he decides not to invest in physical capital will be

$$V(k_0, 0) = \max_{\{e_t, k_t, \varphi_t \in \{\varphi_{t-1}, 1\}\}_{t \geq 1}} \sum_{t=1}^{\infty} (p\phi)^{t-1} [EU(w(q_t)) - G(e_t, k_t) - C(k_t - \mu k_{t-1})] - 1_{\{\varphi_t > \varphi_{t-1}\}} \quad [2]$$

³ Unlike in Rey and Salanié (1990) where long-term contracts can be implemented by short-term renegotiable contracts in a repeated moral hazard environment, in our case the technology and preferences are not time separable because of the accumulation of human capital k and of the lump sum physical investment φ .

where by convention $\varphi_0 = 0$ and $1_{\{\varphi_t > \varphi_{t-1}\}}$ represents the fixed cost of investing in physical capital that has been normalized to 1. It is equal to one if $\varphi_t = 1$ and $\varphi_{t-1} = 0$ and zero for all other periods because this investment choice is made only once ($\varphi_t \in \{\varphi_{t-1}, 1\}$). Then, denoting $\delta = p\phi$, we can write the previous equations in a recursive form as

$$V(k_0, 1) = \max_{\{e_1, k_1\}} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta V(k_1, 1)] \quad [3]$$

and

$$V(k_0, 0) = \max_{\{e_1, k_1, \varphi_1 \in \{0, 1\}\}} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta (V(k_1, \varphi_1) - \varphi_1)], \quad [4]$$

which can also be written as

$$V(k_0, 0) = \max_{e_1, k_1} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta \max(V(k_1, 1) - 1, V(k_1, 0))]. \quad [5]$$

If the contract is a one-period contract with zero probability of renewal, then $V(k, \varphi)$ is simply equal to the agent's one period expected utility $EU(w(q)) - G(e, k) - C(k - \mu k_0)$. If, at each period, the contract has the probability of renewal equal unity (i. e. becomes effectively long-term), then $V(k, \varphi)$ is the sum of the expected discounted utilities. Recall that ϕ and p and thus δ are completely exogenous, but the fact that $\delta > 0$ makes the optimal choice of k different from the one selected when $\delta = 0$. The optimal choice of k also depends on φ . Thus both k_1 and φ_1 (chosen in period 1) depend on δ .

In order to proceed, we simplify the above general framework by assuming that agent's preferences are such that the expected utility of wage w satisfies the mean-variance criterium:

$$EU(w) = Ew - \frac{\gamma}{2} \text{var}(w)$$

where $E(\cdot)$ denotes the expectation operator and γ represents Arrow-Pratt coefficient of risk aversion.⁴ Without loss of generality, let's assume that initially the agent has not invested in φ , hence $\varphi_0 = 0$, and has a stock of knowledge investment k_0 . Now, the agent can choose to invest in which case $\varphi = 1$, or postpone the decision into the next period in which case $\varphi = 0$. If the agent

⁴ This mean-variance criterium can be justified with quadratic utility or with constant absolute risk aversion (CARA) preferences and normally distributed income.

chose not to invest ($\varphi = 0$) then he chooses both effort e and investment k according to

$$\max_{e, k | \varphi = 0} Ew(q) - \frac{\gamma}{2} \text{var}(w(q)) - G(e, k) - C(k - \mu k_0) + \delta \max(V(k, 0), V(k, 1) - 1)$$

where he takes into account the next period value of contracting given his investment in k , which is the maximum of $V(k, 0)$ and $V(k, 1) - 1$, depending on whether he will invest in φ next period. If the agent chooses to invest in φ (paying a unit cost of 1) then he chooses both effort e and investment k (taking into account that φ increases the current productivity of effort) according to

$$\max_{e, k | \varphi = 1} Ew(q) - \frac{\gamma}{2} \text{var}(w(q)) - G(e, k) - C(k - \mu k_0) - 1 + \delta V(k, 1)$$

where $V(k, 1)$ is the next period value of having invested k and having invested in φ .

Given φ and using $\text{var}(w(q)) = \alpha^2 \pi(\varphi)^2 e^2 \sigma^2$, the optimal choice of agent's effort is obtained by solving

$$\max_{e, k | \varphi} \alpha \pi(\varphi) e + \beta - \frac{\gamma}{2} \alpha^2 \pi(\varphi)^2 e^2 \sigma^2 - \frac{e^2}{2k} - C(k - \mu k_0) - \varphi + \delta \max_{\varphi' \in \{\varphi, 1\}} [V(k, \varphi') - 1_{\{\varphi' > \varphi\}}]$$

where $\varphi' \in \{\varphi, 1\}$ denotes the next period investment in physical capital. Assuming the agent is not indifferent between $\varphi' = 0$ or 1 at the optimum, the first-order conditions satisfied by the optimal values e^*, k^* are

$$\frac{e^*}{k^*} = \frac{\alpha \pi(\varphi)}{1 + k^* \gamma \alpha^2 \pi(\varphi)^2 \sigma^2} \quad [6]$$

$$\frac{1}{2} \left(\frac{e^*}{k^*} \right)^2 = C'(k^* - \mu k_0) - \delta V'(k^*, \varphi'). \quad [7]$$

where $V'(\cdot, \varphi)$ denotes the derivative of $V(\cdot, \varphi)$ with respect to its first argument k (and we have used the envelope theorem with respect to φ' which also depends on k). Based on expressions [6] and [7] we can state our main results that are summarized in the following three propositions.

Proposition 1: The optimal investment in specific human capital k^* and the productive effort e^* are increasing in the probability of contract renewal δ .

Proof of Proposition 1:

The proofs that the value functions $V(\cdot, 0)$ and $V(\cdot, 1)$ are increasing and concave functions of their argument k are contained in Lemmas 1 and 2 in the Appendix.

As we are interested in the effect of a higher contract renewal probability, it is useful to explicitly recognize that the endogenous value functions depend on the renewal probability p and thus on δ . Thus, expressions [6] and [7] imply that

$$k^* = \frac{1}{\gamma\sigma^2} \frac{1}{\alpha\pi(\varphi)} \left[T(k^*, \delta) - \frac{1}{\alpha\pi(\varphi)} \right]$$

with $T(k, \delta) = [2C'(k - \mu k_0) - 2\delta V'(k, \varphi', \delta)]^{-\frac{1}{2}}$.

Direct derivation with respect to δ of $V(k, \varphi', \delta)$ using the envelope theorem on expressions [2] and [1] show that $V'(k, \varphi', \delta)$ is increasing convex in δ . Thus $\delta V'(k, \varphi', \delta)$ is increasing in δ because $\frac{\partial T}{\partial \delta} > 0$.

Then

$$\frac{\partial k^*}{\partial \delta} = \frac{\frac{\partial}{\partial \delta} T(k^*, \delta)}{\alpha\pi(\varphi)\gamma\sigma^2 - \frac{\partial}{\partial k} T(k^*, \delta)} > 0$$

because $\frac{\partial T}{\partial k} < 0$ and $\frac{\partial T}{\partial \delta} > 0$.

Since

$$e^* = \frac{\alpha\pi(\varphi)k^*}{1 + k^*\gamma\alpha^2\pi(\varphi)^2\sigma^2},$$

then $\frac{\partial e^*}{\partial \delta} = \frac{\alpha\pi(\varphi)\frac{\partial k^*}{\partial \delta}}{(1 + k^*\gamma\alpha^2\pi(\varphi)^2\sigma^2)^2} > 0$ because $\frac{\partial k^*}{\partial \delta} > 0$. $\square$

Proposition 2: Gross physical capital investment always provides the agent with positive benefits, that is: whatever k_0 , $V(k_0, 1) > V(k_0, 0)$.

Proof of Proposition 2:

Let's treat the productivity parameter $\pi(\varphi)$ as an independent parameter π such that we can define $W(k, 0, \pi)$ and $W(k, 1, \pi)$ as the value functions solution to the recursive formulation

$$W(k_0, 1, \pi) = \max_{\{e_1, k_1\}} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta W(k_1, 1, \pi)]$$

and

$$\begin{aligned} W(k_0, 0, \pi) &= \max_{\{e_1, k_1, \varphi_1 \in \{0, 1\}\}} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) \\ &\quad + \delta(W(k_1, \varphi_1, \pi) - 1_{\{\varphi_1 > 0\}})] \\ W(k_0, 0, \pi) &= \max_{e_1, k_1} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta \max \\ &\quad (W(k_1, 1, \pi) - 1, W(k_1, 0, \pi))]. \end{aligned}$$

Using the same arguments as in Proposition 1, it is clear that value functions $W(k_0, 0, \pi)$ and $W(k_0, 1, \pi)$ are increasing in π . Actually, we can check that this is true by defining

$$T(k_0, 1, \pi) = \max_{\{e_1, k_1\}} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta W(k_1, 1, \pi)]$$

and

$$T(k_0, 0, \pi) = \max_{e_1, k_1} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta \max(W(k_1, 1, \pi) - 1, W(k_1, 0, \pi))].$$

Then if $W(k_0, 0, \pi)$ and $W(k_0, 1, \pi)$ are both increasing in π then $T(k_0, 0, \pi)$ and $T(k_0, 1, \pi)$ are also increasing in π . Actually

$$\begin{aligned} \frac{\partial T_0(\pi)}{\partial \pi} &= \alpha e^* (1 - \gamma \alpha \pi e^* \sigma^2) + \delta \frac{\partial W(k^*, 0, \pi)}{\partial \pi} 1_{W(k^*, 1, \pi) - 1 < W(k^*, 0, \pi)} \\ &\quad + \delta \frac{\partial W(k^*, 1, \pi)}{\partial \pi} 1_{W(k^*, 1, \pi) - 1 \geq W(k^*, 0, \pi)} \end{aligned}$$

is positive because $e^* = \frac{k^* \alpha \pi}{1 + k^* \gamma \alpha^2 \pi^2 \sigma^2}$ and $1 - \gamma \alpha \pi e^* \sigma^2 = \frac{1}{1 + k^* \gamma \alpha^2 \pi^2 \sigma^2} > 0$, and

$$\frac{\partial T_1(\pi)}{\partial \pi} = \alpha e^* (1 - \gamma \alpha \pi e^* \sigma^2) + \delta \frac{\partial W(k^*, 1, \pi)}{\partial \pi} > 0.$$

Thus, using a fixed point argument, $W(k_0, 0, \pi)$ and $W(k_0, 1, \pi)$ are both increasing in π .

Next, if $W(k, 0, \pi) \leq W(k, 1, \pi) \forall k$, then

$$\begin{aligned} T(k_0, 0, \pi) &= \max_{e_1, k_1} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta \max(W(k_1, 1, \pi) - 1, W(k_1, 0, \pi))] \\ &\leq \max_{e_1, k_1} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta \max(W(k_1, 1, \pi) - 1, W(k_1, 1, \pi))] \\ &\leq \max_{e_1, k_1} [EU(w(q_1)) - G(e_1, k_1) - C(k_1 - \mu k_0) + \delta W(k_1, 1, \pi)] = T(k_0, 1, \pi). \end{aligned}$$

Again, using the fixed point argument, $W(k, 0, \pi) \leq W(k, 1, \pi)$ for all k . As $V(k_0, 1) = W(k_0, 1, \pi(1))$ and $V(k_0, 0) = W(k_0, 0, \pi(0))$ we have that

$$V(k_0, 1) = W(k_0, 1, \pi(1)) \geq W(k_0, 1, \pi(0)) \geq W(k_0, 0, \pi(0)) = V(k_0, 0).$$

Therefore, whatever $\delta > 0$ and whatever k_0 , $V(k_0, 1) \geq V(k_0, 0)$. $\square$

Next, because the investment in physical capital is costly (its net value is given by $V(k_0, 1) - 1$), the technology adoption can sometimes be profitable and sometimes not, despite the fact that the adoption *per se* always generates positive benefits. Proposition 3 shows a rather intuitive result that the adoption of new performance enhancing technology could be unprofitable in a given time period where the level of human capital (accumulated knowledge or skills) is low, but could become profitable the next period after more human capital k has been acquired.

Proposition 3: Given contract and technological parameters $\alpha, \delta, \pi(0)$ and $\pi(1)$, and a risk neutral agent; there exists a threshold for the investment in specific capital k_0 above which the investment in physical capital φ is profitable, i. e. $V(k_0, 1) - 1 \geq V(k_0, 0)$.

Proof of Proposition 3:

Looking at the limit case where $\delta = 0$ and $\gamma = 0$ (risk neutrality), we have

$$\begin{aligned} V(k_0, 0) &= k^*(\pi(0))C'(k^*(\pi(0), k_0) - \mu k_0) - C(k^*(\pi(0), k_0) - \mu k_0) + \beta \\ V(k_0, 1) - 1 &= k^*(\pi(1))C'(k^*(\pi(1), k_0) - \mu k_0) - C(k^*(\pi(1), k_0) - \mu k_0) + \beta - 1 \end{aligned}$$

because $\frac{e^*(\pi(\varphi), k_0)}{k^*(\pi(\varphi), k_0)} = \alpha\pi(\varphi) = [2C'(k^*(\pi(\varphi), k_0) - \mu k_0)]^{\frac{1}{2}}$.

Then it follows that

$$\begin{aligned} V(k_0, 1) - 1 - V(k_0, 0) &\geq \mu k_0 [C'(k^*(\pi(1), k_0) - \mu k_0) - C'(k^*(\pi(0), k_0) - \mu k_0)] - 1 \\ &\geq \mu k_0 [\pi(1) - \pi(0)] C''(k^*(\pi(0), k_0) - \mu k_0) - 1 \\ &= \mu k_0 [\pi(1) - \pi(0)] C'' \left(C'^{-1} \left(\frac{\alpha^2 \pi(0)^2}{2} \right) \right) - 1 \\ &> 0 \text{ for sufficiently large } k_0 \end{aligned}$$

because the function $k^*C'(k^* - \mu k_0) - C(k^* - \mu k_0)$ is strictly increasing in k^* by strict convexity of $C(\cdot)$ when $k^* - \mu k_0 > 0$ and $k^*C'(k^* - \mu k_0) - C(k^* - \mu k_0) \geq \mu k_0 C'(k^* - \mu k_0)$, and $k^*(\pi(\varphi), k_0)$ being solution of $\alpha\pi(\varphi) = [2C'(k^*(\pi(\varphi), k_0) - \mu k_0)]^{\frac{1}{2}}$, it shows that $k^*(\pi(\varphi), k_0) = \mu k_0 + C'^{-1} \left(\frac{\alpha^2 \pi(\varphi)^2}{2} \right)$ is increasing in $\pi(\varphi)$.

Therefore, $V(k_0, 1) - 1 - V(k_0, 0)$ is an increasing function of k_0 and it can be positive for sufficiently large k_0 . Hence, given $\alpha, \pi(1), \pi(2), \pi(0), C(\cdot)$ there exists a threshold for k_0 above which adoption of φ is always profitable and below which it is not. Then, for a given k_0 , using the continuity argument, adoption can be profitable or not even if $\delta > 0$. With risk aversion, the sign of $V(k_0, 1) - 1 - V(k_0, 0)$ is ambiguous, but using the continuity argument, the same result obtains at least for low risk aversion. $\square$

Finally, as in other dynamic investment models, it is always important to characterize the steady-state solution. The question of whether the steady state will in practice be reached is outside the scope of this paper, but nevertheless its characterization is interesting. If we consider empirically more relevant case where the agent has already invested in physical capital, we obtain another interesting result that shows that the optimal steady-state behavior of effort and the investment in human capital can either increase or decrease relative to the pre-adoption levels depending on the value of technological and contract

parameters. The characterization of the optimal steady-state effort and investment in specific knowledge in the post-adoption stage can be summarized as the following result.

Corollary 1: At the steady state, optimal effort e^* and optimal human capital k^* are:

- increasing in knowledge depreciation rate μ and discount factor $\delta = p\phi$,
- decreasing in risk aversion coefficient γ and variance of payment σ^2 if and only if $\pi(1) > \frac{1}{\alpha}$,
- increasing in piece rate α if and only if $\pi(1) < \frac{2}{\alpha}$,
- increasing in technology shifter $\pi(1)$ for $\pi(1) \leq \frac{2}{\alpha}$ and
- decreasing in $\pi(1)$ for $\pi(1) \geq \frac{2}{\alpha}$.

Proof of Corollary 1: see Appendix.

In summary, our model gives several potentially empirically testable predictions. First, according to Proposition 1, switching from a short-term to a long-term contract (increasing δ) induces the agent to exert larger effort ($\frac{\partial e^*}{\partial \delta} > 0$) and invest more in the specific human capital ($\frac{\partial k^*}{\partial \delta} > 0$) with the positive effect on output via the production function. Despite the fact that the productive effort (e) has no long-term effect, it is complementary to specific investment in human capital (k) which becomes more valuable if the contract is long-term.⁵ Second, the effect of a switch from a short-term to a long-term contract on the agent's propensity to invest in observable physical capital (φ) is ambiguous. The benefit of this investment has to outweigh the fixed cost of adoption, which does not happen necessarily at all levels of specific human capital but does occur for sufficiently large human capital stock. Finally, in case where the investment in observable physical capital was profitable and was actually carried out, the steady-state level of effort and the level of investment in specific human capital could increase or decrease relative to the pre-adoption stage.

3 A Case Study

Poultry industry is often considered a role model for the industrialization of agriculture. The firms are typically vertically integrated via the production

⁵ If contracts are short-term then the optimal efforts are such that the marginal costs of the investment in human capital is negative at the optimum, meaning that agent under-invests in k . When $\delta > 0$, $\frac{\partial}{\partial k}[G(e, k) + C(k - k_0)]$ can be of any sign at the optimum.

contracts with independent farmers. The production of meat chickens (broilers) involves three stages: raising breeder flock until sexual maturity, housing breeder flock (pullets) for the production of hatching eggs, and the grow-out of broilers until they reach market weight. Various stages are typically covered by different contracts and farmers generally specialize in one production stage under one contract. In order to obtain the first contract with the company, a grower is required to construct fully equipped housing facilities. In addition, growers invest in training and mastery of various special skills (disease detection, culling of sick birds, bio-security practices, feed management and waste management, etc.). These investments are relationship-specific because their value outside the industry is almost nil and their value within the industry but outside the current contract could be significantly reduced.⁶ Despite the long-term nature of these investments, most of the contracts observed in the poultry industry are written such that they cover one flock of birds at the time, i.e. at the end of one production cycle (flock) the contract is tacitly renewed unless explicitly canceled.

Our data comes from the contracts for the production of hatching eggs in two production divisions owned by the same company in the period from 1992 to 2003. Approximately in the middle of that period, the company decided to change the contract duration. The new contract became effective for all flocks delivered on or after January 1, 1997. Compared to the old contract which was a flock-by-flock contract, the new contract guarantees the continuous delivery of flocks for a period of 15 years. The data set consists of contract settlement sheets for 498 flocks tended by 68 contract growers.

In both short-term and long-term contracts the payment mechanism is some variant of the variable piece rate. The payment to the egg producers consists of the finishing fee (salary) and piece rates for hatching eggs and commercial eggs, where the piece rate for hatching eggs is obtained as the sum of the base pay and various bonuses (equipment, hatchability and feed conversion). Over the years, the payment schedule has been amended multiple times but the new long-term contract, when introduced, had exactly the same payment schedule as the last version of the old short-term contract.

The payment mechanism in the new contract has a 2.5 cents per chicken per week finishing fee (until the birds are 25 weeks of age) and a 9 cents per dozen

⁶ The functionalities of broiler houses are specific to broiler production such that retrofitting them for other purposes (e.g., growing swine) may be prohibitively costly. In addition to technological specificity, the location specificity of grower's assets could play an important role when the contract needs to be renewed. In areas with no or only one other integrator competing for agents, contract grower's assets will have relatively low salvage value even within the broiler industry (see Vukina and Leegomonchai 2006).

piece rate for commercial eggs. These two elements of the payment scheme have not changed during the analyzed 12-year interval. As seen from Table 1, the base pay for hatching eggs has been changed multiple times from as low as 27 cents per dozen hatching eggs at the end of 1991 to 32 cents in January of 2000 when the last correction to the payment scheme took place. The contract has two types of equipment bonuses: 2 cents per dozen of hatching eggs (introduced in January 1993) if a grower installs male feeders and high profile grills,⁷ and 2 cents per dozen of hatching eggs (introduced in April 1995, subsequently raised to 3 cents in March 1998) if a grower installs cool cells.⁸ Starting in July 1996, the contract begins to officially distinguish the “in-season” and the “out-of-season” flocks in the sense that the out-of-season flocks receive an additional 1 cent per dozen hatching eggs premium.⁹ Adding the equipment and out-of-season premiums, the composite piece rate for hatching eggs in 2000 for growers with installed male feeders and cool cells was 37 cents per dozen hatching eggs ($32 + 2 + 3$) for in-season flocks and 38 cents ($32 + 1 + 2 + 3$) for the out-of-season flocks. Both contracts have the hatchability and feed conversion bonuses whose specifications also changed over the years, see Table 1 for details. In both old and new contracts the aggregate bonus, i. e., the sum of the hatchability and feed conversion bonuses, cannot be negative. If the sum turns out to be negative, there is always a truncation at zero.

An interesting feature of the initiated contract duration change is the fact that no other element of the actual contract have changed at that time. According to the new contract, the decisions about the number of flocks the grower will receive, the number of birds in each flock and the rotation of flocks remained under the sole discretion of the company. In fact, based on the available 12-year records (1992–2003), the behavior of the integrator regarding the frequency of the delivery of flocks to growers remained the same. Each grower received approximately one flock per year before and after the switch.

7 Male feeders work well in combination with hen only feeders. The two grills combined ensure that the birds receive the optimal nutrition. If the birds are allowed to eat each others feed, the males will get fat (and may develop visceral gout) and their fertility will go down and the hens will not get enough protein or calcium.

8 Cool cells enhance the house environment through increased air flow in the building. This is most important in summer during hot weather. The cooler environment will help the hens maintain feed intake and subsequent egg production. Installing cool cells is rather expensive, for an average 10,000 hens house the cost would have been between \$5,000 and \$6,000 (personal communication with Drs. Ken Anderson and Edgar Oviedo, Poultry Science, North Carolina State University).

9 The out-of-season flocks are flocks that were placed on a pullet farm during the months of November, December, January or February.

Table 1: Payment schedule changes.

Date	Price										Hatching eggs		Commercial eggs
	Base price					Male feeder	Cool cell	Hatching rate		Feed conversion		Price	
								Target	Pay	Target	Pay		
In	Out	In	Out	In	Out	In	Out						
12/31/1991	0.27												0.09
11/1/1992*							85 %	83–85 %	0.005				0.09
1/30/1993	0.28				0.02								0.09
2/19/1994	0.29				0.02								0.09
4/29/1995	0.30				0.02	0.02							0.09
7/1/1996	0.30	0.31			0.02	0.02							0.09
1/1/1997					New long-term (15-year) contract introduced.								
3/1/1998	0.30	0.31			0.02	0.03				7.5	7.75	0.04	0.09
5/25/1998	0.31	0.32			0.02	0.03							0.09
1/1/2000	0.32	0.33			0.02	0.03	84 %	82–84 %	0.01	7.75	8.00	0.04	0.09

Note: *Refers to the date when pullets were started on a pullet farm.

Based on the provided information, a natural question to ask is why the company decided to change the contract from short-term to long-term? In official written communications between the company management and the growers, the company stated that it is changing the contract in response to growers' concerns about the uncertainties related to contract renewal and the desire to build better integrator-grower relations. In a letter to its growers, the company expresses its beliefs that "the new contract will promote a better understanding between the company and its hatching eggs producers, will result in greater economic efficiencies, and will restore and promote trust historically enjoyed between the company and its growers". In addition to the explicitly mentioned reasons, we also believe that the company acted proactively to anticipated federal regulation regarding the type of contracts that poultry integrators and contract growers can sign. At that time, a number of regulatory proposals concerning livestock contracts were focused precisely on contract termination clauses and dispute resolution procedures.¹⁰ Launching the new contract ahead of the competitors could have been a very good investment in reputation and goodwill.

Instead of focusing on the reasons for why did the company decide to change the contract, for which we cannot provide hard empirical evidence, we concentrate on the effects of contract switch from short-term to long-term on the provision of incentives to exert effort and to invest in relationship-specific assets. Before proceeding with the formal analysis of agents' behavior under different contracting environments, we want to see whether we can detect any obvious discrete breaks in various physical performance measures that could have been caused by the contract switch. We use three groups of performance measures: the number of eggs produced (hatching eggs and total eggs), the hatchability of eggs, and the feed conversion ratios. In the first group we look at four indicators: the number (in dozens) of hatching eggs per hen (*ratio*), the number of hatching eggs per square foot (*ratio1*), the total number of eggs (hatching plus commercial) per hen (*ratio2*), and the total number of eggs per square foot (*ratio3*). The results are presented in Table 2. All four performance measures exhibit similar patterns. Two results are worth mentioning. First, the switch from a short-term to the long-term contract in 1997 is correlated with a

10 As a part of the 2008 Farm Bill, the regulatory arm of USDA (Grain Inspection, Packers and Stockyards Administration – GIPSA) issued new regulation regarding four aspects of livestock contracts: the suspension of delivery of birds, additional capital investment criteria, breach of contract and arbitration (see Federal Register, Vol. 76, No. 237, Dec. 9, 2011). None of these new regulations amounts to the request for the long-term contracts but virtually all of them make arbitrary cancelation of the flock-by-flock contracts more difficult.

Table 2: Chronological comparison of performance indicators: mean values.

Year	ratio	ratio1	ratio2	ratio3	hateg	ht	htsqft	fct	fch
1992	13.62	6.504	13.82	6.601	187943.2	11.716	5.593	7.047	7.153
1993	13.85	6.545	14.07	6.646	190723.3	11.795	5.570	6.729	6.833
1994	13.86	6.646	14.06	6.744	192168.8	11.779	5.645	6.744	6.842
1995	13.62	6.568	13.88	6.698	179710	11.419	5.506	6.827	6.962
1996	13.84	6.735	14.11	6.866	209060.3	11.847	5.765	6.656	6.784
1997	14.38	7.012	14.71	7.169	214923.5	12.186	5.939	6.412	6.556
1998	13.54	6.658	13.99	6.879	201863.4	11.320	5.564	6.552	6.769
1999	12.88	6.504	13.25	6.688	199673.8	10.941	5.523	6.640	6.830
2000	12.68	6.449	13.05	6.638	200370.3	10.802	5.494	6.761	6.960
2001	13.26	6.767	13.68	6.981	213757.2	11.299	5.763	6.688	6.901
2002	13.41	6.851	13.79	7.044	210521.4	11.412	5.828	6.703	6.892
2003	12.69	6.415	13.01	6.577	185182.6	10.903	5.511	6.612	6.780

Note: Legend:

ratio: number (in dozens) of hatching eggs per hen.

ratio1: number of hatching eggs per square foot.

ratio2: total number of eggs (hatching plus commercial) per hen.

ratio3: total number of eggs per square foot.

hateg: number of hatching eggs that actually hatched.

ht: number of hatching eggs that hatched per hen.

htsqft: number of hatching eggs that hatched per square foot of the chicken house.

fct: total feed conversion.

fch: feed conversion for hatching eggs.

noticeable improvement in all four performance measures. The production of eggs either per hen or per square foot of the chicken house increased by more than half a dozen eggs. The increase came mainly from the increased production of hatching eggs.

Second, a sharp drop in all performance measures starting in 1998, and continuing in 1999, could be explained by the change in breed.¹¹ To counteract this change, the company increased the base price for hatching eggs as well as the cool cell equipment bonus (see Table 1 for details). However, it looks like that these additional incentives were not sufficient to offset the negative effects of the

¹¹ Starting in 1998, the company started changing the dominant breed of chickens from a Peterson male and Arbor Acre female to a Ross male and a Ross female. The change has been made to improve the feed conversion and processing yield of broilers (this stage of the cycle also owned by the same company) but the egg production and hatchability could have suffered as the new breed is more susceptible to heat stress.

breed change and neither was the massive adoption of cool cells that followed first by the contract duration change and then by the strong encouragement to do so by the company management.¹² As will be explained later, in addition to the change of breed, the deterioration of performance measures could also be the result of a decrease in effort that could have occurred after growers fully adopted the new performance enhancing technologies.

The second group of performance indicators deals with the hatchability of eggs. To be considered a *hatching egg*, an egg must weigh at least 1.75 oz. (21 ounces per dozen), have a normal shell, have no dirt adhering to the shell, and have no stain larger than the size of a nickel. All eggs that do not meet the above criteria, as well as double yolk eggs, are classified as *commercial eggs*. However, not all eggs classified as hatching eggs will eventually hatch. Some hatching eggs may not be fertile or could have some other deformities not visible from the outside. Only hatching eggs that actually hatch are considered a success. Therefore, in the second group we use three performance indicators: the number of hatching eggs that actually hatched (*hateg*), the number of hatching eggs that hatched per hen (*ht*), and the number of hatching eggs that hatched per square foot of the chicken house (*htsqft*). The results exhibit the same patterns as the egg production indicators: the performance improved in 1997 and then deteriorated in 1998/1999.

Finally, we look at feed conversion ratios. In this group we use two performance indicators: total feed conversion (*fct*) and feed conversion for hatching eggs (*fch*). Feed conversion is defined as pounds of feed used to produce one dozen eggs. Clearly the smaller the number, the better the performance. Similarly to prior results, both feed conversion measures improved in 1997 in comparison to the earlier years and both of them deteriorated in 1998 and beyond.

4 Testing the Theory

We start by establishing the link between the developed theoretical model and the empirically observed contract together with the data that it generated. First,

¹² The first communication between the company and the growers mentioning the introduction of the new breed has the date of January 22, 1998, fifteen months after the announcement of the new contract. The same letter announces the increase in the cool cell payment from 2 cents to 3 cents per dozen, effective on March 1, 1998 (see Table 1), and requests the growers to carefully consider the management's recommendation to install the cool cells equipment and inform the company of their intentions also by March 1, 1998.

agents' effort and the investments in specific skills are unobservable by both the principal and the researchers. The investments in physical capital are observable and in this example are materialized as investments in cool cells and male feeders. The piece rate α in the linear payment scheme will consist of the base pay plus various bonuses (equipment, hatchability and feed conversion) and for β we will use the finishing fee. Clearly, the payment scheme used in the theory part is a simplification because, among other things, the piece rate in the actual scheme is based on whether the agent adopted new technologies or not, hence the payment formula should be written as $w(q) = \alpha(\varphi)q + \beta$. However, while complicating the theoretical exposition considerably, this specification would not qualitatively change the results. Also, because both q and φ are observable and verifiable, the optimal static contract would consist of a payment function $w(q)$ but would also specify the investment φ , hence the assumed linear contract would not be optimal even in the static case, much less so in a dynamic context. However, as mentioned before, we do not model the principal's side of the problem and hence take the observed contracts as given without making any claims regarding their optimality.

In line with the obtained theoretical results, we formulate and empirically test several hypotheses about the effects of contract duration change from short-term to long-term on growers' behavior. First, the contract switch should cause effort to initially increase leading to a positive effect on grower performance across various productivity margins. Second, given the fact that contract switch should also cause the investment in human capital to increase, it is possible that it could reach the critical level where the investments in observable physical capital become profitable stimulating its faster adoption. Third, the investments in unobservable human capital could not only trigger the adoption of new technology but should also have a discernible impact on productivity gains via the reduction in cost of effort. Finally, despite the fact that the contract switch would cause effort and investment in skills to initially increase, they could subsequently decrease after the new technology has been adopted, reversing the initial productivity gains.

4.1 Technology Adoption

There are two technological improvements that growers could have adopted to earn equipment and performance bonuses. These are male feeders and cool cells, both of which would automatically earn equipment bonuses and improve the feed conversion ratios and the hatchability of eggs thereby improving chances to earn performance bonuses. The adoption rates, which are presented

Table 3: Technology adoption rates.

Year*	Cool cells				Male feeders			
	No	Yes	Flocks	Rate	No	Yes	Flocks	Rate
1992	4	0	4	0.00 %	2	2	4	50.00 %
1993	28	0	28	0.00 %	9	19	28	67.86 %
1994	41	0	41	0.00 %	9	32	41	78.05 %
1995	47	1	48	2.08 %	7	41	48	85.42 %
1996	47	5	52	9.62 %	6	46	52	88.46 %
1997	45	7	52	13.46 %	4	48	52	92.31 %
1998	36	16	52	30.77 %	2	50	52	96.15 %
1999	26	28	54	51.85 %	0	54	54	100.00 %
2000	19	40	59	67.80 %	0	59	59	100.00 %
2001	16	35	51	68.63 %	0	51	51	100.00 %
2002	14	41	55	74.55 %	0	55	55	100.00 %
2003	0	2	2	100.00 %	0	2	2	100.00 %

Note: *Year corresponds to the date when birds are 25 weeks old.

in Table 3, exhibit stark differences. Prior to the introduction of the new contract in January 1997, 88.5% of the flocks were already grown with male feeders, whereas only 9.6% of the flocks were grown with cool cells. Two factors can explain the difference. First, the equipment bonus for male feeders and high profile grills was introduced 2 years earlier than the equipment bonus for cool cells (January 1993 versus April 1995), so it is reasonable to expect earlier adoption of male feeders than cool cells. Secondly, installing cool cells represents substantially larger investment, so it is not surprising that the more rapid adoption of cool cells followed the introduction of the new long-term contract which gave contract growers some security against abrupt termination. The steady increase in adoption rates for cool cells after the introduction of the new contract is clearly visible from Table 3. The percentage of flocks grown with cool cells was steadily increasing from 13.5% in 1997 to 75.5% in 2002.

A more formal way of capturing the effect of the contract switch on the technology adoption is to run probit regressions. In Table 4 we present the results for cool cells only; the same regressions for male feeders show similar results but seem less relevant given the already high rate of adoption before the switch to long-term contract. The results in Table 4 clearly show that the indicator variable for the contract switch labeled lt , specified to be equal 1 after the switch to long-term contracts and 0 before, is positive and significant. Changing the contract from short-term to long-term increased the probability of technology adoption. This is true even after we include a dummy variable for the post March 1, 1998 which

Table 4: Technology adoption regression results: cool cells.

Variables	Probit	Random effects probit
Long term	0.833** (0.254)	2.344** (0.871)
March 98	1.376*** (0.245)	3.687*** (0.831)
Square footage	5.70e-06 (9.05e-06)	-4.41e-05 (2.94e-05)
Profit Center M	0.647* (0.274)	2.060* (1.009)
Constant	-2.448*** (0.353)	-4.686** (1.529)
$\ln \sigma_u$		2.169*** (0.451)
Observations	498	498
Number of i.d.		68
Log likelihood	-217.79	-143.29506

Note: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. Robust standard errors (clustered at the grower level) are in the parentheses.

marks the period of intense pressure by the company management to install cool cells in conjunction with the introduction of the new breed; see footnote 12.

The other two explanatory variables of interest are the division indicator and the size of the facility. The results show that the probability of technology adoption is larger in division labeled as *M* than in the other division.¹³ Given the fact that growers in both divisions were always operating under identical contract payment schemes, the differences could be due to the systematic differences in the quality of the production facilities and/or growers' abilities and effort. Another possible explanation can be that there are some systematic differences between two divisions regarding location, geography and climate. The expected sign of the size variable is positive as we were expecting to see higher probability of adoption with larger housing facilities. As it turned out, square footage (*sqft*) parameter is not significantly different from zero.

The right column in Table 4 displays the estimates of the same probit model when we allow for grower specific random effects. All results are qualitatively similar lending strong support to our hypothesis that switching from the short-

¹³ This is in line with other results showing consistently superior performance of growers in division *M*. Both divisions are approximately the same size. The total number of flocks settled in *M* division is 242 and in the other one is 256.

term to long-term contract caused the investments in observable physical capital, in this case cool cells, to increase.

4.2 Pure Effort Effect

The fact that the last version of the old contract has the same payment mechanism as the new long-term contract enables us to identify the effects of the contract length on growers' performance. This is accomplished by specifying another indicator variable which equals 1 for the period during which none of the contract parameters have changed (7/1/1996–3/1/1998) and 0 elsewhere and then multiplying that variable with the dummy for the switch to long-term contract previously defined and labeled as *lt*. The product of the two indicator variables gives a new indicator variable, labeled *plt*, which captures the effect of the change in contract duration net of the influences caused by changing other contract parameters.¹⁴

The implemented empirical strategy consists of two steps. In the first step we estimate the performance equations without the technology adoption variables. In the second step we include the technology adoption variable (cool cells) to evaluate its impact on the magnitude and the statistical significance of the *plt* coefficient. The idea is that if switching the contract from short-term to long-term impacted the grower performance only via the investment in the observable productivity enhancing technology, then we should see the magnitude and/or statistical significance of the *plt* coefficient deteriorate. If this did not happen, then we would conclude that in addition to expediting the observable investments, the contract switch also stimulated the unobservable and hence non-contractible investments that are complementary to grower's effort. Given the fact that technology adoption is likely to be endogenous, we allow for grower specific unobserved effects by estimating the same performance equations with grower fixed effects. In this case the identification is done within grower and on the period where no contract parameters change.

The analysis is carried out using different performance measures. The first set of results deals with the egg production. Dependent variables in our regression models are the same four performance indicators used before. The OLS results are presented in the first four columns of Table 5. The results are

¹⁴ A possible alternative approach to estimate the effects of contract change would be to only use a narrow sliver of the data for the time period (7/1/1996–3/1/1998) where none of the other contract provisions have changed. This approach yields essentially the same results but relatively small number of observations renders them less reliable.

Table 5: Performance measures: OLS results.

Ratio	ratio1	ratio2	ratio3	hateg	ht	htsqft	fct	fch
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
M	0.424*** (0.0805)	0.186*** (0.0477)	0.426*** (0.0816)	0.186*** (0.0482)	9.622*** (1,394)	0.523*** (0.0741)	0.239*** (0.0425)	-0.182*** (0.0333)
lt	-0.212* (0.0967)	0.208*** (0.0573)	-0.0457 (0.0980)	0.297*** (0.0579)	-8.581*** (1,981)	-0.467*** (0.105)	-0.0186 (0.0602)	-0.0640 (0.0819)
plt	0.849*** (0.134)	0.193* (0.0791)	0.784*** (0.135)	0.156 (0.0799)	16.989*** (2,500)	0.978*** (0.134)	0.343*** (0.0771)	-0.218*** (0.0609)
seas	-0.152 (0.0870)	-0.0947 (0.0515)	-0.263** (0.0882)	-0.150** (0.0521)	961.9 (1,495)	-0.0291 (0.0805)	-0.0323 (0.0462)	0.0871* (0.0353)
days	0.0444*** (0.00397)	0.0204*** (0.00235)	0.0461*** (0.00403)	0.0212*** (0.00238)	606.4*** (68.55)	0.0325*** (0.00368)	0.0148*** (0.00211)	0.0367 (0.0361)
hens				11.83*** (0.184)				
hd1				585.4 (4,623)	-0.0336 (0.249)	0.0251 (0.143)		
hd2				8,098*** (1,885)	0.431*** (0.101)	0.312*** (0.0582)		
fcd1							-0.0764 (0.0790)	-0.0644 (0.0807)

(continued)

Table 5: (continued)

	Ratio	ratio1	ratio2	ratio3	hateg	ht	htsqft	fct	fch
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
fcd2									
const	1.151 (1.138)	0.842 (0.674)	0.973 (1.154)	0.766 (0.681)	-178,926*** (20,507)	2.315* (1.103)	1.345* (0.633)	0.100* (0.0472)	0.0971* (0.0483)
obs	498	498	498	498	498	498	498	498	6.945***
R ²	0.37	0.20	0.36	0.22	0.91	0.34	0.21	0.14	0.13

Note: Variables:
M Profit center dummy.
lt Long-term contract switch dummy.
plt Product of lt and the time dummy for the period where contract parameters did not change.
seas In-season flocks dummy.
days Number of days hens stay in production.
hens Number of hens in production.
hd1 Time dummy indicating first hatchability bonus change.
hd2 Time dummy indicating second hatchability bonus change.
fcd1 Time dummy indicating first feed conversion bonus change.
fcd2 Time dummy indicating second feed conversion bonus change.

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.
Robust standard errors (clustered at the grower level) are in the parentheses.

virtually identical across different performance measures. The most important point to make is that the *plt* coefficient is positive and significant, which means that the clean impact of switching from a flock-by-flock to a 15-year contract on grower productivity is positive. At the same time the *lt* coefficient is also positive and significant for two performance variables measuring total eggs production (*ratio1* and *ratio3*) but negative for the remaining two performance variables measuring hatching eggs production. This is the first indication that, after the new technology has been adopted, the initial increase in effort could have been reversed, as allowed for by our theoretical model. However, the definitive proof is elusive as the effect could have also been the consequence of the introduction of the new breed that began in 1998.

The other results indicate that the performance of contract growers in division *M* is always superior relative to the performance in the other division, and that the longer the hens stay in production (*days*) the more eggs they will produce, either on a per hen or on a per square foot basis. Finally, somewhat unexpectedly, the performance of the in-season flocks (*seas*) is significantly worse than that the performance of the out-of-season flocks. This is most likely the consequence of consistently higher piece rates for eggs produced by out-of-season flocks, showing that incentives really work.

The next set of results deal with the hatchability of hatching eggs. Same as before, we use three different measures. The results are presented in columns (5)–(7) of Table 5. In addition to the explanatory variables used before, we included two dummy variables capturing the announced changes in hatchability bonuses. Referring to Table 1, one can see that the hatchability bonus has been changed twice during the period covered by the data. The variable *hd1* assumes the value of 1 for all dates larger than or equal to the date of the first change and 0 elsewhere, and *hd2* is defined similarly for the second change in the hatchability bonus. The first change is impossible to evaluate since we don't know what this bonus was prior to this change because it occurred outside our data range. The second change is characterized by an increase in the rate from half a cent to 1 cent and the hatchability target was lowered, so this change should generate positive incentives to exert effort. However, the change was most likely made to offset the negative impact on hatchability associated with the switch to a new breed of birds.

The regression in column (5) also has the number of hens (*hens*) as an explanatory variable. As expected it is positive and significant: more hens will produce more eggs and more of them will have a chance to hatch. The main results are pretty much in line with the previous findings. The *plt* variable is positive and significant in all three cases confirming the positive impact of the contract switch on productivity. However, the *lt* variable is now always negative

and significant in two out of three models, indicating that either the reduction in effort, or the breed change, or both, definitely had negative impact of the hatchability of eggs. Same as before, the coefficient on division M is positive and significant as so is the *days*. The season indicator is not significant when it comes to hatchability measures and only the second change in the hatchability bonuses had a positive impact on the actual hatchability results.

The last two models in columns (8) and (9) of Table 5 deal with the feed conversion ratios. Again, the main results are identical to the ones obtained before. The coefficients on *plt* are this time negative and significant because lower feed utilization per dozen eggs means better performance. However, the *lt* coefficients are not significant meaning that the change in effort did not have appreciable effects on feed conversion. This is in line with the fact that standard husbandry practices for laying hens (and other animals grown in confinement) is described by animals eating *ad libidum* or *at will*, the importance of grower effort is likely to be rather small. Also, the fact that the newly introduced breeds only suffer from decreased egg production and hatchability but not from inferior feed conversion supports the result.

The first change in the feed conversion bonus is captured by dummy variable *fcd1* and the second change with *fcd2*. The definition of these variables mimics the definition of the hatchability bonus variables (see Table 1 for exact dates). The impact of the first change on grower incentives to work hard cannot be evaluated because we don't know what that bonus was before the change. The impact of the second change is most likely negative because the rate stayed the same (plus or minus 4 cents per dozen eggs per each percent outside the target feed conversion rate) but the target feed conversion was increased so it now became easier to earn the bonus (or avoid the penalty) than under the old rules. As seen from columns (8) and (9), the first bonus change dummies are insignificant in both models, but the second are positive and statistically significant. Therefore, the result is in line with our expectations, indicating that increasing the feed conversion ratio target dulled the incentives to exert effort and in fact feed conversion deteriorated (increased).

4.3 Non-contractible Investments

The second step in the estimation procedure is based on the proof by contraposition, i. e. by showing that the hypothesis that all improvements in grower productivity come from the adoption of observable technological improvements (such as cool cells) is false. The specification of all models stayed essentially the same as before, the only difference being the inclusion of the indicator variable

cool which assumes the value of 1 if the flock was grown under the cool cells environment and 0 if not. The dummy variable for male feeders was not used, because, as seen from Table 3, at the time of the contract change virtually all growers have already adopted this inexpensive technology.

The decisions to adopt these new technologies are clearly endogenous. Different growers, depending on their idiosyncrasies, will have different incentives toward technology adoption. To deal with the endogeneity of technology adoption, we exploit the panel nature of the data set and estimate our models with grower fixed effects. The only other difference relative to the previous specification is the omission of the division indicator (M), which becomes redundant with grower fixed effects. The results are presented in Table 6.

The obtained results are surprisingly consistent across all nine models. Several interesting findings are worth pointing out. First, we see that *plt* is always positive and most of the time highly significant which convincingly shows that switching the contract duration from a short-term to long-term contract had positive impact on productivity. Secondly, the technology adoption variable *cool* is positive and significant in seven out of nine models indicating a positive impact of technology adoption on productivity. In the remaining two cases, which are both feed conversion models, *cool* is insignificant (and also has the wrong sign). It looks like cool cells do not significantly improve feed conversion over and above what male feeders do. Finally, we showed that the entire gain in productivity could have not been the result of cool cells adoption only by rejecting the opposite hypothesis. The obtained results indicate that switching the contract from short-term to long-term also solved the under-investment problem by stimulating growers to carry out other unobservable and hence non-contractible investments which turn out to be complementary with the cool cells technology. This conclusion is supported by the results showing that in all nine specifications, the magnitude of the *plt* coefficient after the inclusion of the *cool* variable (Table 6) is larger than before (Table 5).

Finally, notice that the *lt* variable is now almost always negative and statistically significant. The exceptions to this general result are, again, the two feed conversion equations. This result is supportive of our hypothesis that the positive productivity impacts of the contract change could have been subsequently (after cool cells were adopted) wiped out by a decrease in steady-state effort. However, a definitive proof of this result is impossible to construct because the reduction in performance across nearly all productivity margins could have been caused by the introduction of Ross breed birds which perform worse when it comes to egg production and hatchability (especially in hot weather).

Table 6: Performance measures with technology adoption: grower fixed effects.

	ratio	ratio1	ratio2	ratio3	hateg	ht	htsqft	fct	fch
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
lt	-0.581*** (0.167)	-0.0484 (0.100)	-0.403* (0.157)	0.0436 (0.0957)	-11,909*** (2,949)	-0.698*** (0.148)	-0.164 (0.0883)	-0.0719 (0.0804)	0.00327 (0.0809)
plt	1.122*** (0.154)	0.393*** (0.0780)	1.048*** (0.149)	0.353*** (0.0743)	19,386*** (3,064)	1.128*** (0.144)	0.439*** (0.0713)	-0.181** (0.0547)	-0.236*** (0.0566)
seas	-0.244 (0.304)	-0.110 (0.160)	-0.289 (0.302)	-0.132 (0.159)	-2,050 (5,740)	-0.146 (0.309)	-0.0531 (0.163)	0.0685 (0.114)	0.0475 (0.117)
days	0.0362*** (0.00472)	0.0176*** (0.00293)	0.0377*** (0.00484)	0.0183*** (0.00298)	463.0*** (82.96)	0.0240*** (0.00442)	0.0119*** (0.00260)		
cool	0.408* (0.176)	0.394*** (0.113)	0.380* (0.170)	0.386*** (0.111)	5,728 (3,090)	0.316 (0.170)	0.293** (0.106)	0.0381 (0.0807)	0.0184 (0.0858)
hens					11.43*** (0.435)				
fcd1								-0.0650 (0.0685)	-0.0429 (0.0687)
fcd2								0.104 (0.0534)	0.103 (0.0565)
hd1					-3,890 (2,630)	-0.300 (0.154)	-0.0617 (0.0697)		

5 Conclusions

In this paper we analyze differential effects on investment and effort of a regime switch from a short-term to a long-term production contract. At the theoretical core of the paper is a dynamic decision model in which the agent makes three decisions: (a) to invest or not in observable physical capital, (b) how much to invest in unobservable human capital, and (c) how much of the unobservable effort to exert. The first decision is discrete, the other two are continuous. The model links these decisions to the probability of contract renewal and offers predictions about the effects of the contract switch from short-term to long-term on the agent's behavior. Specifically, the model predicts that a switch to long-term contracts should increase both the effort and the unobservable investment in human capital. The key assumption driving this result is the complementarity between effort and human capital. On the other hand, the effect on observable physical capital will be positive only if the starting level of human capital is high enough. In turn, the new steady-state levels of effort and human capital depend on whether the physical capital increased in response to the change in the probability of contract renewal.

The nature of the change in the empirically observed contract parameters enabled us to econometrically isolate the effect of the change in contract duration from other changes in contract parameters on agents' incentives to perform. Using contract settlement data for the production of hatching eggs obtained from one vertically integrated poultry company we showed that switching from a short-term (flock-by-flock) to a long-term (15 years) contract resulted in increased investments in productivity enhancing technologies and practices which improved performance across all productivity margins. The complementarity of unobservable investments with effort created a result where the increased probability of contract renewal increases equilibrium effort, but after the adoption of observable productivity enhancing technology, the steady-state effort could either increase or decrease relative to the pre-adoption stage. The timing of the introduction of new breed of birds together with the ambiguity of the theoretical predictions about the post-adoption equilibrium steady-state effort and investment in human capital prevents us from disentangling the two effects. All that we can say is that observed deterioration in the performance indexes across wide range of productivity margins does not contradict the theoretical prediction of our theoretical model.

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Appendix

Proof of Lemma 1: $V(., 1)$ is increasing concave.

The proof is based on the standard Bellman equations solution techniques (Stokey, Lucas, and Prescott 1989). Consider an operator T_1 defined by $T_1 : v(.) \rightarrow T_1(v(.))$, where for all k_0 : $T_1(v(k_0)) = \max_{e,k} [H(e, k) + \delta v(k)]$ where $H(e, k) = Ew(q) - \frac{\gamma}{2} \text{var}(w(q)) - G(e, k) - C(k - \mu k_0)$.

We can show that T_1 is a contraction mapping of modulus δ .

Actually, for $v(.)$ and $w(.)$, and k_0 , there exist e_v^*, k_v^* such that $T_1(v(k_0)) = H(e_v^*, k_v^*) + \delta v(k_v^*)$ and there exist e_w^*, k_w^* such that $T_1(w(k_0)) = H(e_w^*, k_w^*) + \delta w(k_w^*)$.

By definition $T_1(v(k_0)) \geq H(e_v^*, k_v^*) + \delta v(k_v^*)$ and $T_1(w(k_0)) \geq H(e_v^*, k_v^*) + \delta w(k_v^*)$. Thus, $\forall k_0, \exists k_v^*, k_w^*$ such that

$$\delta [v(k_v^*) - w(k_v^*)] \geq T_1(v(k_0)) - T_1(w(k_0)) \geq \delta [v(k_w^*) - w(k_w^*)]$$

which implies that $\|T_1(v(.)) - T_1(w(.))\|_\infty \leq \delta \|v(.) - w(.)\|_\infty$ where $\|\cdot\|_\infty$ is the sup norm.

Moreover, T_1 keeps monotonicity and concavity. Actually, assume $v(.)$ is increasing concave. Then $T_1(v(.))$ is also because using the envelope theorem

$$\frac{\partial T_1(v(k_0))}{\partial k_0} = C'(k^* - \mu k_0) > 0$$

and

$$\frac{\partial^2 T_1(v(k_0))}{\partial k_0^2} = -C''(k^* - \mu k_0) < 0.$$

As the recursive formulation of $V(., 1)$ shows that it is a fixed point of T_1 , the properties of the operator T_1 show that $V(., 1)$ is an increasing concave function. $\square$

Proof of Lemma 2: $V(., 0)$ is increasing concave.

Consider now the operator T_0 defined by $T_0 : v(\cdot) \rightarrow T_0(v(\cdot))$, where for any k_0 $T_0(v(k_0)) = \max_{e,k} [H(e, k) + \delta \max(V(k, 1) - 1, v(k))]$, where as before $H(e, k) = Ew(q) - \frac{\gamma}{2} \text{var}(w(q)) - G(e, k) - C(k - \mu k_0)$.

We can show that T_0 is also contraction mapping of modulus δ .

Actually, for $v(\cdot)$ and $w(\cdot)$, for any k_0 there exist e_v^*, k_v^* and e_w^*, k_w^* such that $T_0(v(k_0)) = H(e_v^*, k_v^*) + \delta \max(V(k_v^*, 1) - 1, v(k_v^*))$ and $T_0(w(k_0)) = H(e_w^*, k_w^*) + \delta \max(V(k_w^*, 1) - 1, w(k_w^*))$.

By definition $T_0(v(k_0)) \geq H(e_w^*, k_w^*) + \delta \max(V(k_w^*, 1) - 1, v(k_w^*))$ and $T_0(w(k_0)) \geq H(e_v^*, k_v^*) + \delta \max(V(k_v^*, 1) - 1, w(k_v^*))$. Thus

$$\begin{aligned} & \delta [\max(V(k_v^*, 1) - 1, v(k_v^*)) - \max(V(k_w^*, 1) - 1, w(k_w^*))] \\ & \geq T_0(v(k_0)) - T_0(w(k_0)) \\ & \geq \delta [\max(V(k_w^*, 1) - 1, v(k_w^*)) - \max(V(k_w^*, 1) - 1, w(k_w^*))]. \end{aligned}$$

Therefore

$$\begin{aligned} T_0(v(k_0)) - T_0(w(k_0)) & \geq \delta [v(k_w^*) - w(k_w^*)] \text{ if } V(k_w^*, 1) - 1 \leq w(k_w^*) \\ & \geq \delta [V(k_w^*, 1) - 1 - V(k_w^*, 1) + 1] = 0 \text{ if } V(k_w^*, 1) - 1 > w(k_w^*). \\ T_0(v(k_0)) - T_0(w(k_0)) & \leq \delta [v(k_v^*) - w(k_v^*)] \text{ if } V(k_v^*, 1) - 1 \leq v(k_v^*) \\ & \leq \delta [V(k_v^*, 1) - 1 - V(k_v^*, 1) + 1] = 0 \text{ if } V(k_v^*, 1) - 1 > v(k_v^*). \end{aligned}$$

This implies that $\forall k_0, |T_0(v(k_0)) - T_0(w(k_0))| \leq \delta \sup_k |v(k) - w(k)|$ and $\|T_0(v(\cdot)) - T_0(w(\cdot))\|_\infty \leq \delta \|v(\cdot) - w(\cdot)\|_\infty$ where $\|\cdot\|_\infty$ is the sup norm.

Moreover, T_0 keeps monotonicity and concavity. Actually, assume $v(\cdot)$ is increasing concave. Then $T_0(v(\cdot))$ is also because using the envelope theorem

$$\frac{\partial T_0(v(k_0))}{\partial k_0} = C'(k^* - \mu k_0) > 0$$

and

$$\frac{\partial^2 T_0(v(k_0))}{\partial k_0^2} = -C''(k^* - \mu k_0) < 0.$$

As the recursive formulation of $V(\cdot, 0)$ shows that it is a fixed point of T_0 , the properties of the operator T_0 show that $V(\cdot, 0)$ is an increasing concave function. $\square$

Proof of Corollary 1:

At the steady state, we assume that investment in knowledge is such that the level of knowledge is constant and thus $k^* = k_0$, that is $i^* = (1 - \mu)k_0 = (1 - \mu)k^*$, then

$$\frac{e^*}{k^*} = \frac{\alpha \pi(\varphi)}{1 + k^* \gamma \alpha^2 \pi(\varphi)^2 \sigma^2} = [2C'((1 - \mu)k^*) - 2\delta V'(k^*, \varphi)]^{\frac{1}{2}}.$$

Considering the case where $\varphi = 1$ which implies that $\varphi' = 1$, we have

$$2[C'((1-\mu)k^*) - \delta V'(k^*, 1)]k^* = \frac{\alpha\pi(1) - 1}{\gamma\sigma^2\alpha^2\pi(1)^2}.$$

As $2[C'((1-\mu)k) - \delta V'(k, 1)]k \equiv H(\mu, \delta, k)$ is an increasing function of k , k^* is a decreasing function of γ and σ^2 if and only if $\pi(1) > \frac{1}{\alpha}$.

Moreover, $\frac{\partial H(\mu, \delta, k)}{\partial \delta} = -2V'(k, 1)k < 0$, $\frac{\partial H(\mu, \delta, k)}{\partial \mu} < 0$ and

$$\frac{\partial H(\mu, \delta, k)}{\partial k} = 2[C'((1-\mu)k) - \delta V'(k, 1)] + 2k[(1-\mu)C''((1-\mu)k) - \delta V''(k, 1)].$$

Thus $\frac{\partial H(\mu, \delta, k^*)}{\partial k} > 0$ because $C'((1-\mu)k^*) > \delta V'(k^*, 1)$ and therefore k^* is also increasing in μ and δ .

As $\frac{\alpha\pi(1) - 1}{\gamma\sigma^2\alpha^2\pi(1)^2}$ increases in α and $\pi(1)$ if and only if $\frac{2}{\alpha} > \pi(1)$, k^* is increasing in α and $\pi(1)$ if and only if $\frac{2}{\alpha} > \pi(1)$.

As $e^* = \frac{k^*\alpha\pi(1)}{1 + k^*\gamma\alpha^2\pi(1)^2\sigma^2}$, is increasing in k^* and thus replacing k^* by its steady-state value, e^* is also increasing in μ and δ , decreasing in γ and σ^2 if $\pi(1) > \frac{1}{\alpha}$.

As $e^* = k^{*\frac{1}{2}}H(\mu, \delta, k)^{\frac{1}{2}}$, $\frac{\partial e^*}{\partial \alpha}$ and $\frac{\partial e^*}{\partial \pi(1)}$ have the same sign as $\frac{\partial k^*}{\partial \alpha}$ and $\frac{\partial k^*}{\partial \pi(1)}$. $\square$

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