Incentives to Invest in Short-term vs. Long-term Contracts: Evidence from a Natural Experiment

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Abstract

In this paper 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 parameter. The fact that the unobservable investment in human capital is complementary with the agent's effort produces a result that switching from a short-term to a long-term contract increases the 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. The data was generated by a natural experiment where during the period covered by the data the contract had changed from short-term to long-term. The obtained empirical results are largely supportive of the developed theory.

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1 Introduction

The production contracts between integrator firms (principals) and independent farmers (agents) in most agricultural settings (e.g., chickens, hogs, grapes, tobacco) are typically short term, i.e. at the end of one production cycle the contract is tacitly renewed unless explicitly canceled. Recently, however, it came to our attention that some firms converted their short-term contracts into long-term ones. One example of such conversion comes from the contracts for the production of hatching eggs which constitutes an early stage in the production of broiler chickens. Such a contract conversion presents a natural experiment that can be utilized to empirically measure the incentive effects of the contract switch on agents' behavior. We hypothesize that changing a production contract from short-term to long-term should affect agents' incentives to carry out observable and unobservable investments with a measurable impact on agents' performance across various productivity margins.

The basic insight of natural experiments is that incentives effects are easier to assess when they stem from some exogenous change in incentives structure. In this case the selection bias is no longer a problem 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 for firms which 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 Salanie (2003).

The main objective of this paper, however, is not to explain what caused the contract to switch from short-term to long-term, as various smaller changes in the contract's payment mechanism have been rather frequent throughout the period covered by the data, and therefore difficult to explain. Consequently, we make no claims about the optimality of contracts either before or after the switch. Acknowledging the reality that in actual business environments inefficient contracts could exist, we treat the contract change as exogenous and analyze its effect on growers incentives.

Long-term contracts have certain advantages and disadvantages over short-term contracts. First, long-term contracts provide better incentives for non-observable investments. This result can be deduced from the property rights theory of the firm (Grossman and Hart 1986; Hart and Moore, 1990; and Hart, 1995). This theory takes the incompleteness of contracts and the existence of ex-post quasi rents to continuing an existing relationship (due to turnover costs and asset specificity) as critical to understanding the problem of under-investment. The theory then focuses on how ownership of physical assets, which confers residual rights of control over these assets alters the efficiency of trading relationships (Whinston, 2003).[1] Second, long-term contracts can be used to smooth consumption and reduce risk when the agents has no access to credit markets. This result follows from the repeated moral hazard models where long-term contracts which allowed for delayed retaliation tend to be more efficient (Chiappori et al., 1994).[2] Finally, long-term contracts involve lower transaction costs because they need to be agreed upon less frequently (e.g., 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). Secondly, the principal's commitment

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[1] Because the long-term contracts are generally also incomplete, switching from short-term to long-term contracting will not automatically solve the under-investment problem. Under-investment can be overcome by designing the rules that govern the process of contractual renegotiation, for details see Aghion, Dewatripont and Rey (1994).

[2] 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).

to long-term contracts could hinder his supply response to unfavorable market conditions and negatively affect the profitability and perhaps even lead to bankruptcy.[3] On the other hand, with short term contracts, when demand is sluggish or input prices are high, the least productive agents' contracts could be easily terminated.

The empirical literature on contract duration is rather thin, with few 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. Finally, using tenancy contracts from 19th century rural Sicily, Bandiera (2007) found that the choice of 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.

Our paper 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 switching from a short-term to a long-term contract increases the 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. The theoretical predictions are then tested using an unbalanced panel of contract settlement data for the production of hatching eggs. This unique data set comes from one poultry company that contracts the production with 68 growers (farmers) divided in 2 divisions (profit centers). We show that switching from a short-term

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[3] The importance of bankruptcy constraint for the choice of optimal payment scheme in the context of agricultural contracts have been studied by Tsoulouhas and Vukina (1999).

to a long-term contract resulted in increased effort and in faster adoption of both observable and unobservable productivity enhancing technologies and practices that jointly improved performance across various performance margins.

2 The Comparison of Contracts

The production of broiler chickens involves three stages: raising broiler breeder males (cockerels) and hens (pullets), housing the mature breeding flock for the production of hatching eggs, and the production (grow-out) of commercial broilers. Various stages of broiler production are typically covered by different contracts and farmers generally specialize in one production stage under one contract. Our analysis is based on the individual contract settlements for the production of hatching eggs in two production divisions owned by the same company in the period from 1992 to 2003. There are 68 contract growers in the data set and 498 flocks. 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 is written for the period of 15 years.

The division of responsibilities for providing inputs in the production of hatching eggs between the old and the new contract remained unchanged. In both contracts the principal's responsibility is to supply breeder chickens, feed, litter, medication and technical instruction. Agents' responsibilities are to provide proper care and maintenance of flocks, housing, equipment, and other facilities necessary to gather, grade and maintain hatching eggs.

The payment mechanisms in both contracts are some variants of the variable piece rates, sometimes also known as a fixed performance benchmark schemes. The payment mechanism in the old contract consists of the finishing fee, piece rates for the hatching eggs and commercial eggs, the hatchability bonus and the feed conversion bonus. Over the years (see Table 1) the payment mechanism has been amended multiple times, such that the last version of the old contract prior to the introduction of the new contract has the same payment mechanism as the one used in the new long-term contract. In fact the new contract merely incorporated the changes to the payment mechanism that were made to the old contract over the years prior to ushering of the new contract.

The payment mechanism in the new contract has the identical finishing fee (2.5 cents per chicken per week until the birds are 25 weeks of age) and the identical piece rate for commercial eggs (9 cents per dozen) as the old contract. These two elements of the payment scheme have not changed during the analyzed 12-year interval. However, the piece rate 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 base rate in January of 2000 when the last correction to the payment scheme took place. In addition, 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[4], 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.[5] 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. The out-of-season flocks are flocks that were placed on a pullet farm during the months of November, December, January or February. 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 but their specifications

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[4] 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.

[5] 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 be between $5,000 and $6,000 (personal communication with Drs. Ken Anderson and Edgar Oviedo, Poultry Science, North Carolina State University).

also changed multiple times over the years. In the early versions of the old contract the hatchability bonus was symmetric around 85% hatchability, with the bonus/penalty in the amount of 0.5 cents per dozen hatching eggs for each percent deviation from 85%. This formula remained intact for the in-season flocks until January 2000 when the benchmark was lowered to 84% and the rate was increased to 1 cent per dozen hatching eggs. However, beginning with pullets started on November 1, 1992, the formula for the out-of-season flocks changed such that each percent hatchability above 85% carried a bonus of 0.5 cents per dozen hatching eggs, whereas the penalty in the same amount was imposed only for each percent hatchability below 83%. In January 2000, the 83-85% range benchmark hatchability was lowered to 82-84% and the rate was raised from 0.5 cent to 1 cent per dozen hatching eggs.

Prior to July 1996, the feed conversion bonus was symmetric around 7.5 pounds of feed per dozen hatching eggs, with the bonus/penalty in the amount of 4 cents per dozen hatching eggs for each pound deviation from 7.5 pounds. Since then, the feed conversion bonus remained symmetric around 7.5 pounds for the in-season flocks and around 7.75 pounds for the out-of-season flocks. In 2000, the benchmark feed conversion ratios were raised to 7.75 for in-season flocks and 8.00 for out-of-season flocks. For the purposes of calculating bonuses, the individual grower feed conversion ratios and hatchability are always calculated for flocks to 65 weeks of age. If the integrator decides to keep the flocks beyond the 65 weeks of age, the feed conversion and hatchability beyond 65 weeks of age are ignored. 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.

Both old and new contracts have identical minimum guarantee payments and catastrophic payments. The minimum guarantee payment is defined in reference to the total base egg payment (hatching plus commercial) and guarantees the grower that the total base egg payment will not be smaller than 0.75 cents per square foot of the floor space of the chicken house per week for 40 weeks (between age 25 and 65 weeks). In case of certain catastrophic diseases that render eggs produced unsuitable for hatching purposes or in case of some natural calamity, the minimum guarantee payment will not apply. Instead, the grower will be compensated

0.75 cents per square foot of the floor space for the period of time after the chickens are 25 weeks of age until the occurrence of the catastrophic event.

Finally, according to the new contract, the decisions about the number of flocks the grower will receive, the number of pullets and cockerels included in each flock, the time of removing each flock, and the date, time and interval of placement for any future flocks remained under the sole discretion of the company. In this regard, from the grower's perspective, the immediate material consequence of the contract switch appears to be minimal. 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 is the same before and after the switch. Each grower received approximately one flock per year and those growers for which the time-out period was unusually long were awarded an extra payment to compensate them for the loss of income.

In summary, the comparison of the contract forms between the old short-term contract and the new long-term contract leads to the following conclusions: (a) the division of responsibilities for providing inputs between the integrator and the growers is identical in both contracts; (b) frequent changes in the payment mechanism and its parameters are less likely to be caused by the changes in technology (nutrition and genetics) as technological changes do not happen with such frequency, but are more likely due to the adjustments needed to keep the grower remuneration in line with the macroeconomic environment (cost and wage inflation, interest rates, etc.) or are simply the result of a trial and error process in search for the contract that works best; (c) the last version of the payment scheme in the old short-term contract and the first version of the payment scheme in the new long-term contract are identical; in fact, the long-term contract merely incorporated the changes to the payment mechanism that were made to the short-term contract over the years prior to ushering of the new long-term contract.

2.1 Chronological Comparison of Performance Measures

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 4 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 caused a 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 a 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, is very likely due to the change in breed. 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 whose production is part of a vertically integrated chain owned by the same company. However, the problem associated with this switch is that the egg production and hatchability of the new breed could become lower, especially if the hen house environment is not properly controlled, as the Ross males and females are more susceptible to heat stress than the old breeds. 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 the additional incentives were insufficient to offset the negative effects caused by the breed change.

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 an actual 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 1997 due to the contract change, and then the performance deteriorated in 1998/1999 as the results of the breed change.

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. Same as before, the results indicate that both feed conversion measures improved in 1997 in comparison to the earlier years as a result of contract switch and both of them deteriorated in 1998 and beyond as a result of the breed change.

2.2 Chronological Comparison of Contract Payments

Next, we want to see whether we can detect any immediate changes in growers monetary compensations associated with operating in the new contractual environment. We compare grower payoffs chronologically using average annual contract payment per flock, average annual payment per hen, and average annual payment per square foot of the chicken house.[6] Each of these payoff indicators is expressed in nominal (current) dollars and 2002 constant

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[6] The year in which a particular flock belongs is determined by the date when the flock was sold. This is convenient because it allows us to put the realized payments for 1997 squarely into the old regime because flocks sold in 1997 could not have been started under the new contract that became operational for birds delivered on or after January 1, 2007.

dollars obtained by dividing the nominal values by the CPI index. The results are presented in Tables 3a and 3b.

The combined data for both divisions show that the average total payment per flock more or less continuously increased in the 1993-2002 period at an average annual rate of 5% nominally or about 2.5% in constant 2002 dollars.[7] Part of that increase may be due to the increase in capacity (more square footage) or higher population density (more birds per square foot) and as such may not accurately represent growers' returns and overall satisfaction with the introduced changes in the payment scheme. Therefore we look at two other indicators where the impact of the capacity/density increase is eliminated. First, we see that the average payment per hen increased from $4.36 in 1993 to $5.73 in 2002 which amounts to a 3.1% increase nominally or about 0.6% in constant 2002 dollars. Secondly, the payment per square foot of the chicken house increased from $2.07 in 1993 to $2.92 in 2002, which represents an average annual increase of 3.9% nominally or about 1.4% in 2002 dollars. These two indicators measure different things to the extent that the density of birds placed differ across flocks and growers. The casual inspection of the results reveals that the ratio between payment per hen and payment per square foot is not constant but rather varied across years as the company's policy regarding the density of hens changed. Finally, the volatility of the payment per hen and the payment per square foot also increased substantially in the 1993-2002 period as a result of the company's gradual introduction of higher-powered incentives scheme.

If we divide the entire period into 2 sub-periods representing the old (flock-by-flock) and the new (long-term) contracts and compare the average grower payoffs in constant 2002 dollars for these two subperiods, the results show the improvements in the long-term contract period for all three payoffs. In the period 1993-1997, the average annual per flock payment amounted to $92,321, the average per hen payment was $5.63 and the average payment per square foot of the chicken house was $$2.70, whereas in the 1998-2002 period the payoffs were $105,137, $5.74 and $2.88 respectively.[8] The largest difference between the two contracts is

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[7] Since the data for 2003 is not complete, it was excluded from the calculation of annual averages.

[8] The results are not sensitive to inclusion or exclusion of the incomplete data for 2003.

recorded in the payment per flock (13.9%), followed by the payment per square foot (6.7%), whereas the smallest difference is in the payment per hen (2%).

Based on the reported results, it follows that the average annual grower payoffs are consistently higher under the long-run contract than they were under the old flock-by-flock contract. This seems to be indicating that the immediate financial implication of the contract change from the growers' perspective is positive, at least as far as the revenue side is concerned. However, the nature of the data set does not allow us to reconstruct the growers' cost side, therefore the impact of the contract change on the profitability of the enterprise is impossible to determine.

3 Theoretical Model and Testable Predictions

The theoretical framework that we develop in this section is based on a principal-agent model where principal (poultry company) contracts the production of hatching eggs with independent agents (farmers). The central feature of our model is its emphasis on the incentives to invest that could be altered when the contract regime switches from short-term to long-term. We define two types of investments. The agent can invest in physical capital φ which is deemed observable, and human capital or specific knowledge k which is deemed unobservable. The investment in physical capital is discrete, i.e. the agent either installs the cool cells (or male feeders) in which case $\varphi = 1$ or does not in which case $\varphi = 0$. This investment is irreversible and only incurs a fixed cost normalized to 1 paid when acquired. The unobservable investment in specific knowledge k, which lasts only one period is given by $C(k, k_0) = C(k - k_0)$, where k_0 is the previous period investment.

In addition to these two types of investments, the agent also supplies productive effort e which is deemed unobservable.[9] Observable physical investment φ raises the productivity of effort and the unobservable specific knowledge investment reduces the marginal cost of effort.

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[9] 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 the observed contract.

The cost of effort is given by $C(e,k) = \frac{e^2}{2k}$, and the production function is given by

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

where ε is a production shock unknown at the time where efforts are exerted, with $\pi(1) > \pi(0) > 0$. The payment $w(q)$ is assumed to be linear such that $w(q) = \alpha q + \beta$, with the contract parameters α and β chosen by the principal.

The salient feature of our model is the assumption that agents (egg producers) are behaving in a dynamically optimal fashion by maximizing the expected discounted sum of their individual per period utilities. 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:

$$\begin{aligned}
\max_{e_t,k_t} V(k_0,\varphi_0) &= \sum_{t=1}^{\infty} (p\beta)^{t-1} \left[EU(w(q_t)) - C(e_t,k_t) - C(k_t - k_{t-1})\right] \\
&= EU(w(q_1)) - C(e_1,k_1) - C(k_1 - k_0) \\
&+ p\beta \sum_{t=2}^{\infty} (p\beta)^{t-2} \left[EU(w(q_t)) - C(e_t,k_t) - C(k_t - k_{t-1})\right] \\
&= EU(w(q_1)) - C(e_1,k_1) - C(k_1 - k_0) + \delta V(k_1,\varphi_1)
\end{aligned}$$

where $p \in [0,1]$ is the probability that the contract will be renewed, $\beta \in [0,1]$ is the per period discount factor, and $\delta = p\beta$.

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 $EU(w(q)) - C(e,k) - C(k-k_0)$. If the contract has at each period some probability of renewal (i.e. becomes effectively long-term), then $V(k,\varphi)$ is the sum of the expected discounted utilities. Remark that β and p and thus δ are considered 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.

Let's simplify the above general framework by assuming that agent's preferences are such that the expected utility of wage w is given by

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

Also, without a loss of generality, 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 chose not to invest ($\varphi = 0$) then he chooses both effort e and investment k according to

$$\max_{e,k} Ew(q) - \frac{\gamma}{2} var(w(q)) - C(e,k) - C(k - k_0) + \delta \max \left(V\left(k,0\right), V\left(k,1\right)\right) \equiv V\left(k_0, 0\right)$$

where he takes into account the next period value of contracting given his investment in k that is the maximum of $V\left(k,0\right)$ and $V\left(k,1\right)$ depending of 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 according to

$$\max_{e,k} Ew(q) - \frac{\gamma}{2} var(w(q)) - C(e,k) - C(k - k_0) + \delta V\left(k,1\right) - 1 \equiv V\left(k_0, 1\right) - 1$$

where $V\left(k,1\right)$ is the next period value of having invested k and having invested in φ. Thus, the initial problem of the agent boils down to choosing $\varphi = 1$ if $V\left(k_0,1\right) > V\left(k_0,0\right)$ and $\varphi = 0$ otherwise.

Given φ, the optimal choice of agent's efforts is obtained by solving

$$\max_{e,k} \alpha\pi\left(\varphi\right) e + \beta - \frac{\gamma}{2} \alpha^2 \pi\left(\varphi\right)^2 e^2 \sigma^2 - \frac{e^2}{2k} - C(k - k_0) - \varphi + \delta V\left(k, \varphi'\right)$$

where $\varphi' = 1$ if $\varphi = 1$ or if $V\left(k,1\right) > V\left(k,0\right)$ and zero otherwise. The first order conditions are

$$\begin{aligned} \alpha\pi\left(\varphi\right) - \gamma\alpha^2\pi\left(\varphi\right)^2\sigma^2 e - \frac{e}{k} &= 0 \\ \frac{e^2}{2k^2} - C'(k - k_0) + \delta V'\left(k, \varphi'\right) &= 0 \end{aligned}$$

where $V'\left(., \varphi\right)$ denotes the derivatives of $V\left(., \varphi\right)$ with respect to its first argument k (and we have used the envelope theorem with respect to φ' which also depends on k). Thus, the optimal values e^*, k^* satisfy

$$\begin{aligned}\frac{e^*}{k^*} &= \frac{\alpha\pi(\varphi)}{1+k^*\gamma\alpha^2\pi(\varphi)^2\sigma^2} \qquad (1)\\ \frac{1}{2}\left(\frac{e^*}{k^*}\right)^2 &= C'(k^*-k_0)-\delta V'(k^*,\varphi') \qquad (2)\end{aligned}$$

Based on the above derivations we can state our main results that are summarized in the following three propositions.

Proposition 1: The investment in specific human capital k and the application of productive effort e are both increasing in the probability of contract renewal.

Proof:

See Appendix.

Proposition 2: The value functions $V(.,0)$ and $V(.,1)$ are increasing and concave functions of their argument k.

Proof:

See Appendix.

Proposition 3: Ignoring its cost, the physical capital investment always provides the agent with positive benefits, i.e.: whatever k_0, $V(k_0,1) > V(k_0,0)$. Moreover, depending on the parameters, there exists k_0 such that $V(k_0,1)-1 \geq V(k_0,0)$, meaning that there exist some level of human capital investment where the adoption of physical capital investment φ is profitable.

Proof:

See Appendix.

In summary, our model shows two important, empirically testable, results. First, 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 specific human capital ($\frac{\partial k^*}{\partial\delta} > 0$) with the obvious 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.[10] Second, the effect of a switch from a short-term to a long-term contract on the agent's propensity to investment in observable physical capital (φ), which increases the productivity of effort, is ambiguous. The benefit of this investment has to outweigh the fixed cost incurred by the agent, which does not happen necessarily at all levels of specific investment in human capital (knowledge).

4 Empirical Results

Based on the theoretical framework developed in the previous section we formulate and empirically test three hypotheses: switching from a short-term to a long-term contract causes growers to increase: (a) investments in observable physical capital (cool cells), (b) effort, and (c) investments in unobservable human capital (specific knowledge) which all improve grower performance across various productivity margins.

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 in Table 4, 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 (January 1993) than the equipment bonus for cools cells (April 1995), so it is reasonable to expect earlier adoption of male feeders than cool cells. Secondly, installing cool

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[10] 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 $\delta > 0$, $\frac{\partial}{\partial k}\left[C(e,k) + C(k - k_0)\right]$ can be of any sign at the optimum.

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 4. The percentage of flocks grown with cool cells was steadily increasing from 13.5% in 1997 to 75.5% in 2002. The installation of cool cells was also strongly encouraged by the company managers, especially after 1998 when the company decided to switch to Ross breed of birds that are more susceptible to heat stress.

A more formal way of capturing the effect of the contract switch on the technology adoption is to run simple probit regressions. The results, summarized in Table 5, clearly show that the indicator variable for the contract switch labeled lt, specified to be equal 1 if the year is greater or equal 1997 and 0 otherwise, is positive and significant in both regressions. Changing the contract from short-term to long-term increased the probability of technology adoption for both cool cells and male feeders. This is true even after we include the individual yearly dummies that are picking up other unspecified changes in the incentive structure of the contract as well as the introduction of the new breed.

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 M then in division H.[11] 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 ($sqft$) has the correct positive sign, however, the

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[11] 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 H is 256.

parameter is not significantly different from zero.

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 previously defined lt. The product of the two indicator variables gives new indicator variable, labeled plt, which captures the effect of the change in contract length net of influences caused by changing other contract parameters.

The empirical strategy that we implemented 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 (say 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 does not happened, then we would conclude that in addition to expediting the observable investments, the contract switch also stimulated the unobservable and hence non-contractible investments.

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 6. The results are 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 the introduction of the new breed that began in 1998 could have reversed the productivity gains achieved by the contract switch. The other results indicate the the performance of contract growers in division M is always superior to the performance in division H, 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 6. 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 then 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 2 out of 3 models, indicating that the breed change most 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 6 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. The lt coefficients are not significant meaning that, most likely, the positive effects of the contract switch and negative consequences of the breed change approximately cancel each other out. 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 male feeders or cool cells is false. The decisions to adopt these new technologies are clearly endogenous. Different growers, depending on their idiosyncrasies, will gave different incentives towards 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 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 4, at the time of the contract change virtually all growers have already adopted this inexpensive technology. 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 7.

The obtained results are surprisingly consistent across all 9 models. Several interesting findings are worth pointing out. First, we see that *plt* is always positive and most of the time significant at 1% 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 7 out of 9 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. Thirdly, the final hypothesis of this paper is confirmed by showing that the opposite hypothesis that the entire gain in productivity came about via cool cells adoption is false. This result seems to be indicating 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.[12] This conclusion is supported by the results showing that in

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[12] Vukina and Leegomochai (2006, p. 592) talking about contract production of broiler chickens wrote: "In addition to investing in chicken houses, growers invest in their own education, training and mastery of various special skills (disease detection, culling of sick birds, bio-security practices, feed management and waste management, etc.) and they also invest in other piece of equipment and machinery that are not exclusively used for the chicken contract operation but are rather shared with other enterprises on the farm (front-end loader, tractor, manure spreader, etc.). All these investments are hard to observe by the integrator

all 9 specifications, the magnitude of the *plt* coefficient after the inclusion of the *cool* variable (Table 7) is larger than before (Table 6).

Finally, notice that the *lt* variable is now almost always negative and statistically significant. The exceptions to this general result are the two feed conversion equations. This result seems to be proving our earlier conjecture that the positive productivity impacts of the contract change were subsequently wiped out by the introduction of Ross breed birds which perform worse when it comes to egg production and hatchability (especially in hot weather) but hatched chicks would subsequently become superior broilers.

5 Conclusions

In this paper we present the results of a natural experiment where a poultry company that contract the production of hatching eggs with independent growers converted their short-term contract into a long-term contract. The nature of the change in contract parameters enabled us to isolate the effect of the change in contract length from other changes in contract parameters on agents' incentives to perform. Using contract settlement data we showed that switching from a short-term to a long-term contract resulted in increased effort and investments in productivity enhancing technologies and practices which improved performance across all productivity margins.

The result showing an increase in equilibrium effort resulting from the contract switch from short-term to long-term is rather opaque and not in line with the main-stream contracting literature. The basic intuition would tell us that the effort should decrease as the long-term contracts eliminate the threat of abrupt contract termination due to shirking. Our result is due to the complementarity of effort and the investments in human capital (specific knowledge) which makes the effort increase together with increasing the incentives to invest as the contract changes from short-term to long-term.

An interesting side story in the presented empirical investigation, which is also somewhat

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and would be even harder to verify by the courts, hence they are deemed non-contractible."

muddying our results, is that positive productivity gains that resulted from the contract duration change were subsequently undone by the company's deciding to switch to lower productivity breed of laying hens. This new breed of birds perform worse along virtually all margins that hatching egg producers are remunerated against, but at the same time produce broiler chicks of superior genetic characteristics. The strategy makes sense from the perspective of the vertically integrated broiler company who in addition to contracting the production of hatching eggs, owns it own hatcheries, and also contract the production of broilers. The animal input in the production of broilers, which when grown to market weight would get slaughtered and processed for meat, are the one-day-old chicks hatched from the same hatching eggs whose production has been contracted in the previous stage.

The poultry company's decision to change the breed of birds has not been explicitly studied in this paper. However, the problem of coordination among various links in a vertically integrated production chain seems to be an intriguing topic for future research. However, the second stage (production of broiler chickens) contract settlement data for this company is not available.

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6 Appendix

Proof of Proposition 1:

Expressions (

Then

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

because $T\left(k,\delta\right)=\left[2C'(k^*-k_0)-2\delta V'\left(k^*,\varphi'\right)\right]^{-\frac{1}{2}}$, where $T>0$, and $\frac{\partial T}{\partial k}>0$ and $\frac{\partial T}{\partial \delta}>0$.

As

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

then

$$\frac{\partial e^*}{\partial \delta}=\frac{\partial k^*}{\partial \delta}\sqrt{2}\left[\left[C'(k-k_0)-\delta V'\left(k,\varphi'\right)\right]^{\frac{1}{2}}+\frac{k^*}{2}\left[C'(k-k_0)-\delta V'\left(k,\varphi'\right)\right]^{-\frac{1}{2}}\left[C''(k-k_0)-\delta V''\left(k,\varphi'\right)\right]\right]$$

Thus $\frac{\partial e^*}{\partial \delta}>0$ because $C''(k-k_0)-\delta V''\left(k,\varphi'\right)>0$, $C'(k-k_0)-\delta V'\left(k,\varphi'\right)>0$ and $\frac{\partial k^*}{\partial \delta}>0$.
□

Proof of Proposition 2:

The proof is based on the standard Bellman equations solution techniques (Stokey, Lucas, Prescott, 1989). Consider an operator T_1 defined by $T_1 : V\left(.,1\right)\rightarrow T_1\left(V\left(.,1\right)\right)$, where $T_1\left(V\left(k_0,1\right)\right)=\max\limits_{e,k}\left[Ew(q)-\frac{\gamma}{2}var(w(q))-C(e,k)-C(k-k_0)+\delta V\left(k,1\right)\right]$, and define $H(.,.)$ such that $T_1\left(V\left(k_0,1\right)\right)=\max_{e,k}\left[H(e,k)+\delta V\left(k,1\right)\right]$.

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

Actually, for $V\left(.,1\right)$ and $W\left(.,1\right)$, $T_1\left(V\left(k_0,1\right)\right)=\left[H(e_V^*,k_V^*)+\delta V\left(k_V^*,1\right)\right]$ and $T_1\left(W\left(k_0,1\right)\right)=\left[H(e_W^*,k_W^*)+\delta W\left(k_W^*,1\right)\right]$.

By definition

$T_1\left(V\left(k_0,1\right)\right)\geq\left[H(e_W^*,k_W^*)+\delta V\left(k_W^*,1\right)\right]$ and $T_1\left(W\left(k_0,1\right)\right)\geq\left[H(e_V^*,k_V^*)+\delta W\left(k_V^*,1\right)\right]$. Thus

$$\delta\left[V\left(k_V^*,1\right)-W\left(k_V^*,1\right)\right]\geq T_1\left(V\left(k_0,1\right)\right)-T_1\left(W\left(k_0,1\right)\right)\geq\delta\left[V\left(k_W^*,1\right)-W\left(k_W^*,1\right)\right]$$

which implies that $\forall k_0$, $\left|T_1\left(V\left(k_0,1\right)\right)-T_1\left(W\left(k_0,1\right)\right)\right|\leq\delta\underset{k}{Sup}\left|V\left(k,1\right)-W\left(k,1\right)\right|$

and $\left\|T_1\left(V\left(.,1\right)\right)-T_1\left(W\left(.,1\right)\right)\right\|_\infty \leq \delta\left\|V\left(.,1\right)-W\left(.,1\right)\right\|_\infty$ where $\left\|.\right\|_\infty$ is the sup norm.

Moreover, T_1 keeps monotonicity and concavity. Thus $V\left(.,1\right)$ is increasing concave. Actually, assume $V\left(.,1\right)$ is increasing concave. Then $T_1\left(V\left(.,1\right)\right)$ is also because using the envelope theorem

$$\frac{\partial T_1\left(V\left(k_0,1\right)\right)}{\partial k_0}=C'(k^*-k_0)>0$$

and

$$\frac{\partial^2 T_1\left(V\left(k_0,1\right)\right)}{\partial k_0^2}=-C''(k^*-k_0)<0.$$

Consider the operator T_0 defined by $T_0: V\left(.,0\right)\rightarrow T_0\left(V\left(.,0\right)\right)$, where $T_0\left(V\left(k_0,0\right)\right)=\max\limits_{e,k}\left[Ew(q)-\frac{\gamma}{2}var(w(q))-C(e,k)-C(k-k_0)+\delta\max\left(V\left(k,1\right)-1,V\left(k,0\right)\right)\right]$, and define $G(.,.)$ such that $T_0\left(V\left(k_0,0\right)\right)=\max_{e,k}\left[G(e,k)+\delta\max\left(V\left(k,1\right)-1,V\left(k,0\right)\right)\right]$.

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

Actually, for $V\left(.,0\right)$ and $W\left(.,0\right)$, $T_0\left(V\left(k_0,0\right)\right)=G(e_V^*,k_V^*)+\delta\max\left(V\left(k_V^*,1\right)-1,V\left(k_V^*,0\right)\right)$ and $T_0\left(W\left(k_0,0\right)\right)=G(e_W^*,k_W^*)+\delta\max\left(V\left(k_W^*,1\right)-1,W\left(k_W^*,0\right)\right)$.

By definition $T_0\left(V\left(k_0,0\right)\right)\geq G(e_W^*,k_W^*)+\delta\max\left(V\left(k_W^*,1\right)-1,V\left(k_W^*,0\right)\right)$ and $T_0\left(W\left(k_0,0\right)\right)\geq G(e_V^*,k_V^*)+\delta\max\left(V\left(k_V^*,1\right)-1,W\left(k_V^*,0\right)\right)$. Thus

$$\begin{aligned}
&\delta\left[\max\left(V\left(k_V^*,1\right)-1,V\left(k_V^*,0\right)\right)-\max\left(V\left(k_V^*,1\right)-1,W\left(k_V^*,0\right)\right)\right]\\
\geq\ & T_0\left(V\left(k_0,0\right)\right)-T_0\left(W\left(k_0,0\right)\right)\\
\geq\ & \delta\left[\max\left(V\left(k_W^*,1\right)-1,V\left(k_W^*,0\right)\right)-\max\left(V\left(k_W^*,1\right)-1,W\left(k_W^*,0\right)\right)\right].
\end{aligned}$$

Therefore

$$\begin{aligned}
&T_0\left(V\left(k_0,0\right)\right)-T_0\left(W\left(k_0,0\right)\right)\\
\geq\ & \delta\left[\max\left(V\left(k_W^*,1\right)-1,V\left(k_W^*,0\right)\right)-\max\left(V\left(k_W^*,1\right)-1,W\left(k_W^*,0\right)\right)\right]\\
\geq\ & \delta\left[V\left(k_W^*,0\right)-W\left(k_W^*,0\right)\right]\text{ if } V\left(k_W^*,1\right)-1\leq W\left(k_W^*,0\right)\\
\geq\ & \delta\left[V\left(k_W^*,1\right)-1-V\left(k_W^*,1\right)+1\right]=0\text{ if } V\left(k_W^*,1\right)-1>W\left(k_W^*,0\right).
\end{aligned}$$

$$\begin{aligned}
T_0\left(V\left(k_0,0\right)\right)-T_0\left(W\left(k_0,0\right)\right) &\leq \delta\left[\max\left(V\left(k_V^*,1\right)-1,V\left(k_V^*,0\right)\right)-\max\left(V\left(k_V^*,1\right)-1,W\left(k_V^*,0\right)\right)\right]\\
&\leq \delta\left[V\left(k_V^*,0\right)-W\left(k_V^*,0\right)\right]\text{ if } V\left(k_V^*,1\right)-1\leq V\left(k_V^*,0\right)\\
&\leq \delta\left[V\left(k_V^*,1\right)-1-V\left(k_V^*,1\right)+1\right]=0\text{ if } V\left(k_V^*,1\right)-1>V\left(k_V^*,0\right).
\end{aligned}$$

This implies that $\forall k_0$, $\left|T_0\left(V\left(k_0,0\right)\right)-T_0\left(W\left(k_0,0\right)\right)\right|\leq \delta \underset{k}{Sup}\left|V\left(k,0\right)-W\left(k,0\right)\right|$

and $\left\|T_0\left(V\left(.,0\right)\right)-T_0\left(W\left(.,0\right)\right)\right\|_\infty \leq \delta\left\|V\left(.,0\right)-W\left(.,0\right)\right\|_\infty$ where $\left\|.\right\|_\infty$ is the sup norm.

Moreover, T_0 keeps monotonicity and concavity. Thus $V\left(.,0\right)$ is increasing concave. Actually, assume $V\left(.,0\right)$ is increasing concave. Then $T_0\left(V\left(.,0\right)\right)$ is also because using the envelope theorem

$$\frac{\partial T_0\left(V\left(k_0,0\right)\right)}{\partial k_0}=C'(k^*-k_0)>0$$

and

$$\frac{\partial^2 T_0\left(V\left(k_0,0\right)\right)}{\partial k_0^2}=-C''(k^*-k_0)<0.$$

□

Proof of Proposition 3:

Denote

$$\begin{aligned} H\left(\pi\right) &= \max_{e,k}\left[Ew(q)-\frac{\gamma}{2}var(w(q))-C(e,k)-C(k-k_0)+\delta\max\left(V\left(k,0\right),V\left(k,1\right)-1\right)\right] \\ &= \max(H_0\left(\pi\right),H_1\left(\pi\right)) \end{aligned}$$

where

$$H_0\left(V\left(k,0,\pi\right)\right)=\max_{e,k}Ew(q)-\frac{\gamma}{2}var(w(q))-C(e,k)-C(k-k_0)+\delta V\left(k,0,\pi\right)$$

and

$$H_1\left(V\left(k,1,\pi\right)\right)=\max_{e,k}Ew(q)-\frac{\gamma}{2}var(w(q))-C(e,k)-C(k-k_0)+\delta V\left(k,1,\pi\right)-\delta.$$

As

$$\frac{\partial H_0\left(\pi\right)}{\partial\pi}=\alpha e^*(1-\gamma\alpha\pi e^*\sigma^2)+\delta\frac{\partial V\left(k,0,\pi\right)}{\partial\pi}>0 \text{ if } \frac{\partial V\left(k,0,\pi\right)}{\partial\pi}>0$$

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

$$\frac{\partial H_1\left(\pi\right)}{\partial\pi}=\alpha e^*(1-\gamma\alpha\pi e^*\sigma^2)+\delta\frac{\partial V\left(k,1,\pi\right)}{\partial\pi}>0 \text{ if } \frac{\partial V\left(k,1,\pi\right)}{\partial\pi}.$$

Thus, H_0 and H_1 are increasing in π and so is H. This implies that $V\left(k_0,1\right)>V\left(k_0,0\right)$ whatever $\delta>0$ and whatever k_0.

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

$$\begin{aligned} V(k_0, 0) &= \alpha e^* = \alpha^2 \pi k^*(\pi) \\ V(k_0, 1) - 1 &= \alpha e^* - 1 = \alpha^2 \pi k^*(\pi) - 1 \end{aligned}$$

because $\frac{e^*}{k^*} = \alpha\pi$ and where $k^*(\pi) = k_0 + C'^{-1}\left(\frac{1}{2}(\alpha\pi)^2\right)$ which is increasing in π. Thus

$$\begin{aligned} V(k_0, 1) - 1 - V(k_0, 0) &= \alpha^2 \left[\pi(1) k^*(\pi(1)) - \pi(0) k^*(\pi(0))\right] - 1 \\ &> 0 \text{ if } \pi(1) k^*(\pi(1)) - \pi(0) k^*(\pi(0)) > \frac{1}{\alpha^2} \end{aligned}$$

which is possible if $\pi(1)$ is sufficiently large since $\pi k^*(\pi) = \pi\left[k_0 + C'^{-1}\left(\frac{1}{2}(\alpha\pi)^2\right)\right]$ is larger than πk_0 and also increasing in π.

This limit case shows that depending on technological and contract parameters, adoption of φ can be profitable or not. When $\delta > 0$, both cases can happen. Remark that when $\delta = 1$ adoption is never profitable because delaying investment is never costly. Actually, when $\delta = 1$,

$$\begin{aligned} V(k_0, 0) &= \frac{\alpha e^*}{1 + k^* \gamma \alpha^2 \pi^2 \sigma^2} + \max\left(V(k^*, 0), V(k^*, 1) - 1\right) \\ &> \max\left(V(k^*, 0), V(k^*, 1) - 1\right) \\ &> V(k^*, 1) - 1 \geq V(k_0, 1) - 1 \text{ because } k^* \geq k_0. \end{aligned}$$

$\square$

Table 1. Payment Schedule Changes

	Base Price		**Male**	**Cool**	**H-Eggs**		**C-Eggs**	**H-Bonus**			**FC-Bonus**		
Date	**H-Eggs**		**Feeder**	**Cell**	**Pay**		**Pay**	**Target**		**Pay**	**Target**		**Pay**
	In	**Out**			**In**	**Out**		**In**	**Out**		**In**	**Out**	
12/31/1991	0.27				0.27		0.09						
11/1/1992	For pullets started on							85%	83-85%	0.005			
1/30/1993	0.28		0.02		0.30		0.09						
2/19/1994	0.29		0.02		0.31		0.09						
4/29/1995	0.30		0.02	0.02	0.34		0.09						
7/1/1996	0.30	0.31	0.02	0.02	0.34	0.35	0.09				7.5	7.75	0.04
2/1/1997			New long-term (15-year) contract introduced.										
3/1/1998	0.30	0.31	0.02	0.03	0.35	0.36	0.09						
5/25/1998	0.31	0.32	0.02	0.03	0.36	0.37	0.09						
1/1/2000	0.32	0.33	0.02	0.03	0.37	0.38	0.09	84%	82-84%	0.01	7.75	8.00	0.04

Table 2. Chronological Comparison of Performance Indicators: Mean Values

year	ratio	ratio1	ratio2	ratio3	hateg	ht	htsqft	fct	fch
1992	13.62352	6.504174	13.82734	6.601533	187943.2	11.71633	5.593549	7.0477	7.153063
1993	13.85631	6.545372	14.07112	6.646476	190723.3	11.79551	5.570035	6.729341	6.833485
1994	13.86231	6.646389	14.06521	6.744217	192168.8	11.77972	5.645693	6.744444	6.842645
1995	13.62012	6.568796	13.88926	6.698501	179710	11.41979	5.506977	6.82725	6.962161
1996	13.84207	6.735941	14.11094	6.866744	209060.3	11.8473	5.765253	6.656639	6.784405
1997	14.38927	7.012739	14.71136	7.169715	214923.5	12.18633	5.93943	6.412504	6.556086
1998	13.54823	6.658701	13.99965	6.879692	201863.4	11.32	5.564179	6.552951	6.769077
1999	12.88502	6.504866	13.25001	6.68879	199673.8	10.94152	5.523543	6.640927	6.830006
2000	12.68112	6.449746	13.05201	6.63808	200370.3	10.80281	5.494542	6.76171	6.960388
2001	13.26973	6.767959	13.68906	6.981626	213757.2	11.29958	5.763346	6.688801	6.901891
2002	13.41724	6.85166	13.79517	7.044735	210521.4	11.41284	5.828001	6.703446	6.892663
2003	12.69295	6.415357	13.01453	6.577991	185182.6	10.90392	5.511386	6.612257	6.780168

Legend:

ratio = number (in dozens) of hatching eggs per hen; *ratio*1 = number of hatching eggs per square foot; *ratio*2 = total number of eggs (hatching plus commercial) per hen; *ratio*3 = 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.

Table 3a. Chronological Comparison of Grower Payments: Current Dollars

Year	Flocks	Mean(TP)	St.Dev.(TP)	Mean(PPH)	St.Dev.(PPH)	Mean(PPSQ)	St.Dev.(PPSQ)
1993	8	69,595.64	4,998.48	4.36	0.29	2.07	0.15
1994	34	75,919.85	5,513.35	4.69	0.35	2.22	0.23
1995	45	74,231.26	14,629.13	4.75	0.54	2.28	0.31
1996	47	80,985.62	9,378.93	4.93	0.58	2.38	0.31
1997	54	91,284.68	27,777.63	5.17	0.58	2.51	0.29
1998	50	96,581.62	25,133.39	5.45	0.53	2.66	0.26
1999	53	93,281.75	27,509.24	5.19	0.67	2.57	0.33
2000	54	100,240.31	31,775.89	5.45	0.87	2.76	0.44
2001	58	104,098.85	31,741.12	5.60	0.93	2.85	0.48
2002	53	108,137.51	35,004.95	5.73	0.70	2.92	0.36
2003	42	107,666.79	33,702.35	5.71	0.78	2.91	0.40
Total	498	93,757.35	28,920.21	5.28	0.77	2.62	0.43

Table 3b. Chronological Comparison of Grower Payments: 2002 Dollars

Year	Flocks	Mean(TP)	St.Dev.(TP)	Mean(PPH)	St.Dev.(PPH)	Mean(PPSQ)	St.Dev.(PPSQ)
1993	8	86,645.36	6,223.02	5.42	0.36	2.58	0.19
1994	34	92,159.12	6,692.65	5.69	0.43	2.70	0.28
1995	45	87,626.01	17,268.90	5.60	0.64	2.69	0.36
1996	47	92,857.32	10,753.79	5.66	0.66	2.73	0.36
1997	54	102,318.46	31,135.18	5.79	0.65	2.82	0.32
1998	50	106,595.30	27,739.24	6.02	0.58	2.94	0.29
1999	53	100,728.61	29,705.35	5.60	0.73	2.77	0.35
2000	54	104,479.90	33,119.83	5.68	0.91	2.88	0.46
2001	58	105,744.68	32,242.95	5.69	0.95	2.90	0.49
2002	53	108,137.51	35,004.95	5.73	0.70	2.92	0.36
2003	42	105,669.70	33,077.21	5.60	0.76	2.86	0.40
Total	498	100,948.07	28,505.24	5.70	0.73	2.82	0.38

Legend:

TP = total payment per flock; PPH = payment per hen; $PPSQ$ = payment per square foot.

Table 4. Technology Adoption Rates

	Cool Cells				Male Feeders			
Year*	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%

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

Table 5. Technology Adoption Results: Probit Regressions

Cool Cells

Obs. = 427

LR chi2(10) = 177.91

Log L. = -199.28809 Pseudo R^2 = 0.3086

	Coef.	Std. Error	z	p	95% Conf. Interval	
lt	6.991878	0.4759	14.69	0.000	6.059131	7.924625
M	0.683731	0.15003	4.56	0.000	0.389678	0.977783
sqft	7.21E-06	9.18E-06	0.79	0.432	-1.1E-05	2.52E-05
1995	4.321457	.	.	.	.	.
1996	5.065826	0.502211	10.09	0.000	4.08151	6.050141
1997	-1.70003	0.29619	-5.74	0.000	-2.28055	-1.11951
1998	-1.04965	0.264875	-3.96	0.000	-1.56879	-0.5305
1999	-0.46209	0.25683	-1.8	0.072	-0.96547	0.041286
2000	-0.02038	0.254866	-0.08	0.936	-0.51991	0.479151
2002	0.181701	0.263378	0.69	0.490	-0.33451	0.697912
const	-7.0665	0.532899	-13.26	0.000	-8.11096	-6.02203

Male Feeders

Obs. = 277

LR chi2(8) = 30.18

Log L. = -97.483984 Pseudo R^2 = 0.1340

	Coef.	Std. Error	z	p	95% Conf. Interval	
lt	1.809001	0.709658	2.55	0.011	0.418097	3.199905
M	0.627557	0.212791	2.95	0.003	0.210494	1.04462
sqft	2.52E-05	2.56E-05	0.98	0.326	-2.5E-05	7.53E-05
1993	0.441427	0.677693	0.65	0.515	-0.88683	1.769681
1994	0.806232	0.668278	1.21	0.228	-0.50357	2.116034
1995	1.140799	0.671481	1.7	0.089	-0.17528	2.456878
1996	1.264637	0.675794	1.87	0.061	-0.05989	2.589169
1997	-0.33417	0.419315	-0.8	0.425	-1.15601	0.487671
const	-1.15884	1.071201	-1.08	0.279	-3.25835	0.940677

Table 6. Performance Measures: OLS Results

	ratio	**ratio1**	**ratio2**	**ratio3**	**hateg**	**ht**	**htsqft**	**fct**	**fch**
M	**0.424**	**0.186**	**0.426**	**0.186**	**9,622**	**0.523**	**0.239**	**-0.182**	**-0.194**
	(0.081)**	(0.048)**	(0.082)**	(0.048)**	(1,394)**	(0.074)**	(0.043)**	(0.033)**	(0.034)**
lt	**-0.212**	**0.208**	**-0.046**	**0.297**	**-8,581**	**-0.467**	**-0.019**	**-0.064**	**0.009**
	(0.097)*	(0.057)**	(0.098)	(0.058)**	(1,981)**	(0.105)**	(0.060)	(0.082)	(0.084)
plt	**0.849**	**0.193**	**0.784**	**0.156**	**16,989**	**0.978**	**0.343**	**-0.218**	**-0.267**
	(0.134)**	(0.079)*	(0.135)**	(0.080)	(2,500)**	(0.134)**	(0.077)**	(0.061)**	(0.062)**
seas	**-0.152**	**-0.095**	**-0.263**	**-0.150**	**962**	**-0.029**	**-0.032**	**0.087**	**0.037**
	(0.087)	(0.052)	(0.088)**	(0.052)**	-1,495	(0.080)	(0.046)	(0.035)*	(0.036)
days	**0.044**	**0.020**	**0.046**	**0.021**	**606**	**0.033**	**0.015**		
	(0.004)**	(0.002)**	(0.004)**	(0.002)**	(68.5)**	(0.004)**	(0.002)**		
hens					**11.8**				
					(0.184)**				
fcd1								**-0.076**	**-0.064**
								(0.079)	(0.081)
fcd2								**0.100**	**0.097**
								(0.047)*	(0.048)*
const	**1.151**	**0.842**	**0.973**	**0.766**	**-178,926**	**2.315**	**1.345**	**6.789**	**6.945**
	(1.138)	(0.674)	(1.154)	(0.681)	(20,507)**	(1.103)*	(0.633)*	(0.042)**	(0.043)**
hd1					**585.3**	**-0.034**	**0.025**		
					-4,623	(0.249)	(0.143)		
hd2					**8,098**	**0.431**	**0.312**		
					(1,885)**	(0.101)**	(0.058)**		
obs	498	498	498	498	498	498	498	498	498
R^2	0.37	0.20	0.36	0.22	0.91	0.34	0.21	0.14	0.13

Standard errors in parentheses; * significant at 5%; ** significant at 1%.

Table 7. Performance Measures with Technology Adoption: Grower Fixed Effects

	ratio	**ratio1**	**ratio2**	**ratio3**	**hateg**	**ht**	**htsqft**	**fct**	**fch**
lt	**-0.581**	**-0.048**	**-0.403**	**0.044**	**-11,909**	**-0.698**	**-0.164**	**-0.072**	**0.003**
	(0.117)**	(0.070)	(0.119)**	(0.071)	(2,109)**	(0.110)**	(0.065)*	(0.074)	(0.076)
plt	**1.122**	**0.393**	**1.048**	**0.353**	**19,386**	**1.128**	**0.439**	**-0.181**	**-0.236**
	(0.140)**	(0.084)**	(0.141)**	(0.084)**	(2,430)**	(0.130)**	(0.077)**	(0.055)**	(0.057)**
seas	**-0.244**	**-0.110**	**-0.289**	**-0.132**	**-2,050**	**-0.146**	**-0.053**	**0.068**	**0.047**
	(0.199)	(0.119)	(0.201)	(0.120)	-3,365	(0.180)	(0.106)	(0.077)	(0.079)
days	**0.036**	**0.018**	**0.038**	**0.018**	**463**	**0.024**	**0.012**		
	(0.004)**	(0.002)**	(0.004)**	(0.002)**	(70)**	(0.004)**	(0.002)**		
cool	**0.408**	**0.394**	**0.380**	**0.386**	**5,728**	**0.316**	**0.293**	**0.038**	**0.018**
	(0.133)**	(0.080)**	(0.134)**	(0.080)**	(2,356)*	(0.126)*	(0.075)**	(0.054)	(0.055)
hens					**11.428**				
					(0.252)**				
fcd1								**-0.065**	**-0.043**
								(0.071)	(0.073)
fcd2								**0.104**	**0.103**
								(0.044)*	(0.046)*
const	**3.741**	**1.718**	**3.589**	**1.652**	**-120,618**	**5.334**	**2.356**	**6.691**	**6.820**
	(1.174)**	(0.705)*	(1.189)**	(0.711)*	(21,668)**	(1.131)**	(0.670)**	(0.056)**	(0.058)**
hd1					**-3,890**	**-0.300**	**-0.062**		
					-4,579	(0.245)	(0.145)		
hd2					**6,018**	**0.303**	**0.220**		
					(1,891)**	(0.101)**	(0.060)**		
obs	498	498	498	498	498	498	498	498	498
i.d.	68	68	68	68	68	68	68	68	68
R^2	0.36	0.20	0.34	0.21	0.85	0.32	0.19	0.10	0.10

Standard errors in parentheses; * significant at 5%; ** significant at 1%.