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 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

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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.

1 Introduction

The production contracts between integrator firms (principals) and independent farmers (agents) in many 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. The reason for short-term contracting in repeated transactions is the desire of parties to retain flexibility in uncertain business environments. The lack of commitment to continue the relationship beyond the current period is also a source of implicit incentives that can be utilized to mitigate asymmetric information problems.[1] Occasionally, one can observe situations where changes in contracting environments cause parties to change the duration of their contractual relationship. One such example that has recently come to our attention is the conversion of a short-term contract for the production of hatching eggs into a long-term one. The production of hatching eggs constitutes an early stage in the production of broiler chickens, which is usually organized as a profit center within a completely vertically integrated company involved in the production and distribution of poultry products.

In this paper we argue that 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 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 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 there 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

[1]According to Salanié (1997), commitment refers to the ability of agents to restrict their future actions by pledging that they will stick to the contract until some predetermined date, and breach of contract and renegotiation are the opposite of commitment. For the dynamics of contracts under full commitment see Laffont and Martimort (2002) and for the dynamics of complete contracts under various degrees of commitment see also Salanié (1997).

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 Salanié (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 argue that the observed contract changed in a response to exogenous change in the regulatory environment 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).[2] Second, long-term contracts can be used to smooth consumption and reduce risk when the

[2]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).

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).[3] 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 to long-term contracts could hinder his supply response to unfavorable market conditions and negatively affect the profitability and perhaps even lead to bankruptcy.[4] 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 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)

[3] 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).

[4] 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).

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 heterogenous transactions.

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 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.

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 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.

2 The Comparison of Contracts

The broiler industry is often considered a role model for the industrialization of agriculture. The industry is entirely vertically integrated from breeding flocks and hatcheries, to production (grow-out) of broiler chickens, to feed mills, transportation divisions and processing plants. The production of broiler involves three stages: raising broiler breeder males (cockerels) and hens (pullets), housing the mature breeding flock for the production of hatching eggs, and growing 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. 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 the period of 15 years.

The data set consists of contract settlement sheets for 498 flocks tended by 68 contract growers. The list includes all growers under contract with two different profit centers of the same company. The largest number of flocks per grower is 11 (6 growers) and the smallest number of flocks is 1 (3 growers). Since the data for 2003 is incomplete, there is also substantial number of growers that had 10 or 9 flocks (27 growers). Growers with 8, 9, 10 or 11 flocks amount to 55% of the data. Growers with only a few flocks are those that signed the contract with the company or left the company during the period covered by the data. As seen from those numbers, there is very limited entry and exit of growers into the pool. This is perfectly normal in other contracts of this type. When the company opens a new profit center (processing plant and hatchery) they try to hire all growers they need to keep this division running at full capacity all at once. Once enough growers are signed up, hiring stops and will typically occur only as replacement for growers that are leaving (retiring, switching integrators or whose contracts were terminated). Since none of this happens very frequently, the turn-over is relatively small. More noticeable changes in the steady-state number of growers happens rarely, only in cases of capacity expansion or severe and prolonged reduction in global demand for poultry meat.[5]

[5]Regular fluctuations in demand are met by increasing or decreasing the number of flocks per existing grower (by extending or shrinking the down-time periods among flocks). Only in extreme cases the supply response would involve terminating the contracts with existing growers, as hiring them back on a short notice would be nearly impossible.

The true reasons for the contract duration change are unknown. 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 addition to increasing pressure from the contract growers associations, we also believe that the company acted proactively to anticipated government regulation regarding the type of contracts that poultry integrators and contract growers can sign. At that time, among other things, a number of regulatory proposals were focused precisely on contract termination clauses and dispute resolution procedures.[6]

Aside from the frequent changes in the payment mechanism (precisely documented below), which appears to be totally unrelated to the contract duration change, the immediate material consequences of the contract switch appears to be minimal from the growers' perspective. 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 fact, based on the available 12-year records (1992-2003),

[6]The main federal legislation concerning contracts in agriculture is the Packers and Stockyard Act of 1921 (P&S Act) enforced by the Grain Inspection, Packers and Stockyards Administration (GIPSA) of the US Department of Agriculture. The 1987 amendments brought the poultry contracts under the P&S Act. From that time on, the list of numerous state and federal governments' attempts to regulate the poultry industry contracts grew larger and larger. The period around the time this company decided to change the contract duration is concentrated with regulatory proposals. For example, 1997 in an advanced notice of proposed rule making, GIPSA announced that it is considering the need for issuing substantive regulation of poultry contracts; for an overview see Vukina and Leegomonchai (2006b). Interestingly enough, over the years most of the substantive regulatory proposals were successfully derailed by the industry lobbying. Most recently, however, GIPSA promulgated a final rule (published on December 3, 2009 at 74 Fed. Reg. 63271) that takes aim at the lack of transparency in the poultry market. Of course the rule does not go as far as requiring that all contract be long-term, it only requires the live poultry dealers to provide a 90-day written termination notice if the poultry growing agreement is terminated, not renewed, or expires with no subsequent replacement of the agreement. The notice must state the reason(s) for termination, the effective date of termination, and any appeal rights that the grower may have with the live poultry dealer.

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.

The division of responsibilities for providing inputs in the production of hatching eggs between the old and the new contract also 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.

Table 1: here

The payment mechanism in the new contract has an identical finishing fee (2.5 cents per chicken per week until the birds are 25 weeks of age) and an identical piece rate for commercial eggs (9 cents per dozen) as in 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[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. 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 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.

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

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.

Finally, 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.

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) all strategic decisions about the timing of placements and removals of flocks and also their size and density, as well as the division of responsibilities for providing inputs between the integrator and the growers are all 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. The only material change is the commitment on the part of the integrator to deliver the new flocks of birds to the growers' farms for the period of 15 years.[9]

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.

Table 2: here

Second, a sharp drop in all performance measures starting in 1998, and continuing in 1999, could be explained by the change in breed. Starting in 1998, the company started changing

[9]The stipulations for the unilateral termination of contracts in cases of grower's gross negligence, theft of birds, eggs or feed, etc., still remained the same as in the old flock-by-flock contract.

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 these additional incentives were not sufficient to offset the negative effects caused by the breed change and neither was the massive adoption of cool cells that followed the contract duration change from short-term to long-term. 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 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.[10] The results are presented in Table 3.

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.[11] 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

[10]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.

[11]Constant 2002 dollars values are obtained by dividing the nominal values by the CPI index. Since the data for 2003 is not complete, it was excluded from the calculation of annual averages.

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.

Table 3: here

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 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, all expressed in constant 2002 dollars.[12] The largest difference between the two contracts is 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.

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

3 Theoretical Model and Testable Predictions

The theoretical framework that we develop in this section is based on a principal-agent model where the principal (poultry company) contracts the production of hatching eggs with an independent agent (farmer). 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 (production technology) φ 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 and paid when acquired. The unobservable investment i in specific knowledge 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 investment. 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 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.[13] Physical investment φ raises the productivity of effort such that 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

[13] 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.

contract parameters α and β chosen by the principal.[14]

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. 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, which are the solution to the Principal's intertemporal optimization problem, are then treated as exogenous and fixed in the Agent's decision problem.[15]

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 $U(.)$ 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 $V(k_0, 1) - 1$ (where 1 is the fixed cost)

[14]Obviously, 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 is not optimal even in the static case, much less so in a dynamic context. However, as mentioned before, we take the observed contracts as given without making any claims regarding their optimality.

[15]Notice that we do not allow the renegotiation of contract parameters based on the agent's performance. In this case we cannot assume that the long term optimal contract can be implemented with short term contracts as in Rey and Salanié (1990). Unlike in their general model 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

$$V\left(k_0,1\right)=\max_{\{e_t,k_t|\varphi_t=1\}_{t\geq1}}\sum_{t=1}^{\infty}\left(p\phi\right)^{t-1}\left[EU(w(q_t))-G(e_t,k_t)-C(k_t-\mu k_{t-1})\right]$$

and the expected discounted utility of the agent who has initial knowledge k_0 if he decides not to invest in physical capital will be

$$V\left(k_0,0\right)=\max_{\{e_t,k_t,,\varphi_t\in\{\varphi_{t-1},1\}\}_{t\geq1}}\sum_{t=1}^{\infty}\left(p\phi\right)^{t-1}\left[EU(w(q_t))-G(e_t,k_t)-C(k_t-\mu k_{t-1})\right]-1_{\{\varphi_t>\varphi_{t-1}\}}$$

where $\phi\in[0,1]$ is the per period discount factor and by convention $\varphi_{-1}=0$. Remark that $1_{\{\varphi_t>\varphi_{t-1}\}}$ 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

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

and

$$V\left(k_0,0\right)=\max_{\{e_1,k_1,\varphi_1\in\{0,1\}\}}\left[EU(w(q_1))-G(e_1,k_1)-C(k_1-\mu k_0)+\delta\left(V\left(k_1,\varphi_1\right)-1_{\{\varphi_1>0\}}\right)\right]. \tag{2}$$

Remark that (2) can also be written as

$$V\left(k_0,0\right)=\max_{e_1,k_1}\left[EU(w(q_1))-G(e_1,k_1)-C(k_1-\mu k_0)+\delta\max\left(V\left(k_1,1\right)-1,V\left(k_1,0\right)\right)\right]. \tag{3}$$

If the contract is a one-period contract with zero probability of renewal, then $V\left(k,\varphi\right)$ 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 1 (i.e. becomes effectively long-term), then $V\left(k,\varphi\right)$ 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.

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

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

This assumption of mean-variance criterium can be justified with Constant Absolute Risk Aversion preferences and normally distributed income or with quadratic utility, in which case the expected utility of the Agent is an increasing concave function of this mean-variance criterium. Then, the value function for the Agent when it has invested in physical capital $V(.,1)$ and the value function $V(.,0)$ when it has not invested in physical capital both satisfy the following proposition.

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

Proof of Proposition 1: See Appendix.

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

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

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

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

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

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

$$\max_{e,k|\varphi} \alpha\pi(\varphi) e + \beta - \frac{\gamma}{2}\alpha^2 \pi(\varphi)^2 e^2 \sigma^2 - \frac{e^2}{2k} - C(k - \mu k_0) - \varphi + \delta \max_{\varphi' \in \{0,1\}} \left[V(k, \varphi') - 1_{\{\varphi' > \varphi\}}\right]$$

where $\varphi' = 1$ if $\varphi = 1$ or if $V(k,1) - 1 > V(k,0)$ and zero otherwise. 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

$$\frac{e^*}{k^*} = \frac{\alpha\pi(\varphi)}{1 + k^* \gamma \alpha^2 \pi(\varphi)^2 \sigma^2} \tag{4}$$

$$\frac{1}{2}\left(\frac{e^*}{k^*}\right)^2 = C'(k^* - \mu k_0) - \delta V'(k^*, \varphi'). \tag{5}$$

where $V'(., \varphi)$ denotes the derivative of $V(., \varphi)$ 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 the above derivations we can state our main results that are summarized in Propositions 2, 3 and 4.

Proposition 2: The optimal investment in specific human capital k^* is increasing in the probability of contract renewal δ . Moreover, the application of productive effort e^* is also increasing in the probability of contract renewal if the value function is sufficiently concave or the investment cost function is sufficiently convex.

Proof of Proposition 2: see Appendix.

Proposition 3: Ignoring its fixed cost, the physical capital investment always provides the agent with positive benefits, i.e.: whatever k_0, $V(k_0, 1) > V(k_0, 0)$.

Proof of Proposition 3: see Appendix.

However, since the investment in physical capital is costly, its adoption can sometimes be profitable and sometimes not, despite the fact that the adoption *per se* always generates positive benefits. As shown in Proposition 4, whether the adoption is profitable or not depends on the level of knowledge k_0.

Proposition 4: Given contract and technological parameters α, δ, $\pi(0)$ and $\pi(1)$, and a risk neutral Agent; there exist 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 4: see Appendix.

Proposition 4 thus 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. The result is obtained for risk-neutral agents, but is also true for cases of low risk aversion via the continuity argument.

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.

Result 1: At the steady state, e^* and k^* are: increasing in μ and δ, decreasing in γ and σ^2 if and only if $\pi(1) > \frac{1}{\alpha}$, increasing in α if and only if $\pi(1) < \frac{2}{\alpha}$ and increasing in $\pi(1)$ for $\pi(1) \leq \frac{2}{\alpha}$ and decreasing in $\pi(1)$ for $\pi(1) \geq \frac{2}{\alpha}$.

Proof of Result 1: see Appendix.

In summary, our model gives several potentially empirically testable predictions. First, according to Proposition 2, 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.[16] 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), which increases the productivity of effort, 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.

4 Empirical Results

In line with the theoretical results developed in the previous section we formulate and empirically test three hypotheses about the effects of contract duration change from short-term to long-term on growers' behavior. First, the contract switch will cause the investments in unobservable human capital (specific knowledge) to increase. Second, the investments in observable physical capital (cool cells) will increase as well. Both of those effects will improve grower performance across various productivity margins. Finally, the contract switch will cause effort to initially increases with a positive effect on all productivity measures but, after the new technology has been adopted, could subsequently decrease 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

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

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 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.

Table 4: here

A more formal way of capturing the effect of the contract switch on the technology adoption is to run 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.[17]

Table 5: here

[17]Notice that coefficient estimates for some years are missing. This is because insufficient variability of the dependent variable on those years prevented the identification of these year effects.

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.[18] 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 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 a new indicator variable, labeled plt, which captures the effect of the change in contract duration 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

[18] 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.

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.

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, after the new technology has been adopted, the initial increase in effort could have been reversed despite the additional incentives provided by the increase in the base price for hatching eggs on June 25, 1998 and then again on January 1, 2000 (see Table 1 for details). This effect has been most likely magnified by 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 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 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 2 out of 3 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 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. However, the lt coefficients are not significant meaning that the change in effort and breed did not have appreciable effects on feed conversion. This is in line with the fact that these newly introduced breeds only suffer from decreased egg production and hatchability but not from inferior feed conversion. Also, the fact that standard husbandry practices for laying hens (and most 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.

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).

Table 6: here

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.

Table 7: here

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.[19] This conclusion is supported by the results showing that in all 9 specifications, the magnitude of the *plt* coefficient after the inclusion of the *cool* variable (Table 7) is larger than before (Table 6).

[19]Vukina and Leegomochai (2006a, 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 pieces 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 and would be even harder to verify by the courts, hence they are deemed non-contractible."

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 supporting 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. In all likelihood, the reduction in performance across nearly all productivity margins was exacerbated 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 with lower feed conversion and better meat yields.

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 (flock-by-flock) into a long-term contract (15 years). The nature of the change in contract parameters enabled us to isolate the effect of the change in contract duration 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 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.

An interesting side story in the presented empirical investigation, is that in period of 1-2 years after the introduction of the new long-term contract, the company also decided to switch to lower productivity breed of laying hens. This new breed of birds perform worse along all margins that hatching egg producers are remunerated against except feed conversion, 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. These new broilers that will grow from eggs from new breed laying hens will have better (lower) feed conversion and will have better meat yields (larger breasts) than old ones.

The timing of the introduction of new breed together with the ambiguity of the theoretical prediction about the post-adoption equilibrium steady-state effort levels 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.

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 of future research. However, the second stage (production of broiler chickens) contract settlement data for this company is not available, effectively closing this avenue of further research.

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6 Appendix

Proof of Proposition 1:

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

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

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 $\|.\|_\infty$ 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.

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

Consider now the operator T_0 defined by $T_0 : v(.) \rightarrow T_0(v(.))$, 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 $H(e,k) = Ew(q) - \frac{\gamma}{2}var(w(q)) - G(e,k) - C(k - \mu k_0)$.

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

Actually, for $v(.)$ and $w(.)$, 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

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

Therefore

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

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

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 $\|T_0(v(.)) - T_0(w(.))\|_\infty \leq \delta \|v(.) - w(.)\|_\infty$ where $\|.\|_\infty$ is the sup norm.

Moreover, T_0 keeps monotonicity and concavity. Actually, assume $v(.)$ is increasing concave. Then $T_0(v(.))$ 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 $V(.,0)$ shows that it is a fixed point of T_0, the properties of the operator T_0 show that $V(.,0)$ is an increasing concave function. $\square$

Proof of Proposition 2:

Expressions (4) and (5) imply that

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

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

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

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

As

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

$\frac{\partial\left(\frac{e^*}{k^*}\right)}{\partial\delta} > 0$ if $C''(k^*-\mu k_0) - \delta V''(k^*,\varphi') - V'(k^*,\varphi') > 0$ which will be the case if the cost function is sufficiently convex or the value function sufficiently concave. A sufficient condition whatever the convexity of the cost function is that $\frac{-V''(k^*,\varphi')}{V'(k^*,\varphi')} > \frac{1}{\delta}$ which means that the curvature of $V(.,\varphi')$ is sufficiently large.

Then $\frac{\partial}{\partial\delta}\left(\frac{e^*}{k^*}\right) > 0$ implies $\frac{\partial e^*}{\partial\delta} > 0$ because $\frac{\partial e^*}{\partial\delta} = k^*\frac{\partial}{\partial\delta}\left(\frac{e^*}{k^*}\right) + \frac{e^*}{k^*}\frac{\partial k^*}{\partial\delta}$ and we know that $\frac{\partial k^*}{\partial\delta} > 0$.

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

Proof of Proposition 3:

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

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

and

$$W(k_0,0,\pi) = \max_{\{e_1,k_1,\varphi_1\in\{0,1\}\}} \left[EU(w(q_1)) - G(e_1,k_1) - C(k_1 - \mu k_0) + \delta\left(W(k_1,\varphi_1,\pi) - 1_{\{\varphi_1>0\}}\right)\right]$$

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

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 by defining

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

and

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

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:

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

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

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

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, $V(k_0,1) \geq V(k_0,0)$. $\square$

Proof of Proposition 4:

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:

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

because the function $k^* C'(k^* - \mu k_0) - C(k^* - \mu k_0)$ is strictly increasing in k^* by strict convexity of $C(.)$ 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 α, $\pi(1)$, $\pi(0)$, $C(.)$ 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. $\square$

Proof of Result 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

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

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

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

As $2\left[C'((1-\mu)k)-\delta V'(k,1)\right]k\equiv H(\mu,\delta,k)$ 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

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

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 $\frac{\partial k^*}{\partial\pi(1)}$. $\square$

Table 1. Payment Schedule Changes

Date	Base Price H-Eggs In	Base Price H-Eggs Out	Male Feeder	Cool Cell	H-Eggs Pay In	H-Eggs Pay Out	C-Eggs Pay	H-Bonus Target In	H-Bonus Target Out	H-Bonus Pay	FC-Bonus Target In	FC-Bonus Target Out	FC-Bonus Pay
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; $ratio1$ = 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.

Table 3. Chronological Comparison of Grower Payments

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

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 with Robust Standard Errors

Cool Cells	Obs. = 427			
Log pseudolikelihood = -199.28809	Wald $\chi^2(10)$= 1151.64	Prob.> χ^2=0.0000	Pseudo R^2 = 0.3086	
	Coef.	Std. Error	z	p
lt	5.717894	0.2681786	21.32	0.000
M	0.6837216	0.2986322	2.29	0.022
sqft	7.21E-06	9.60E-06	0.75	0.453
1995	2.865977	0.4490581	6.38	0.000
1996	3.61016	0.3394443	10.64	0.000
1997	-1.881707	0.2744702	-6.86	0.000
1998	-1.231332	0.2328823	-5.29	0.000
1999	-0.6437748	0.1962207	-3.28	0.001
2000	-0.2020698	0.1503272	-1.34	0.179
2001	-0.1816939	0.0810308	-2.24	0.0.025
2002	(omitted)			
const.	-5.610823	0.337196	-16.64	0.000

Male Feeders	Obs. = 277			
Log pseudolikelihood = -97.483984	Wald $\chi^2(8)$ = 35.79	Prob.> χ^2=0.0000	Pseudo R^2 = 0.1340	
	Coef.	Std. Error	z	p
lt	1.809001	0.5809108	3.11	0.002
M	0.6275569	0.4229988	1.48	0.138
sqft	0.0000252	0.000011	2.29	0.022
1993	0.441427	0.677693	0.65	0.515
1994	0.806232	0.668278	1.21	0.228
1995	1.140799	0.671481	1.7	0.089
1996	1.264637	0.675794	1.87	0.061
1997	-0.33417	0.419315	-0.8	0.425
1998	(omitted)			
const	-1.158838	0.7070426	-1.64	0.101

Years for which the estimates are missing means that in those years there was no adoption.

Standard errors are clustered at the grower level.

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%.