ABSTRACT

Title of Dissertation: INSTITUTIONAL STRUCTURE
IN CORPORATE AGRICULTURE

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In this dissertation, a state-contingent, principal-agent model is developed to examine the institution of input provision by a corporate firm that contracts with agents for the production of a given commodity. "Input provision" entails not only the provision and delivery of key inputs by the principal but also their purchases (or in-house production), as well as contract design to ensure their optimal use.

The provision of key inputs is modeled in the context of production contracts for poultry and pork, such as those offered by Perdue Farms, Smithfield Foods, and Tyson Foods in the United States. The decision in question is the levels of inputs (e.g. feed, medication) that the contracting company provides to the farmer. This decision is endogenous to the model, and facilitates comparison of production contracts (input provision) with marketing contracts (no input provision, with all inputs purchased and/or provided by the farmer himself).

The theoretical model formalizes Coase's idea that an institutional arrangement emerges if the benefits associated with it exceed the costs. In particular, I characterize the case of no input provision as a corner solution for the optimal choice of inputs provided. The extent of input provision, in turn, reflects "limits to firm size". I also examine conditions under which incentives relating to one of two output dimensions (produced by the agent) tend to zero, when both dimensions are observable and verifiable. The state-contingent approach is used as it allows for a general production technology, and the inclusion of transaction costs in a general theoretical model.

The possibility of reservation utility being endogenous in dyadic relationships is also examined. This is explored formally by incorporating pre-contract interactions in a contractual framework with the principal and the agent competing as independent producers prior to contracting. Investment decisions of the principal in this framework favorably impact his variable costs both as an independent producer and as the principal party to a contract. I show that the higher these benefits, the stronger is the incentive for the principal to decide in favor of higher initial investment levels and realize a more competitive position vis-à-vis the smaller producer.

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IN CORPORATE AGRICULTURE

by

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DEDICATION

To My Teachers

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Introduction

The research question that this dissertation addresses is the following: In a principal-agent setting, where the principal contracts with an agent(s) to produce a given commodity, what incentive does the principal have to provide the agent(s) with the inputs that play a key role in the production process? This thesis is a contribution to the economics of institutions - the institution of input provision in particular.[1] "Input provision" here refers not only to the provision and delivery of key inputs by the principal but also their purchases (or in-house production), as well as contract design to ensure that the agent uses them optimally.

The provision of key inputs in this thesis is modeled in the context of production contracts (PCs) for poultry and pork, such as those offered by Perdue Farms, Smithfield Foods, and Tyson Foods in the United States (U.S.).[2] As a matter of fact, the production of chicken and/or pork in the U.S. today is almost entirely or increasingly being undertaken through the organizational arrangements that underlie PCs. These contracts are agreements where, a contracting company, for example, contracts with a group of growers (or farmers) whose role is to grow

[1] It also contributes to Contract Theory and Applied Microeconomics in general.

[2] PCs are also used for crops like corn and soybean in the U.S. and green peas in Denmark. For countries like India, contract farming through production contracts is a more recent phenomenon primarily applicable in the states of Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, and West Bengal. While I use the structure of organization in American meat producing companies as the point of reference, the results obtained in the thesis can also be extended to other production contract operations. Further, the specific kind of pork and/or broiler PC that I focus on is the finishing contract that involves growing animals to slaughter weight. As applied to PCs for crops, the contract would entail the grower's involvement from the planting stage till the point the plants are ready for harvest.

chickens or hogs to market weight. What is unique about these contracts is the fact that the key inputs to be used by the growers in the production process, such as feed, antibiotics, and animals, are provided by the contracting company. Input provision of this kind allows for considerable control of production practices by contracting companies, through the choice of feed quality, antibiotics, and genetic lines. This is in contrast to other contractual arrangements in the industry, namely, marketing contracts (MCs), where a grower's inputs are self-provided and/or self-purchased.

Input provision by the principal through PCs also bears historic resemblance to the early phase of the putting out system that characterized precapitalist Europe. In this system, raw materials were provided by a merchant to craftsmen who, in turn, worked these into the final product in their own workshops mostly using their own tools. The product at all stages of production was owned by the merchant.

In this dissertation, I develop a state-contingent principal-agent model to analyze the institution of input provision through production contracts as against no input provision typical of marketing contracts. Within this framework, the possibility of reservation utility being endogenous is also examined and is the main focus of Chapter 4. The model of the dissertation is set in a production-theoretic setting and incorporates fundamental principles of production theory under uncertainty. Overall, this production-theoretic state-contingent approach has the advantage of allowing for a sufficiently general and rational representation of the production technology with multiple inputs and state-contingent outputs, in contrast to the existing mainstream literature on contracts and institutions. For a formal exposition to this approach and its comparison with the traditional approach, see Chambers and Quiggin (2000).

The main model is a multi-task model where the agent is engaged in the production of two outputs – a quantity dimension (weight gain), and a quality dimension (leanness). An important characteristic of the model is that both outputs produced by the grower are observable and measurable. This is in contrast to the multi-task model developed by Holmstrom and Milgrom (1991) where some aspects of performance are not measurable thereby causing the agent to substitute attention away from these tasks to those that can be measured and are rewarded. A multitask analysis using the state-contingent approach can be found in Chambers and Quiggin (1996) where they look at the design of an insurance mechanism that provides incentives with respect to corn production and chemical runoff.

A significant issue in the dissertation is the representation of the production technology. The mainstream literature in general is based on a production function approach which leads to a Leontief representation of the production technology (See Chambers and Quiggin, 2000). In regards to the literature on broiler and pork contracts particularly relevant for this thesis, Tsoulouhas and Vukina (1999) specify a production technology originally outlined by Knoeber and Thurman (1994). The latter assumed that if flock size and the target market weight are the same for all growers, they will also produce roughly the same number of pounds so that weight gain can be treated as non stochastic. Even though Tsoulouhas and Vukina recognize early on in their paper that growers' effort stochastically influence both feed utilization and weight gain, their model has effort affecting only the former. Thus, the growers' performance is based only on feed utilization with the target output being the same for all the growers.

In other words, weight gain is non stochastic while feed utilization is stochastic. This explains why in their result, the optimal contract is based only on one signal - feed utilization. The importance of weight gain in the problem of hidden action and incentives is not addressed. However, given the fact that live weight does figure in the actual contract, one must recognize that there must be incentive issues associated with this. The dissertation directly addresses this issue, and at the same time, also addresses incentive issues associated with quality measured in terms of lean percentage.

The dissertation is organized into four chapters - Chapter 1 provides the institutional background of the main theme namely, production and marketing contracts in corporate agriculture, addressed in the thesis. This is followed by chapter 2 that provides a review of the current literature. Chapter 3 is a technical analysis of the institution of input provision in hybrid contracts modeled in reference to production contracts and marketing contracts in agriculture. Chapter 4 examines the possibility and implications of endogenous reservation utility in the framework developed in chapters 2 and 3. Chapter 5 concludes and compiles all the major results obtained in the technical analyses of Chapters 3 and 4.

Chapter 1

The Institutional Setting

The Production Side

Production contracts (PCs) have emerged as an important means of coordinating production of certain agricultural commodities in the United States (U.S.). Such contracts are a common feature in the broiler and hog industries but are also used for crops like corn and soybean. While PCs may be in use in agricultural areas other than livestock, the main focus in this dissertation is on hog and broiler production contracts.

PCs assume different forms based on what stage of production they correspond to. Hog production, for instance, involves four specialized phases: 1) breeding and gestation; 2) farrowing (birth of a litter up to the weaning stage); 3) nursery (care after weaning until the hogs weigh 30-80 pounds), and 4) finishing (feeding hogs weighing 30-80 pounds until they reach slaughter weight of 225-300 pounds). As such, contracts signed with growers may involve different stages of production: a) farrow-to-weanling (phases 1 and 2); b) weanling-to-feeder pig (phase 3); c) farrow-to-feeder pig (phases 1, 2 and 3); d) feeder pig-to-finish (phase 4), and e) farrow-to-finish (all 4 phases). (McBride and Key, 2003). The specific kind of PC that I focus on is the finishing contract that involves growing animals to slaughter weight. Both d) and e) correspond to finishing contracts.

What is unique about PCs as against other contracts in agriculture is the presence of an integrator - a firm (e.g. Perdue Farms, Smithfield Foods, Tyson Foods), or a cooperative (e.g. Farmland Industries) or a large farmer - that controls more than one stage of production. The integrator, in turn, establishes a contractual relationship with a grower (or the "farmer", in the context of agriculture in general) to produce a specified commodity. The contract terms delineate, among other things, the obligations of both the integrator and the grower with respect to the provision of different inputs, as well as the payment schedule to determine grower compensation (Tsoulouhas and Vukina, 1999).

The broiler industry on the Eastern Shore in the U.S., for instance, is an industry almost entirely vertically integrated through production contracts.[1] The main players in the region include companies like Alan, Mountaire, Perdue, and Tyson Foods. Of these, Mountaire grows roasters (used in Kentucky Fried Chicken, Golden Crown, and the supermarket) that grow larger in size as compared to broilers. While a broiler matures in about 6 weeks and weighs about 5.5 pounds, a 9 pound roaster takes about 9 weeks to mature. Each company contracts with a number of growers who are required to grow the chicks to market weight.

As Nerlove (1996) notes: "Today's large scale poultry operations grew from the feed suppliers who ultimately integrated their business with the production and marketing of the final product to take advantage of new technology in marketing, genetics and poultry nutrition." John Tyson, Founder of Tyson Foods, for instance, initially had a trucking business and made a living hauling hay, fruit,

[1] The details of the broiler industry in the Eastern Shore are based on the author's personal interaction with local growers in the region.

and chickens for local growers. He then bought a hatchery (due to his chick supplier's refusal to supply birds) and also started milling his own feed (when supply of feed from the local feed mill was delayed). In 1943, the company invested in a broiler farm in Arkansas (Source Webpage shown in Appendix A).

A key feature of PCs that this dissertation emphasizes is the fact that the crucial inputs in the production process are provided by the company in question. These inputs include the chicks or hogs, feed, bedding and litter (comprising sawdust), fuel (e.g. propane gas) for heating, technical and veterinary help, managerial guidelines and, as one grower of the Eastern Shore revealed, interest free credit for renovation and upgrade. The delivery and removal of animals to and from the grower's facility are also taken care of by the integrator company that usually owns the hatcheries (in the case of broilers), and the processing plant. Similarly, the integrator is responsible for the transportation of feed that typically comes from its own feed mills in which raw grain is mixed with vitamins, minerals and other nutrients. (Tsoulouhas and Vukina, 1999; inputs received from growers of the Eastern Shore). Decisions over genetics are made by the integrator company through wholly-owned subsidiaries (e.g. Cobb Vantress, in the case of Tyson Foods division producing chicken) or by contracting with genetic companies (e.g. Pig Improvement Company, Babcock Genetics, Inc.).

The task of raising the chicks or hogs to market weight is performed by the growers. The grower, on his part, provides labor, land, the building (chicken house or the hog barn), and equipment (ancillary and necessary). He is further required to make proper provisions for utilities (electricity, heat and water), maintenance, adequate ingress and egress, manure management and dead animal disposal for the duration of the contract. (Tsoulouhas and Vukina, 1999; inputs received from growers of the Eastern Shore).

The experience of the Eastern Shore growers I spoke to ranged from 10 to 30 years. Not all growers interviewed engaged in chicken farming as a primary activity. Their primary occupations ranged from being an educationist to being employed in a tractor company to being an investment professional. Not much time went into supervision of the birds. Technology has given the growers an edge in the sense that growers, after installing a computer-based controller in the chicken house, can monitor their chicken-houses sitting anywhere in the world from their computers.

Alternatives to the PC mode of organization include independent production and marketing, and production under a marketing contract (MC). Independent production and marketing entails self-purchase and/or provision of inputs by the grower, and the sale of the product in the open market to the party willing to pay the highest price. A MC specifies the quantity and quality of slaughter hogs to be delivered by the grower at a future date in accordance with a specific pricing schedule as outlined in the contract. Unlike PCs, marketing contracts do not involve the provision of inputs by the contracting company to the grower - inputs are purchased and/or provided by the grower himself as is true in independent production. However, the company may provide certain guidelines relating to feeding and/or the choice of genetic strain, or may require the grower to obtain prior approval by the company in making these choices. Some MCs, in fact, may just require the grower's actions to be consistent with good animal husbandry thereby allowing for sufficient freedom relating to production practices (Martinez and Zering, 2004). Thus, an important advantage that MCs and independent production have over PCs is that they leave the growers with considerable autonomy in everyday production decisions. This aspect is important as some growers may attach substantial value to independent decision making.

The Compensation Side

Payments under production contracts are made as per a fixed performance (applicable to hogs only) or a relative performance (applicable to both hogs and broilers) payment schedule. In the latter case, growers can be said to be participating in "tournaments". Alternatively, the latter also resembles area-yield insurance contracts where the indemnity is based on the aggregate yield of a risk pool and not on any individual producer's yield (Chambers and Quiggin, 2002).

Under a fixed or absolute performance production contract (APPC), the total payment made to the grower consists of two parts – a fixed payment and an incentive payment, both of which are subject to review and can be adjusted upward or downward during the contract period. The fixed payment is a fixed sum paid out periodically during the term of the contract and may, in some contracts, be specified on a per animal growing facility basis. While the incentive payment is determined in different ways in different contracts, I shall use the example of the incentive payment used by Land O' Lakes, Inc. (a swine contract from 1997) because this is also the one most commonly found in the literature on broiler and hog contracts (See attachment; source for contract document - www.iowaattorneygeneral.org). The incentive payment used by Land O' Lakes consists of two parts: (a) a base payment calculated as the base pay per pound of weight gain times the total number of pounds gained, and (b) a bonus calculated as the deviation of the facility's feed efficiency from a base feed efficiency times the piece or bonus rate times the total number of pounds gained. The feed efficiency or the feed conversion ratio (FCR) is defined as the total number of pounds of feed used divided by the total number of pounds of weight gain. It is a measure of performance and is indicative of how efficiently the feed is used. The facility's actual FCR is compared with a base FCR (a predetermined technological standard (Tsoulouhas and Vukina, 1999)) that varies from company to company, for the purpose of determining the total bonus per pound.

While hog PCs tend to be of the absolute performance variety, broiler contracts tend to be of the relative performance kind. Payment under a relative performance production contract (RPPC) also consists of a fixed payment as defined under APPC. However, the incentive component is now determined differently. While a base payment is still made in the same way as in APPC, the bonus is now calculated by comparing the FCR of the facility not with a base FCR, but with the average FCR of the entire group of growers that harvest their flocks around the same time period. For instance, the average feed conversion ratio of the broiler farms in my study of the Eastern Shore was about 2.0.

Payments to broiler growers of the Eastern Shore are largely based on weight gain and feed conversion ratio. Often, companies may also include fuel usage, mortality, and bruising of birds as product characteristics relevant for determining payment. In general, there is a tier system under which payments are directly related to how technologically advanced a chicken house is. This, in turn, requires growers to invest, from time to time, in state-of-the-art equipment as outlined by the contracting company. Renovation and upgrade entail incurring expenditures on recirculation pads, tunnel fans, radiant heaters, tunnel curtains, computer based controllers and so on.

Now, the compensation in a marketing contract involves providing incentives both with respect to weight gain and quality (leanness) unlike PCs where quality based incentives typically tend to be absent. Payment associated with quality under an MC is based on a carcass merit program that specifies carcass pricing grids. The payment for weight gain may be made in one of the following ways (in contrast to absolute or relative performance based payments in PCs): (a) it may be a fixed price tied to the costs of production (for e.g. soybean meal and corn prices), or (b) the price may be tied to the one prevailing in a publicly quoted market, or (c) a price window may be specified within which the contract price will be the same as the market price, but if, for example, the market price is greater than the maximum price specified in the price window, their difference will be shared between the two parties.

Rationale for Input Provision

The provision of feed and other inputs by the integrator in a PC carries a number of advantages for both the integrator and the grower. [Note that some of the arguments made below are similar to the benefits outlined by Bardhan (1989) as a justification for interlinked rural economic arrangements in developing countries]:

1. Input provision on the part of the integrator decreases price risk for the grower thus leading to a more predictable cash flow.[2] Payments under PCs are such that prices (hog/broiler, feed and so on) do not enter at all, at

[2] The risk borne by growers is of two kinds: price risk and production risk. Price risk originates from both stochastic input and output prices. As far as production risk is concerned, Knoeber and Thurman (1995) note, "Part of the production risk is idiosyncratic and affects only a single producer (if, for example, an automatic feeder breaks down), but part is common and therefore affects many producers (if, for example, the ambient air temperature becomes very high." Note that the common production risk applies only for farmers located in a particular geographical area.

least not explicitly. This, in turn, shifts price risk from the growers to the integrator. Payments based on absolute or relative performance, in turn, affect the extent to which growers face production risk. Under an absolute performance production contract (APPC), growers face both the common and idiosyncratic components of production risk. However, if payments are based on a relative performance production contract (RPPC), they face the idiosyncratic portion of the production risk and only some portion of the common production risk. This is because bonuses under RPPCs are based on relative production outcomes so that any production risk that affects all growers bunched together in one geographical area will not significantly affect the bonus for a given grower as would be the case when performance is compared with a fixed standard. With base payments still being subject to variability on account of common production risk, one can conclude that RPPCs partially protect the growers from production risk of this kind.[3]

Knoeber and Thurman (1995) and Martin (1997) use risk sharing to examine the rationale for coordinating production through PCs. Risk in this literature has been assessed in terms of variability in grower income.[4] Using simulation methods, three mechanisms of livestock production have been analyzed - independent production and marketing, APPCs and RPPCs. Knoeber and Thurman find that RPPC production shifts nearly 84%

[3] As far as marketing contracts (MCs) are concerned, they leave the grower free of only output price risk and, in some instances, input price risk.

[4] However, it should be noted that this is not a proper measure of risk as it is the variability in consumption that is important. While the two measures may be the same, this may not be true given large asset holdings

of risk from broiler growers to integrator companies as compared to independent production where the producer bears all risk. Martin compares APPCs with independent production in the pork industry and finds the income variability of pork growers to be reduced significantly by about 90% upon entering into APPCs with the integrator company. As far as the comparison of RPPCs with APPCs is concerned, Knoeber and Thurman find that risk reduction through compensation by tournaments is statistically significant for 78% of broiler growers. However, the evidence that RPPCs further reduce income variability as against APPCs is not strong enough in Martin's study of hog contracts with reduction in income variability being statistically significant for 36.4%, 51.9% and 70% growers under three different simulated RPPC scenarios.

2. Contracting through a PC reduces transaction costs for both the integrator and the grower. Transaction costs here include both neoclassical production costs and costs associated with negotiating and administering an ongoing production relationship (Joskow, 1985).Outside of the PC arrangement, it is possible that a hog or broiler grower may incur significant costs associated with searching, for instance, low cost feed sources and deciding on the appropriate feed mixtures that would maximize expected return. With integrator companies having their own feed mills and devoting a large part of research expenditures to designing feed mixes, contracting enables growers to allocate more time to other production decisions. The integrator company also gains from input provision because it may be able to obtain inputs, bought in bulk, at lower prices due its size or power.

3. As Netanyahu, Mitra and Just (1995) point out, input provision reduces

the magnitude of the moral hazard problem by decreasing the number of unobservable inputs. It also allows the integrator company to choose the quality of the inputs that it provides in a way that maximizes expected profits. [5]

4. Finally, the incentive to provide key inputs may be inspired by a desire to bring out a uniform product quality to the market to facilitate easier marketing and monitoring of the growers, or to cater to the tastes of consumers in terms of product characteristics desired by them. As a matter of fact, the whole process of production is such that the role of Nature is reduced (though not eliminated) when animals are reared in confinement under highly controlled conditions to check climate and disease. As Allen and Lueck (2002) note, "The introduction of antibiotics and other drugs have allowed poultry to be bred, hatched, and grown in highly controlled indoor environments in which disease, climate, food, water, and vitamins and other inputs are regulated to the point where poultry barns are virtually assembly lines." This aspect, along with gains from specialization are important factors in explaining the move to factory farming in livestock production (Allen and Lueck, 2002). Production can now be organized along textbook lines as there is less dependence on location-specific factors such as land and managerial human capital. In particular, the corporate

[5] However, there also arises, a possible two-sided moral hazard problem (Netanyahu, Mitra and Just, 1995). On the one hand, growers' feeding schedules and other activities may not be in line with the expectation of the integrator as their actions may be taken so as to only maximize their own utilities. On the other hand, the integrator may compromise on the care of chicks or quality of chicks provided or might try to economize on the costs per chick (e.g. in terms of quality of inputs like feed).

> form of organization is characterized by the separation of the management function from the ownership of the factors of production so that decisions requiring intimate knowledge of disease, genetics, feed and so on are no longer made by an individual grower (Nerlove, 1996).

The growers of the Eastern Shore whom I spoke to were also of the view that input provision was essential for bringing out the quantity and the quality (lean and uniform quality chicken) as necessitated by market conditions. The provision of key inputs ensured better biosecurity, and better control of the quality of chicks and feed rations. Further, with the specialized stages involved in the production process, the growers felt that it would be very costly to produce on their own. They felt that the contracting companies, undertaking extensive research and development, were in a better position to handle these specialized stages. It was also felt that the company, was in a better position to obtain or produce inputs at a lower cost. All of this feedback from the growers confirms the points made above in favor of input provision.

On the downside, the monopsony power of the integrator may lead to a kind of captive interlinking of transactions, with virtually all-or-nothing choices for the weaker partners. This is an issue that I address in Chapter 4. These contracts may also potentially lower on-farm productivity if they reduce incentives for growers to work efficiently or to invest fully in specific productive assets (Bardhan, 1989).

Some growers of the Eastern Shore, for instance, expressed concern about renovation being too costly even though it made them eligible for a higher return under the tier system. According to some growers, it is almost always the case that when one company introduces a new technology, the others have a tendency to follow suit even when the adoption of the new technology may not make a big difference to productivity. Ultimately, it is the grower who may suffer in the process of his company jumping on the bandwagon. They were also of the view that one cannot be too mechanical in farming and that the company should trust their judgement a little more about on-farm decisions. For instance, the grower may feel that the birds need medication but the company may think otherwise. Giving the growers the benefit of the doubt may be of value given that it is they who are directly associated with the production process. Finally, some growers felt that they could manage the bedding and litter on their own and wouldn't mind paying for their own litter.

Challenges have also emerged with the trend towards antibiotic-free meat is gaining popularity. Perdue Farms, for instance, gets a premium on the market for its antibiotic-free chicken. However, growers may experience increased bird mortality on account of this trend where, unless there is a major outbreak of disease, it is preferable to have a dead bird than encourage the use of antibiotics. The growers I spoke to therefore felt that they should be adequately compensated as an increase in the mortality rate affects their payment.

Overall, PCs, as can be inferred from the pattern of input provision, represent a high degree of vertical coordination unlike alternative modes of market organization in the industry that include independent production and marketing (or no contract), and production under a marketing contract. These alternative forms of organization are mostly relevant for hog production because the broiler industry is almost entirely vertically coordinated through production contracts.

As a matter of fact, both production contracts and marketing contracts fall under the category of hybrid organizations that are a mix of two extremes, namely markets and hierarchies, and range from loose clusters of firms to quasi-integrated firms. These can be described as "...arrangements among legally autonomous entities doing business together, mutually adjusting with little help from the price system, and sharing or exchanging technologies, capital, products, and services, but without a unified ownership" (Menard, 2004). As pointed out by Williamson (1991), and Coase (1988), these hybrid forms constitute the more common and dominant form of conducting business.

While there is a diverse set of arrangements that falls in the category of hybrid organizations, Menard (2004) identifies certain regularities in these thereby suggesting an underlying pattern that captures all hybrid forms. First, organization in any hybrid form is characterized by resource pooling that entails, among other things, a sort of joint planning requiring cooperation and coordination with respect to inputs, quality standards, prices, quantities and so on. Second, the relationships among participating entities in hybrid forms are regulated through contracting. Herein, hybrids pose a challenge in that contracts should minimize costly or even impossible negotiations or renegotiations. Finally, as is true for organization within a firm and/or hierarchy, hybrid arrangements are also shaped under the pressure of competition. However, as Menard notes, "The fundamental difference in hybrids is that partners remain independent residual claimants with full capacity to make autonomous decisions as a last resort."

This thesis identifies input provision by the contracting company as the chief distinguishing characteristic of PCs. This organizational feature also bears historic resemblance (as also observed in Menard, 2006) to the early phase of the putting out system that characterized precapitalist Western Europe. The putting out system first developed around the 16th century mainly in the textile industries and marked the onset of capitalism in the towns. Under this system, the merchant-capitalist provided raw materials to a craftsman who, in turn, worked in an independent workshop (with his own tools, in most cases) and transformed the raw materials into the finished product for a fee. The ownership of the product, throughout all stages of production, was concentrated in the hands of the capitalist. The putting out system was built over and replaced traditional handicraft production where the craftsman functioned as an independent, small-scale entrepreneur, and owned not only the tools and the workshop but also the raw materials (Hunt, 2004; Lazerson,1995). Production under PCs and MCs can be seen as modern day, rural equivalents of the putting out system and traditional handicraft production, respectively.

Chapter 2

Literature Review

The technical analysis in the dissertation is organized as two chapters - "Input Provision in Hybrid Contracts - The Case of Corporate Agriculture" and "Economic Power and Endogenous Reservation Utility in Corporate Dyads". In what follows, I review the current state of the literature for each one of the two analyses.

2.1 Literature review for "Input Provision in Hybrid Contracts - The Case of Corporate Agriculture" (Chapter 3)

"Input Provision in Hybrid Contracts - The Case of Corporate Agriculture" examines the rationale behind the institution of input provision under contract. This chapter emphasizes that this institutional arrangement is largely a response to changing market conditions and consumer preferences for lean meat or a superior product quality in general. In particular, I show that the likelihood of input provision under a production contract increases with an increase in the principal's market premium per unit of the quality dimension of output, and with a decrease in the principal's costs of obtaining an input, other things remaining the same. Formally, the case of no input provision is characterized by a corner solution for the optimal choice of inputs. That is, there is an incentive for the principal to provide inputs under a production contract if at the boundary, where no inputs are provided, the marginal benefits of input provision exceed the marginal costs.

In the context of the firm as an institution, Coase (1937) attributes its emergence to costs associated with using the price mechanism or the market. In particular, if all the relevant prices are not known, it may be more efficient to organize factors of production through the firm rather than the market. My theoretical model formalizes, in a production-theoretic setting, Coase's (1937, 1991) idea that an institutional arrangement will materialize if the benefits associated with it exceed the costs. The weighing of costs against benefits in my model also reflects limits to firm size as outlined by Coase (1937). In this respect, Coase (1937) maintains that a firm will tend to expand until the costs of organizing an extra transaction within the firm become equal to the costs of carrying out the same transaction through the open market. In a similar vein, Alchian and Demsetz (1972) attribute joint input production in teams to the benefits associated with cooperative specialization realized through team activity. This is provided that the net increase in productivity through team activity outweighs the costs of metering input productivity and determining individual rewards in accordance with productivity.

The main theme of this chapter, namely, input provision, can also be viewed in terms of allocation of decision rights where the decision in question is made by the principal as to what inputs he should provide the agent for production.[1]

[1] A decision right, according to Jensen and Meckling (1992), is defined as "the right to decide

If he chooses not to provide certain inputs, the corresponding input choices are then made by the agent. The degree of vertical integration, and the degree of centralization or decentralization are yet other interpretations that are relevant here. In this context, Hayek (1945), who argues in favor of decentralization, emphasizes that decision making is best left to the institution that can be expected to make fuller use of the existing knowledge.

According to Jensen and Meckling (1992), there are two ways of collocating knowledge with decision rights: (a) moving knowledge to the party with the decision rights and, (b) moving the decision rights to the party that has the knowledge. The first option, in the context of Hayek's (1945) work, entails providing all the required information to a central authority which, in turn, can be costly. Ultimately, it is the relatively high costs associated with transferring knowledge to those with decision rights that encourage the lodging of decision rights with those who have the relevant knowledge (Jensen and Meckling, 1992). My thesis formalizes allocation of decision rights by the principal where decision rights are distributed between the principal and the agent based on what the principal deems fit.

While a true market system is associated with alienable private rights, this is not true for the internal organization of the capitalist firm.[2] The internal organization of the capitalist firm is such that the assignment and enforcement of decision rights is a matter of organizational policy, with rights seldom being alienable. As Jensen and Meckling (1992) point out: "The assignment of

on and to take an action."

[2]Alienability is contingent upon (a) having the right to sell or transfer the decision right and, (b) having the right to capture the proceeds of exchange (Jensen and Meckling, 1992).

decision-making rights in modern societies is largely a matter of law. But once assigned, rights are regularly reshuffled by contracts, by purchase and sale, and by managerial assignment within firms." It is this idea where the allocation of resources may occur independently of the price mechanism that constitutes the background for the emergence of the firm as analyzed by Coase (1937). That is, in matters of the firm, it may be optimal for less informed parties (e.g. the CEO, or the entrepreneur) to hold the decision rights (Coase, 1937; Athey and Roberts 2001; Jensen and Meckling, 1992).

The central trade-off in the allocation of rights is between costs associated with poor decisions under centralization, and costs associated with inconsistent objectives under decentralization due to, for instance, separation of ownership and control. The optimal degree of delegation requires balancing these costs (Dessein, 2002; Jensen and Meckling, 1992). Delegation is a useful instrument for utilizing the local knowledge of the agent as long as there is not too large an inconsistency between the objectives of the principal and the agent relative to the principal's uncertainty about the environment (Dessein, 2002). Aghion and Tirole (1997) argue that delegation is more likely for decisions that are relatively unimportant to the principal, all other things remaining the same. In the same vein, an increase in the agent's informational advantage increases the attractiveness of delegation of an investment decision by the principal (Harris and Raviv, 2005).

Of particular relevance here are the results obtained by Grossman and Hart (1986), and Hart and Moore (1990) in regard to limits to the size of the firm or the costs and benefits of integration. The essence of Grossman and Hart's work is that when there are two parties and an investment decision is particularly important for party 1 but not for party 2, it is efficient for the first party to control the asset associated with that investment decision. Some of the key results that Hart and Moore arrive at are that the agent who is indispensable to a coalition of trading partners should own the asset and that assets that are strictly complementary should be owned together by the same party.

The interaction between incentive schemes and allocation of decision rights is examined by Athey and Roberts (2001) and Melkonyan (2007). In particular, Athey and Roberts argue that it may be optimal to lodge decision rights with "someone other than the best-informed party" if this facilitates higher overall value creation within the firm. Melkonyan (2007) demonstrates the optimality of decentralization under conditions of low cost of agent effort, small informational asymmetry between principal and the agent, and a significant impact of the agent's effort on the performance measure. The present thesis also endogenizes the input provision decision in the incentive contract, with the principal deciding the assignment of the decision rights after weighing the benefits and costs associated with providing different inputs. However, in contrast to the analysis of Athey and Roberts, this thesis allows for the principal to participate in the relevant investment decision.

An adverse selection perspective to contracting through PCs is provided by Goodhue (2000) who examines input control in these contracts and attributes it to grower heterogeneity, grower risk aversion, and systemic uncertainty. Goodhue (1999) concludes that regulation of nonlabor inputs of one party by another may lead to a reduction in production costs and asymmetric information, greater control over intellectual property rights, and greater consistency in the quality of final product. In my analysis, however, I examine input provision in contrast to input control in Goodhue (1999). Input control as examined by Goodhue involves regulation by the integrator of the amount of input to be used by the grower. Input provision, in contrast, entails the provision and delivery of key inputs, their purchases (or in-house production), and the design of incentives by the contracting company to induce and ensure the optimal use of the inputs.

The analysis of input provision in this thesis can be viewed in terms of contract choice between PCs and MCs depending on whether or not there is input provision. Contractual choice has also been examined by Eswaran and Kotwal (1985), in the context of fixed wage, fixed rent, and share contracts as also by Murrell (1983). Eswaran and Kotwal contend that parties to a contract contribute 'unmarketed resources' in the production process (such as the managerial ability of the landlord to make production decisions or the farmer's ability to supervise labor) and it is these resources that determine contractual structure. Murrell (1983) uses the transactions cost approach to show the relative transactional efficiency of share contracts as against fixed wage or fixed rent contracts, as sharing facilitates better coordination and trust building, and reduces opportunism. Allen and Lueck (2002) also use the transaction costs approach to examine contract choice between cash rent and cropshare contracts, optimal input and output sharing rules in sharecropping, asset ownership, and vertical control. Their analysis, in large part, hinges on whether or not farmers face the true opportunity costs of the inputs that they use so that an agent will tend to overuse unpriced attributes of an input or an asset that he does not own (since his marginal cost is less than the true opportunity cost). Transaction costs also come in when a marginal cost higher than what it would be in a zero transaction cost scenario leads to an underprovision of inputs by the agent.

This thesis is an attempt to make operational the inclusion of transaction costs in a general theoretical model. To this end, cost minimization by the agent is modeled so as to include not only the direct costs of purchasing inputs but also consideration of possible costs that arise in the process of carrying out transactions relating to the production process. Transaction costs in my analysis therefore include both neoclassical production costs and costs associated with negotiating and administering an ongoing production relationship as is also true in the analysis by Joskow (1985).

In particular, transaction costs include the costs of finding the best buyers or sellers, costs of drawing contracts and undertaking negotiations, costs of making arrangements to settle disputes, costs incurred in making inspections, and so on (Coase, 1991). Another kind of transaction cost imposed by the market, according to Klein, Crawford and Alchian (1978) and Williamson (1985) is post market opportunism which, in turn, can be attributed to asset specificities or the hold-up problem. Asset specificities arise in situations where an installed asset may become so specialized to suit the requirements of a particular party that it may have little or no value in an alternative use. As a result, opportunities may be created for one party to appropriate the specialized quasi rents of the assets involved at the expense of the other party. Vertical integration, in fact, is viewed by Klein, Crawford and Alchian, and Williamson as a means of avoiding opportunistic and inefficient behavior in situations where the impossibility of writing a completely contingent long term contract obliterates the specification of a clear-cut distribution of the ex post surplus arising out of highly specialized assets.

Chapter 3 also explores the possibility of input provision in PCs leading to what is known as "interlinkage" in the development literature. Interlinkage refers to the practice of offering contracts that combine transactions over several dimensions (Basu, Bell and Bose, 2000). Thus, as applied to the case in question, it refers to the contracting company superseding individual markets and contracting over several aspects like feed, weight gain, and so on.

There are two instances of interlinkage that have been the focus of attention in the development literature – (1) linked credit and product markets and (2) linked credit and labor markets.

In the context of linked credit and product markets, Gangopadhyay and Sengupta (1987) explore a scenario where farmers are assumed to have perfect accessibility to the product market. The credit market, however, is imperfect so that credit institutions charge the farmer (with little or no collateral) a higher interest rate as opposed to the landlord, thereby leading to a possibility of mutually advantageous trade. Interlinkage then involves the farmer selling output to and buying credit from the landlord at prices different from market prices, despite having access to the organized (formal) credit or product markets. The optimal interlinked solution, with the credit market imperfection driving the result, is characterized by the landlord charging an interest rate lower than what he (and, therefore, the farmer) faces in the credit market while paying the farmer a price lower than the market price.

In Basu's (1983) analysis of interlinked credit and labor markets, it is the 'potential' risk in the credit market that constitutes the core of interlinkage. This potential risk is a critical factor influencing the structuring of rural markets whereby landlords lend only to their employees (and employees can borrow only from their landlords), and offer contracts that are interlinked. With all contracts being equally acceptable or 'utility equivalent', Basu proposes three scenarios: (a) contract interest rate higher than organized sector rate; wage higher than marginal product, (b) contract interest rate lower than organized sector rate; wage lower than marginal product, and (c) contract interest rate equal to organized sector rate; wage equal to marginal product .

Bonded labor as collateral for a loan may be seen as a manifestation of interlinkage between credit and labor markets (Gangopadhyay, 1994). Here the question of interest is whether the monopoly power of the lender in the credit market manifests itself in an undervaluation of labor which is offered as collateral. The offer of labor as collateral may occur when a farmer cannot get a loan from the organized credit market on account of not possessing (or possessing insufficient) marketable collateral.

Another explanation of interlinkage is based on the analysis of Braverman and Stiglitz (1982) who view the phenomenon as a device for monitoring work effort. In this context (with a bonded labor clause), the interlinked contract is one that provides subsidized credit that induces the tenant to borrow more and also work harder to repay the higher debt so as to avoid being put into bonded labor. Yet another possibility explored by them entails the landlord requiring that the tenant borrow only from him and charging an interest rate higher than the market rate. The idea here is to restrict borrowing, as a high borrowed amount may result in the tenant being too concerned about defaulting on outstanding loans which, in turn, may lead him to be too conservative in his choice of techniques.

A special case in this context is the case of no interlinkage with a particular aspect of production so that incentives with respect to a particular contractible dimension are absent or low-powered - that is, there is absence of interlinking with a particular contractible input or output. The aspect of missing incentives has been examined in the multitask model of Holmstrom and Milgrom (1991). The authors attribute low-powered or no incentives with respect to a certain task to the fact that rewarding that task may cause the agent to substitute his attention away from other tasks. This is especially true for a situation where errors associated with the measurement of the other tasks are large so that the other tasks cannot be observed and verified easily. In Chapter 3, however, technical conditions are derived under which incentives relating to one of two output dimensions (produced by the agent) tend to zero when *both* dimensions are observable and verifiable.[3] These conditions reflect the considerable control that the principal has over the output dimension for which no or weak incentives are provided. Even though that output dimension itself is turned out by the agent, it can be viewed more as a "free" by-product for the agent that is effectively produced by the principal and results from the principal's effort. In this respect, the result that I obtain in this chapter provides a rationale for low-powered or missing incentives that has not been captured in the literature on contracts and organization.

[3] The two output dimensions are weight gain and leanness both of which are observable and verifiable. Incentives with respect to leanness are absent in PCs as against MCs where quality based incentives are important.

2.2 Literature review for "Economic Power and Endogenous Reservation Utility in Corporate Dyads" (Chapter 4)

In Chapter 4 titled "Economic Power and Endogenous Reservation Utility in Corporate Dyads", I examine the equilibrium determination of an agent's reservation utility in the context of dyadic relationships involving two firms interacting pairwise. The possibility of reservation utility being endogenous is explored formally by incorporating pre-contract interactions in a contractual framework. In particular, prior to contracting, the principal and the agent compete as independent producers with the principal being the larger, more competitive and more cost effective party. Investment decisions of the principal in this framework, taken once and for all in the pre-contract phase, favorably impact his variable costs both as an independent producer and as the principal party to a contract. However, benefits that directly work to the advantage of the principal may also adversely affect the smaller player's expected returns. One option available to the smaller player, in the face of reduced profitability, is to opt for contract production - with or without input provision - for the larger firm. In this event, however, it is the (induced) reduced returns of the smaller player that form the benchmark against which any contract will be designed and constitute an indirect benefit for the principal from his investments. In this chapter, therefore, I formalize both the direct and the indirect benefits of fixed investments undertaken by the principal. The higher these benefits, the stronger is the incentive for the principal to decide in favor of higher initial investment levels in order to realize a more competitive position vis-à-vis the smaller producer.

The possibility of reservation utility being endogenous has been explored formally in a seminal paper by Basu (1986), as also in Naqvi and Wemhoner (1995), and Chambers and Quiggin (2000). All these papers are interesting in that they attempt to incorporate qualitative issues such as influence and power that tend to get marginalized in conventional economic modeling. In particular, it is in the exploitation of the agent by the principal through extra-contract means in which endogeneity in reservation utility is manifested.

Basu (1986) analyzes influence and power in the context of triadic relationships – relationships where two parties interact with each other both directly, and indirectly, through a third party. This is in contrast to a dyadic relationship where parties act pairwise. One instance of a triadic relation that Basu analyzes involves a landlord, a laborer and a merchant. In this setting, a labor contract offered by the landlord to the laborer is accompanied by a threat whereby, in the event of this contract not being accepted by the laborer, the landlord ensures that the merchant will also refuse to trade with him. Basu brings out the exploitative nature of the exchange by showing that such a transaction that involves a threat may actually leave the laborer with a negative utility. Naqvi and Wemhoner's contribution is in terms of examining the credibility of threats that underlie the landlord-tenant-merchant interaction. Hart and Holmstrom (1987) too recognize that reservation expected utility will be endogenous when ex ante competition is imperfect so that the parties involved will bargain over the ex ante surplus in the contract.

A formal analysis of the abovementioned endogeneity property can also be found in Chambers and Quiggin (2000) where a landlord can affect a peasant's reservation utility through political or other extra-contract exploitative means, and the equilibrium reservation utility falls with a reduction in the cost of exploitation and with an increase in the crop price. Exploitative activities, as examined by Chambers and Quiggin (2000) are directly unproductive profit-seeking (DUP) activities that a landlord engages in *within* the contractual set-up, and a rise in the cost of such activities raises the peasant's equilibrium reservation utility. Similarly, a rise in the crop price, equated with more favorable market opportunities that encourage the landlord to increase his exploitative activities, leads to a reduction in the equilibrium reservation utility. Again, this happens *within* the existing contract. In the present framework, however, it is outside-of-contract interactions that influence the reservation utility and not extra-contract means within an existing contractual framework. The pre-contract interactions that I examine are perfectly legitimate economic activities and need not be of the nature of DUP activities. The interaction in the model below therefore adds a different flavor to how reservation utility may become endogenous in economic interactions.

A key component of this chapter is the investments undertaken by the principal in the beginning of the game and it is shown that the higher the benefits associated with the initial investments, the stronger is the incentive for the principal to decide in favor of higher levels of such investments so as to realize a more competitive position with respect to the smaller producers. Investment decisions taken prior to the production stage have also been examined by Laffont and Tirole (2002). While they consider two kinds of investment - contractible and noncontractible, these investments are undertaken by the agent. For the case of contractible investments, a cost reimbursement rule is offered by the principal at the optimum. However, the cost reimbursement rule needs to be suitably adjusted towards high powered incentives in the case where investment is noncontractible.

Chapter 3

Input Provision in Hybrid Contracts - The Case of Corporate Agriculture

3.1 Introduction

In this chapter, I develop a state-contingent principal-agent model to analyze the institution of input provision by a corporate firm that contracts with an agent for the production of a given commodity. "Input provision" entails not only the provision and delivery of key inputs but also their purchases (or in-house production), as well as contract design to ensure their optimal use.

The provision of key inputs is modeled in the context of American poultry and pork production contracts such as those offered by Perdue Farms, Smithfield Foods, and Tyson Foods. The decision in question is the levels of inputs (e.g. feed, genetic lines, and medication) that the principal (e.g. a contracting company) provides to the agent (or the grower). This decision is endogenous to the model, and facilitates comparison of production contracts (characterized by input provision) with marketing contracts (characterized by no input provision, with all inputs purchased and/or provided by the grower himself).

While production contracts are common in the meat producing industries in the United States, they are also used for crops like corn and soybean (United States) and green peas (Denmark). For countries like India, contract farming through production contracts is a more recent phenomenon primarily applicable in the states of Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, and West Bengal. While I use the structure of organization of American meat producing companies as the point of reference, the results obtained in the thesis can also be extended to other production contract operations.

The theoretical model formalizes Coase's idea that an institutional arrangement emerges if the benefits associated with it exceed the costs. Formally, the case of no input provision is characterized by a corner solution for the optimal choice of inputs. Moreover, the likelihood of input provision under a production contract increases with an increase in the principal's market premium per unit of the quality dimension of output, and with a decrease in the principal's costs of obtaining a particular contractible or noncontractible input, other things remaining the same. I use a production-theoretic state-contingent approach to construct the model because it allows for a general production technology, and the inclusion of transaction costs within the framework of a general theoretical model.

This chapter also examines the motivation for interlinking contracts in the context of preferences towards risk and the presence of uncertainty. In this context, one can also examine conditions under which incentives are absent or low-powered - that is, there is absence of interlinking with a particular contractible input or output. Technical conditions are derived under which incentives relating to one of two output dimensions (produced by the agent) tend to zero when both dimensions are observable and verifiable. These conditions reflect the considerable control that the principal has over the output dimension for which no or weak incentives are provided. Even though that output dimension itself is turned out by the agent, it can be viewed more as a "free" by-product for the agent that is effectively produced by the principal and results from the principal's effort. Because the product, for which incentives are low-powered or missing, is a result of the principal's effort, the principal has no reason to provide the agent any incentives associated with this output dimension.

In the section that follows, I develop the economic model for input provision, and outline the production technology, pattern of input provision, the preference and return structures of the principal and the grower, the strategy for modeling transaction costs, and the timing of the game. Section 3.3 presents the formal analysis of the two-stage optimization problem including the rationale for input provision that emerges from the model set-up, and the comparative statics for the grower. This is followed, in section 3.4, by an analysis of interlinked contracts along with a discussion on the rationale for the absence of quality based incentives in PCs. The final section concludes.

3.2 Model

A multitask principal-agent model is developed in this section for the analysis of the economics of input provision with the principal and the agent both assumed to be rational individuals guided by their self-interests. In particular, the principal is a company or an individual or a cooperative that hires an agent - an individual grower, to perform a task(s) through a contract.[1] The agent, in my model, has an informational advantage by virtue of the actions that he takes - that is, there is a problem of hidden action or moral hazard.[2] The agent moves before Nature, and neither the agent's actions nor the state of nature that materializes is observed by the principal.

Definition 3.1 *(adapted from Mas-Colell, Whinston, and Green, 1995)*

The "principal" in a contract is the party that hires another party (the "agent") to take some action(s) for him.

For the analysis that follows, the terms "principal" and "contracting company" are used interchangeably, while the term "grower" refers to the agent. The term "integrator" is specific to a PC, applies to the principal party, and is meant to reflect the furnishing of inputs by the principal - that is, a relatively more integrated arrangement. The contracting environment is modeled so as to allow for the analysis of the optimal incentive contract for both PCs (characterized by input provision by the integrator) and MCs (characterized by independent choice of inputs by the grower).

3.2.1 The Production Technology

In the production of market hogs and broilers, we have a multi-output stochastic production technology with the vector of outputs consisting of two components: a quantity dimension captured by weight gain, y, and a quality dimension measured

[1] The principal, in the context of the broiler and/or pork industries, is also referred to as a packer if it processes and packages foods in addition to organizing contract production through growers.

[2] There could also be a double-sided moral hazard problem where each party to the contract (between two parties) lacks full information about what the other party does.

in terms of lean-fat ratio or lean percentage, q. While leanness is a characteristic that is considerably controlled for by the integrator under PCs through his choice of genetics and feed quality, it constitutes a vital output produced by the grower under MCs. In fact, given the importance of bringing out a consistent product quality, hog MCs typically specify that lean percentage for the grower's animals will not be less than a certain value which is usually around 50%. The output vector is represented by $z = (y, q)$.

Suppose there are M fixed inputs denoted by the vector $\mathbf{h} \in \Re_{+}^{M}$ (e.g. land area devoted to production). It is assumed that there are N variable inputs with the variable input vector represented by $\mathbf{x} \in \Re_{+}^{N}$. Components of $\mathbf{x}$ include different dimensions of human effort, feed quantity, and feed quality. "Effort" (meant to subsume the labor activities of the grower) includes activities such as supplying feed and making sure that the feed is not stale or infested, maintaining the right temperature in the barn or the chicken-house and keeping it clean, and taking care of the animals through immunization and timely medication so as to minimize animal mortality. The total number of pounds of feed used by the grower is meant to capture the quantity dimension of feed usage. Feed quality is indicated by the nutrient content of the feed captured by the content of lysine, calcium, vitamins and so on. For example, a grower who wants to produce leaner hogs will need a higher lysine content in the feed till a certain stage of the production process. Also included in the category of inputs that represent feed quality is the use of feed additives which fall in one or more of the following categories: animal drugs (antibiotics, chemotherapeutics and dewormers), growth promoting minerals, enzymes and organic acids (that serve to improve the digestibility of the diet), and probiotics which have an effect opposite to that of antibiotics and increase the population of desirable microorganisms. Thus, different nutrients, minerals and chemicals in the feed define the various input dimensions that determine feed quality.

The stochastic nature of production is reflected by the presence of uncertainty. Uncertainty entails "Nature", a neutral player, making a choice from among S mutually exclusive states. Let the set of states of nature be represented by $\Omega = \{1, 2, ..., S\}$. Such a set serves to highlight the uncertain aspects of production such as those relating to temperature, disease and the biological processes (e.g. those associated with genetics) in animals. Let $\pi_1, \pi_2, ..., \pi_S$ be the probabilities with which states 1, 2,...,S occur, respectively. Multiple dimensions of the state of the world may also be considered by taking all possible combinations - that is, the cartesian product - of the different characteristics of "Nature".

The sequence of moves that govern production on the "field" is as follows: The grower, given $\mathbf{h}$, and prior to the resolution of uncertainty, commits a vector $\mathbf{x}$ of non stochastic variable inputs to production. This, in turn, allows him to choose ex ante a matrix of state contingent outputs, $\mathbf{z} \in \Re_+^{2\times S}$, realized from the application of $\mathbf{x}$, with the typical element being $z_s = (y_s, q_s)$, where (y_s, q_s) represents the amount of outputs y (weight gain) and q (lean percentage) produced in state s ($s = 1, 2, ..., S$). It may be noted that (y, q) is a random variable in finite $2 \times S$ dimensional state space. Nature then makes a draw from Ω which, along with $\mathbf{x}$, determines a vector of two state contingent outputs, y_s and q_s, corresponding to the state s that materializes. That is, (y_s, q_s) are realizations of the random variable (y, q). For the complete structure and timing of the game that incorporates the pattern of input provision, see Section 3.2.6.

I describe the production technology associated with the economic problem in terms of an input correspondence or its image, the input set, $X(\mathbf{y}, \mathbf{q}, \mathbf{h})$ that consists of the sets of variable inputs that can produce a particular state-contingent output matrix $\mathbf{z}$ given a vector of fixed inputs ($\mathbf{h}$):

$$X(\mathbf{y}, \mathbf{q}, \mathbf{h}) = \{\mathbf{x} \in \Re_{+}^{N} : \mathbf{x} \in \Re_{+}^{N} \text{ can produce } \mathbf{z} \text{ given } \mathbf{h}\}^{3} \tag{3.0}$$

For the ensuing analysis, it is assumed that both the principal and the agent know the technology and each other's preferences.

Note that the process of application of inputs and the realization of outputs spans two periods. Though the time dimension is suppressed in the analysis, the input vector $\mathbf{x}$ is committed today (time t) and produces two state-contingent outputs in the next period - weight gain ($\mathbf{y}^{t+1}$) and leanness ($\mathbf{q}^{t+1}$). In the context of the given problem and the preference structure developed in sections 3.2.3 and 3.2.4, I make the assumption:

Assumption 3.1

Both the principal and the agent have the same subjective discount factor η. This may happen if, for example, both the principal and the agent have access to the same capital markets, all other things remaining the same.

[3] The state-contingent outputs are expressed equivalently as the vector $(\mathbf{y}, \mathbf{q}) = (y_1, y_2, ...y_S, q_1, q_{2,}...q_S)$ or the matrix $\mathbf{z}$ with the typical element being $z_s = (y_s, q_s)$. That is,

$$\begin{aligned} \mathbf{z} &= \begin{bmatrix} z_1 & z_2 & z_3 & z_4 & z_5 & . & . & . & z_s \end{bmatrix} \\ &= \begin{bmatrix} (y_1, q_1) & (y_2, q_2) & . & . & . & (y_S, q_S) \end{bmatrix} \end{aligned}$$

3.2.2 Pattern of Input Provision

The vector of inputs $\mathbf{x} \in \Re_+^N$, committed prior to the resolution of uncertainty, is decomposed into two components - the inputs provided by the grower-agent, and the inputs provided by the integrator-principal. Let $\mathbf{x}^G \in \Re_+^N$ and $\mathbf{x}^I \in \Re_+^N$ denote the input bundles provided by the grower and the integrator, respectively, with $\mathbf{x}^G + \mathbf{x}^I = \mathbf{x}$. Then, the case of a marketing contract is reflected by $\mathbf{x}^I = 0$ so that all the relevant inputs are chosen by the grower through $\mathbf{x}^G$. On the other hand, a production contract is characterized by $\mathbf{x}^I \geq 0; \mathbf{x}^I \neq 0$.

The vector of inputs provided by the integrator-principal can be further decomposed into two components, $\mathbf{x}^c$ and $\mathbf{x}^{Nc}$, where:

$\mathbf{x}^c$: represents the vector of inputs that the principal contracts upon with the agent (e.g. feed quantity), with "contractibility" referring to the input being observable and verifiable, and

$\mathbf{x}^{Nc}$: represents the vector of noncontractible inputs provided by the principal (e.g. feed quality, genetics).

The decomposition here is meant to reflect the possibility that certain inputs (input attributes, in particular), while provided by the principal, are chosen through the grower. These are the inputs in $\mathbf{x}^c$ that the principal contracts upon with the grower. For instance, in PCs, while the feed is provided by the integrator, the grower is implicitly charged for the number of pounds of feed used when feed quantity enters the payment scheme in terms of the feed conversion ratio. However, other inputs such as those corresponding to feed quality, antibiotics, and the animals are supplied by the principal to the grower but the principal cannot verify that the grower has actually used them correctly. As a result, he cannot enforce their proper usage and these inputs are, therefore, not contractible and do not figure in the payment scheme.

The principal therefore directly provides and chooses the noncontractibles as they may be very costly to contract upon and verify with each individual grower. Integrator companies may also be better equipped to take decisions with respect to the noncontractible inputs given that they undertake considerable research in improving the quality of their final product. Decisions over genetics, for example, are made by the integrator company through wholly-owned subsidiaries (e.g. Cobb Vantress, in the case of Tyson Foods division producing chicken) or by contracting with genetic companies (e.g. Pig Improvement Company, Babcock Genetics, Inc.). Similarly, the integrator owns feed mills in which raw grain is mixed with vitamins, minerals and other nutrients. From the point of view of the grower, a potential moral hazard problem exists even at the integrator's end. However, it is assumed in this model that the grower has full information about the integrator's decisions with respect to the noncontractibles.

Thus, let $\mathbf{x}^I = \begin{bmatrix} \mathbf{x}^{Nc} \\ \mathbf{x}^c \end{bmatrix}$ with $\mathbf{x}^{Nc} \in \Re^J_+$ and $\mathbf{x}^c \in \Re^K_+$; $J + K = N$. In terms of this decomposition, a PC is characterized as one where $\mathbf{x}^{Nc} \geq 0, \mathbf{x}^{Nc} \neq 0, \mathbf{x}^c \geq 0, \mathbf{x}^c \neq 0$ while an MC is defined as one where $\mathbf{x}^{Nc} = 0$ and $\mathbf{x}^c = 0$.[4] The vital question here relates to why the principal takes over decisions relating to certain inputs (more importantly, the noncontractibles) instead of leaving them to be decided through $\mathbf{x}^G$.

[4]Intermediate combinations such as $\mathbf{x}^{Nc} \geq 0, \mathbf{x}^{Nc} \neq 0, \mathbf{x}^c = 0$, and $\mathbf{x}^{Nc} = 0, \mathbf{x}^c \geq 0, \mathbf{x}^c \neq 0$ are also theoretical possibilities that can be considered in the model. Here, the former may be considered as a variant of a production contract and the latter a variant of a marketing contract. However, these situations are more hypothetical than real (as far as the sample contracts and corresponding literature that I have seen are concerned) and are discussed in **Section 3.3.4.**

To illustrate the pattern of input provision, the entries corresponding to a contractible input such as feed quantity, for instance, will figure in (i) $\mathbf{x}^G$, representing the feed quantity provided by the grower himself, and (ii) $\mathbf{x}^c$, representing the number of pounds of the feed provided by the principal. Similarly, the entries corresponding to a noncontractible input such as concentration of a particular vitamin in the feed will figure in both $\mathbf{x}^G$ and $\mathbf{x}^{Nc}$ depending on which party provides the input. Moreover, to account for the possibility where different attributes of an input are chosen by different parties (for e.g., feed quantity by the agent and feed quality by the principal), it is assumed that different input attributes can be priced separately. Thus, to faciltate analysis, it is assumed that feed quantity and feed quality (and, if applicable, quantity and quality attributes of other inputs) can be priced separately. In practice, when the feed conversion ratio (FCR) enters the payment scheme of the grower in PCs, the feed component is described in terms of the quantity of feed used and it is not clear if the grower implicitly pays a premium on feed quality too (Note that feed quality is a noncontractible that the principal provides and chooses directly). This aspect is analyzed as part of the section on Interlinkage.

Note that $\mathbf{x}^I$ represents the inputs actually provided and *delivered* (and therefore accounted for) by the principal to the grower's farm. Whether or not the grower will actually apply these inputs depends on the incentive structure faced by the grower to use the inputs that are provided to him - contract terms and transaction costs for the contractible inputs, and transaction costs for the noncontractible inputs. That is, it may well be that the grower finds he is better off augmenting the feed quality, for instance, on his own in which case the feed quality dimension will have an entry in both $\mathbf{x}^G$ and $\mathbf{x}^{Nc}$. It is incumbent on the principal to legally design the contract to get the agent to implement usage of the corresponding inputs that are provided. This would then feature atleast two kinds of transaction costs - the transaction costs incurred by the principal in detecting non-usage of an input, and transaction costs for the agent of facing potential legal action vis-a-vis purchasing the corresponding input from the market. For a more detailed discussion of transaction costs, see section 3.2.5. Overall, the vector of inputs $\mathbf{x}$ measures the totality of inputs that are (i) provided and delivered by the principal (and may or may not be applied depending on the incentive structure) - measured by $\mathbf{x}^I$, and (ii) self-provided and actually applied by the grower (measured by $\mathbf{x}^G$).

3.2.3 Preference and Return Structure of the Principal

From the point of view of the principal, the observables in this problem are the inputs provided by him ($\mathbf{x}^I$) and the ex post output characteristics – weight gain (y) and lean-fat ratio (q). While $\mathbf{x}^I$, y and q constitute the observables, the state of nature and the grower's decisions with respect to the self provided inputs cannot be observed. Thus, it is only the grower who can observe the conditions under which production of y and q takes place once (and if) the inputs are delivered to him by the principal. Moreover, the principal has no direct preferences over the grower's decision variables in $\mathbf{x}^G$.

The principal is assumed to be risk neutral, and maximizes his expected return. The production structure that he wants to implement is $(\mathbf{y}, \mathbf{q}, \mathbf{x}^c)$ - that is, $(y_s, q_s, \mathbf{x}^c)$ in a particular state s. Let $g^I(\mathbf{x}^{Nc}) : \Re^J_+ \to \Re$ be the effort-evaluation function for the principal that gives his evaluation over a particular input bundle $\mathbf{x}^{Nc} \in \Re^J_+$ directly chosen by him. It is assumed that $g^I(\mathbf{x}^{Nc})$ is nondecreasing, continuous, and convex for all $\mathbf{x}^{Nc}$ (Chambers and Quiggin, 2000).

Properties of the Effort Evaluation Function $g^I(x^{Nc})$ (based on properties of the effort evaluation function discussed in Chambers and Quiggin, 2000):

I.1. The effort evaluation function of the principal $g^I(\mathbf{x}^{Nc})$ is non-decreasing and smooth for all $\mathbf{x}^{Nc}$.

I.2. $g^I(\mathbf{x}^{Nc})$ is positively linearly homogeneous so that $g^I(\mu\mathbf{x}^{Nc}) = \mu g^I(\mathbf{x}^{Nc})$ for all $\mu > 0$. This property carries the interpretation that a proportional increase in $\mathbf{x}^{Nc}$ along a ray from the origin (or a proportional decrease along the same ray) leads to an increase (decrease) in the value of g by exactly the same proportion.

I.3. $g^I(\mathbf{x}^{Nc} + \mathbf{x}^{Nc'}) \leq g^I(\mathbf{x}^{Nc}) + g^I(\mathbf{x}^{Nc'})$ for all $\mathbf{x}^{Nc}, \mathbf{x}^{Nc'} \in \Re^J_+$. This property implies that the principal finds it less costly to concentrate any two input bundles $\mathbf{x}^{Nc}$ and $\mathbf{x}^{Nc'}$ in one operation than employ them separately so that the corresponding effort evaluation is lower in the first situation than in the second.

From **I.2**. and **I.3**, it follows that the effort evaluation function $g^I(\mathbf{x}^{Nc})$ is convex in $\mathbf{x}^{Nc}$. That is, $g^I(\mu\mathbf{x}^{Nc} + (1-\mu)\mathbf{x}^{Nc'}) \leq \mu g^I(\mathbf{x}^{Nc}) + (1-\mu)g^I(\mathbf{x}^{Nc'})$ for $\mu \in [0, 1]$.

Proof of property I.4. (Chambers and Quiggin, 2000)

Following from **I.3**., $g^I(\mu\mathbf{x}^{Nc} + (1-\mu)\mathbf{x}^{Nc'}) \leq g^I(\mu\mathbf{x}^{Nc}) + g^I((1-\mu)\mathbf{x}^{Nc'})$ for bundles $\mu\mathbf{x}^{Nc} \in \Re^J_+$ and $(1-\mu)\mathbf{x}^{Nc'} \in \Re^J_+$ and $\mu \in [0, 1]$. Using property **I.2**. in the right hand side of the inequality gives $g^I(\mu\mathbf{x}^{Nc} + (1-\mu)\mathbf{x}^{Nc'}) \leq \mu g^I(\mathbf{x}^{Nc}) + (1-\mu)g^I(\mathbf{x}^{Nc'})$.

The return to the principal per pound of weight gain y is normalized to 1, return per unit lean percentage q is P, and the per unit cost to the principal associated with the input vector $\mathbf{x}^c$ is reflected by the vector $\mathbf{v} \in \Re^K_{++}$. Thus, the principal's gross return from y, q, and $\mathbf{x}^I$ in state s (gross of payments made to the agent) is given by $y_s + Pq_s - \sum\limits_k v_k x_k^c - g^I(\mathbf{x}^{Nc}),\ s = 1, 2, ..., S;\ k = 1, 2, ...K.$

3.2.4 Preference and Return Structure of the Agent

Denoting the ex post payments made by the principal to the grower by 'r', the grower receives a state-contingent amount r_s in state s ($s = 1, 2, ..., S$). That is, the principal pays the grower $r_s(y_s, q_s, \mathbf{x}^c)$ in state s if $(y_s, q_s, \mathbf{x}^c)$ is realized. Note that for any two states i and s ($i, s \in S$), both r_i and r_s refer to the same payment schedule the only difference being that r_i is the payment schedule evaluated at $(y_i, q_i, \mathbf{x}^c)$ and r_s is the payment schedule evaluated at $(y_s, q_s, \mathbf{x}^c)$. Thus, if $z_i = z_s$, where $z_i = (y_i, q_i)$ and $z_s = (y_s, q_s)$, this implies that $r_i = r_s$.

To facilitate analysis in situations where the the model becomes intractable on account of the general payment structure outlined by r, a linear payment schedule for the grower will be assumed so that his incentive payment r_s in state s is given by:[5]

$$r_s = \delta + \alpha y_s + \beta q_s + \sum_k \lambda_k x_k^c, \quad s = 1, 2, ..., S;\ k = 1, 2, ...K \qquad (3.1)$$

where δ is a fixed transfer, α is the payment per pound of weight gain, β is the premium per unit percentage of lean-fat ratio, and λ_k is the contract parameter associated with the k^{th} contractible input. The fixed payment δ is a fixed sum paid out periodically during the term of the contract and may, in some contracts, be specified on a per animal growing facility basis. Note that $\mathbf{x}^c = 0$ if the payment is made for a marketing contract.

[5]While a linear payment scheme is adopted for the purpose of some analyses, payment schedules, in practice, tend to be quite complicated as can be seen in specimen contracts that can be found at www.iowaattorneygeneral.org. However, note that there are situations when linear contracts are optimal as illustrated in Holmstrom and Milgrom (1987, 1994)

It is assumed that the grower's joint evaluation over self provided inputs and contract payment received in period $t+1$ are separable. The joint evaluation is given by:

$$\eta W(\mathbf{r}) - g^G(\mathbf{x}^G; \mathbf{x}^I),$$

where η is the grower's subjective discount factor that captures impatience, and $W(\mathbf{r})$ represents the preference function over $\mathbf{r}$ received in period $t+1$. Further, $g^G(\mathbf{x}^G; \mathbf{x}^I) : \Re^N_+ \rightarrow \Re$ is the effort-evaluation function or the effort-cost function that gives the grower's evaluation over a particular input bundle, $\mathbf{x}^G \in \Re^N_+$, given $\mathbf{x}^I$. It is assumed that the grower is a rational cost minimizer and makes his choices of inputs (either through $\mathbf{x}^G$ or $\mathbf{x}^c$) accordingly.

Properties of the Effort Evaluation Function $g^G(\mathbf{x}^G; \mathbf{x}^I)$:

G.1.$g^G(\mathbf{x}^G; \mathbf{x}^I)$ is nondecreasing and continuous in $\mathbf{x}^G$, and nonincreasing and continuous in $\mathbf{x}^I$. The first part of G.1. follows from Chambers and Quiggin (2000) and has the interpretation that it costs more to employ greater amounts of inputs for production. The second part carries the interpretation that input provision leads to an overall reduction in the grower's own costs. Even though some cost components will increase (possibly due to the higher scale of production), it is reasonable to assume that there is an overall decline in costs associated with the grower's self provided inputs. This is because most of the crucial input purchases are the responsibility of the integrator under input provision and the grower need only focus on inputs like labor and utilities. As is evident from data, the costs of self-provided inputs for a typical hog grower under an MC average $ 336,440 with the corresponding average under a PC being $ 27,122.92 (Agricultural Resource Management Survey, 2004). The continuity property allows for analytical tractability.

G.2. $g^G(\mathbf{x}^G; \mathbf{x}^I)$ is convex in both $\mathbf{x}^G$ and $\mathbf{x}^I$ (Chambers and Quiggin, 2000). The rationale for convexity here is the same as that outlined in **I.2.**, **I.3.** and **I.4.** with the underlying intuition being that averages are preferred to choosing between two extremes.

The agent's preferences over '$\mathbf{r}$' are based on the expected utility model so that preferences assume the form ($\sum\limits_s$ below represents summation over S states $\sum\limits_{s=1}^{S}$):

$$W(\mathbf{r}) = \sum_s \pi_s u(r_s)$$

where $u : \Re \rightarrow \Re$ represents the utility function of the agent. The utility function is strictly increasing and strictly concave so that the agent is strictly risk averse over state-contingent returns.

I also specifically address the case of constant risk averse (CRA) preferences for the grower where the preference function exhibits both constant absolute and constant relative risk aversion (Safra and Segal, 1998; Chambers and Quiggin, 2000). In particular, the preferences in this framework are of the form:

$$W(\mathbf{r}) = \overline{r} - \kappa\sigma[\mathbf{r}], \tag{3.2}$$

where $\overline{r}$ is the mean income equal to $E(r)$ with $E(.)$ representing the expectation operator, and the expectation being conditional on time-t information. Further, κ is an index of risk aversion and σ is the standard deviation associated with $\mathbf{r}$. Note that:

$$
\begin{aligned}
\sigma^2[\mathbf{r}] &= E(r - Er)^2 \\
&= \sum_s \pi_s (r_s - Er)^2 \\
&= \sum_s \pi_s (r_s - \sum_s \pi_s r_s)^2 \\
&= \sum_s \pi_s [(1 - \pi_s) r_s - \sum_{i \neq s} \pi_i r_i]^2, \quad i \in \Omega \\
&= \sum_s \pi_s [\sum_{i \neq s} \pi_i r_s - \sum_{i \neq s} \pi_i r_i]^2, \quad i \in \Omega \\
&= \sum_s \pi_s [\sum_{i \neq s} \pi_i (r_s - r_i)]^2, \quad i \in \Omega
\end{aligned}
$$

The standard deviation associated with $\mathbf{r}$ is obtained by taking the positive square root of the expression for the variance above. Therefore,

$$
\sigma[\mathbf{r}] = [\sum_s \pi_s [\sum_{i \neq s} \pi_i (r_s - r_i)]^2]^{1/2} \tag{3.3}
$$

For a graphical representation of expected utility preferences and CRA preferences, see Appendix B. Note that CRA preferences are consistent with the expected utility model only under risk neutrality.

3.2.5 A Note on Transaction Costs

This dissertation is a first attempt to make operational the inclusion of transaction costs in a general state-contingent theoretical model. To this end, cost minimization by the principal and/or the agent is modeled so as to include not only the direct costs of purchasing inputs but also consideration of possible costs that arise in the process of carrying out transactions relating to the production process. Transaction costs in this thesis therefore include both neoclassical production costs and costs associated with negotiating and administering an ongoing production relationship as is also true for the analysis by Joskow (1985).

While there is no precise definition of transaction costs in the literature, the examples cited in the literature are insightful. According to Coase (1991), transaction costs include the costs of finding the best buyers or sellers, costs of drawing contracts and undertaking negotiations, costs of making arrangements to settle disputes, costs incurred in making inspections, and so on. A specific kind of transaction cost imposed by the market, according to Klein, Crawford and Alchian (1978) and Williamson (1985) is post market opportunism which, in turn, can be attributed to asset specificities or the hold-up problem. Asset specificities arise in situations where an installed asset is so specialized to suit the requirements of a particular party that it may have little or no value in an alternative use.

An illustration of the asset specificity problem can be found in Martinez and Zering (2004) who look at genetics as a specific asset in relation to marketing contracts. Thus, given that different packers have different genetic requirements, a particular type of genetics relied upon by a hog producer for a given packer may have significantly less value for other packers. As a result, the packer with whom the grower contracts will have an incentive to appropriate the specialized quasi-rent (in the sense of Klein, Crawford and Alchian, 1978) of the asset concerned and as long as the price offered exceeds that from the next best alternative, the grower may have few options outside of selling hogs to this packer.

The housing facility that needs to be constructed as per the integrator's specifications in a PC is another example of a specific asset. For instance, the Christensen Farms (CF) contract has the following precondition: "the selection of contractors (by the grower) and all Facility site plans and specifications shall be subject to CF's advance approval." Further, it is often the case that the integrator collaborates with a particular building company to get the building constructed for the grower who enters into the contract, as per its requirements. For example, Swinton and Martin (1997) in their case study of hog contracts mention how Pork Partners had an agreement with Hog Slat, Inc., to construct a specific, highly automated finishing barn. Given the highly specific nature of the asset involved, a competitive outcome results only as long as the integrator can commit himself to compensating the grower for the entire useful life of the facility. If this is not the case, then the company comes to enjoy monopsony power at the time of contract renewal (Inoue and Vukina, 2005).

The approach in my analysis is such that any cost minimization exercise involves incorporation of transaction costs in addition to considering the direct costs of purchasing inputs. In particular, it is assumed that the effort evalulation functions for the principal $(g^I(\mathbf{x}^{Nc}))$ and the grower $(g^G(\mathbf{x}^G;\mathbf{x}^I))$, respectively, are such that they are convex on $\Re^J_+$ and $\Re^N_+$, respectively. Thus, the functions are such that the evaluation over each input can vary linearly or nonlinearly with the amount of the input used. The linear formulation allows the agent to purchase inputs that are in perfectly elastic supply. Chambers and Quiggin (2000) argue that the nonlinear generalization can prove relevant in analyzing situations where some inputs are not purchased in the market, as is the case for allocation of family labor or the percentage of personal time devoted to production. In this context, one can exploit the general, convex formulation of the effort evaluation function further and incorporate consideration of transaction costs in the input evaluation functions. Even though the world of transaction costs may be "complex" and difficult to identify for the outsider, such costs are, nevertheless, taken into account by the decision maker who is assumed to be a rational cost minimizer.

To illustrate, suppose there is only one input x priced at w per unit, then an effort evaluation function (illustrated independently of the principal or the agent) that is linear is given by $g(x) = wx$. However, it may be the case that inspection costs - a category of transaction costs described above, increase as one increases the scale on which inputs are purchased. A simple formulation like wx will not capture this effect except linearly where one assumes that w carries some element of inspection cost per unit. To capture the effect of cost of inspections in a more general sense, one can specify an effort evaluation function (while dispensing with the positive linear homogeneity property as outlined in sections 3.2.3 and 3.2.4) such as $g(x) = wx + (x - k)^2$ where k is any constant.

One can also take into account the possibility of a conflict leading to judicial costs in the state-contingent framework. In this case, one can specify a non-linear function to reflect judicial expenditures relating to purchases of input x. However, there is one additional dimension that one must keep in mind while factoring a transaction cost of this kind. One will now have to modify the state-contingent commodities to reflect uncertainty associated with the emergence of a conflict. This can be done if "Nature" has a dimension in addition to that described in the production technology where uncertain aspects of production include not only temperature, disease and the biological or metabolic processes in animals (as outlined in the production technology) but also the possibility of a conflict.

3.2.6 Game Structure and Timing

The timing of the game is as follows:

The game begins at time t with the principal offering the agent a take-it-or-

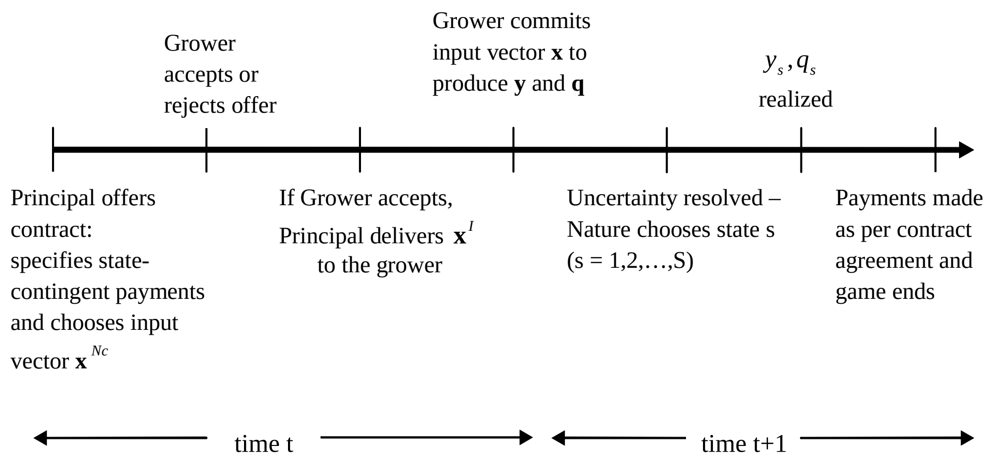


Figure 3.1: Timing of the Game

leave-it contract that specifies the state-contingent payments and the principal's decision (implemented once the contract is accepted) with respect to the non-contractible inputs $\mathbf{x}^{Nc}$. It is assumed in this model that the grower has full information about the principal's decision of $\mathbf{x}^{Nc}$ and that there is no hidden action problem with respect to $\mathbf{x}^{Nc}$. Contracts, in practice, do not clearly specify what the exact choices of the noncontractible inputs will be. However, such information may be gleaned through repeated contracting or from other growers who have earlier contracted with the same company or, as revealed by some broiler growers, from the company itself. In any case, this is information in a broad sense - it is possible for the grower to obtain information about the animal breed but not each and every detail relating to the genetic composition, or it's possible to know the different grades of feed but not details about each and every nutrient. For instance, most growers of the Eastern Shore with whom I've interacted had a good idea about the kind of bird they were growing. The birds delivered to the growers' farms were selected at random from different genetic pools and carried different flock numbers. Essentially, there were about 5 breeds that the growers are concerned with depending on the company with which they had a contract - Arbor Acres, Case, Cobb, Cornish and Ross. Similarly, they are also able to infer feed quality from the feed that is delivered. Feed that is of poor quality tends to have too much dust or may be too fine like flour. Good feed is palletized feed. Further, when the feed is sent to the grower, he gets a feed ticket that specifies the feed composition.

Based on the offered state-contingent payments and the principal's choice of the noncontractibles, the grower accepts or rejects the contract. If the grower accepts the offer, the principal delivers the contractible and the noncontractible inputs.[6] Once the inputs are delivered by the principal, the grower commits the input vector $\mathbf{x} = \mathbf{x}^G + \mathbf{x}^I$ to produce $(\mathbf{y}, \mathbf{q})$. At time $t + 1$, Nature makes a draw from among the S states that, along with $\mathbf{x}$, determines a vector of state-contingent outputs, (y_s, q_s) corresponding to the state s that Nature chooses. The principal is the residual claimant or the legal owner of the product produced by the agent.

[6] The inputs are actually delivered after a lag of a few months during which actual arrangements are made for input provision. For the purpose of modeling, this act is clubbed with other activities in time period t. It is also assumed that choices of noncontractible inputs are made as per the decisions made in the beginning of the game, and that the lag of a few months does not affect the commitments made in the beginning.

3.3 Analysis

The model is solved as a two-stage game where the principal first chooses $\mathbf{x}^{Nc}$ and the state-contingent payments $\mathbf{r} = (r_1,\ r_2, ...r_S)$. Then, given $\mathbf{r}, \mathbf{x}^{Nc}$, the grower chooses inputs $\mathbf{x}^G$ and $\mathbf{x}^c$, and the state contingent output vectors (y_s, q_s), $s = 1, 2, ..., S$. In both stages, the optimal choices are made so as to maximize the payoffs of the party concerned. I solve backwards to characterize equilibrium behavior. Thus, I first examine the optimal decisions of the agent given $\mathbf{x}^{Nc}$ and the specified payment structure. Then, having obtained the optimal $\mathbf{x}^G$ and $\mathbf{x}^c$ and the optimal state-contingent output vectors from the grower's optimization problem, I examine the principal's optimal choice of $\mathbf{x}^{Nc}$ and $\mathbf{r}$, with the principal maximizing his expected payoff subject to the agent receiving no less than his reservation utility $\underline{u}$.

The problem can formally be stated as:

$$\left\{ \begin{array}{c} \underset{\mathbf{r},\mathbf{y},\mathbf{q},\mathbf{x}^G,\mathbf{x}^I}{max} \quad \eta[\sum\limits_s \pi_s\{y_s + Pq_s - r_s(y_s, q_s, \mathbf{x}^c)\}] - \sum\limits_k v_k x_k^c - g^I(\mathbf{x}^{Nc}),\ k = 1, 2, ...K \\ subject\ to: \\ \eta\{\sum\limits_s \pi_s u(r_s(y_s, q_s, \mathbf{x}^c))\} - g^G(\mathbf{x}^G; \mathbf{x}^I)\ \geq \underline{u} \qquad (IR) \\ (\mathbf{y}, \mathbf{q}, \mathbf{x}^G, \mathbf{x}^c) \in \arg\max \eta\{\sum\limits_s \pi_s u(r_s(y_s, q_s, \mathbf{x}^c))\} - g^G(\mathbf{x}^G; \mathbf{x}^I) \qquad (IC) \\ : \mathbf{x} \in X(\mathbf{y}, \mathbf{q}, \mathbf{h}) \end{array} \right\}$$

[A]

where (IR) is the individual rationality constraint or the participation constraint that guarantees a minimum expected payoff $\underline{u}$ to the agent. The constraints represented by (IC) are the incentive compatibility constraints that make it rational for the agent to privately choose the state-contingent output vector and vector of contractible inputs as desired by the principal.

Let $C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$ represent the grower's variable cost function that reflects the (ex ante) minimum cost of producing a given state contingent $\mathbf{y}, \mathbf{q} \in \Re_{+}^{S}$ given $\mathbf{h}$ and $\mathbf{x}^{I}$. It reflects the grower's cost minimizing choices of $\mathbf{x}^{G}$, and is defined as:

$$C(\mathbf{x}^{I}, \mathbf{y}, \mathbf{q}, \mathbf{h}) = \min_{\mathbf{x}^{G}} \ \{g^{G}(\mathbf{x}^{G}; \mathbf{x}^{I}) : \mathbf{x} \in X(\mathbf{y}, \mathbf{q}, \mathbf{h})\},$$

if there is an input vector $\mathbf{x} \in \Re_{+}^{N}$ that can produce a given $\mathbf{y}$ and $\mathbf{q}$ and ∞ otherwise. It is assumed that the production technology is such that it guarantees the existence of a cost function that is twice continuously differentiable, strictly increasing and strictly convex in state-contingent outputs (Chambers, 2002). Convexity of the cost function in state-contingent outputs is based on the property of the input set where if both $\mathbf{x}$ and $\mathbf{x}'$ can produce $\mathbf{z}$, then any convex combination of $\mathbf{x}$ and $\mathbf{x}'$ must also be able to produce $\mathbf{z}$ (Chambers and Quiggin, 2000). Moreover, the cost function is strictly decreasing and strictly convex in $\mathbf{x}^{I}$.

By the principle of conditional optimization, I take $\mathbf{x}^{I}, \mathbf{y}, \mathbf{q}, \mathbf{r}$ as given so that all terms in problem [A] except $g^{G}(\mathbf{x}^{G}; \mathbf{x}^{I})$ are fixed. Conditional on a given $\mathbf{x}^{I}, \mathbf{y}, \mathbf{q}, \mathbf{r}$, I can first simplify [A] by minimizing $g^{G}(\mathbf{x}^{G}; \mathbf{x}^{I})$ subject to the constraint that $\mathbf{x} \in X(\mathbf{y}, \mathbf{q}, \mathbf{h})$ which, in turn yields the cost function $C(\mathbf{x}^{I}, \mathbf{y}, \mathbf{q}, \mathbf{h})$ defined above. I then allow $\mathbf{x}^{I}, \mathbf{y}, \mathbf{q}, \mathbf{r}$ to vary and use the cost function for the grower to express [A] as:

$$\underset{\mathbf{r},\mathbf{y},\mathbf{q},\mathbf{x}^{I}}{max} \ \eta[\sum_{s} \pi_s\{y_s + Pq_s - r_s(y_s, q_s, \mathbf{x}^{c})\}] - \sum_{k} v_k x_k^{c} - g^{I}(\mathbf{x}^{Nc}), \qquad k = 1, 2, ...K$$

subject to:

$$\eta\{\sum_{s} \pi_s u(r_s(y_s, q_s, \mathbf{x}^{c}))\} - C(\mathbf{x}^{I}, \mathbf{y}, \mathbf{q}, \mathbf{h}) \ \geq \underline{u} \qquad (IR)$$

$$(\mathbf{y}, \mathbf{q}, \mathbf{x}^{c}) \in \eta\{\sum_{s} \pi_s u(r_s(y_s, q_s, \mathbf{x}^{c}))\} - C(\mathbf{x}^{I}, \mathbf{y}, \mathbf{q}, \mathbf{h}) \quad (IC)$$

The optimal contracts that are dicussed in the literature are typically those that have payments monotonically increasing in the observed output. This result is derived in Chambers and Quiggin (2000) and follows from the assumption that $C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$ is strictly increasing in state-contingent outputs (See Appendix B). Now, in the case of pork, there exists, in general, a direct relationship between payments and lean percentage. However, lean premiums are lower for hogs that exceed 58.9% lean percent for the weight categories 197-216 lbs and 232-292 lbs (Martinez and Zering, 2004). This may be attributed to the fact that excessive leanness is not a favorable trait when considering pork quality. While the property of free disposability of output would allow the grower to do away with any excessive output, it no longer applies here as the lean percentage, once realized, cannot be altered.

Proposition 3.1

Payments monotonically increase in state-contingent outputs under the assumption that the effort-cost function strictly increases in state-contingent outputs. However, if the effort-cost function decreases in state-contingent outputs for some range of production and there is no free disposability of output, payments in that range will be nonmonotonic - that is, the optimal payment structure will be such that the payment will decrease with an increase in state-contingent output.

See Appendix C for proof.

3.3.1 Agent's Maximization Problem

The grower chooses optimal $\mathbf{x}^c$ and state-contingent $\mathbf{y}$ and $\mathbf{q}$ given $\mathbf{r}, \mathbf{x}^{Nc}$ to maximize:

$$\max_{\mathbf{y},\mathbf{q},\mathbf{x}^c} \eta\{\sum_s \pi_s u(r_s(y_s, q_s, \mathbf{x}^c))\} - C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$$

The grower's optimal choices are characterized by the following first order conditions (Note that the first subscript of r refers to the state of nature and the second subscript the argument with respect to which the second-order partial derivative is being taken. For example, the second subscripts $1, 2, k$ refer to partial derivatives taken with respect to weight gain, leanness, and the k^{th} contractible input, respectively. The subscript of the cost function $C(.)$ represents the argument itself with respect to which the partial derivative is being taken):

$$y_l : \eta[\pi_l u'(r_l) r_{l1}(y_l, q_l, \mathbf{x}^c)] - C_{y_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad y_l \geq 0; \; l \in \Omega \tag{3.4}$$

$$q_l : \eta[\pi_l u'(r_l) r_{l2}(y_l, q_l, \mathbf{x}^c)] - C_{q_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad q_l \geq 0; \; l \in \Omega \tag{3.5}$$

$$x_k^c : \eta[\sum_s \pi_s u'(r_s) r_{s,k}(y_s, q_s, \mathbf{x}^c)] - C_{x_k^c}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad x_k^c \geq 0, \qquad k = 1, 2, ...K \tag{3.6}$$

in the notation of complementary slackness.

The solution to the grower's optimization problem is obtained by solving simultaneously the system of equalities and/or inequalilties described by (3.4), (3.5), and (3.6). The optimal solution can be expressed in terms of best response functions of the general form: $y_s = y_s(\mathbf{r}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $q_s = q_s(\mathbf{r}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $\mathbf{x}^c = \mathbf{x}^c(\mathbf{r}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $s = 1, 2, ..., S$. These expressions are functions of the parameters that the grower treats as given - that is, $\mathbf{r}, \mathbf{x}^{Nc}, \mathbf{h}$, and η.

Taking the ratio of (3.4) to (3.5) gives:

$$\frac{\partial C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})/\partial y_l}{\partial C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})/\partial q_l} = \frac{\partial r_l(y_l, q_l, \mathbf{x}^c)/\partial y_l}{\partial r_l(y_l, q_l, \mathbf{x}^c)/\partial q_l}, \qquad l \in \Omega \tag{3.7}$$

The left hand side of (3.7) represents the agent's marginal rate of transformation (MRT) between y_l and q_l which, in turn, reflects the rate at which the agent is willing to substitute q_l for y_l - that is, willingness to substitute state-contingent goods within a particular state. The right hand side of (3.7) is representative of the rate at which the contract allows him to substitute q_l for y_l. In equilibrium, the agent equates his MRT to the rate of transformation as dictated in the contract.

Proposition 3.2

Within a particular state, the optimal levels of outputs y_l and q_l, $l \in S$, are such that the agent equates their marginal rate of transformation to the ratio of the partial derivatives of the contract payment schedule with respect to y_l and q_l, $l \in S$, respectively.

With a linear payment schedule as outlined in (3.1), I get in (3.7):

$$\frac{\partial C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})/\partial y_l}{\partial C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})/\partial q_l} = \frac{\alpha}{\beta}, \qquad l \in \Omega$$

That is, in equlibrium, with a linear payment schedule, the agent equates the state-contingent marginal rate of transformation (MRT) between y_l and q_l (or outputs within a state) to the ratio of the contract parameters associated with y_l *and* q_l. Thus, within a particular state, the optimal levels of outputs y_l and q_l are such that their rate of transformation is given by the ratio of the contract parameters. In particular, note that the marginal rate of transformation is exactly what would be obtained if the grower were risk neutral (or, for that matter, risk loving) and faced a linear payment schedule. The intuition here is that risk attitudes should not matter at the margin (for the characterization of behavior at the optimum within a state) as there is effectively no uncertainty within a state, and hence, a risk neutral agent and a risk averse agent can be expected to have a similar decision rule. A similar within-state reasoning can be applied to the state-contingent outputs corresponding to the other states.

Corollary 3.1

For a linear payment schedule, irrespective of preferences towards risk, the *optimal levels of outputs y_l and q_l, $l \in S$, within a particular state are such that their rate of transformation is given by the ratio of the contract parameters.*

Assuming interior solutions, and adding the left hand side terms of first order conditions corresponding to $y_s, s \neq l$ to both sides of the first order condition for y_l gives, in equilibrium:

$$\eta \sum_s \pi_s u'(r_s) r_{s1}(y_s, q_s, \mathbf{x}^c) = \sum_s C_{y_s}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \tag{3.8}$$

A similar calculation with reference to quality yields:

$$\eta \sum_s \pi_s u'(r_s) r_{s2}(y_s, q_s, \mathbf{x}^c) = \sum_s C_{q_s}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \tag{3.9}$$

The left hand side of (3.8) is the discounted, expected benefit of bringing about a nonstochastic increase in y or producing an extra unit of all state-contingent $y's$. This interpretation can be understood as follows: Given the agent's utility function, and the probabilities π_1, $\pi_2, ...\pi_S$ with which states $1, 2, ..., S$ occur, respectively, the discounted expected marginal benefit of producing an extra unit of y in all states is $\eta(\sum_s \pi_s \frac{\partial u(r_s(y_s, q_s, \mathbf{x}^c))}{\partial y_s}) = \eta(\sum_s \pi_s \frac{\partial u(r_s(y_s, q_s, \mathbf{x}^c))}{\partial r_s} \frac{\partial r_s}{\partial y_s})$ which is the same as the left hand side of (3.8). The corresponding cost at the margin of bringing about a nonstochastic increase in y is $\sum_s C_{y_s}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$, the right hand side of (3.8). At the optimum, the agent equates his marginal benefit to the marginal cost in the direction of a nonstochastic increase in quantity. The optimal solution characterized by (3.9) can be interpreted in the same way as (3.8) except that it is with reference to quality.

Proposition 3.3

The agent, at the optimum, equates his discounted expected marginal benefit to the discounted expected marginal cost in the direction of a nonstochastic increase in quantity (quality).

3.3.2 Comparative Statics for the Agent (Linear Payment Schedule)

To examine the comparative statics for the agent, I use the linear payment scheme from (3.1) so that the payment made to the agent in state s is given by $r_s = \delta + \alpha y_s + \beta q_s + \sum_k \lambda_k x_k^c$, $s = 1, 2, ..., S$; $k = 1, 2, ...K$. The comparative statics for the agent's choice variables are worked out with respect to the contract parameters α, β, and λ using Topkis's Monotonicity Theorem. This theorem constitutes a methodology for conducting comparative statics with the attractive feature that it dispenses with superfluous assumptions required in the classical method that uses the Implicit Function Theorem (Amir, 2005). As Amir (2005) points out: "The main insight is indeed quite simple. If, in a maximization problem, the objective reflects a complementarity between an endogenous variable and an exogenous parameter, in the sense that having more of one increases the marginal return to having more of the other, then the optimal value of the former will be increasing in the latter".

Let the parameter vector and the vector of choice variables be represented by $\boldsymbol{\theta} = (\alpha, \beta, \lambda, \delta)$ and $\mathbf{a} = (\mathbf{y}, \mathbf{q}, \mathbf{x}^c)$, respectively. The set of values that $\boldsymbol{\theta}$ can take are given by the parameter space Θ, such that $\boldsymbol{\theta} \in \Theta$ and $\Theta \in \Re^4$. Similarly, the action space is defined as $A \subset \Re^{2S+K}$ where $\mathbf{a} \in A$. Let $\boldsymbol{\theta} = (\alpha, \beta, \lambda, \delta) = (\theta_1, ..\theta_4)$ and $\mathbf{a} = (\mathbf{y}, \mathbf{q}, \mathbf{x}^c) = (a_1, a_2, ...a_{2S+K})$.

With the linear payment schedule, the agent's maximization problem can now be written as follows:

$$\max_{\mathbf{y},\mathbf{q},\mathbf{x}^c} F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h}) = \max_{\mathbf{y},\mathbf{q},\mathbf{x}^c} \eta\{\sum_s \pi_s u(\delta + \alpha y_s + \beta q_s + \sum_k \lambda_k x_k^c)\} - C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$$

The corresponding first order conditions are:

$$y_l : \eta\pi_l u'(r_l)\alpha - C_{y_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \le 0, \quad y_l \ge 0; \quad l \in \Omega \tag{3.10}$$

$$q_l : \eta\pi_l u'(r_l)\beta - C_{q_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \le 0, \quad q_l \ge 0; \quad l \in \Omega \tag{3.11}$$

$$x_k^c : \eta\lambda_k \sum_s \pi_s u'(r_s) - C_{x_k^c}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \le 0, \quad x_k^c \ge 0, \quad k = 1, 2, ...K \tag{3.12}$$

in the notation of complementary slackness.

Suppose $B(\boldsymbol{\theta})$ represents the optimal action correspondence with $\mathbf{a}^*(\boldsymbol{\theta}) \in \arg\max F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ s.t. $\mathbf{a} \in B(\boldsymbol{\theta})$. Inherent in the Topkis Monotonicity Theorem (formally stated below) is an order structure relating to the parameter space Θ and action space A that warrants some explanation. In particular, the function $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ exhibits *increasing differences* in $(\mathbf{a}, \boldsymbol{\theta})$ if $\mathbf{a} \ge \mathbf{a}'$ and $\boldsymbol{\theta} \ge \boldsymbol{\theta}'$ implies:[7]

$$F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h}) - F(\mathbf{a}', \boldsymbol{\theta}, \mathbf{h}) \ge F(\mathbf{a}, \boldsymbol{\theta}', \mathbf{h}) - F(\mathbf{a}', \boldsymbol{\theta}', \mathbf{h})$$

for all pairs $(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ and $(\mathbf{a}', \boldsymbol{\theta}', \mathbf{h})$ in $A \times \Theta$. The function $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ is said to be *supermodular* in $\mathbf{a}$ for each fixed $\boldsymbol{\theta}$ and $\mathbf{h}$ if for any $\mathbf{a}$ and $\mathbf{a}'$ in A, and any fixed θ, we have:

$$F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h}) + F(\mathbf{a}', \boldsymbol{\theta}, \mathbf{h}) \le F(\mathbf{a} \vee \mathbf{a}', \boldsymbol{\theta}, \mathbf{h}) + F(\mathbf{a} \wedge \mathbf{a}', \boldsymbol{\theta}, \mathbf{h}),$$

where $\mathbf{a} \vee \mathbf{a}'$ defines the "meet" of $\mathbf{a}$ and $\mathbf{a}'$ given by the coordinate-wise maximum of $\mathbf{a}$ and $\mathbf{a}'$, and $\mathbf{a} \wedge \mathbf{a}'$ defines the "join" of $\mathbf{a}$ and $\mathbf{a}'$ given by the coordinate-wise minimum of $\mathbf{a}$ and $\mathbf{a}'$. That is, $\mathbf{a} \vee \mathbf{a}' = (\max[a_1, a_1'], \max[a_1, a_1'], ..., \max[a_{2S+K}, a_{2S+K}'],$ and $\mathbf{a} \wedge \mathbf{a}' = (\min[a_1, a_1'], \min[a_1, a_1'], ..., \min[a_{2S+K}, a_{2S+K}']$. A set is said to be a lattice if the "meet" and the "join" of any two of its elements are also contained

[7] Given any two vectors $\mathbf{a}$ and $\mathbf{a}'$, $\mathbf{a} \in A$, $\mathbf{a} \ge \mathbf{a}'$ if $a_i \ge a_i'$, $i = 1, 2, ...2S + K$. Similarly, for the vectors $\boldsymbol{\theta}$ and $\boldsymbol{\theta}'$, $\boldsymbol{\theta} \ge \boldsymbol{\theta}'$ if $\theta_i \ge \theta_i'$, $i = 1, 2, 3, 4$.

in the set. A subset of a lattice is called a sublattice and also satisfies the property of a lattice in that it contains the meet and join of each pair of its elements. Overall, if a function $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ is *supermodular* in $(\mathbf{a}, \boldsymbol{\theta})$ given $\mathbf{h}$ then:

1) $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ is supermodular in $\mathbf{a}$ for each fixed $\boldsymbol{\theta}$ and $\mathbf{h}$, and

2) $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ exhibits increasing differences in $(\mathbf{a}, \boldsymbol{\theta})$. (Sundaram, 1999)

Theorem 3.1

[Topkis's Monotonicity Theorem] *Let $A \subset \Re^{2S+K}$ be a compact lattice, $\Theta \subset \Re^4$ be a lattice, and $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ be a continuous function on A for each $\boldsymbol{\theta}$. Suppose $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ has increasing differences in $(\mathbf{a}, \boldsymbol{\theta})$ and is supermodular in $\mathbf{a}$ for each fixed $\boldsymbol{\theta}$. In addition, suppose that $B(\boldsymbol{\theta})$ is a compact, ascending correspondence. Then, $\mathbf{a}^*(\boldsymbol{\theta}) = \arg\max F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ s.t. $\mathbf{a} \in B(\boldsymbol{\theta})$*

(i) is a nonempty compact sublattice that admits maximal(mx) and minimal(ml) selections[8]:

$$\mathbf{a}^{*mx}(\boldsymbol{\theta}) = \sup\{\mathbf{a} \in \mathbf{a}^*(\boldsymbol{\theta})\} \text{ and } \mathbf{a}^{*ml}(\boldsymbol{\theta}) = \inf\{\mathbf{a} \in \mathbf{a}^*(\boldsymbol{\theta})\}$$

(ii) is an ascending correspondence, and

(iii) $\mathbf{a}^{*mx}(\boldsymbol{\theta})$ and $\mathbf{a}^{*ml}(\boldsymbol{\theta})$ are nondecreasing functions. (Sundaram, 1999)

In particular, if $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ is smooth (twice continuously differentiable), the properties of increasing differences in $(\mathbf{a}, \boldsymbol{\theta})$ and supermodularity in $\mathbf{a}$ for each fixed $\boldsymbol{\theta}$ are, respectively, equivalent to:

$$\frac{\partial^2 F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})}{\partial a_i \partial \theta_j} \geq 0, \quad a_i \in \mathbf{a};\ \theta_j \in \boldsymbol{\theta}, \tag{3.13}$$

and

$$\frac{\partial^2 F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})}{\partial a_i \partial a_j} \geq 0, \quad a_i \neq a_j; \quad a_i, a_j \in \mathbf{a} \tag{3.14}$$

[8]If $\mathbf{a}^*(\boldsymbol{\theta})$ is a subset of A for each $\boldsymbol{\theta}$ in Θ, and $\mathbf{a}^{**}(\boldsymbol{\theta})$ is in $\mathbf{a}^*(\boldsymbol{\theta})$ for each $\boldsymbol{\theta}$ in Θ, then the function $\mathbf{a}^{**}(\boldsymbol{\theta})$ from Θ into A is a selection from $\mathbf{a}^*(\boldsymbol{\theta})$ (Topkis, 1998).

To accommodate those cases where, in the agent's maximization problem, $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial a_i \partial \theta_j} \leq 0, \quad a_i \in \mathbf{a};\ \theta_j \in \boldsymbol{\theta}$, and $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial a_i \partial a_j} \leq 0,\ a_i \neq a_j;\ \ a_i, a_j \in \mathbf{a}$, I consider the corresponding decision in a_i as being $(-a_i)$ so that $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-a_i)\partial \theta_j} \geq 0$ and $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-a_i)\partial a_j} \geq 0$. This order-reversing strategy also allows me to take into consideration complementarities and substitutabilities between different choice variables. Therefore, to illustrate the comparative statics, I first partition the choice set $\mathbf{a} = (y_1, y_2, ..., y_S, q_1, q_2, ..., q_S,\ x_1^c, x_2^c, ...x_K^c)$ as $(-\mathbf{y}^{pI}, -\mathbf{q}^{pI}, -\mathbf{x}^{c,pI} \vdots \mathbf{y}^{pII}, \mathbf{q}^{pII}, \mathbf{x}^{c,pII})$ or $(-\mathbf{a}^{pI} \vdots \mathbf{a}^{pII})$ where the two partitions pI and pII are mutually exclusive. Here, $S^{pI} = \{1, 2, ..., s^{pI}\}$ state-contingent outputs and $K^{pI} = \{1, 2, ..., k^{pI}\}$ contractible inputs are placed in $-\mathbf{a}^{pI}$, and $S^{pII} = \{1, 2, ..., s^{pII}\}$ state-contingent outputs and $K^{pII} = \{1, 2, ..., k^{pII}\}$ contractible inputs are placed in $\mathbf{a}^{pII}$, with the distribution being such that $s^{pI} + s^{pII} = 2S$ and $k^{pI} + k^{pII} = K$. The partition $(-\mathbf{a}^{pI} \vdots \mathbf{a}^{pII})$ defines two groupings of choice vectors, $-\mathbf{a}^{pI}$ and $\mathbf{a}^{pII}$, and the division is such that two state-contingent outputs or inputs within any one grouping defined by the partition are technical complements and two outputs or inputs from different groupings are technical substitutes. Formally, the following assumptions apply to the comparative statics exercise:

Assumption 3.2

(i) The choice set $\mathbf{a} = (y_1, y_2, ..., y_S, q_1, q_2, ..., q_S,\ x_1^c, x_2^c, ...x_K^c)$ is partitioned into two as $(-\mathbf{y}^{pI}, -\mathbf{q}^{pI}, -\mathbf{x}^{c,pI} \vdots \mathbf{y}^{pII}, \mathbf{q}^{pII}, \mathbf{x}^{c,pII})$ or $(-\mathbf{a}^{pI} \vdots \mathbf{a}^{pII})$, with $S^{pI} = \{1, 2, ..., s^{pI}\}$ state-contingent outputs and $K^{pI} = \{1, 2, ..., k^{pI}\}$ contractible inputs placed in $-\mathbf{a}^{pI}$, and $S^{pII} = \{1, 2, ..., s^{pII}\}$ state-contingent outputs and $K^{pII} = \{1, 2, ..., k^{pII}\}$ contractible inputs placed in $\mathbf{a}^{pII}$. The distribution is such that $s^{pI} + s^{pII} = 2S$ and $k^{pI} + k^{pII} = K$.

(ii) The choice variables a_i and a_j are technical complements if (a) $i, j \in S^{pI}$

or K^{pI}, $i \neq j$ or (b) $i, j \in S^{pII}$ or K^{pII}, $i \neq j$. In contrast, a_i and a_j are technical substitutes if (a) $i \in S^{pI}$ or K^{pI}, and $j \in S^{pII}$ or K^{pII} or (b) $j \in S^{pI}$ or K^{pI}, and $i \in S^{pII}$ or K^{pII}.

(iii) There are no sign reversals - that is, a change in the manner in which a given partition is defined, when levels of outputs and/or inputs change.

In the literature (see Holmstrom (1991) for example), if two state-contingent outputs are technical complements, increasing one state-contingent output will decrease the marginal cost of producing the other state-contingent output so that the second-order cross partial derivative of the effort cost function will be negative or $\frac{\partial^2 C(\mathbf{a},\mathbf{h})}{\partial a_i \partial a_j} \leq 0$ $(a_i, a_j \in \mathbf{a}, a_i \neq a_j)$. The opposite holds true for technical substitutes, that is, $\frac{\partial^2 C(\mathbf{a},\mathbf{h})}{\partial a_i \partial a_j} \geq 0$ $(a_i, a_j \in \mathbf{a}, a_i \neq a_j)$. If all the cross partial derivatives of the cost function are zero, the tasks are technically independent. Note that the notion of technical dependence (or independence) described here is not strictly the same as what is found in the literature (see Holmstrom and Milgrom (1991)). The concept here refers to technical dependence or independence *given* the inputs $\mathbf{x}^{Nc}$ chosen by the principal and complementarity entails taking derivatives of the objective function $F(.)$ and not just the cost function $C(.)$.

Appendix D lists the set of sufficient conditions (derived from first order conditions (3.10) through (3.12)) for the monotone comparative statics with respect to $[(-\mathbf{y}^{\alpha I*}, -\mathbf{q}^{\alpha I*}, -\mathbf{x}^{c,\alpha I*} \vdots \mathbf{y}^{\alpha II*});\ \alpha]$ - a modified version of the partition defined in Assumption 3.2.[9] Here, $(-\mathbf{y}^{\alpha I*}, -\mathbf{q}^{\alpha I*}, -\mathbf{x}^{c,\alpha I*} \vdots \mathbf{y}^{\alpha II*})$ represents a partition in which (i) weight gain corresponding to $S^{\alpha I} = \{1, 2, ..., s^{\alpha I}\}$ states is

[9] The notation αI and αII is used to illustrate the monotone comparative statics with respect to α. Similarly, the modified partitions for the comparative statics with respect to β and λ_k are represented by βI and βII, and λI and λII, respectively.

placed in $-\mathbf{y}^{\alpha I*}$ and weight gain corresponding to $S^{\alpha II} = \{1, 2, ..., s^{\alpha II}\}$ states is placed in $\mathbf{y}^{\alpha II*}$, with $s^{\alpha I} + s^{\alpha II} = S$, (ii) quality corresponding to all states is placed in $-\mathbf{q}^{\alpha I*}$ ($\mathbf{q}^{pII*}$ in the original partition is a null vector), and (iii) $\mathbf{x}^{c,pII*}$ in the original partition is a null vector and all contractibles are placed in the first partition in the vector $-\mathbf{x}^{c,\alpha I*}$. The comparative statics were taken for $(-\mathbf{y}^{\alpha I*}, -\mathbf{q}^{\alpha I*}, -\mathbf{x}^{c,\alpha I*} \vdots \mathbf{y}^{\alpha II*})$ and not the general $(-\mathbf{y}^{pI*}, -\mathbf{q}^{pI*}, -\mathbf{x}^{c,pI*} \vdots \mathbf{y}^{pII*}, \mathbf{q}^{pII*}, \mathbf{x}^{c,pII*})$ as $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(q_b^{pII})\partial\alpha} \leq 0, b \in S^{pII}$ and $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(x_k^{c,pII})\partial\alpha} \leq 0, \quad k \in K^{pII}$ so that the inequality (3.13) is not satisfied.

The corresponding sufficient conditions for $(-\mathbf{y}^{\alpha I*}, -\mathbf{q}^{\alpha I*}, -\mathbf{x}^{c,\alpha I*} \vdots \mathbf{y}^{\alpha II*})$ to be increasing in α are derived in Appendix D, and show that an increase in α leads to an increase in weight gain in the states that correspond to $\mathbf{y}^{\alpha II*}$. These changes resulting from an increase in α are also accompanied by a decrease in (i) weight gain in the states corresponding to $-\mathbf{y}^{\alpha I*}$, (ii) quality in all states, and (ii) all the contractible inputs.

Similarly, on account of $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(y_b^{pII})\partial\beta} \leq 0, \quad b \in S^{pII}$ and $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(x_k^{c,pII})\partial\beta} \leq 0, \ k \in K^{pII}$, sufficient conditions were derived for the optimal decision vector $(-\mathbf{y}^{\beta I*}, -\mathbf{q}^{\beta I*}, -\mathbf{x}^{c,\beta I*} \vdots \mathbf{q}^{\beta II*})$ to be increasing in β. The vector $(-\mathbf{y}^{\beta I*}, -\mathbf{q}^{\beta I*}, -\mathbf{x}^{c,\beta I*} \vdots \mathbf{q}^{\beta II*})$ is such that (i) weight gain corresponding to all states is placed in $-\mathbf{y}^{\beta I*}$ ($\mathbf{y}^{pII*}$ in the original partition is a null vector), (ii) quality corresponding to $S^{\beta I} = \{1, 2, ..., s^{\beta I}\}$ states is placed in $-\mathbf{q}^{\beta I*}$ and quality corresponding to $S^{\beta II} = \{1, 2, ..., s^{\beta II}\}$ states is placed in $\mathbf{q}^{\beta II*}$, with $s^{\beta I} + s^{\beta II} = S$, and (iii) all contractibles are placed in the first partition in the vector $-\mathbf{x}^{c,\beta I*}$

Again, as $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(y_b^{pII})\partial\lambda_k} \leq 0, \ b \in S^{pII}$ and $\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(q_b^{pII})\partial\lambda_k} \leq 0, \quad b \in S^{pII}$, sufficient conditions were only derived for the optimal decision vector $(-\mathbf{y}^{\lambda I*}, -\mathbf{q}^{\lambda I*}, -\mathbf{x}^{c,\lambda I*} \vdots \mathbf{x}^{c,\lambda II*})$ to be increasing in λ_k. The partition is such that (i) weight gain corresponding to all states is placed in $-\mathbf{y}^{\lambda I*}$ ($\mathbf{y}^{pII*}$ in the original partition is a null vector), (ii) quality corresponding to all states is placed in $-\mathbf{q}^{\lambda I*}$ ($\mathbf{q}^{pII*}$ in the original partition is a null vector), and (iii) $K^{\lambda I} = \{1, 2, ...k^{\lambda I}\}$ contractible inputs are placed in the first partition and $K^{\lambda II} = \{1, 2, ...k^{\lambda II}\}$ in the second with $k^{\lambda I} + k^{\lambda II} = K$.

The corresponding sufficient conditions are listed in Appendix D.

Proposition 3.4

Let $A \subset \Re^{2S+K}$ be a compact lattice, $\Theta \subset \Re^4$ be a lattice, and $F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})$ be a continuous function on A for each $\boldsymbol{\theta}$. Then, under conditions of technical complementarity and increasing differences in $(\mathbf{a}, \boldsymbol{\theta})$, (i) the optimal choice vector $(-\mathbf{y}^{\alpha I*}, -\mathbf{q}^{\alpha I*}, -\mathbf{x}^{c,\alpha I*} \vdots \mathbf{y}^{\alpha II*})$ increases in α, (ii) the vector $(-\mathbf{y}^{\beta I*}, -\mathbf{q}^{\beta I*}, -\mathbf{x}^{c,\beta I*} \vdots \mathbf{q}^{\beta II*})$ increases in β, and (iii) *the vector $(-\mathbf{y}^{\lambda I*}, -\mathbf{q}^{\lambda I*}, -\mathbf{x}^{c,\lambda I*} \vdots \mathbf{x}^{c*,\lambda II*})$ increases in λ_k.*

3.3.3 Principal's Maximization Problem

The principal's maximization problem can be stated as:

$$\max_{\mathbf{r},\mathbf{y},\mathbf{q},\mathbf{x}^I} \ \eta[\sum_s \pi_s\{y_s + Pq_s - r_s(y_s, q_s, \mathbf{x}^c)\}] - \sum_k v_k x_k^c - g^I(\mathbf{x}^{Nc}), \qquad k = 1, 2, ...K$$

subject to:

$$\eta\{\sum_s \pi_s u(r_s(y_s, q_s, \mathbf{x}^c))\} - C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \ \geq \underline{u} \qquad (IR)$$

and incentive constraints (3.4) through (3.6).

To examine this problem further, I assume a linear payment structure for the agent as given by (3.1), with the agent having CRA preferences over $\mathbf{r}$ as outlined in (3.2). The model is the same as that examined in [A] except that with a linear incentive payment, the principal now first chooses $\mathbf{x}^{Nc}$ and the contract parameters $\alpha, \beta, \delta, \boldsymbol{\lambda}$ (instead of aggregated state-specific payments), and then, given $\alpha, \beta, \delta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}$, the grower chooses inputs $\mathbf{x}^G$ and $\mathbf{x}^c$, and the state contingent output vectors (y_s, q_s), $s = 1, 2, ..., S$. I solve backwards to characterize equilibrium behavior.

The agent, in particular, chooses optimal $\mathbf{x}^G$ and $\mathbf{x}^c$ and state-contingent $\mathbf{y}$ and $\mathbf{q}$ given $\alpha, \beta, \delta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}$ to maximize:

$$\max_{\mathbf{y},\mathbf{q},\mathbf{x}^c}\{\eta E[\delta + \alpha y + \beta q] - \kappa\eta T^{1/2} + \eta\sum_k \lambda_k x_k^c - C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})\}, \quad k = 1, 2, ...K$$

where $T = \sigma^2[\mathbf{r}]$ - that is, T represents the variance associated with $\mathbf{r}$. For a linear payment scheme $r_s = \delta + \alpha y_s + \beta q_s + \sum_k \lambda_k x_k^c$, (3.3) simplifies to give:

$$T^{1/2} = \sigma[\mathbf{r}] = [\sum_s \pi_s[\sum_{i \neq s} \pi_i\{\alpha(y_s - y_i) + \beta(q_s - q_i)\}]^2]^{1/2}$$

so that

$$W(\mathbf{r}) = \sum_s \pi_s[\delta + \alpha y_s + \beta q_s] - \kappa T^{1/2} + \sum_k \lambda_k x_k^c, \qquad k = 1, 2, ...K$$

The agent's optimal choices are characterized by the following first order conditions (see Appendix E for the derivation of the first order conditions):

$$y_l : \eta[\pi_l\alpha - \kappa T^{-1/2}\{\pi_l[\sum_{i \neq l} \pi_i(r_l - r_i)]\alpha\}] - C_{y_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \;\; y_l \geq 0; \; i, l, s \in \Omega \tag{3.15}$$

$$q_l : \eta[\pi_l\beta - \kappa T^{-1/2}\{\pi_l[\sum_{i \neq l} \pi_i(r_l - r_i)]\beta\}] - C_{q_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad q_l \geq 0; \; i, l, s \in \Omega \tag{3.16}$$

$$x_k^c : \eta\lambda_k - C_{x_k^c}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad x_k^c \geq 0, \qquad k = 1, 2, ...K \tag{3.17}$$

in the notation of complementary slackness. For the first order conditions (for both the principal and the agent) that correspond to a more general payment structure such as $r_s = \delta + p_s$, where δ is a fixed transfer and $p_s(y_{s,}q_s, \mathbf{x}^c)$ is a state-contingent incentive payment, see Appendix F.

The solution to the agent's optimization problem is obtained by solving simultaneously the system of equalities and/or inequalities described by (3.15), (3.16), and (3.17). The solution to (3.15) - (3.17) can be expressed in terms of the parameters that the grower treats as given and is of the general form: $y_s = y_s(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $q_s = q_s(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $\mathbf{x}^c = \mathbf{x}^c(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $s = 1, 2, ..., S$.

The principal's maximization problem with a linear payment schedule and CRA preferences for the agent can now be rewritten as:

$$\left\{ \begin{array}{c} \underset{\alpha,\beta,\delta,\lambda,\mathbf{y},\mathbf{q},\mathbf{x}^I}{max} \quad \eta E[(1-\alpha)y + (P-\beta)q] - \eta\delta - \eta\sum_k \lambda_k x_k^c - \sum_k v_k x_k^c - g^I(\mathbf{x}^{Nc}) \\ subject\ to: \\ \eta E[\alpha y + \beta q] - \kappa\eta T^{1/2} + \eta\delta + \eta\sum_k \lambda_k x_k^c - C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq \underline{u} \qquad (IR) \\ and\ incentive\ constraints\ (3.15)\ through\ (3.17). \end{array} \right\}$$

[B]

The solution to this problem is such that the agent's individual rationality (IR) constraint holds with an equality. If this were not the case, then the principal could reduce δ (or, in general, reduce payment r_s in all states s, $s = 1, 2, ...S$, by the same amount) until the constraint were to bind, without affecting the incentive constraints (3.15) through (3.17) which are independent of δ. Since this would lead to an outcome that would be strictly preferred by the principal, the solution to the problem is characterized by a binding participation constraint.

Proposition 3.5

The agent's participation constraint or the individual rationality constraint holds with an equality in the solution to the principal-agent problem described by [A] or [B].

Further, the preference structure is such that the term $\eta\delta + \eta\sum_k \lambda_k x_k^c$ in the IR constraint plays the role of a transfer from/ to the principal to/ from the agent so that one can substitute for this term from this constraint into the principal's objective function. To see this, note that for a binding IR constraint:

$$\eta\delta + \eta \sum_k \lambda_k x_k^c = \underline{u} - \eta E[\alpha y + \beta q] + \kappa\eta T^{1/2} + C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$$

Substituting for $\eta\delta + \eta \sum_k \lambda_k x_k^c$ in the principal's objective function in [B] gives:

$$\eta E[y + Pq] - \sum_k v_k x_k^c - \kappa\eta T^{1/2} - C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) - g^I(\mathbf{x}^{Nc}) - \underline{u}$$

Using the expression above as the principal's objective function, and using the solution from the incentive constraints (3.15)-(3.17), $y_s = y_s(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $q_s = q_s(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$, $\mathbf{x}^c = \mathbf{x}^c(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$; $s = 1, 2, ..., S$, the maximization problem becomes (for compactness, I denote $(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$ by Ψ):

$$\begin{aligned} \max_{\alpha,\boldsymbol{\beta},\boldsymbol{\lambda},\mathbf{x}^{Nc}} \quad & \{\eta \sum_s \pi_s [y_s(\Psi) + P q_s(\Psi)] - \sum_k v_k x_k^c(\Psi) - \\ & - \kappa\eta [\sum_s \pi_s [\sum_{i \neq s} \pi_i \{\alpha(y_s(\Psi) - y_i(\Psi)) + \beta(q_s(\Psi) - q_i(\Psi))\}]^2]^{1/2} - \\ & - C(\mathbf{x}^{Nc}, \mathbf{x}^c(\Psi), \mathbf{y}(\Psi), \mathbf{q}(\Psi), \mathbf{h}) - g^I(\mathbf{x}^{Nc}) - \underline{u}\} \end{aligned} \tag{3.18}$$

The corresponding first order conditions are given by (The subscript for "C" reflects the argument with respect to which the partial derivative of the agent's effort cost function is taken. The arguments $(\mathbf{x}^{Nc}, \mathbf{x}^c(\Psi), \mathbf{y}(\Psi), \mathbf{q}(\Psi), \mathbf{h})$ of the function $C(.)$ are suppressed in the interest of space):

$$\alpha: \; \eta \sum_s \pi_s (1-\alpha) \frac{\partial y_s}{\partial \alpha} + \eta \sum_s \pi_s (P-\beta) \frac{\partial q_s}{\partial \alpha} - \kappa\eta T^{-1/2} [\sum_s \pi_s [\sum_{i\neq s} \pi_i (r_s - r_i)][\sum_{i \neq s} (y_s - y_i)]] -$$

$$- \sum_k \{v_k + \eta\lambda_k\} \frac{\partial x_k^c}{\partial \alpha} \leq 0, \qquad \alpha \geq 0 \tag{3.19}$$

$$\beta:\ \eta\sum_s\pi_s(1-\alpha)\frac{\partial y_s}{\partial\beta}+\eta\sum_s\pi_s(P-\beta)\frac{\partial q_s}{\partial\beta}-\kappa\eta T^{-1/2}[\sum_s\pi_s[\sum_{i\neq s}\pi_i(r_s-r_i)][\sum_{i\neq s}(q_s-q_i)]]-$$

$$-\sum_k\{v_k+\eta\lambda_k\}\frac{\partial x_k^c}{\partial\beta}\leq 0,\quad \beta\geq 0 \tag{3.20}$$

$$\lambda_k:\eta\sum_s\pi_s(1-\alpha)\frac{\partial y_s}{\partial\lambda_k}+\eta\sum_s\pi_s(P-\beta)\frac{\partial q_s}{\partial\lambda_k}-\sum_k\{v_k+\eta\lambda_k\}\frac{\partial x_k^c}{\partial\lambda_k}\leq 0,\quad \lambda_k\geq 0,\quad k=1,2,....K \tag{3.21}$$

$$x_j^{Nc}:\quad \eta\sum_s\pi_s(1-\alpha)\frac{\partial y_s}{\partial x_j^{Nc}}+\eta\sum_s\pi_s(P-\beta)\frac{\partial q_s}{\partial x_j^{Nc}}-\sum_k\{v_k+\eta\lambda_k\}\frac{\partial x_k^c}{\partial x_j^{Nc}}-C_{x_j^{Nc}}-\frac{\partial g^I(\mathbf{x}^{Nc})}{\partial x_j^{Nc}}\leq 0,$$

$$x_j^{Nc}\geq 0,\quad k=1,2,....K,\ j=1,2,....J \tag{3.22}$$

The subsections and/or sections that follow formally examine the first order conditions (3.19) - (3.22).

3.3.4 Input Provision in Production Contracts

The rationale for input provision can be understood in terms of conditions that determine when a marketing contract involving no input provision occurs (equivalent to the case where a PC that allows for input provision does not occur). In particular, an MC is associated with $\mathbf{x}^{Nc}=0,\mathbf{x}^c=0$, that is, corner solutions where the first order conditions in (3.17) (from the agent's maximization problem) and (3.22) (from the principal's maximization problem) are represented by the following system of inequalities:

$$\eta\lambda_k - C_{x_k^c}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h})\leq 0,\qquad x_k^c=0,\qquad k=1,2,....K \tag{3.23}$$

for the k^{th} contractible input provided by the principal, and

$$\eta\sum_s\pi_s(1-\alpha)\frac{\partial y_s}{\partial x_j^{Nc}}+\eta\sum_s\pi_s(P-\beta)\frac{\partial q_s}{\partial x_j^{Nc}}-\sum_k\{v_k+\eta\lambda_k\}\frac{\partial x_k^c}{\partial x_j^{Nc}}-C_{x_j^{Nc}}-\frac{\partial g^I(\mathbf{x}^{Nc})}{\partial x_j^{Nc}}\leq 0,$$

$$x_j^{Nc} = 0, \quad k = 1, 2, ...K, \; j = 1, 2, ...J \tag{3.24}$$

for the j^{th} noncontractible input provided by the principal.

The first order condition in (3.24) can be separated into two parts: (a) the marginal benefit, net of contractual payments, associated with the provision of the j^{th} noncontractible input (at the boundary where $x_j^{Nc} = 0$) and represented by $\{\eta \sum_s \pi_s (1-\alpha) \frac{\partial y_s}{\partial x_j^{Nc}} + \eta \sum_s \pi_s (P-\beta) \frac{\partial q_s}{\partial x_j^{Nc}} - \sum_k \{v_k + \eta \lambda_k\} \frac{\partial x_k^c}{\partial x_j^{Nc}}\}$, and (b) the marginal cost (at the boundary where $x_j^{Nc} = 0$) represented by the sum of $\frac{\partial g^I(\mathbf{x}^{Nc})}{\partial x_j^{Nc}}$ and an indirect cost component ("indirect" as it originates from the agent's side) given by $C_{x_j^{Nc}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$. Note that the change in the agent's minimum costs, reflected in $C_{x_j^{Nc}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$, is internalized by the principal in making his optimal decision as regards input provision. Moreover, the expression $C_{x_j^{Nc}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$ will reflect a benefit if it's value is negative. This is, indeed, the case for PCs where the grower's costs fall substantially on account of inputs being provided by the integrator. The inequality in (3.24) therefore implies that as long as the net benefit at the margin associated with a particular noncontractible input is non-positive (when the maxima is at the boundary), there will be no incentive for the principal to provide inputs in x^{Nc}. Similarly, at $x_k^c = 0$, following from (3.23), if the discounted contract price $\eta \lambda_k$ associated with a contractible input x_k^c is less than than the grower's marginal cost of using that input, there is no incentive for the grower to use the k^{th} contractible input provided by the integrator. All relevant costs and benefits are weighed when taking into account whether or not a particular decision must be implemented. In other words, it is the relatively high marginal costs (or the relatively low marginal benefits) at the boundary that drive the result.

Now, note that the solution represented by (3.23) for the contractibles is already reflected in (3.24) for the noncontractibles following from the second stage of optimization. As a result, a MC can be defined in terms of the first order conditions given by (3.24) for the noncontractibles while also having $\mathbf{x}^c = 0$. Summing up all the first order conditions represented by (3.24), in turn, yields in equilibrium:

$$\eta\sum_j E[(1-\alpha)\frac{\partial y}{\partial x_j^{Nc}}+(P-\beta)\frac{\partial q}{\partial x_j^{Nc}}]-\sum_j\sum_k\{\upsilon_k+\eta\lambda_k\}\frac{\partial x_k^c}{\partial x_j^{Nc}}-\sum_j\frac{\partial C}{\partial x_j^{Nc}}-\sum_j\frac{\partial g^I(\mathbf{x}^{Nc})}{\partial x_j^{Nc}}<0$$

$$\mathbf{x}^{Nc}=0;\sum_j x_j^{Nc}=0;\ \mathbf{x}^c=0 \qquad (3.25)$$

The inequality in (3.25) can be viewed as an alternative corner optimum representation of a marketing contract. Note that it is equilibrium behavior that is being examined here, and that the first order conditions in (3.24) are necessary but not sufficient to identify a maxima. Further, the left hand side of the inequality (3.25) is the directional derivative of the principal's objective function (3.18) in the direction $(\mathbf{r},\mathbf{x}^{Nc})=(\mathbf{0},\mathbf{1})$. The expression can be interpreted as the amount by which the principal's net payoff changes when the principal increases all noncontractible inputs from 0 by a marginal amount at the same rate. Overall, the principal, in his decisionmaking, weighs his discounted, marginal benefits net of contractual payments, as reflected by $\eta\sum_j E[(1-\alpha)\frac{\partial y}{\partial x_j^{Nc}}+(P-\beta)\frac{\partial q}{\partial x_j^{Nc}}]-\sum_j\sum_k\{\upsilon_k+\eta\lambda_k\}\frac{\partial x_k^c}{\partial x_j^{Nc}}$ in (3.25), against the marginal costs as reflected by $\sum_j\frac{\partial C}{\partial x_j^{Nc}}+\sum_j\frac{\partial g^I(\mathbf{x}^{Nc})}{\partial x_j^{Nc}}$. A production contract is optimal if, at the boundary, where no inputs are provided, the marginal benefit of input provision exceeds the marginal cost. This is then the formalization of a principle standard to economic decision making by a contracting company that needs to examine the profitability of input provision *in equilibrium*.

If the principal does decide to opt for input provision based on a production contract, then the exact nature of provision will be determined by the optimal values of $\mathbf{x}^{Nc}$ and $\mathbf{x}^{c}$ that result from an interior solution such that $\mathbf{x}^{Nc} \geq 0, \mathbf{x}^{c} \geq 0, \mathbf{x}^{Nc} \neq 0, \mathbf{x}^{c} \neq 0$. This then reflects the extent of input provision giving a formal mathematical expression to "limits to firm size" as described by Coase.

A PC therefore corresponds to $\mathbf{x}^{Nc} \geq 0, \mathbf{x}^{c} \geq 0, \mathbf{x}^{Nc} \neq 0, \mathbf{x}^{c} \neq 0$. The nature of the solution will differ depending on how many contractible and/or noncontractible inputs are provided by the principal. Once the principal decides to provide a particular contractible or a noncontractible input under contract, this decision has two effects:

a) Providing more inputs reduces the extent of the hidden action problem and, therefore, the number of unobservable inputs for the principal in the event that he left these decisions to be taken by the grower through $\mathbf{x}^{G}$. This, in turn, gives the principal more control over the production process.

b) As far as the contractibles are concerned, the principal's decision to provide a particular level of a contractible input has to be implemented through the agent. Therefore, the power of the incentives will have an important role to play here.

In general, when more inputs (contractible or noncontractible) are provided by the principal, one can expect the optimal incentive contract to provide more intensive or high-powered incentives for the agent with respect to the contractibles so that he uses inputs (or produces state-contingent outputs) as desired by the principal. The corresponding incentives with respect to the state-contingent outputs can also be expected to become more high-powered so as to realize a more desirable outcome. All this may be achieved through higher λ's, for instance, or through a higher α or β.

Apart from the interior solution discussed above, there also exist theoretical possibilities where interior solutions may exist only for one of the categories of inputs - either the contractible or the noncontractible category of inputs. That is, intermediate combinations such as $\mathbf{x}^{Nc} \geq 0, \mathbf{x}^{c} = 0, \mathbf{x}^{Nc} \neq 0$ and $\mathbf{x}^{Nc} = 0, \mathbf{x}^{c} \geq 0, \mathbf{x}^{c} \neq 0$ are also theoretical possibilities that can be considered in the model. Here, the former may be considered as a variant of a production contract whereby it is plausible that the quantity dimension of feed (which is contractible), for example, is bought by the agent from the open market while the feed quality (a noncontractible) of the feed "purchased" is decided by the principal. The second possibility where $\mathbf{x}^{Nc} = 0, \mathbf{x}^{c} \geq 0, \mathbf{x}^{c} \neq 0$ can be seen as a variant of a marketing contract reflecting a situation where, for example, the quality of the feed (now obtained from the principal) is something that the agent chooses. However, in practice, as far as the sample contracts and corresponding literature that I have seen are concerned, these intermediate combinations constitute possibilities that are more hypothetical than real.

Definition 3.2

A marketing contract that involves no input provision by the principal is a corner solution for the optimal choice of all inputs in $\mathbf{x}^{I}$.

Based on definition 3.2, one can conclude that there is incentive for the principal to provide inputs under a production contract if, at the boundary, where no inputs are provided, the benefit at the margin associated with input provision exceeds the corresponding costs.

Further, the higher the relative market premium 'P' associated with quality, other things remaining the same, the higher is the net marginal benefit (NMB) of input provision at $\mathbf{x}^{Nc}=0$, where NMB at $\mathbf{x}^{Nc}=0$ is measured by the expression $\eta\sum_{j}E[(1-\alpha)\frac{\partial y}{\partial x_j^{Nc}}+(P-\beta)\frac{\partial q}{\partial x_j^{Nc}}]-\sum_{j}\sum_{k}\{v_k+\eta\lambda_k\}\frac{\partial x_k^c}{\partial x_j^{Nc}}-\sum_{j}\frac{\partial C}{\partial x_j^{Nc}}-\sum_{j}\frac{\partial g^I(\mathbf{x}^{Nc})}{\partial x_j^{Nc}}$ in (3.25) that takes into account all the first order conditions. A higher NMB, in turn, raises the likelihood that input provision will take place through a PC. The concept of "likelihood" can be understood as follows (the intuition provided here is also what is found in latent utility models in econometrics): Let D be a binary variable where $D=1$ if the grower has a PC, and $D=0$ if the grower has an MC. In particular, $D=1$ if $NMB\geq 0$, and $D=0$ if $NMB<0$. Then, $\Pr(D=1)=\Pr(NMB\geq 0)$, and since a higher P will raise the NMB at the corner, this will also raise the probability of having a PC, all other things remaining the same. Using the same kind of reasoning, the likelihood of input provision also rises with a fall in the principal's costs v_k of obtaining the k^{th} contractible input, other things remaining the same.

Proposition 3.6

The likelihood of input provision under a production contract increases with an increase in the market premium received per unit of lean percentage, and with a decrease in the principal's cost of obtaining a particular contractible or noncontractible input, other things remaining the same.

The definition for a marketing contract and a production contract as outlined above captures Coase's idea that an institutional arrangement will materialize if the benefits associated with it exceed the costs (Coase, 1991). And, the extent of input provision, as garnered from the interior solution optimal values obtained for $\mathbf{x}^c$ and $\mathbf{x}^{Nc}$, reflects "limits to firm size" as described by Coase. However, the analysis of limits to firm size, as reflected by the model structure of this chapter, is not confined to a comparison of costs only - costs of carrying out an extra transaction within the firm with the costs of carrying it out in the open market (Coase, 1937). The analysis here boils down to equating marginal benefits to marginal costs in the neoclassical scheme of things while taking into account several dimensions of a specific problem in a production theoretic setting.

3.4 Interlinkage in Production Contracts

The characteristic feature of production contracts is the provision of certain key inputs by the integrator, a phenomenon that is associated with 'interlinkage' in the development and/or sharecropping literature. Interlinkage can be defined as the practice of offering contracts that combine transactions over several dimensions (Basu, Bell and Bose, 2000). In the case of PCs, interlinkage involves the contracting company contracting over not just the outputs (weight gain and/or output quality) but also some or all of the contractible inputs that it provides.

Interlinkage arises in the context of PCs with the contracting company contracting over weight gain and feed with incentives based on leanness typically being absent. In what follows, I examine (i) the economic rationale for the absence of quality based incentives in PCs, and (ii) the optimality of a production contract where the payment is based both on weight gain and feed usage. The analysis of (i) and (ii) follows from the analysis of the principal's maximization problem where I assume a linear payment structure for the agent who has CRA preferences over $\mathbf{r}$.

3.4.1 Absence of (or Weak) quality based incentives under production contracts

This section examines conditions under which the contracting company provides no incentives (or only weak) incentives with respect to leanness or the quality dimension of output, which is something that is frequently observed in the case of production contracts. The compensation in a marketing contract involves providing incentives both with respect to weight gain and quality unlike PCs where quality based incentives typically tend to be absent.[10] To examine this, consider the principal's objective function in (3.18):

$$\begin{aligned} \underset{\alpha,\boldsymbol{\beta},\boldsymbol{\lambda},\mathbf{x}^{Nc}}{max} \quad & \{\eta\sum_s \pi_s[y_s(\Psi) + Pq_s(\Psi)] - \sum_k v_k x_k^c(\Psi) - \\ & - \kappa\eta[\sum_s \pi_s[\sum_{i\neq s}\pi_i\{\alpha(y_s(\Psi) - y_i(\Psi)) + \beta(q_s(\Psi) - q_i(\Psi))\}]^2]^{1/2} - \\ & - C(\mathbf{x}^{Nc}, \mathbf{x}^c(\Psi), \mathbf{y}(\Psi), \mathbf{q}(\Psi), \mathbf{h}) - g^I(\mathbf{x}^{Nc}) - \underline{u}\} \end{aligned} \tag{3.26}$$

where $\Psi = (\alpha, \beta, \boldsymbol{\lambda}, \mathbf{x}^{Nc}, \mathbf{h}, \eta)$. Now, let $C^I(\mathbf{y}, \mathbf{q}, \mathbf{h}, \overline{L})$ be the principal's cost function derived as:

$$C^I(\mathbf{y}, \mathbf{q}, \mathbf{h}, \overline{L}) = \min_{\mathbf{x}^{Nc}} \; g^I(\mathbf{x}^{Nc})$$

subject to:

$$\{\eta\sum_s \pi_s[y_s(\Psi) + Pq_s(\Psi)] - \sum_k v_k x_k^c(\Psi) - \kappa\eta[\sum_s \pi_s[\sum_{i\neq s}\pi_i\{\alpha(y_s(\Psi) - y_i(\Psi)) +$$

[10] I find no clause that specifies payments based on quality in the PC samples available on www.iowaattorneygeneral.org. The same was conveyed in informal conversations with Dr. James MacDonald (Economic Research Service, USDA), Prof. Kelly Zering (Department of Agricultural and Resource Economics, North Carolina State University), and a group of broiler growers.

$$+\beta(q_s(\Psi) - q_i(\Psi))\}]^2]^{1/2} - C(\mathbf{x}^{Nc}, \mathbf{x}^c(\Psi), \mathbf{y}(\Psi), \mathbf{q}(\Psi), \mathbf{h}) - \underline{u}\} \geq \overline{L},$$

where $\overline{L}$ is some constant, $\overline{L} \in \Re_+$ and measures the principal's expected payoff exclusive of his costs of obtaining the noncontractible inputs. The principal's cost function $C^I(\mathbf{y}, \mathbf{q}, \mathbf{h}, \overline{L})$ represents the principal's (ex ante) minimum cost of producing a given state contingent $\mathbf{y}, \mathbf{q} \in \Re_+^S$ given $\mathbf{h}$. An interior solution, especially for the noncontractible inputs that determine leanness, characterizes a production contract by definition.

By the principle of conditional optimization, the problem corresponding to (3.26) above has an alternative representation and is restated as:

$$\begin{aligned} \max_{\alpha,\boldsymbol{\beta},\boldsymbol{\lambda}} \ &\{\eta \sum_s \pi_s [y_s(\Gamma) + P q_s(\Gamma)] - \sum_k v_k x_k^c(\Gamma) - \\ &- \kappa\eta [\sum_s \pi_s [\sum_{i \neq s} \pi_i \{\alpha(y_s(\Gamma) - y_i(\Gamma)) + \beta(q_s(\Gamma) - q_i(\Gamma))\}]^2]^{1/2} - \\ &- C(\mathbf{x}^c(\Gamma), \mathbf{y}(\Gamma), \mathbf{q}(\Gamma), \mathbf{h}) - C^I(\mathbf{y}(\Gamma), \mathbf{q}(\Gamma), \mathbf{h}, \overline{L}) - \underline{u}\} \end{aligned}$$

with Γ representing the set of parameters $(\alpha, \beta, \boldsymbol{\lambda}, \mathbf{h}, \eta)$.

The corresponding first order conditions are:

$$\begin{aligned} \alpha:\ &\eta \sum_s [\pi_s(1-\alpha) - C^I_{y_s}] \frac{\partial y_s}{\partial \alpha} + \eta \sum_s [\pi_s(P - \beta) - C^I_{q_s}] \frac{\partial q_s}{\partial \alpha} - \\ -\kappa\eta T^{-1/2} &[\sum_s \pi_s [\sum_{i \neq s} \pi_i (r_s - r_i)][\sum_{i \neq s} (y_s - y_i)]] - \sum_k \{v_k + \eta\lambda_k\} \frac{\partial x_k^c}{\partial \alpha} \leq 0, \qquad \alpha \geq 0 \end{aligned} \tag{3.27}$$

$$\begin{aligned} \beta:\ &\eta \sum_s [\pi_s(1-\alpha) - C^I_{y_s}] \frac{\partial y_s}{\partial \beta} + \eta \sum_s [\pi_s(P - \beta) - C^I_{q_s}] \frac{\partial q_s}{\partial \beta} - \\ -\kappa\eta T^{-1/2} &[\sum_s \pi_s [\sum_{i \neq s} \pi_i (r_s - r_i)][\sum_{i \neq s} (q_s - q_i)]] - \sum_k \{v_k + \eta\lambda_k\} \frac{\partial x_k^c}{\partial \beta} \leq 0, \quad \beta \geq 0 \end{aligned} \tag{3.28}$$

$$\lambda_k : \eta \sum_s [\pi_s(1-\alpha) - C^I_{y_s}] \frac{\partial y_s}{\partial \lambda_k} + \eta \sum_s [\pi_s(P-\beta) - C^I_{q_s}] \frac{\partial q_s}{\partial \lambda_k} - \sum_k \{v_k + \eta\lambda_k\} \frac{\partial x^c_k}{\partial \lambda_k} \leq 0,$$

$$\lambda_k \geq 0, \quad k = 1, 2, ...K \tag{3.29}$$

To examine no incentives (or only weak) incentives with respect to quality, I assume that:

(a) Quality is nonstochastic - The lean percentage for each state approaches q, with quality primarily determined by genetics and feed quality. Once genetics and feed quality are chosen by the integrator, the lean percentage is assumed to be practically invariant to the state of nature. Since it is the integrator's decisions with respect to genetics and feed quality that are crucial to determining q, the quality dimension of production is said to be sufficiently controlled by the integrator.

(b) Tasks are technically independent of leanness - Technical independence in the context of this paper arises when $\frac{\partial y_s}{\partial \beta} = \frac{\partial x^c_k}{\partial \beta} = 0, \forall s, k$. As mentioned earlier, the notion of technical dependence (or independence) described here is not strictly the same as what is found in the literature (for instance, Holmstrom and Milgrom, 1991). For tasks to be technically independent of leanness -that is, $\frac{\partial y_s}{\partial \beta} = \frac{\partial x^c_k}{\partial \beta} = 0, \forall s, k$, in the sense of Holmstrom and Milgrom (1991), the second-order cross partial derivatives of the grower's effort cost function (in this case, the cross partial derivatives involving leanness-weight gain and leanness-input use) must be zero. In other words, an increase in leanness should not affect the marginal cost of producing an extra unit of a state-contingent y ($C_{y_l q_s}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) = 0, \forall l, s \in S$). Similarly, an increase in leanness should not affect the marginal cost of using an extra unit of the contractible input provided by the integrator ($C_{x_k^c q_s}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) = 0, \forall s, k$). The concept of technical dependence or independence in this thesis refers to technical dependence or independence *given* the inputs $\mathbf{x}^{Nc}$ chosen by the principal and complementarity entails taking derivatives of the objective function $F(.)$ in the agent's maximization problem and not just the cost function $C(.)$.

Substituting $\frac{\partial y_s}{\partial \beta} = \frac{\partial x_k^c}{\partial \beta} = 0, \forall s, k$ into (3.28), and using the assumption $q_s = q, \forall s \in S$, gives the optimal β:

$$\beta \rightarrow P - C_q^I(\mathbf{y}, \mathbf{q}, \mathbf{h}, \overline{L}),$$

or, in the limit,

$$\beta = P - C_q^I(\mathbf{y}, \mathbf{q}, \mathbf{h}, \overline{L})$$

so that the principal adjusts y, q, and β so as to equate P (the premium associated with leanness) and his marginal cost associated with an extra unit of q. This scenario becomes plausible when the principal chooses the optimal q as if he faces a perfectly competitive market for quality, with the marginal cost schedule given by $C_q^I(\mathbf{y}, \mathbf{q}, \mathbf{h}, \overline{L})$. In this scenario, the optimal quality is such that the principal equates price to marginal cost as is the case in a perfectly competitive market. This, in turn, causes the optimal β to tend to zero. This optimal β corresponds to the optimal level of leanness that is actually produced by the integrator, but turned out by the grower in the production process. That is, even though the quality dimension itself is turned out by the agent, it can be viewed more as a "free" by-product for the agent that results from the principal's effort.

Proposition 3.7

If the noncontractible inputs that determine leanness are provided by the principal and (i) quality is nonstochastic, (ii) tasks are technically independent of *leanness, and (iii) the principal chooses optimal q so that $C_q^I(\mathbf{y}, \mathbf{q}, \mathbf{h}, \overline{L})$ tends to P, the principal does not provide any incentives (or provides only weak incentives) with respect to quality so that $\beta = 0$ ($\beta \rightarrow 0$) at the optimum.*

Therefore, under PCs, the grower only "turns out" the quality dimension so that the degree of leanness is realized only at the end of the production cycle when the grower delivers the animals grown to market weight (which also makes leanness a potential signal that can be rewarded). However, the major factors that determine leanness - genetic composition of the animals, and feed quality - are controlled by the integrator and "programmed" for when the young animals are delivered to the grower in the beginning of the production cycle. That is, leanness is effectively produced by the integrator. Overall, input provision by the integrator, through his investment in genetic composition and feed quality, plays a key role in explaining the absence of (or weak) quality based incentives under PCs. This feature of contracting provides an explanation that is different from what Holmstrom and Milgrom have for the provision of low powered or no incentives with respect to a certain task. In the Holmstrom and Milgrom framework, low powered or no incentives with respect to a certain task are attributed to the fact that rewarding that task may cause the agent to substitute his attention away from other tasks especially in a situation where errors associated with the measurement of the other tasks are large. The conditions obtained here therefore provide yet another perspective on multitask contracting. Finally, the presence of quality based incentives in a MC can be attributed to the non-fulfilment of any one of the conditions outlines in Proposition 3.7.

3.4.2 Interlinkage over weight gain and feed in production contracts

Interlinkage arises in the context of PCs with the contracting company contracting over both weight gain and feed. The picture that emerges is one where the grower effectively "buys" feed from the integrator.[11] In what follows, the optimality of a contract that is based on both weight gain and feed is examined.

To facilitate the analysis of interlinkage in a PC, I restrict attention to the markets for weight gain and inputs only. The incentives based on leanness are assumed to be absent so that $\beta = 0$ as is common in PCs (www.iowaattorneygeneral.org). It is also assumed that the input market for contractible and noncontractible inputs is competitive and that the grower is able to obtain inputs at the same price as the integrator. Finally, to facilitate comparison, the effort evaluation function, $g^I(\mathbf{x}^{Nc})$, of the integrator is assumed to be linear with w_j being the integrator's per unit cost associated with the j^{th} noncontractible input. The payment to the grower in state s is now given by:

$$r_s = \delta + \alpha y_s + \sum_k \lambda_k x_k^c, \quad s = 1, 2, ..., S;\ k = 1, 2, ...K, \text{ and}$$

$$\begin{aligned} \sigma[\mathbf{r}] &= [\sum_s \pi_s [\sum_{i \neq s} \pi_i \{\alpha(y_s - y_i)\}]^2]^{1/2} \\ &= T^{1/2} \end{aligned}$$

where,

$$T = [\sum_s \pi_s [\sum_{i \neq s} \pi_i \{\alpha(y_s - y_i)\}]^2]$$

[11] However, given that incentives in the contract are typically described in terms of the feed conversion ratio (FCR), the exact payment that the grower makes per pound of feed gets confounded in practice.

The first order conditions (3.19), (3.21) and (3.22), assuming interior solutions, are now written as:

$$\alpha: \ \eta\sum_s \pi_s(1-\alpha)\frac{\partial y_s}{\partial \alpha} - \kappa\eta T^{-1/2}[\sum_s \pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)][\sum_{i\neq s}(y_s - y_i)]]-$$

$$-\sum_k \{v_k + \eta\lambda_k\}\frac{\partial x_k^c}{\partial \alpha} \leq 0, \qquad \alpha \geq 0 \tag{3.30}$$

$$\lambda_k : \eta\sum_s \pi_s(1-\alpha)\frac{\partial y_s}{\partial \lambda_k} - \sum_k \{v_k + \eta\lambda_k\}\frac{\partial x_k^c}{\partial \lambda_k} \leq 0, \qquad \lambda_k \geq 0, \quad k = 1, 2, ...K \tag{3.31}$$

$$x_j^{Nc}: \quad \eta\sum_s \pi_s(1-\alpha)\frac{\partial y_s}{\partial x_j^{Nc}} - \sum_k \{v_k + \eta\lambda_k\}\frac{\partial x_k^c}{\partial x_j^{Nc}} - C_{x_j^{Nc}}(\mathbf{x}^I, \mathbf{y}, \mathbf{h}) - w_j \leq 0,$$

$$x_j^{Nc} \geq 0, \quad k = 1, 2, ...K, \ j = 1, 2, ...J \tag{3.32}$$

In this context, I examine what corresponds to no interlinkage and if no interlinkage is optimal. In the case of no interlinkage,

$$\begin{aligned} \eta\lambda_k &= -v_k, \text{ and} \\ C_{x_j^{Nc}}(\mathbf{x}^I, \mathbf{y}, \mathbf{h}) &= -w_j \end{aligned} \tag{3.33}$$

That is, the principal provides the k^{th} contractible input in a way that the grower effectively purchases that input from the integrator at the market price, instead of buying it from the market. And, the price that the grower pays for the k^{th} contractible input equals $\frac{v_k}{\lambda}$, the value of v_k in period $t+1$. At the same time, when noncontractible inputs are provided under PCs, this leads to a reduction in the grower's own minimum costs. In the case of no interlinkage, the grower's cost saving $C_{x_j^{Nc}}(\mathbf{x}^I, \mathbf{y}, \mathbf{h})$ associated with the principal directly choosing an extra unit of the j^{th} noncontractible input *exactly* equals w_j - the principal's per unit cost of buying that input.

Now, for the conditions in (3.33) to be consistent with the first order conditions in (3.31) and (3.32), it is also required that $\alpha = 1$. However, (3.30) also needs to be satisfied along with the rest of the first order conditions for no interlinkage to be optimal. Substituting, $\alpha = 1$, $\eta\lambda_k = -v_k$, and $C_{x_j^{Nc}}(\mathbf{x}^I, \mathbf{y}, \mathbf{h}) = -w_j$ in (3.30) gives:

$$-\kappa\eta T^{-1/2}[\sum_s \pi_s[\sum_{i \neq s} \pi_i(r_s - r_i)][\sum_{i \neq s}(y_s - y_i)]] \neq 0$$

implying that (3.30) is not satisfied unless there is no uncertainty with respect to weight gain and/ or the grower is risk neutral. This implies that the integrator, in a production contract arrangement with input provision, finds it optimal to offer an interlinked contract.

If the agent is risk neutral and/or there is no uncertainty in weight gain, the principal offers independent contracts for the different relevant dimensions, or the payment for a specific task does not cut across transactions in other dimensions. That is, the optimality of no interlinkage with respect to weight gain and feed usage under a production contract is consistent with: (a) the agent being risk neutral and/or (b) no uncertainty associated with weight gain. Note that nonfulfilment of either one of these conditions reduces the marginal benefit of raising α at the margin (in the first order condition given by 3.30). The principal then might want to interlink contracts over weight gain and feed so that what is lost on account of uncertainty due to weight gain, for instance, is made up through an appropriate charge for feed usage.

Proposition 3.8

Interlinkage over weight gain and contractible inputs is optimal for the principal under a production contract unless the grower is risk neutral and/or there is no uncertainty.

3.5 Conclusion

The rationale for input provision, as is common to standard microeconomic theory, boils down to weighing benefits against costs at the margin. All relevant costs and benefits are taken into consideration when the principal chooses the optimal level of inputs to be provided. The case of a marketing (production) contract with no input provision (input provision) is then characterized by a corner (interior) solution for the optimal choice of inputs. Moreover, the likelihood of input provision under a production contract increases with an increase in the market premium received per unit of lean percentage, and with a decrease in the principal's cost of obtaining a particular contractible or noncontractible input, other things remaining the same.

With respect to internal organization, the economic rationale for the absence of quality based incentives in production contracts is examined. This is intended to provide yet another perspective to the Holmstrom and Milgrom multi-task model. Interlinkage is also seen as relevant for PCs, with an optimal contract being based on both feed usage and weight gain.

It will be interesting to see where agriculture is headed with regard to production contracts and whether it will mimic the "true" capitalist mode of organization. As Hunt (2004) notes, the transition to capitalism became complete when, in the later period of the putting out system, the capitalists started to own not just the raw materials required for production but also the tools, machinery, and often the building in which production took place. This was accompanied by the creation of a large working class that only had its labor power to sell in the market. It remains to be seen what course agriculture as a sector will now follow.

Chapter 4

Economic Power and Endogenous Reservation Utility in Corporate Dyads

4.1 Introduction

Reservation utility, or the amount that an agent gets in his next best alternative use, is a vital component of all principal-agent models. Any contract, in theory, must offer the agent at least his reservation expected utility, in order for it to be accepted. This then forms the basis for the individual rationality constraint or the participation constraint in economic modeling. Contracting models, however, typically take this reservation utility as exogenously given. The possibility of reservation utility being endogenous has been explored formally in a seminal paper by Basu (1986), as also in Naqvi and Wemhoner (1995), and Chambers and Quiggin (2000). All these papers are interesting in that they attempt to incorporate qualitative issues such as influence and power that tend to get marginalized in conventional economic modeling. In particular, it is in the exploitation of the agent by the principal through extra-contract means *within* an existing contractual framework in which endogeneity in reservation utility in these papers is manifested.

This chapter, in contrast to the studies mentioned above, focuses on *pre-contract* (before the contract is signed) or outside-of-contract interactions that influence the reservation utility and not extra-contract means within an existing contractual framework. Moreover, unlike the present literature that emphasizes the emergence of endogenous reservation utility in triadic relationships, this chapter illustrates that such a possibility may even arise in a dyadic setting.[1]

As far as the methodology is concerned, I examine the equilibrium determination of the agent's reservation utility in the context of dyadic relationships involving two firms (I and II) interacting pair-wise. There are two levels of interaction – one, under contract where one firm works for another, and second, before the contract is signed when both firms operate independently. As independent producers, both firms compete in a duopoly setting with one firm (firm II) being relatively smaller, less competitive, and relatively less cost-effective than the other (firm I). I show that these factors, in turn, make it difficult for firm II to compete with firm I, thereby reducing its profitability of independent production. This then may cause the smaller player namely, firm II, to opt for contract production as an agent with firm I as the "principal" firm. In the contract interaction, the principal firm contracts with the agent firm for the production of the given commodity and the contract is such that it offers the agent no more than his reservation utility. However, the agent's reservation utility now depends on the price that the agent gets for his product in his outside option under which he

[1] A triadic relationship is one where two parties interact with each other both directly, and indirectly, through a third party. This is in contrast to a dyadic relationship where parties act pairwise.

produces independently the same product that he would under contract.[2] That is, the agent in his outside option competes with the principal firm as an independent but relatively smaller and relatively less cost-effective producer - a situation modeled as being one identical to the pre-contract phase - and the reservation utility under contract is affected by this competition on the price front.

In what follows, I first cite background case studies that illustrate how reservation utility is endogenously determined. Section 4.3 develops and examines the model for the equilibrium determination of reservation utility - (i) the production technology, (ii) the determination of reservation utility in a strategic Cournot duopoly setting, and (iii) an analysis of contract production with endogenous reservation utility that includes the pattern of input provision, the preference and return structures of the principal and the agent, the timing of the game, the set up of the agency problem, the possibility of a hold-up problem, and the three stage solution to the agency problem. The fourth and final section concludes.

4.2 Background Case-Studies

The dyadic relationship in this chapter is specifically examined in the context of corporate agrarian contracting in the United States with special reference to the pork and broiler industries . These industries have undergone significant changes over time in their structure of organization. One such structural change includes increasing concentration of agricultural production in large farms and the growing inability of the smaller players to compete. Further, as Macdonald

[2]Note that the "outside" option or the "next best alternative use" that determines reservation utility in this chapter entails firms engaging in independent production as in the pre-contract phase.

(2006) argues, "The structural upheavals reflect, in some and perhaps most cases, the exploitation of new scale economies...As such, structural change can lead to lower costs, lower prices to consumers, and higher returns to resource providers; it also leads to lower returns for those competing producers who do not adapt to new technologies." The challenge faced by smaller producers is reflected in a 1998 New York Times news-item: "It is agreed that falling hog prices in 1998, for instance, are to be mainly attributed to the overproduction of swine.....The growing dominance of factory-like hog companies makes it increasingly difficult for smaller, independent operations to compete." (Johnson, 1998).

An illustration of the inability of smaller producers to compete with the larger players is the case study 'A contract on hogs: A Decision Case' by Swinton and Martin (1997) that describes the factors underlying a Michigan farm couple's decision to go for contract production with the company "Pork Partners". This is a couple that was operating independently - raising hogs outdoors and selling them to an agent of Michigan Livestock Exchange. However, declining hogs prices in the late 1980s and the inability to earn the premium offered on the production of leaner hogs (hogs raised outdoors tend to be fatter) were among the important factors adversely affecting their profit margins, eventually leading them to opt for contract production with Pork Partners.

The above facts suggest that the inability to compete with bigger operations reduces the profitability of independent production for smaller players. And, in this scenario, if the smaller player opts for contract production under the bigger player, it is the reduced profitability under the independent production arrangement that will constitute the benchmark against which contracts will be designed.

It may be noted here that investments of bigger operations may be undertaken primarily to reduce costs and become more competitive vis-à-vis other players. The activities need not be directly and "consciously" targeted towards ultimately getting the smaller players to work under contract. However, the linkages in the economy may be such as to lead to an outcome of this kind and it is these linkages that the present chapter explores.

Another case in point is Wal-Mart that is well-known for having acquired a key competitive advantage by not only investing heavily in cutting-edge technology but doing so faster than any of its competitors. Wal-Mart's strength lies in the relatively low prices that it charges as compared to its competitors comprising supermarkets and local "mom and pop" stores. Its low cost culture reflects a market philosophy and can be attributed to several factors such as purchasing goods in bulk directly from manufacturers instead of relying on wholesalers, constantly innovating and improving its IT infrastructure, and so on. Overall, low prices can be attributed to the scale and scope efficiencies that Wal-Mart has invested in. (Friedman, 2005; Basker, 2007)

However, low prices charged by Wal-Mart and other retail chains have also received considerable attention on account of the difficulty they pose for the small players to compete. The company has also come under scrutiny for its low wages and benefits. The demise of several mom and pop stores has been attributed to their inability to match Wal-Mart prices. Goetz and Swaminathan (2004) suggest that one of the options available to such storeowners (and their employees) once they shut down is to work for Wal-Mart itself. If contracts pay no more than the reservation utility, the Wal-mart contract with this former store owner or employee will offer him no more than the new reduced income that results from the store's inability to compete.

The possibility of reservation utility being endogenous can also be seen in the context of business takeovers. This is especially true for those takeover decisions triggered by the target firm's inability to compete with the leading firms (including the acquiring firm) on account of falling prices. An example of a takeover in this genre is the takeover of India's Ranbaxy, a family owned business, by the Japanese firm Daiichi Sankyo in 2008. Ranbaxy, in its early years of operation, was able to take advantage of lax patent protection and enjoy scale economies in the manufacture of generic drugs. What proved to be its undoing was its decision to develop original drug compounds - an aspect with respect to which India has not yet come of age. On the generic front too, it has been facing competition from smaller, more nimble firms (Sheth, 2008).[3] The Ranbaxy Chief Executive Officer (CEO), also a part of the family that owned the pharmaceutical company, sold his entire stake in the company, and initially agreed to continue working as the CEO. He, however, stepped down as Ranbaxy Chief soon thereafter presumably because the overall scheme of things after the takeover may not have been satisfactory enough.

As a matter of fact, one can argue that the pork contract example in the Swinton and Martin study would effectively amount to a takeover by the contracting company in corporate parlance (especially when the contract in question is a production contract). However, the takeover is indirect in the sense that even though there is no shift of ownership or voting rights, the decision making authority largely shifts to the contracting company. While the land and other

[3] Note that this example differs from the examples cited above in that competition was posed by smaller (and not larger) firms.

assets continue to be owned by the farmer, it is the company that makes the key production decisions and effectively determines how assets will be used.

Definition 4.1

A (production) contract takeover is the taking over of control and/or management of a firm under a contract without there taking place a transfer of "shares" or ownership of the firm.

The case studies discussed above are illustrative of the fact that reservation utility may be endogenously determined within the model. In all the examples discussed above, the opportunity cost of an agent is lowered on account of increased competition on the price front under independent operation. This, in turn, implies that factors that reduce prices (e.g. reduced costs and/or large-scale production) should benefit the integrator (in the context of the thesis model). The specific benefit that I focus on is the fact that reduced costs and the associated mass production by the integrator lead to a downward pressure on prices which, in turn, lower the reservation utility of the smaller player(s), thereby inducing him to go for contract production but getting paid the lower reservation utility. And, restricting attention to only two players, one can view a production contract as involving the more competitive firm taking over the operations of the less competitive firm (without a transfer of formal ownership of assets), and the owner of the latter accepting a contract to work with the former.

Now, endogenous reservation utility has been examined in the context of triadic relationships by Basu (1986). In this context, Basu notes: "A transaction that leaves one agent actually worse off can be explained in a model with rational agents only if we allow for triadic relationships." However, in the light of the discussion above and in what follows formally in this chapter, endogenous reservation utility:

- is seen to emerge in a dyadic setting where parties interact pairwise in a strategic manner. As a matter of fact, the scenario in Basu can also be seen in terms of a dyadic relationship if, for example, one allows for the landlord to "legally" enter into a partnership with the merchant (or even take over the merchant's business) and then offer his contract and the merchant's goods to the laborer as a package. Even though the outcome will be the same as that in Basu, the means to achieving that outcome seem part of normal economic behavior!

- may not be a consequence of a "coercive" threat but may be a consequence of the exertion of economic power (or, in more extreme situations, economic coercion).[4]

The scenario outlined in this chapter is also different from that described in the context of the traditional landlord who takes the market price as given with a rise in market price causing him to increase his exploitative activities which, in turn, lead to a fall in the peasant's reservation utility (Chambers and Quiggin, 2000). However, I show, in this chapter, that there are two ex post price schedules that need to be taken into account: 1) the market price that results from the interaction between economic players in the pre-contract phase, and (2) the market price that results when the smaller player decides to work under contract for the larger player. In particular, for the case in question, what is relevant is a rise in the pre-contract market price, also endogenously determined, a rise in which now leads to a rise in the farmer's reservation utility.

[4]Whether a situation is interpreted as threatening (and therefore subject to antitrust legislation) or as part of "regular" rational economic behavior can be a subjective issue and depends on the legal and/or moral evaluation of the situation by the adjudicating authority.

4.3 Model

Suppose there are two players - I and II, and currently II works (as the agent) for I (the principal) under contract - production contract or marketing contract, depending on whether or not there is input provision. This is the status quo and was preceded by player II operating, like player I, as an independent producer. While the contract is such that it pays II no more than his reservation utility, this reservation utility is no longer exogenous as is the case in standard moral hazard models. In particular, it is assumed that the reservation utility of the agent in this model is determined in a strategic Cournot duopoly setting where both I and II make their production decisions simultaneously and independently.

Note that the organizational structure (in terms of independent production followed by contract production for player II) is taken as a "given" in contrast to the first part of the thesis where the organizational structure (in terms of input provision) was endogenously determined.[5] The focus in this chapter is on the equilibrium determination of reservation utility *given* a specific organizational form.

4.3.1 The Production Technology

In this chapter also, I continue with the same production technology specification as in Chapter 3 except that only one output (z) is produced, where z represents weight gain or output quality. There are M fixed inputs denoted by $\mathbf{h} \in \Re_+^M$ (e.g. land area devoted to production), and N variable inputs with the variable input vector represented by $\mathbf{x} \in \Re_+^N$. The non stochastic inputs are committed

[5] An alternative organizational structure may be one where firm II, who initially produces independently, simply opts to work in firm II as an employee.

prior to the resolution of uncertainty. Uncertainty entails 'Nature', a neutral player, making a choice from among two mutually exclusive states. Let the set of states of nature be represented by $\Omega = \{1, 2\}$. Such a set serves to highlight the uncertain aspects of production such as those relating to temperature, disease and the biological or metabolic processes in animals. Let π_1, and π_2 be the probabilities with which states 1 and 2 occur, respectively.

The production technology is described in terms of the input correspondence $X(z_1, z_2, \mathbf{h})$ that consists of the sets of variable inputs that can produce a particular state-contingent output vector $\mathbf{z} = (z_1, z_2) \in \Re^2_+$ given a vector of fixed inputs ($\mathbf{h}$). Note that the input correspondence in no way determines which state of nature corresponds to high output and the state that corresponds to low output. It is, therefore, assumed, without loss of generality, that the relative probabilities are such that state 1 is the good state.

Assumption 4.1

It is assumed, without loss of generality, that state 1 *is the good state.*

The sequence of moves that govern production on the "field" is as follows: A grower, given $\mathbf{h}$, first commits a vector $\mathbf{x}$ of non stochastic inputs to production that allows him to produce a vector of state-contingent outputs, $(z_1, z_2) \in \Re^2_+$, with the typical element being z_s, where z_s represents the amount of output that is realized in state s $(s = 1, 2)$. Nature then makes a draw from Ω which, along with $\mathbf{x}$, determines the output z_s, corresponding to the state s that materializes. For the complete structure and timing of the game, see Section 4.3.3. It is assumed, as before, that both growers are cognizant of the technology and each other's preferences.

4.3.2 Determination of reservation utility in a Cournot Setting

The reservation utility of the agent is determined by what he gets in his next best alternative use which is characterized here by the agent operating independently as grower II, and competing with grower I (who, under contract, acts as the principal). The situation outside of the contract is modeled in terms of a state-contingent Cournot duopoly model where the parties concerned are assumed to engage in independent production and act simultaneously and non-cooperatively. This is in contrast to cooperative behavior where the equilibrium concept is based on the Nash bargaining solution (See Appendix G).

To see the exact mechanism under which the growers interact, denote grower $i's$ production by (z_1^i, z_2^i), $i = I, II$, corresponding to the two states of nature. Let $z_1^I + z_1^{II} = Z_1$ and $z_2^I + z_2^{II} = Z_2$ with Z_s representing the total production of the two firms taken together in state s, $s = 1, 2$. Suppose, the market price is no longer exogenous as was true for Chapter 3 but is given by the inverse demand function $P(Z_s)$ for state s. In particular, $P(Z_s)$ is assumed to be linear and is given by $P(Z_s) = 1 - Z_s$, $s = 1, 2$.

Grower i $(i = I, II)$ receives a gross amount $r_s^i = P(Z_s)z_s^i$ in state s, $s = 1, 2$. It is assumed that grower I is risk neutral and his preferences over **r** are of the linear form $\pi_1 r_1^I + \pi_2 r_2^I$. Grower II's preferences over '**r**' are based on the expected utility model so that preferences assume the form ($\sum\limits_s$ below represents summation over S states $\sum\limits_{s=1}^{S}$):

$$W(\mathbf{r}) = \sum_s \pi_s u(r_s^{II})$$

where $u : \Re \rightarrow \Re$ represents the utility function of the agent. The utility function is strictly increasing and strictly concave so that the agent is strictly risk averse over state-contingent returns. I specifically address the case of constant risk averse (CRA) preferences for grower II so that:

$$\begin{aligned} W(\mathbf{r}) &= \pi_1 r_1^{II} + \pi_2 r_2^{II} - \kappa\sigma[\mathbf{r}^{II}] \\ &= \pi_1 r_1^{II} + \pi_2 r_2^{II} - \kappa\sqrt{\pi_1\pi_2}[P(Z_1)z_1^{II} - P(Z_2)z_2^{II}], \end{aligned}$$

using Assumption 4.1 where $r_1 > r_2$. Here, κ is the index of risk aversion, and σ is the standard deviation associated with $\mathbf{r}$, with $\sigma[\mathbf{r}] = \sqrt{\pi_1\pi_2}[P(Z_1)z_1^{II} - P(Z_2)z_2^{II}]$.[6]

Let $g^i(\mathbf{x}) : \Re_+^N \to \Re$ be the effort-evaluation function for grower i ($i = I, II$) under the organizational arrangement characterized by independent production.[7] The function $g^i(\mathbf{x})$ gives grower $i's$ ($i = I, II$) evaluation over a particular input bundle $\mathbf{x} \in \Re_+^N$ chosen by him. It is assumed that $g^i(\mathbf{x})$ is nondecreasing, continuous, and convex for all $\mathbf{x}$ (Chambers and Quiggin, 2000). Let $C^i(z_1, z_2)$ represent grower $i's$ variable cost function that reflects the (ex ante) minimum cost of producing a given state contingent $(z_1, z_2) \in \Re_+^2$ given $\mathbf{h}$. It reflects the grower's cost minimizing choices of $\mathbf{x}$, and is defined as:

$$C^i(z_1, z_2) = \min_{\mathbf{x}} \ \{g^i(\mathbf{x}) : \mathbf{x} \in X(z_1, z_2, \mathbf{h})\},$$

[6] Note that CRA preferences are consistent with the expected utility model only under risk neutrality.

[7] Note that the effort evaluation function under independent production namely, $g^i(\mathbf{x})$ reflects a cost structure that is different from the one that is outlined in the second half of the model that characterizes contract production. The rationale for this is that the organizational structures are "givens" in this model and not endogenously determined so that cost structures may differ depending on the pattern of production that producers engage in. The case where the cost structures coincide is a special case within this more general set-up that allows for different cost structures.

if there is an input vector $\mathbf{x} \in \Re_+^N$ that can produce a given $\mathbf{z}$ and ∞ otherwise. In particular, I assume a linear cost function that is characterized by constant returns to scale so that:

$$\begin{aligned} C^I(z_1^I, z_2^I) &= c_1 z_1^I + c_2 z_2^I \text{ for grower I, and} \\ C^{II}(z_1^{II}, z_2^{II}) &= d_1 z_1^{II} + d_2 z_2^{II} \text{ for grower II.} \end{aligned}$$

It is assumed that firm I is the more cost effective firm and has a distinct cost advantage so that $c_1 < d_1$, and $c_2 < d_2$.

The model below examines strategic interaction between two players - (1) Firm I represented either by an individual grower producing independently or a contracting company, and (2) Firm II who is an individual grower producing independently. The players make their output decisions simultaneously and independently in a state-contingent Cournot framework. In each state, each firm maximizes expected returns and chooses its optimal output based on its conjecture of what the other player does.[8] This then determines a reaction curve for each firm, and the reaction curves for the two firms simultaneously determine the mutual best response in state-contingent outputs that constitute the Nash equlibrium. The state-contingent market price is then determined by the inverse demand function, assuming that demand equals the total quantity produced by the two firms.

Grower II's optimization problem, given the state-contingent output choices

[8] In particular, each firm acts as the monopolist over its residual demand.

of grower I, can be stated as:[9]

$$\max_{z_1^{II},z_2^{II}} \pi_1 u(P(z_1^I + z_1^{II})z_1^{II}) + \pi_2 u(P(z_2^I + z_2^{II})z_2^{II}) - C^{II}(z_1^{II}, z_2^{II}).$$

Substituting the linear demand function gives:

$$\max_{z_1^{II},z_2^{II}} \pi_1 u((1 - z_1^I - z_1^{II})z_1^{II}) + \pi_2 u((1 - z_2^I - z_2^{II})z_2^{II}) - C^{II}(z_1^{II}, z_2^{II}).$$

Assuming an interior solution, the first order conditions are given as follows:

$$\begin{aligned} z_1^{II} &: \quad \pi_1 u'(r_1^{II})(1 - z_1^I - 2z_1^{II}) - C^{II}_{z_1^{II}}(z_1^{II}, z_2^{II}) = 0 \\ z_2^{II} &: \quad \pi_2 u'(r_2^{II})(1 - z_2^I - 2z_2^{II}) - C^{II}_{z_2^{II}}(z_1^{II}, z_2^{II}) = 0. \end{aligned}$$

In order to be able to get a specific expression for the reservation utility so as to facilitate analysis in the second half of the model, I assume CRA preferences for grower II and a linear cost function. With CRA preferences and a linear cost function, grower II's optimization problem can be written as follows:

$$\max_{z_1^{II},z_2^{II}} \pi_1(1 - z_1^I - z_1^{II})z_1^{II} + \pi_2(1 - z_2^I - z_2^{II})z_2^{II} - \kappa\sqrt{\pi_1\pi_2}[(1 - z_1^I - z_1^{II})z_1^{II} -$$
$$-(1 - z_2^I - z_2^{II})z_2^{II}] - d_1 z_1^{II} - d_2 z_2^{II}.$$

Assuming an interior solution, the first order conditions are:

$$\begin{aligned} z_1^{II} &: \quad (\pi_1 - \kappa\sqrt{\pi_1\pi_2})(1 - z_1^I - 2z_1^{II}) - d_1 = 0 \\ z_2^{II} &: \quad (\pi_2 + \kappa\sqrt{\pi_1\pi_2})(1 - z_2^I - 2z_2^{II}) - d_2 = 0. \end{aligned}$$

[9]It is assumed that for both growers, the joint evaluation over the input vector $\mathbf{x}$, and over the receipts $\mathbf{r}$ are separable.

The reaction functions for grower II corresponding to states 1 and 2, respectively, as derived from his first order conditions, are represented as:

$$1 - z_1^I - 2z_1^{II} = \frac{d_1}{\pi_1 - \kappa\sqrt{\pi_1\pi_2}} \tag{4.1}$$

$$1 - z_2^I - 2z_2^{II} = \frac{d_2}{\pi_2 + \kappa\sqrt{\pi_1\pi_2}} \tag{4.2}$$

Now, looking at grower I's maximization problem (with a linear cost function in order to facilitate analysis), we get:

$$\max_{z_1^I, z_2^I} \pi_1(1 - z_1^I - z_1^{II})z_1^I + \pi_2(1 - z_2^I - z_2^{II})z_2^I - c_1 z_1^{II} - c_2 z_2^{II}.$$

The corresponding state-contingent reaction functions for grower I in states 1 and 2, respectively, are obtained from:

$$1 - 2z_1^I - z_1^{II} = \frac{c_1}{\pi_1} \tag{4.3}$$

$$1 - 2z_2^I - z_2^{II} = \frac{c_2}{\pi_1} \tag{4.4}$$

Solving (4.1) and (4.3) simultaneously for the optimal state-contingent outputs corresponding to state 1 gives:

$$z_1^{I*} = \frac{1}{3} - \frac{2c_1}{3\pi_1} + \frac{d_1}{3(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}, \tag{4.5}$$

$$z_1^{II*} = \frac{1}{3} + \frac{c_1}{3\pi_1} - \frac{2d_1}{3(\pi_1 - \kappa\sqrt{\pi_1\pi_2})} \tag{4.6}$$

As can be seen from the results above, grower $II's$ optimal state-contingent output is decreasing in its own marginal cost in state 1, and increasing in grower $I's$ marginal cost c_1.The same kind of argument holds for grower I but we are concerned here with grower II and his returns in each state, as his expected returns from this game are assumed to determine his reservation utility under contract.

Similarly, by solving (4.2) and (4.4) simultaneously, we get the optimal production levels corresponding to state 2 for growers I and II, respectively:

$$z_2^{I*} = \frac{1}{3} - \frac{2c_2}{3\pi_2} + \frac{d_2}{3(\pi_2 + \kappa\sqrt{\pi_1\pi_2})} \tag{4.7}$$

$$z_2^{II*} = \frac{1}{3} + \frac{c_2}{3\pi_2} - \frac{2d_2}{3(\pi_2 + \kappa\sqrt{\pi_1\pi_2})} \tag{4.8}$$

Substituting the results obtained in (4.5) - (4.8) into the expression for grower $II's$ expected payoff gives:

$$\pi_1(1 - z_1^{I*} - z_1^{II*})z_1^{II*} + \pi_2(1 - z_2^{I*} - z_2^{II*})z_2^{II*} - \kappa\sqrt{\pi_1\pi_2}[(1 - z_1^{I*} - z_1^{II*})z_1^{II*} -$$
$$-(1 - z_2^{I*} - z_2^{II*})z_2^{II*}] - d_1 z_1^{II*} - d_2 z_2^{II*}$$

The expression above is the expected reservation utility of grower II if he decides to produce under contract for grower I and is represented as[10]:

$$\begin{aligned} E_2(c_1, c_2) &= (\pi_1 - \kappa\sqrt{\pi_1\pi_2})[\frac{1}{3} + \frac{c_1}{3\pi_1} - \frac{2d_1}{3(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}]^2 + \\ &\quad +(\pi_2 + \kappa\sqrt{\pi_1\pi_2})[\frac{1}{3} + \frac{c_2}{3\pi_2} - \frac{2d_2}{3(\pi_2 + \kappa\sqrt{\pi_1\pi_2})}]^2 \end{aligned} \tag{4.9}$$

Taking the derivative of $E_2(c_1, c_2)$ in (4.9) with respect to c_1, I get:

$$\frac{2}{3\pi_1}(\pi_1 - \kappa\sqrt{\pi_1\pi_2})z_1^{II*} > 0 \quad \text{if } (\pi_1 - \kappa\sqrt{\pi_1\pi_2}) > 0$$

Similarly, the derivative of $E_2(c_1, c_2)$ with respect to c_2 is:

$$\frac{2}{3\pi_2}(\pi_2 + \kappa\sqrt{\pi_1\pi_2})z_2^{II*} > 0$$

[10] Note that grower I's expected profits E_1equal:

$$E_1 = \pi_1[\frac{1}{3} - \frac{2c_1}{3\pi_1} + \frac{d_1}{3(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}]^2 + \pi_2[\frac{1}{3} - \frac{2c_2}{3\pi_2} + \frac{d_2}{3(\pi_2 + \kappa\sqrt{\pi_1\pi_2})}]^2 \tag{4.10}$$

This then leads us to the following proposition:

Proposition 4.1

A reduction in grower I's marginal cost in state 1 and/or state 2 causes a decline in grower II's expected payoff and therefore his expected reservation utility.

The expressions for the state-contingent prices established in equilibrium are:

$$P^*(Z_1) = \frac{1}{3} + \frac{c_1}{3\pi_1} + \frac{d_1}{3(\pi_1 - \kappa\sqrt{\pi_1\pi_2})} \text{ in state 1, and}$$

$$P^*(Z_2) = \frac{1}{3} + \frac{c_2}{3\pi_2} + \frac{d_2}{3(\pi_2 + \kappa\sqrt{\pi_1\pi_2})} \text{ in state 2.}$$

That is, the equilibrium market price is nondecreasing in the growers' state-contingent marginal costs. The situation illustrated here is different from that described in the context of the traditional landlord who takes the market price as given with a fall in market price causing him to decrease his exploitative activities and leading to a rise in the peasant's reservation utility. In particular, for the case in question, a fall in price (now endogenously determined) through, say, a reduction in grower I's marginal costs c_1 and/or c_2 results in a fall in reservation utility. However, note that the market price that drives the result here is the ex post price that results from the strategic interaction between the two economic players while they are producing independently. This price need not be the same as the price that results from contract production with the larger firm as the residual claimant. Overall, this analysis shows that a landlord can bring about a reduction in the expected reservation utility of the agent through a fall in the market price achieved by focusing attention on cost reducing investments. That is, the same outcome - a fall in the expected reservation utility - may result even when one is not engaging in unproductive exploitative activities.

Corollary 4.1

A reduction in the equilibrium outside-of-the-contract market price on account of a reduction in grower I's marginal cost in either state or both states leads to a decline in grower II's expected payoff and therefore his expected reservation utility.

4.3.3 Contract Production with Endogenous Reservation Utility

Once grower II decides to produce for grower I under contract, the relationship between the two growers changes from one involving strategic interaction in a Cournot duopoly to one where grower I is the principal and grower II becomes the agent, as is the case in a principal-agent problem. With the main competitor having become the agent, Grower I now acts as a monopolist in the market for pork or chicken. Note that while the players acting in an independent capacity compete noncooperatively outside of the contract situation, the game under contract is such that the agent (grower II) now makes his decisions in light of the decisions made by the principal or the provisions outlined under the formal contract. Thus, the nature of the game switches from a non-cooperative game to a leader-follower game with grower I being the leader and grower II the follower. As a matter of fact, grower I can also be viewed as being equivalent to the contracting/integrator company that has been the main focus of attention with respect to marketing and production contracts in the thesis.

The game is assumed to span two periods. That is, inputs committed today (time t) produce state-contingent output z_s^{t+1} in the next period corresponding to state s. For the ensuing analysis, the time superscripts associated with z_s^{t+1}

will not be written explicitly unless it is necessary to do so. Following from Assumption 3.1 in Chapter 3, both the principal and the agent are assumed to have the same subjective discount factor η.

Pattern of Input Provision under Contract

As is true for Chapter 3, I allow for input provision by the principal in the model as this is an essential feature of the contracts in question. To allow for the possibility of different patterns of input provision, the vector of inputs $\mathbf{x} \in \Re_{+}^{N}$ is decomposed into two components - the inputs provided by the grower-agent, and the inputs provided by the integrator-principal. Let $\mathbf{x}^{G} \in \Re_{+}^{N}$ and $\mathbf{x}^{I} \in \Re_{+}^{N}$ denote the input bundles provided by the grower and the integrator, respectively, with $\mathbf{x}^{G} + \mathbf{x}^{I} = \mathbf{x}$. Following from Definition 3.2, the contract is a marketing contract if it is characterized by $\mathbf{x}^{I} = 0$, and a production contract if $\mathbf{x}^{I} \geq 0; \mathbf{x}^{I} \neq 0$.

The vector of inputs provided by the integrator-principal is further decomposed into two components, $\mathbf{x}^{c}$ and $\mathbf{x}^{Nc}$, where:

$\mathbf{x}^{c}$: represents the vector of inputs that the principal contracts upon with the agent (e.g. feed quantity), with contractibility depending on the input being observable and verifiable, and

$\mathbf{x}^{Nc}$: represents the vector of noncontractible inputs provided by the principal (e.g. feed quality, genetics).

Thus, $\mathbf{x}^{I} = \begin{bmatrix} \mathbf{x}^{Nc} \\ \mathbf{x}^{c} \end{bmatrix}$ with $\mathbf{x}^{Nc} \in \Re_{+}^{J}$ and $\mathbf{x}^{c} \in \Re_{+}^{K}$; $J + K = N$. In terms of this decomposition, a PC is characterized as one where $\mathbf{x}^{Nc} \geq 0, \mathbf{x}^{Nc} \neq 0, \mathbf{x}^{c} \geq 0, \mathbf{x}^{c} \neq 0$ while an MC is defined as one where $\mathbf{x}^{Nc} = 0$, $\mathbf{x}^{c} = 0$.

Preference and Return Structure of the Principal

From the point of view of the principal, the observables in this problem are the inputs provided by him (x^I), if any, and the output z. While x^I and z constitute the observables, the state of nature and the agent's decisions with respect to the self provided inputs cannot be observed. Thus, it is only the agent who can observe the conditions under which production takes place once (and if) the inputs are delivered to him by the principal. It is assumed that the agent is a rational cost minimizer and that the principal has no direct preferences over the agent's decision variables in x^G. That is, what the principal cares about are the cost minimizing choices of x^I and his return from z.

The principal is assumed to be risk neutral and maximizes his expected return. The production structure that he wants to implement is $(\mathbf{z}, \mathbf{x}^c)$,that is, $(z_s, \mathbf{x}^c)$ in a particular state s. Let $g^I(\mathbf{x}^{Nc}) : \Re^J_+ \rightarrow \Re$ be the effort-evaluation function for the principal that gives his evaluation over a particular input bundle $\mathbf{x}^{Nc} \in \Re^J_+$ directly chosen by him. It is assumed that $g^I(\mathbf{x}^{Nc})$ is nondecreasing, continuous, and convex for all $\mathbf{x}^{Nc}$ (Chambers and Quiggin, 2000). The market price is given by the inverse demand function $P(z_s)$ for state s, assumed to be linear and given by $P(z_s) = 1 - z_s$, $s = 1, 2.$, and the per unit cost to the principal associated with the input vector $\mathbf{x}^c$ is reflected by the vector $\mathbf{v} \in \Re^K_{++}$. Thus, the principal's gross return from z and $\mathbf{x}^I$ in state s (gross of payments made to the agent) is given by $P(z_s)z_s - \sum\limits_k v_k x^c_k - g^I(\mathbf{x}^{Nc}),\ s = 1, 2;\ k = 1, 2, ...K.$

Preference and Return Structure of the Agent

The ex post payments made by the principal to the agent (grower II) under contract are represented by r^{II}_1 and r^{II}_2 for states 1 and 2, respectively. To simplify the notation, I use r_1 and r_2 to represent the agent's state-contingent receipts as in Chapter 3. Thus, r_s represents the agent's gross return when $(z_s, \mathbf{x}^c)$ is realized. It is assumed that the agent's joint evaluation over self provided inputs and contract payment received in period $t+1$ is given by:

$$\eta W(\mathbf{r}) - g^G(\mathbf{x}^G; \mathbf{x}^I),$$

where η is the agent's subjective discount factor that captures impatience, and $W(\mathbf{r})$ represents the preference function over $\mathbf{r}$. The agent's preference structure, is constant risk averse of the form:

$$\begin{aligned} & \bar{r} - \kappa\sigma[\mathbf{r}] \\ = \quad & \pi_1 r_1 + \pi_2 r_2 - \kappa\sqrt{\pi_1\pi_2}[r_1 - r_2], \end{aligned}$$

Moreover, under contract production, and after allowing for the possibility of input provision, the agent's effort evaluation function is given by $g^{II}(\mathbf{x}) = g^G(\mathbf{x}^G; \mathbf{x}^I) : \Re_+^N \to \Re$. Further, $g^G(\mathbf{x}^G; \mathbf{x}^I) : \Re_+^N \to \Re$ is the effort-evaluation function that gives the grower's evaluation over a particular input bundle, $\mathbf{x}^G \in \Re_+^N$, given $\mathbf{x}^I$. From this, I obtain the grower's variable cost function under contract production $C(\mathbf{x}^I, z_1, z_{2,}\mathbf{h})$ that reflects the (ex ante) minimum cost of producing a given state contingent $(z_1, z_2) \in \Re_+^2$ given h and x^I. It reflects the grower's cost minimizing choices of $\mathbf{x}^G$ given $\mathbf{x}^I$ and $\mathbf{h}$, and is defined as:

$$C(\mathbf{x}^I, z_1, z_{2,}\mathbf{h}) = \min_{\mathbf{x}^G}\{g^G(\mathbf{x}^G; \mathbf{x}^I) : \mathbf{x} \in X(\mathbf{z}, \mathbf{h})\},$$

if there is an input vector $\mathbf{x} \in \Re_+^N$ that can produce a given $\mathbf{z}$ and ∞ otherwise. It is assumed that the production technology is such that it guarantees the existence of a cost function that is twice continuously differentiable, strictly increasing and strictly convex in state-contingent outputs (Chambers, 2002). To facilitate the analysis, I make the following assumption:

Assumption 4.2

Suppose that $C(\mathbf{x}^I, z_1, z_2, \mathbf{h})$ is positively linearly homogeneous in the state-contingent outputs.

Game Structure and Timing

The timing of the game is as follows:

The timeline of the game shown in Figure 4.1 indicates that as an independent producer, grower I makes investments (included in the vector $\mathbf{h}$) that affect:

(a) its state-contingent marginal costs c_1 and c_2 as an independent producer,

(b) its costs under contract (specified as a function of c_1 and c_2, and incorporated formally in the model below). In particular, let the function $f(c_1, c_2)$ represent the benefits from grower I's investments that are carried over into contract production through the parameters c_1 and c_2, in the form of, say, economies of scale. The function $f(.)$ is assumed to be decreasing and concave in the state-contingent marginal costs, and

(c) grower II's reservation utility that is also a function of c_1 and c_2, as reflected in equation 4.9. That is:

$$\begin{aligned} E_2(c_1, c_2) &= (\pi_1 - \kappa\sqrt{\pi_1\pi_2})[\frac{1}{3} + \frac{c_1}{3\pi_1} - \frac{2d_1}{3(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}]^2 + \\ &\quad +(\pi_2 + \kappa\sqrt{\pi_1\pi_2})[\frac{1}{3} + \frac{c_2}{3\pi_2} - \frac{2d_2}{3(\pi_2 + \kappa\sqrt{\pi_1\pi_2})}]^2 \end{aligned}$$

In both (b) and (c), the impact of the investments is indirect and is channeled through (a). This is because investments affect c_1 and c_2 which, in turn, impact both costs under contract and the agent's reservation utility. Thus, the technology allows for a direct mapping from a fixed long-term investment onto the variables c_1 and c_2, and investments are made accordingly. For instance, hog

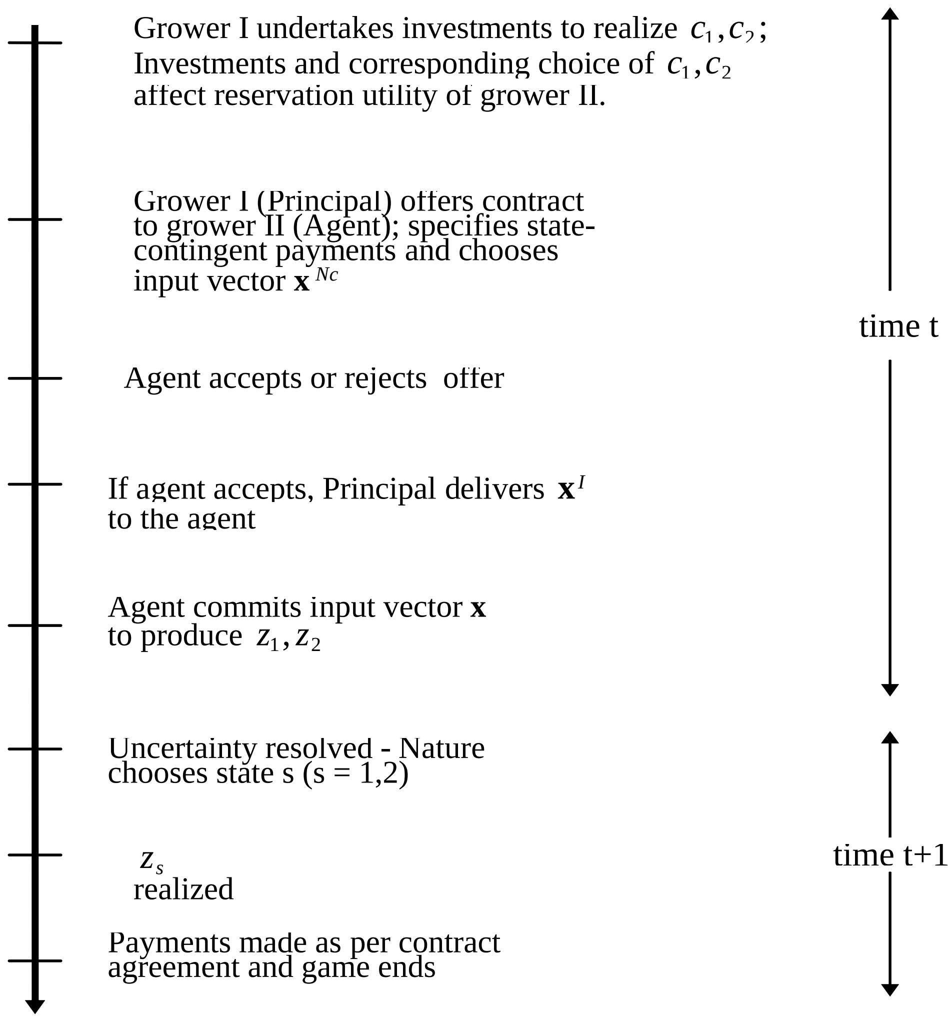


Figure 4.1: Timing of the Game

or bird growing time, and therefore variable costs (whether production is undertaken independently or under contract), have reduced considerably on account of considerable research and develoment undertaken by an integrator company

Once the investments are in place, grower I, in his capacity as the principal, offers grower II - the agent, operating independently prior to contracting - a take-it-or-leave-it contract that specifies the state-contingent payments and the principal's decisions (implemented once the contract is accepted) with respect to the noncontractible inputs $\mathbf{x}^{Nc}$. It is assumed (as in Chapter 3) that the agent has full information about the principal's decision of $\mathbf{x}^{Nc}$ and that there is no hidden action problem with respect to $\mathbf{x}^{Nc}$. Contracts, in practice, do not clearly specify what the exact choices of the noncontractible inputs will be. However, such information may be gleaned through repeated contracting or from other agents who have earlier contracted with the same company or, as revealed by some broiler growers, from the company itself. In any case, this is information in a broad sense - for instance, it is possible for the agent to obtain information about the animal breed but not each and every detail relating to the genetic composition, or it's possible to know the different grades of feed but not details about each and every nutrient.

Based on the offered state-contingent payments and the principal's choice of the noncontractibles, the agent accepts or rejects the contract. If the agent accepts the offer, the principal delivers the contractible and the noncontractible inputs.[11] Once the inputs are delivered by the principal, the agent commits the

[11]The inputs are actually delivered after a lag of a few months during which actual arrangements are made for input provision. For the purpose of modeling, this act is clubbed with other activities in time period t. It is also assumed that choices of noncontractible inputs are made as per the investment decisions made in the beginning of the game, and that the lag of a few

input vector $\mathbf{x} = \mathbf{x}^G + \mathbf{x}^I$ to produce (z_1, z_2). At time $t+1$, Nature makes a draw from one of the two states that, along with $\mathbf{x}$, determines a vector of state-contingent outputs, z_s, corresponding to the state s that Nature chooses. The principal is the residual claimant or the legal owner of the product produced by the agent.

4.4 Analysis of the Agency Problem

The second-best agency problem can be stated in terms of the following maximization problem for the principal:

$$\left\{ \begin{array}{ll} \underset{\mathbf{r},\mathbf{z},\mathbf{x}^I,c_1,c_2}{max} \quad \eta[\pi_1(P(z_1)z_1 - r_1) + \pi_2(P(z_2)z_2 - r_2)] - \sum_k v_k x_k^c - g^I(\mathbf{x}^{Nc}) + Af(c_1, c_2) & \\ \qquad\qquad\qquad\qquad\qquad \textit{subject to}: & \\ \eta[\pi_1 r_1 + \pi_2 r_2] - k\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^I, z_1, z_2, \mathbf{h}) \geq E_2(c_1, c_2) & (IR) \\ z_1, z_2, \mathbf{x}^c \in \arg\max\{\eta[\pi_1 r_1 + \pi_2 r_2] - k\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^I, z_1, z_2, \mathbf{h})\} & (IC) \end{array} \right\}$$

[A]

where $E_2(c_1, c_2)$ is the expected reservation utility obtained from (4.9), and $P(z_1) = 1 - z_1$, and $P(z_2) = 1 - z_2$ with grower I acting as the monopolist and total output being determined by what is produced under contract. The function $f(c_1, c_2)$ represents the benefits from grower I's investments that are carried over into contract production through the parameters c_1 and c_2, in the form of, say, economies of scale. Once these benefits of investments are accounted for, the cost structure represented by $\sum_k v_k x_k^c + g^I(\mathbf{x}^{Nc})$ gets scaled down by $Af(c_1, c_2)$, with $A > 0$. That is, the parameter A represents a benefit scale factor that scales up benefits of contracting indicated by $f(c_1, c_2)$ by a strictly positive amount.

The IR constraint, as before, states that the agent must receive at least

months does not affect the commitments made in the beginning.

his expected reservation utility in order for him to accept the contract. The constraints as outlined by (IC) are the incentive constraints, and ensure that the agent finds it privately rational to choose the state-contingent output vector and contractible input levels that the principal would like to implement. In what follows, an alternative but equivalent specification to the agency problem is employed as nonlinear programming methods can then be used to facilitate the desired comparative statics associated with the main issue being addressed (see Chambers and Quiggin, 2000). This alternative representation of the agency problem requires the principal to pay to the agent an amount r_1 if z_1 is realized, r_2 if z_2 is realized, and if any output other than z_1 or z_2 is reported by the agent, an arbitrarily large fine is imposed on him.

In the alternative specification, the principal's maximization problem is formally stated as:

$$\max_{\mathbf{r},\mathbf{z},\mathbf{x}^I,c_1,c_2} \eta[\pi_1(P(z_1)z_1-r_1)+\pi_2(P(z_2)z_2-r_2)]-\sum_k \upsilon_k x_k^c - g^I(\mathbf{x}^{Nc})+Af(c_1,c_2)$$

subject to:

$$\eta[\pi_1 r_1+\pi_2 r_2]-\kappa\eta\sqrt{\pi_1\pi_2}[r_1-r_2]-C(\mathbf{x}^I,z_1,z_2,\mathbf{h})\geq E_2(c_1,c_2) \qquad (IR)$$

$$\eta[\pi_1 r_1+\pi_2 r_2]-\kappa\eta\sqrt{\pi_1\pi_2}[r_1-r_2]-C(\mathbf{x}^I,z_1,z_2,\mathbf{h})\geq \eta r_1-C(\mathbf{x}^I,z_1,z_1,\mathbf{h}) \qquad (IC_1)$$

$$\eta[\pi_1 r_1+\pi_2 r_2]-\kappa\eta\sqrt{\pi_1\pi_2}[r_1-r_2]-C(\mathbf{x}^I,z_1,z_2,\mathbf{h})\geq \eta r_2-C(\mathbf{x}^I,z_2,z_2,\mathbf{h}) \qquad (IC_2)$$

$$\begin{aligned}\eta[\pi_1 r_1+\pi_2 r_2]-\kappa\eta\sqrt{\pi_1\pi_2}[r_1-r_2]-C(\mathbf{x}^I,z_1,z_2,\mathbf{h}) \quad \geq \quad & \eta[\pi_1 r_2+\pi_2 r_1]-\kappa\eta\sqrt{\pi_1\pi_2}[r_2-r_1] \\ & -C(\mathbf{x}^I,z_2,z_1,\mathbf{h}) \quad (IC_3)\end{aligned}$$

where (IR) represents the agent's individual rationality constraint or his participation constraint. The incentive compatibility constraints that make it incentive compatible to choose the state-contingent output vector as desired by the principal are given by $(IC_1) - (IC_3)$.

To see that this specification leads to the same solution as the one given in [A], suppose the solution to the second best problem in [A] is given by (z_1^*, z_2^*).Now, if the solution (z_1^*, z_2^*) is anything other than the vector (z_1, z_2) that the principal would like to implement as is true for the alternative specification, the agent would have to bear the arbitrarily large penalty. Assuming that the penalty approaches ∞, and that $u(-\infty) \to -\infty$, it will never be rational for the agent to choose anything but (z_1, z_2) that coincides with (z_1^*, z_2^*).

4.4.1 The Agency Problem and the Possibility of a Hold-up

A possiblity of a hold-up or an asset specificity problem for grower I may arise once his fixed investments are in place. Hold-ups or asset specificities arise in situations where an installed asset may become so specialized to suit the requirements of a particular party that it may have little or no value in an alternative use. An illustration, in this context, is a situation where grower I undertakes investments in animals and ensures their timely delivery to the agent. However, the agent may decide to hold up the principal by refusing to undertake production unless certain demands, say, a fee increase, are met. If the principal is not able to find other suitable agents that have made the necessary arrangements to undertake production as per his requirements, he then faces a hold-up problem.[12]

[12] Grower II, in the capacity of the agent, also faces a potential hold-up problem (See section 3.2.5). Theoretically, this situation may be reflected in the agent's optimization problem in the same manner as what is described for the principal below in Proposition 4.2.

As also proposed in Section 3.2.5, a hold-up situation may be factored into the problem by considering the hold-up case as the outcome of a particular state of nature. That is, there are four possibilities that arise in the framework of the given model. These are given by the cartesian product of the sets {state 1, state 2} as described by the model above, and {hold-up, no hold-up) - that is, (state 1, hold-up), (state 1, no hold-up), (state 2, hold-up), (state 2, no hold-up). The possibility of a hold-up is, therefore, a part of the uncertain portfolio that is associated with any production problem and this needs to be reflected in the optimization problem. Moreover, since a hold-up is related to fixed assets in which grower I invests, this aspect is tackled in terms of the benefit scale factor A. In particular, I define a hold-up situation as one that is associated with A (and therefore $Af(c_1, c_2)$) approaching $-\infty$. This then leads to a modification of the principal's optimization ptoblem where his expected payoff becomes $-\infty$ in the event of a hold-up. In this scenario, the principal can be assumed to take recourse to legal measures, or one can even allow for renegotiation, or else the principal can look for alternative outlets for undertaking contract production. In any case, the outcome is $-\infty$. And, if no hold-up occurs, the principal's expected return is determined by the solution to the program as outlined originally:

$$\left\{ \begin{array}{c} \underset{\mathbf{r},\mathbf{z},\mathbf{x}^I,c_1,c_2}{max} \{\eta[\pi_1(P(z_1)z_1 - r_1) + \pi_2(P(z_2)z_2 - r_2)] - \sum_k v_k x_k^c - g^I(\mathbf{x}^{Nc}) + Af(c_1, c_2)\} \\ subject\ to: \\ IR, IC_1 - IC_3 \end{array} \right\}$$

[B]

Proposition 4.2

The solution to the second-best agency problem is represented by: (a) the optimal value to the program [B], if no hold-up occurs, and (b) $-\infty$, if a hold-up *occurs.*

Now, let $C^I(\mathbf{z}, \mathbf{h})$ be the principal's cost function derived as:

$$C^I(z_1, z_{2,}\mathbf{h}) = \min_{\mathbf{x}^{Nc}} g^I(\mathbf{x}^{Nc})$$

subject to:

$$IR, IC_1 - IC_3,$$

where $C^I(z_1, z_{2,}\mathbf{h})$ is the principal's cost function that represents the principal's (ex ante) minimum cost of producing a given state contingent $\mathbf{z} \in \Re^S_+$ that also satisfies the (IR) and the (IC) constraints. After introducing the principal's cost function, the problem boils down to:

$$\underset{\mathbf{r},\mathbf{z},\mathbf{x}^c,c_1,c_2}{max} \{\eta[\pi_1(P(z_1)z_1 - r_1) + \pi_2(P(z_2)z_2 - r_2)] - \sum_k v_k x^c_k - C^I(z_1, z_{2,}\mathbf{h}) + Af(c_1, c_2)\}$$

subject to:

$$\eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \geq E_2(c_1, c_2) \qquad (IR^*)$$

$$\eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \geq \eta r_1 - C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) \qquad (IC^*_1)$$

$$\eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_2, \mathbf{h}) \geq \eta r_2 - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) \qquad (IC^*_2)$$

$$\begin{aligned} \eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \quad &\geq \quad \eta[\pi_1 r_2 + \pi_2 r_1] - \kappa\eta\sqrt{\pi_1\pi_2}[r_2 - r_1] \\ &\quad -C(\mathbf{x}^c, z_2, z_{1,}\mathbf{h}) \qquad (IC^*_3) \end{aligned}$$

In this standard, no hold-up case, the model is solved as a three-stage game where grower I first undertakes investments to choose and realize a cost structure defined by c_1 and c_2.[13] Grower I then, in the capacity of a principal offers a contract to grower II (the agent) and chooses the state-contingent payments r_1 and r_2, given c_1 and c_2, corresponding to outputs z_1 and z_2 that are to be produced by the agent. Finally, given r_1 and r_2 (and c_1 and c_2), the grower chooses inputs $\mathbf{x}^c$, and the state contingent output vector (z_1, z_2). In all stages, the optimal choices are made so as to maximize net returns of the party concerned.

The model is solved as follows: In the first stage, the principal chooses optimal r_1 and r_2, subject to the participation and incentive constraints, to minimize the present discounted value of the expected payment associated with implementing a given z_1, z_2, and $\mathbf{x}^c$. The second stage involves the optimal choices of z_1, z_2, and $\mathbf{x}^c$ that are to be implemented through the contract, given the solution from the first stage. The third and final stage uses the solutions from the first and the second stages to examine the principal's optimal choice of c_1 and c_2 (reflecting his fixed investments) which, in turn establishes the optimal level of the agent's reservation utility.

4.4.2 The First-Stage Problem and Agency Cost functions

In the first stage, the principal chooses r_1 and r_2 to minimize the dicounted expected payment made in time period $t+1$:

$$\{\eta(\pi_1 r_1 + \pi_2 r_2)\}$$

subject to

[13] The analysis in terms of a three stage game is similar to the Grossman and Hart (1983) formulation of the moral hazard problem as a two stage game.

$$\eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \geq E_2(c_1, c_2) \qquad (IR^*)$$

$$\eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \geq \eta r_1 - C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) \qquad (IC_1^*)$$

$$\eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_2, \mathbf{h}) \geq \eta r_2 - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) \qquad (IC_2^*)$$

$$\begin{aligned} \eta[\pi_1 r_1 + \pi_2 r_2] - \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2] - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \quad &\geq \quad \eta[\pi_1 r_2 + \pi_2 r_1] - \kappa\eta\sqrt{\pi_1\pi_2}[r_2 - r_1] \\ &\quad -C(\mathbf{x}^c, z_2, z_{1,}\mathbf{h}) \qquad (IC_3^*) \end{aligned}$$

As in Chapter 3, the (IR) constraint for the agent holds with an equality so that the contract, at the optimum, pays the agent exactly the value of his reservation utility. To see this, consider the IC constraints expressed as:

$$\eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})(r_2 - r_1) \geq C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) \qquad (IC_1')$$

$$\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})(r_1 - r_2) \geq C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) \qquad (IC_2')$$

$$\eta(\pi_1 - \pi_2 - 2\kappa\sqrt{\pi_1\pi_2})(r_1 - r_2) \geq C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_2, z_{1,}\mathbf{h}) \qquad (IC_3')$$

The constraints $(IC_1') - (IC_3')$ are illustrative of the fact that they are invariant to the principal reducing payments by an equal amount in both states. Thus, if the (IR) constraint does not bind, the principal can reduce payments in both states until it does bind, and increase his own expected return without affecting any of the (IC) constraints.

The solution to the first stage problem defines the second-best agency cost function $Y(z_1, z_2; \pi_2, c_1, c_2)$ that gives the principal's minimum cost of implementing a given state-contingent output vector (z_1, z_2) by the agent subject to the condition that the (IR^*) and the (IC^*) constraints be satisfied. Since the agent's participation constraint binds exactly, the information from this constraint can be used to define a lower bound to the principal's objective function. To see this, consider the binding (IR^*) constraint expressed as:

$$\eta[\pi_1 r_1 + \pi_2 r_2] = E_2(c_1, c_2) + C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) + \kappa\eta\sqrt{\pi_1\pi_2}[r_1 - r_2]$$

This, in turn, implies,

$$\eta[\pi_1 r_1 + \pi_2 r_2] \geq E_2(c_1, c_2) + C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h})$$

The above inequality then establishes $E_2(c_1, c_2) + C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h})$ as the lower bound to the principal's objective function.

In what follows, I show that among the (IC) constraints, (IC_1^*) and (IC_3^*) are satisfied by an (IC_2^*) that holds with an equality. To see this, suppose (IC_2^*) binds exactly. This then implies:

$$r_1 - r_2 = \frac{C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})}{\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})} \tag{4.11}$$

To see if (IC_1^*) is satisfied, consider the following inequality implied by (IC_1^*):

$$r_1 - r_2 \leq \frac{C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h})}{\eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})}$$

Substituting for $r_1 - r_2$ from (4.11) gives:

$$\frac{C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})}{\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})} \leq \frac{C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h})}{\eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})}$$

that is,

$$\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) + \eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \geq 0 \tag{4.12}$$

Thus, (IC_1^*) will be satisfied by a binding (IC_2^*) if the inequality in (4.12) is satisfied. This relationship indeed holds - Multiplying (IC_1^*) by $\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})$ and (IC_2^*) by $\eta(\pi_2+\kappa\sqrt{\pi_1\pi_2})$, and adding the terms, shows that (4.12) is implied by (IC_1^*) and (IC_2^*).

Now, multiplying (IC_1^*) by $\eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})$ and (IC_2^*) by $\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})$, and adding the terms, gives:

$$\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})r_1 + \eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})r_2 - C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) \geq \eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})r_1 +$$

$$\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})r_2 - \eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) - \eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})$$

Clearly, the left hand side of the above inequality is the same as those for any one of the (IC) constraints as it is generated as a linear combination of (IC_1^*) and (IC_2^*). Thus, if both (IC_1^*) and (IC_2^*) hold, (IC_3^*) should also be satisfied provided that:

$$\begin{aligned} & \eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})r_1 + \eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})r_2 - \eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) \\ & -\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) \\ \geq \; & \eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})r_1 + \eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})r_2 - C(\mathbf{x}^c, z_2, z_{1,}\mathbf{h}) \end{aligned}$$

That is, (IC_3^*) is satisfied if:

$$\eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) + \eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) \leq C(\mathbf{x}^c, z_2, z_{1,}\mathbf{h}) \tag{4.13}$$

Since $(\pi_2 + \kappa\sqrt{\pi_1\pi_2}) = 1 - (\pi_1 - \kappa\sqrt{\pi_1\pi_2})$, the left hand side of (4.13) is nothing but a convex combination of $C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h})$ and $C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})$. Also, convexity of the effort-cost function in $\mathbf{z}$ implies:

$$\eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_1, z_{1,}\mathbf{h}) + \eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) \leq$$

$$C(\mathbf{x}^c, \eta(\pi_2+\kappa\sqrt{\pi_1\pi_2})z_1+\eta(\pi_1-\kappa\sqrt{\pi_1\pi_2})z_2, \eta(\pi_2+\kappa\sqrt{\pi_1\pi_2})z_1+\eta(\pi_1-\kappa\sqrt{\pi_1\pi_2})z_2, \mathbf{h}) \tag{4.14}$$

Further, it follows from Assumption 4.2 where C is positively linearly homogeneous in state-contingent outputs that:

$$C(\mathbf{x}^c, \eta(\pi_2+\kappa\sqrt{\pi_1\pi_2})z_1+\eta(\pi_1-\kappa\sqrt{\pi_1\pi_2})z_2, \eta(\pi_2+\kappa\sqrt{\pi_1\pi_2})z_1+\eta(\pi_1-\kappa\sqrt{\pi_1\pi_2})z_2, \mathbf{h})$$
$$\leq C(\mathbf{x}^c, z_2, z_{1,}\mathbf{h}) \tag{4.15}$$

In words, (4.15) will hold if it is less costly to produce the same output $\eta(\pi_2 + \kappa\sqrt{\pi_1\pi_2})z_1 + \eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})z_2$ in each state than to report z_2 in state 1 and z_1 in state 2. Then, assuming that (4.15) holds, (4.14) and (4.15) together imply that (4.13) will also be satisfied.

Given that (IR^*) and (IC_2^*) bind exactly, the second-best agency cost function can now be obtained by solving (IR^*) and (IC_2^*) simultaneously for r_1 and r_2. In particular, the expressions for r_1 and r_2 are:

$$r_1 = E_2(c_1, c_2) + C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) + \frac{C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})}{\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}$$

and,

$$r_2 = E_2(c_1, c_2) + C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})$$

Thus, the expression for the second-best agency cost function is given by:

$$\begin{aligned} Y(z_1, z_2; \pi_2, c_1, c_2) \quad = \quad & \eta\{E_2(c_1, c_2) + C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) + \\ & + \frac{\pi_1}{\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}[C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})]\} \end{aligned} \tag{4.16}$$

Proposition 4.3

The second-best agency cost function $Y(z_1, z_2; \pi_2, c_1, c_2)$ is strictly increasing and linear in the expected reservation utility $E_2(c_1, c_2)$, with $Y_{E_2} = \eta$, so that the minimum cost of implementing a given state-contingent output vector increases with an increase in $E_2(c_1, c_2)$, by the discount factor η.

4.4.3 The Second-Stage Problem

The second stage of the principal's optimization problem is formulated as:

$$\begin{aligned} U(c_1, c_2, v, \pi) &= \underset{\mathbf{z},\mathbf{x}^c}{Max}\{\eta[\pi_1(P(z_1)z_1 + \pi_2(P(z_2)z_2] - \sum_k v_k x_k^c - C^I(z_1, z_{2,}\mathbf{h}) - \\ &\quad -Y(z_1, z_2; \pi_2, c_1, c_2)\} \end{aligned}$$

Substituting the expression for the second-best agency cost function from equation (4.16) into the objective function above gives:

$$\begin{aligned} &\underset{\mathbf{z},\mathbf{x}^c}{Max}\{\eta[\pi_1(P(z_1)z_1 + \pi_2(P(z_2)z_2] - \sum_k v_k x_k^c - C^I(z_1, z_{2,}\mathbf{h}) - \\ &-\eta\{E_2(c_1, c_2) + C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h}) + \frac{\pi_1}{\eta(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}[C(\mathbf{x}^c, z_1, z_{2,}\mathbf{h}) - C(\mathbf{x}^c, z_2, z_{2,}\mathbf{h})]\}\ \} \end{aligned}$$

The following proposition then follows from the envelope theorem:

Proposition 4.4

For a given $E_2(c_1, c_2)$, the optimal value of the second-stage agency problem $U(c_1, c_2, v, \pi)$ is strictly decreasing and linear in the expected reservation utility of the agent.

4.4.4 The Final-Stage Problem and the Equilibrium Determination of State-Contingent Marginal Costs

In the final stage of the contracting problem, the principal chooses the optimal levels of state-contingent marginal costs as an independent firm which, in turn, impact the expected reservation utility. The principal's optimization problem is stated as:

$$\underset{c_1,c_2}{Max}\{U(c_1, c_2, v, \pi) + Af(c_1, c_2)\}$$

where $U(c_1, c_2, v, \pi)$ is the optimal value of the second-stage objective function. Suppose, the optimal values in this stage of the optimization problem are given by $\mathbf{c}(A)$ defined as:

$$\mathbf{c}(A) \in \arg\max\{U(c_1, c_2, v, \pi) + Af(c_1, c_2)\}$$

Employing standard comparative static techniques yields:

$$[A^\circ - A][f(c_1(A^\circ), c_2(A^\circ)) - f(c_1(A), c_2(A))] \geq 0$$

That is, if $A^\circ \geq A$, then $f(c_1(A^\circ), c_2(A^\circ)) \geq f(c_1(A), c_2(A))$. In other words, as the benefit scale factor A increases, the principal will have a stronger incentive to undertake higher initial investments so as to realize a lower c in each state. This follows from the assumption that the function f is monotonically decreasing in $\mathbf{c}$.

Proposition 4.5

An increase in the benefit scale factor leads to a fall in the marginal cost in each state for the independently operating principal which, in turn, leads to a fall in the expected reservation utility for the agent.

The proposition above and proposition 4.3 can be used to infer the following, formally stated as a corollary:

Corollary 4.2

A reduction in the expected reservation utility $E_2(c_1, c_2)$ unambiguously works to the advantage of the principal, all other things remaining the same. It is, therefore, in his interest, to adopt measures that enable him to realize a fall in $E_2(c_1, c_2)$.

A natural fall-out of the principal's effort (in terms of his fixed investments) to reduce his variable costs as an independent operator is a decline in the agent's expected reservation utility. And, once an independent grower opts for contracting, the principal's optimal decisions of c_1 and c_2 then accrues to the principal as indirect benefits through (a) a fall in the principal's expected payment, and (b) a rise in the principal's optimal net expected returns. This result holds as long as the parameter A has no direct impact on the principal's expected payment and his net optimal expected returns. Formally, it follows from propositions 4.3, 4.4, and 4.5 that:

Corollary 4.3

(a) The expected payment to the agent is nonincreasing in the benefit scale factor A. Moreover, (b) the principal's optimal net expected returns $U(c_1, c_2, v, \pi)$ from the second-stage problem are nondecreasing in A.

4.5 Conclusion

This chapter examines the role of outside-of-contract dyadic interactions in the equilibrium determination of reservation utility. Prior to or outside contracting, the agent and the principal compete as independent producers, and investment decisions taken by the principal (as the larger, more competitive firm) to reduce its own costs adversely impact the smaller player's expected returns. This works to the advantage of the principal as it is the reduced returns of the smaller player that form the benchmark against which any contract will be designed in the event of the smaller player deciding to produce under contract for the larger player. Benefits of initial investments undertaken by the larger producer also get carried over into contracting in the form of economies of scale. The higher these benefits, the stronger is the incentive for the principal to decide in favor of higher initial investment levels in order to realize a more competitive position vis-a-vis the smaller producer.

Chapter 5

Conclusion

This dissertation examines input provision as the chief organizational characteristic of production contracts in contrast to no input provision in marketing contracts, in the context of corporate agriculture. “Input Provision” is modeled so as to reflect:

- the provision and delivery of key inputs by the principal,

- purchases of inputs by the principal (from the spot market or under contract), or in-house production, and

- contract design to ensure the optimal use of those inputs by the agent.

I examine input provision through a state-contingent principal-agent model in a production theoretic setting. This production-theoretic state-contingent approach has the advantage that it allows for a sufficiently general production technology and the modeling of multiple outputs (weight gain and leanness) and inputs.

The choice variables in question are the levels of inputs (e.g. feed, genetic lines, and medication) that the principal (e.g. the contracting company) provides and delivers to the agent (the grower). This decision is endogenous to the model, and facilitates comparison of production contracts (characterized by input provision) with marketing contracts (characterized by no input provision, with all inputs purchased and/or provided by the grower himself). The inputs that can be potentially provided by the principal are categorized into contractible and noncontractible inputs for the purpose of analysis, where “contractible” refers to an input being observable and verifiable. Input dimensions that are contractible include, for example, the number of pounds of feed used by the grower. These aspects are explicitly contracted upon and enter into the payment scheme for the grower. Inputs such as feed quality fall under the category of noncontractibles. These are inputs whose usage the principal cannot verify, and finds it very costly to contract upon. Therefore, these inputs do not figure in the payment scheme.

My theoretical model formalizes Coase’s idea that an institutional arrangement will materialize if the benefits associated with it exceed the costs. In particular, I characterize the case of no input provision as a corner solution for the optimal choice of inputs (contractible and noncontractible). That is, there is an incentive for the principal to provide inputs under a production contract if, at the boundary, where no inputs are provided, the marginal benefits of input provision exceed the marginal costs. And, the extent of input provision, as garnered from the interior solution optimal values obtained for a production contract, reflects "limits to firm size" as described by Coase. The analysis of limits to firm size, as reflected by the model structure of this chapter, reflects a comparison of costs in the Coasian sense - costs of carrying out an extra transaction within the firm with the costs of carrying it out in the open market (Coase, 1937). In particular, the analysis here boils down to equating marginal benefits to marginal costs in the neoclassical scheme of things while taking into account several dimensions of a specific problem in a production theoretic setting.

Moreover, the likelihood of input provision under a production contract increases with an increase in the principal's market premium per unit of the quality dimension of output, and with a decrease in the principal's costs of obtaining a particular contractible or noncontractible input, other things remaining the same.

I also make a preliminary attempt to model transaction costs within the framework of a general state-contingent theoretical model. Transaction costs in this thesis include both neoclassical production costs and costs associated with negotiating and administering an ongoing production relationship as is also true for the analysis by Joskow (1985). The cost minimization problems of the principal and/or the agent are, therefore, modeled so as to include not only the direct costs of purchasing inputs but also consideration of possible costs that arise in the process of carrying out transactions relating to the production process. To this end, the effort evaluation function that gives the evaluation over a particular input bundle chosen by the principal or the agent is assumed to be convex so that the evaluation over each input can vary linearly or non-linearly with the amount of input used. While the linear formulation entails the purchase of inputs that are in perfectly elastic supply and/ or where any additional costs incurred per unit are a constant, I argue that a general non-linear formulation allows one to capture a more realistic cost structure. Even though the world of transaction costs may be "complex" and difficult to identify for the outsider, such costs are, nevertheless, taken into account by the agent who is assumed to be a rational cost minimizer. I introduce and illustrate this idea through a series of examples outlined in Section 3.2.5.

Moreover, Chapter 3 explores the possibility of input provision in PCs leading to what is known as "interlinkage" in the development literature. Interlinkage refers to the practice of offering contracts that combine transactions over several dimensions (Basu, Bell and Bose, 2000). Thus, as applied to the case in question, it refers to the contracting company superseding individual markets and contracting over several aspects like feed, weight gain, and so on. In particular, interlinkage in this dissertation is seen to emerge as a means of dealing with an aversion to risk and/or uncertainty in production.

A special case in the context of interlinkage or the lack of it is one where incentives with respect to a particular contractible dimension are absent or low-powered - that is, there is absence of interlinking with a particular contractible input or output. In Chapter 3, technical conditions are derived under which, in a production contract, incentives relating to one of two output dimensions (leanness) tend to zero when both dimensions (weight gain and leanness) are observable and verifiable.[1][2] These conditions reflect the considerable control that the principal has over the output dimension for which no or weak incentives are provided – leanness programmed into the animals by the integrator when they are delivered in the beginning of the production cycle, and exhibiting little or no variability among different states of nature; other tasks in production being technically independent of leanness; and the principal choosing the optimal lean

[1] This is in contrast to the Holmstrom and Milgrom (1991) multi-task model where all tasks cannot be suitably measured. The authors attribute low-powered or no incentives with respect to a certain task to the fact that rewarding that task may cause the agent to substitute his attention away from other tasks. This is especially true for a situation where errors associated with the measurement of the other tasks are large so that the other tasks cannot be observed and verified easily.

[2] Incentives with respect to leanness are absent in PCs as against MCs where quality based incentives are important.

percentage in a perfectly competitive set-up. The essence of this result is that even though leanness itself is “turned out” or delivered by the agent when it is realized at the end of the production cycle, it can be viewed more as a "free" by-product for the agent that is effectively produced by the principal and results from the principal’s effort. This then does away with the need to provide incentives with respect to leanness in a production contract.The result here provides a rationale for missing incentives that has not been captured in the literature on contracts and organization.

The technical analysis in Chapter 4 titled “Economic Power and Endogenous Reservation Utility in Corporate Dyads” explores the possibility of reservation utility being endogenous in the framework of the model developed in Chapter 3. This chapter illustrates that irrespective of the pattern of input provision that emerges under contract, there is always a distinct possibility of reservation utility becoming endogenous on account of out-of-contract interactions. There are two points of deviation from the existing literature – first, where endogenous reservation utility emerges in a dyadic setting (unlike the existing literature that emphasizes triadic relationships), and second, where outside-of-contract, perfectly legitimate economic interactions (rather than extra-contract exploitative means within an existing contract set-up, as is true for the existing literature) influence reservation utility.

The specific kind of outside-of-contract interaction that is examined in this thesis involves the principal firm (firm I) and the agent firm (firm II) interacting prior to contracting as independent producers in a Cournot duopoly setting. It is in this Cournot duopoly setting, where both firms make their production decisions simultaneously and independently, that reservation utility is determined. The principal firm is assumed to be the larger, more competitive, and more cost effective party both under contract and prior to contracting.

Moreover, prior to contracting, firm I makes investment decisions once and for all, and these decisions benefit it both directly and indirectly: There are benefits that accrue to it directly through a reduction in production costs as an independent producer, and indirectly when the benefits are carried over into contract production. At the same time, however, such investments and the resulting fall in costs and market prices may make it difficult for the smaller player – firm II, to compete and therefore, result in reduced profitability for firm II in the pre-contract phase. One option available to the smaller player, in the face of reduced profitability, is to opt for contract production with firm I as the principal firm. In this event, however, it is the (induced) reduced returns of the smaller player that form the benchmark against which any contract will be designed and constitute an indirect benefit for the principal from his investments. In this chapter, therefore, I formalize both the direct and the indirect benefits of fixed investments undertaken by the principal. The main result of this chapter is that the higher the benefits associated with the initial investments, the stronger is the incentive for the principal to decide in favor of higher levels of such investments so as to realize a more competitive position with respect to the smaller producers. Moreover, a production contract arrangement between the two firms is likened to a "takeover" by the principal of the control and/ or management of the agent firm without there taking place a transfer of ownership.

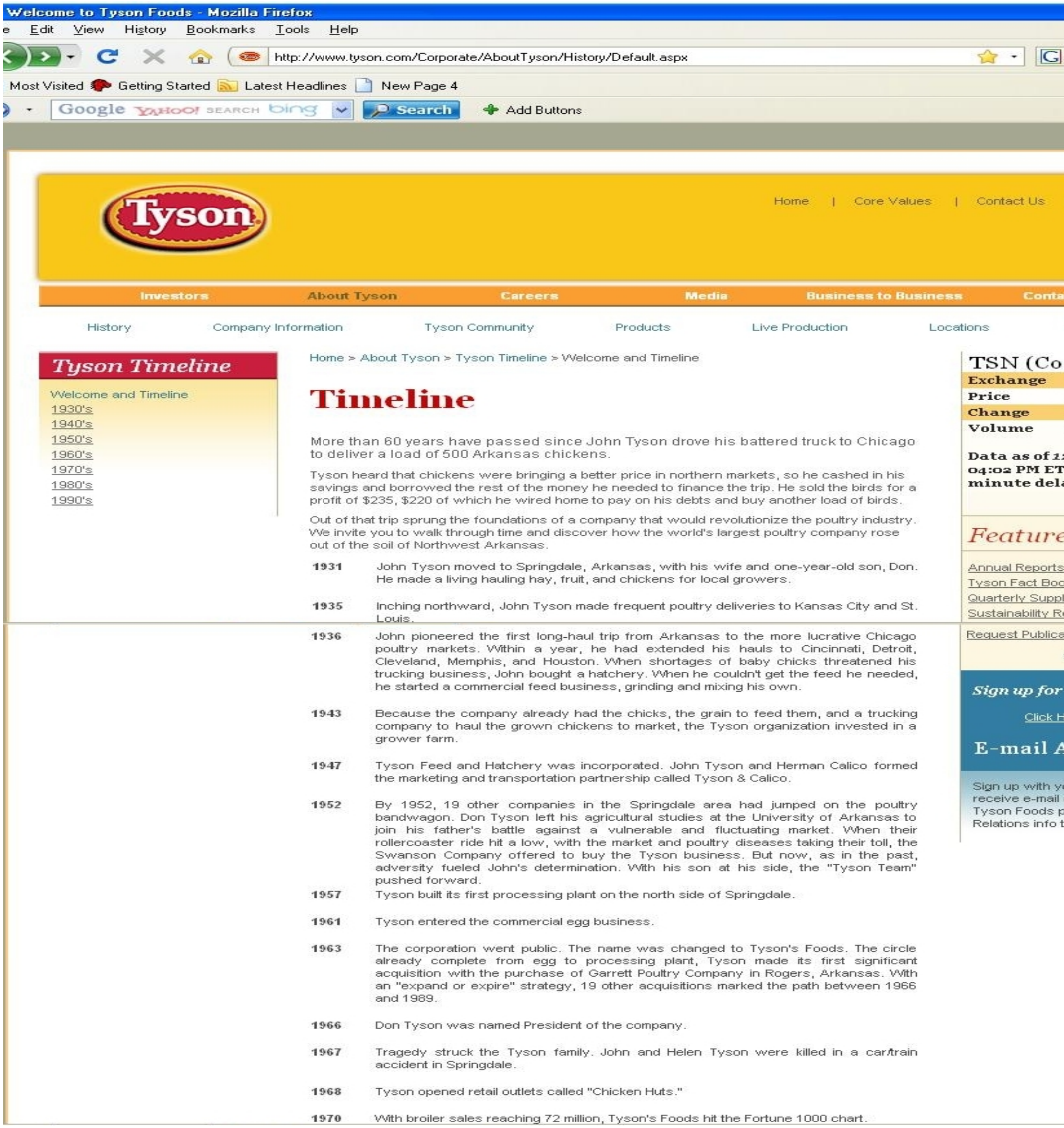
The scenario outlined in Chapter 4 is different from that described in the context of the traditional landlord who takes the market price as given with a rise in market price causing him to increase his exploitative activities which, in turn, lead to a fall in the peasant's reservation utility (Chambers and Quiggin, 2000). However, I show, in this chapter, that there are two ex post price schedules that need to be taken into account: 1) the market price that results from the interaction between economic players in the pre-contract phase, and 2) the market price that results when the smaller player decides to work under contract for the larger player. For the case in question, what is relevant is a fall in the pre-contract market price, also endogenously determined, on account of a fall in marginal cost of the larger, more competitive player. The corresponding fall in market price, in turn, leads to a fall in the smaller player's expected payoff and, therefore, reservation utility.

Finally, the possibility of a hold-up problem for the principal firm is also explored and the strategy of incorporating this problem into the economic model is discussed wherein a hold-up corresponds to the outcome of a particular state of nature. The possibility of a hold-up is part of the uncertain portfolio that is associated with any production problem, and the optimization problem has to be suitably modified to reflect this. In particular, the solution to the principal's optimization problem in the event of a hold-up is one where his expected payoff becomes $-\infty$, in which case he is assumed to take recourse to legal measures, or renegotiate, or else look for alternative outlets for undertaking contract production.

Appendix A

Webpage of Tyson Foods

Source (as of Dec 30, 2009): http://www.tyson.com/Corporate/AboutTyson/History/Default.asp


Welcome to Tyson Foods - Mozilla Firefox

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http://www.tyson.com/Corporate/AboutTyson/History/Default.aspx

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Tyson

Home | Core Values | Contact Us |

Investors About Tyson Careers Media Business to Business Contac

History Company Information Tyson Community Products Live Production Locations

Tyson Timeline

Welcome and Timeline
1930's
1940's
1950's
1960's
1970's
1980's
1990's

Home > About Tyson > Tyson Timeline > Welcome and Timeline

Timeline

More than 60 years have passed since John Tyson drove his battered truck to Chicago to deliver a load of 500 Arkansas chickens.

Tyson heard that chickens were bringing a better price in northern markets, so he cashed in his savings and borrowed the rest of the money he needed to finance the trip. He sold the birds for a profit of $235, $220 of which he wired home to pay on his debts and buy another load of birds.

Out of that trip sprung the foundations of a company that would revolutionize the poultry industry. We invite you to walk through time and discover how the world's largest poultry company rose out of the soil of Northwest Arkansas.

1931	John Tyson moved to Springdale, Arkansas, with his wife and one-year-old son, Don. He made a living hauling hay, fruit, and chickens for local growers.
1935	Inching northward, John Tyson made frequent poultry deliveries to Kansas City and St. Louis.
1936	John pioneered the first long-haul trip from Arkansas to the more lucrative Chicago poultry markets. Within a year, he had extended his hauls to Cincinnati, Detroit, Cleveland, Memphis, and Houston. When shortages of baby chicks threatened his trucking business, John bought a hatchery. When he couldn't get the feed he needed, he started a commercial feed business, grinding and mixing his own.
1943	Because the company already had the chicks, the grain to feed them, and a trucking company to haul the grown chickens to market, the Tyson organization invested in a grower farm.
1947	Tyson Feed and Hatchery was incorporated. John Tyson and Herman Calico formed the marketing and transportation partnership called Tyson & Calico.
1952	By 1952, 19 other companies in the Springdale area had jumped on the poultry bandwagon. Don Tyson left his agricultural studies at the University of Arkansas to join his father's battle against a vulnerable and fluctuating market. When their rollercoaster ride hit a low, with the market and poultry diseases taking their toll, the Swanson Company offered to buy the Tyson business. But now, as in the past, adversity fueled John's determination. With his son at his side, the "Tyson Team" pushed forward.
1957	Tyson built its first processing plant on the north side of Springdale.
1961	Tyson entered the commercial egg business.
1963	The corporation went public. The name was changed to Tyson's Foods. The circle already complete from egg to processing plant, Tyson made its first significant acquisition with the purchase of Garrett Poultry Company in Rogers, Arkansas. With an "expand or expire" strategy, 19 other acquisitions marked the path between 1966 and 1989.
1966	Don Tyson was named President of the company.
1967	Tragedy struck the Tyson family. John and Helen Tyson were killed in a car/train accident in Springdale.
1968	Tyson opened retail outlets called "Chicken Huts."
1970	With broiler sales reaching 72 million, Tyson's Foods hit the Fortune 1000 chart.

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Appendix B

Graphical Representation of Preferences (EU and CRA) in two-state space

Expected Utility:

$$W(r_1, r_2) = \pi_1 u(r_1) + \pi_2 u(r_2)$$

Along an iso-preference curve,

$$dw = \pi_1 u\prime(r_1) dr_1 + \pi_2 u\prime(r_2) dr_2 = 0$$

so that the slope of the iso-preference curve is given by:

$$\frac{dr_2}{dr_1} = -\frac{\pi_1 u\prime(r_1)}{\pi_2 u\prime(r_2)} < 0 \tag{B1}$$

as $u\prime(.) > 0$.

Further, examining the second derivative properties gives:

$$\frac{d^2 r_2}{dr_1^2} = -\frac{\pi_1}{\pi_2}\left[\frac{u\prime(r_2) u\prime\prime(r_1) - u\prime(r_1) u\prime(r_2)\frac{dr_2}{dr_1}}{(u\prime(r_2))^2}\right] > 0 \tag{B2}$$

as the utility function is strictly increasing and strictly concave and $\frac{dr_2}{dr_1} < 0$.

From (1) and (2), it follows that the iso-preference curves under the expected utility model are downward sloping and convex to the origin.

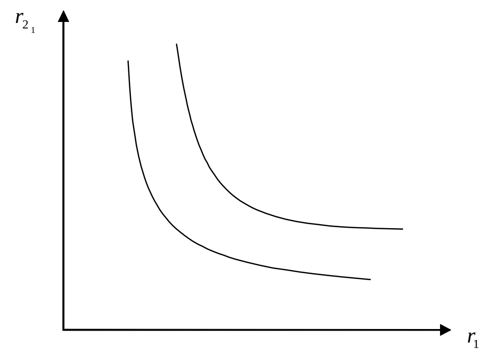

Figure B.1: Expected utility preferences

Constant Risk Aversion:

The CRA preference structure in the two-state case is given by:

$$W(\mathbf{r}) = \overline{r} - \kappa\sigma[\mathbf{r}],$$

where $\overline{r}$ is the mean income equal to $\pi_1 r_1 + \pi_2 r_2$, and σ is the standard deviation associated with $\mathbf{r}$. Note that:

$$\begin{aligned}
\sigma^2[\mathbf{r}] &= E(r - Er)^2 \\
&= \pi_1(r_1 - Er)^2 + \pi_2(r_2 - Er)^2 \\
&= \pi_1(r_1 - \pi_1 r_1 - \pi_2 r_2)^2 + \pi_2(r_2 - \pi_1 r_1 - \pi_2 r_2)^2 \\
&= \pi_1(\pi_2 r_1 - \pi_2 r_2)^2 + \pi_2(\pi_1 r_2 - \pi_1 r_1)^2 \\
&= \pi_1 \pi_2^2 (r_1 - r_2)^2 + \pi_1^2 \pi_2 (r_2 - r_1)^2 \\
&= \pi_1 \pi_2 (r_1 - r_2)^2 (\pi_2 + \pi_1) \\
&= \pi_1 \pi_2 (r_1 - r_2)^2 \quad \text{(since } \pi_2 + \pi_1 = 1)
\end{aligned}$$

The standard deviation associated with $\mathbf{r}$ is obtained by taking the positive square root of the expression above. Therefore,

$$\sigma[\mathbf{r}] = \sqrt{\pi_1\pi_2} \mid r_1 - r_2 \mid$$

which, in turn implies that:

$$W(\mathbf{r}) = \pi_1 r_1 + \pi_2 r_2 - \kappa\sqrt{\pi_1\pi_2} \mid r_1 - r_2 \mid$$

That is,

$$\begin{aligned} W(\mathbf{r}) &= (\pi_1 - \kappa\sqrt{\pi_1\pi_2})r_1 + (\pi_2 + \kappa\sqrt{\pi_1\pi_2})r_2 \ , \qquad r_1 \geq r_2 \qquad \text{(B3)} \\ &= (\pi_1 + \kappa\sqrt{\pi_1\pi_2})r_1 + (\pi_2 - \kappa\sqrt{\pi_1\pi_2})r_2 \ , \qquad r_1 < r_2 \end{aligned}$$

Thus, if $r_1 \geq r_2$, the slope of the iso-preference curve is given by:

$$\frac{dr_2}{dr_1} = -\frac{(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}{(\pi_2 + \kappa\sqrt{\pi_1\pi_2})} < 0, \qquad (\pi_1 - \kappa\sqrt{\pi_1\pi_2}) > 0 \qquad \text{(B4)}$$

and if $r_1 < r_2$, the corresponding slope is:

$$\frac{dr_2}{dr_1} = -\frac{(\pi_1 + \kappa\sqrt{\pi_1\pi_2})}{(\pi_2 - \kappa\sqrt{\pi_1\pi_2})} < 0, \qquad (\pi_2 - \kappa\sqrt{\pi_1\pi_2}) > 0 \qquad \text{(B5)}$$

That is, the iso-preference curves are straight lines on both sides of the bisector and since,

$$\frac{(\pi_1 - \kappa\sqrt{\pi_1\pi_2})}{(\pi_2 + \kappa\sqrt{\pi_1\pi_2})} < \frac{(\pi_1 + \kappa\sqrt{\pi_1\pi_2})}{(\pi_2 - \kappa\sqrt{\pi_1\pi_2})},$$

the straigh line segments on the right side of the bisector where $r_1 \geq r_2$ will be flatter than those in the $r_1 < r_2$ region. Graphically, CRA preferences can be represented as:

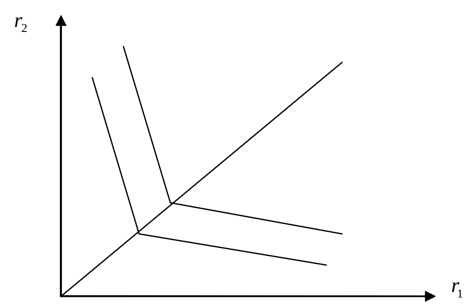

Figure B.2: CRA Preferences

Appendix C

Monotonicity of Payments in Observed Output

To examine monotonicity in payments, let $(z_1^*, z_2^*, ...z_S^*)$ represent the optimal pattern of state-contingent production with $z_S^* \geq z_{S-1}^* \geq .... \geq z_2^* \geq z_1^*$ and $z_s^* = (y_s, q_s)$, $s = 1, 2, ...S$. Then, optimality of $(z_1^*, z_2^*, ...z_S^*)$ over another output vector such as $(z_1^*, z_2^*, ., z_{l-1}^*, z_{l-1}^*, ...z_S^*)$ involving production of z_{l-1}^* in both states l and $l-1$ implies (For compactness, the arguments of $C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h})$ have been rearranged to express it as $C(\mathbf{x}^I, \mathbf{z}, \mathbf{h})$):

$$\eta\{\sum_s \pi_s u(r_s(z_s^*, \mathbf{x}^c))\} - C(\mathbf{x}^I, z_1^*, z_2^*, ...z_S^*, \mathbf{h})$$

$$\geq \eta\{\sum_{s \neq l} \pi_s u(r_s(z_s^*, \mathbf{x}^c)) + \pi_l u(r_{l-1}(z_{l-1}^*, \mathbf{x}^c))\} - C(\mathbf{x}^I, z_1^*, z_2^*, ., z_{l-1}^*, z_{l-1}^*, z_{l+1}^*, ...z_S^*, \mathbf{h})$$

The expression above boils down to the following:

$$\eta\pi_l[u(r_l(z_l^*, \mathbf{x}^c)) - u(r_{l-1}(z_{l-1}^*, \mathbf{x}^c))] \geq C(\mathbf{x}^I, z_1^*, z_2^*, ...z_S^*, \mathbf{h}) -$$

$$-C(\mathbf{x}^I, z_1^*, z_2^*, ., z_{l-1}^*, z_{l-1}^*, z_{l+1}^*, ...z_S^*, \mathbf{h}) > 0$$

the last inequality following from the assumption that costs are strictly increasing in state-contingent outputs. Therefore, we have:

$$\eta\pi_l[u(r_l(z_l^*, \mathbf{x}^c)) - u(r_{l-1}(z_{l-1}^*, \mathbf{x}^c))] > 0$$

If $\eta\pi_l > 0$, the assumption that the utility function is strictly increasing yields that:

$$r_l(z_l^*, \mathbf{x}^c)) > r_{l-1}(z_{l-1}^*, \mathbf{x}^c))$$

implying that payments are monotonic in observed output.

To examine the possibility of disincentives associated with excessive leanness, suppose that the agent's cost function is not everywhere increasing in state-contingent ouputs. In particular, let costs decrease if $q \geq \overline{q}$ given y, where $\overline{q}$ is some constant and $\overline{q} \in \Re_+$. I assume that weight gain y is the same irrespective of the state so as to focus only on the quality dimension of output, . Moreover, suppose $q_l^* \geq q_{l-1}^*$, $l \in S$ with $q_{l-1} < \overline{q} < q_l$.

Then, optimality of $(q_1^*, q_2^*, ...q_S^*)$ over another output vector, say, $(q_1^*, q_2^*, ., q_l^*, q_l^*, q_{l+1}...q_S^*)$ where q_l^* is produced in both states $l-1$ and l implies:

$$\eta\{\sum_s \pi_s u(r_s(y, q_s^*, \mathbf{x}^c))\} - C(\mathbf{x}^I, y, q_1^*, q_2^*, ...q_S^*, \mathbf{h})$$

$$\geq \eta\{\sum_{s \neq l-1} \pi_s u(r_s(y, q_s^*, \mathbf{x}^c)) + \pi_{l-1} u(r_l(y, q_l^*, \mathbf{x}^c))\} - C(\mathbf{x}^I, y, q_1^*, q_2^*, ., q_l^*, q_l^*, q_{l+1}...q_S^*, \mathbf{h})$$

or,

$$\begin{aligned}\eta\pi_{l-1}[u(r_{l-1}(y, q_{l-1}^*, \mathbf{x}^c)) - u(r_l(y, q_l^*, \mathbf{x}^c))] \quad \geq \quad & C(\mathbf{x}^I, y, q_1^*, q_2^*, ...q_S^*, \mathbf{h}) - \\ & -C(\mathbf{x}^I, y, q_1^*, q_2^*, ., q_l^*, q_l^*, q_{l+1}...q_S^*, \mathbf{h})\end{aligned}$$

Thus, if $C(\mathbf{x}^I, y, q_1^*, q_2^*, ...q_S^*, \mathbf{h}) > C(\mathbf{x}^I, y, q_1^*, q_2^*, ., q_l^*, q_l^*, q_{l+1}...q_S^*, \mathbf{h})$ and $\eta\pi_{l-1} > 0$, it follows that:

$$\eta\pi_{l-1}[u(r_{l-1}(y, q_{l-1}^*, \mathbf{x}^c)) - u(r_l(y, q_l^*, \mathbf{x}^c))] > 0$$

The assumption that the utility function is strictly increasing then yields that:

$$r_l(y, q_l^*, \mathbf{x}^c)) < r_{l-1}(y, q_{l-1}^*, \mathbf{x}^c))$$

Appendix D

Comparative Statics for the Agent

The sufficient conditions for the monotone comparative statics with respect to the set $[(-\mathbf{y}^{\alpha I*}, -\mathbf{q}^{\alpha I*}, -\mathbf{x}^{c,\alpha I*} \vdots \mathbf{y}^{\alpha II*});\ \alpha]$ (with $pI = \alpha I$ and $pII = \alpha II$ below) are:

$$\frac{\partial^2 F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})}{\partial y_l^m \partial y_b^m} = -C_{y_l^m y_b^m}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0,\ \ l, b \in S^m; l \neq b;\ \ m = p1, pII \qquad \text{(D1)}$$

$$\frac{\partial^2 F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})}{\partial (-y_l^{pI}) \partial y_b^{pII}} = C_{y_l^{pI} y_b^{pII}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0, \quad l \in S^{pI}, b \in S^{pII}; l \neq b \quad \text{(D2)}$$

$$\frac{\partial^2 F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})}{\partial (y_l^{pI}) \partial q_l^{pI}} = \eta \pi_l \alpha \beta u''(r_l) - C_{y_l^{pI} q_l^{pI}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0, \qquad l \in S^{pI} \qquad \text{(D3a)}$$

or[1],

$$\frac{\partial^2 F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})}{\partial (-q_l^{pI}) \partial y_l^{pII}} = -\eta \pi_l \alpha \beta u''(r_l) + C_{y_l^{pII} q_l^{pI}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0, \qquad l \in \Omega \qquad \text{(D3b)}$$

$$\frac{\partial^2 F(\mathbf{a}, \boldsymbol{\theta}, \mathbf{h})}{\partial (y_l^{pI}) \partial q_b^{pI}} = -C_{y_l^{pI} q_b^{pI}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0,\ \ l, b \in S^{pI};\ \ l \neq b \qquad \text{(D4)}$$

[1] (D3a) and (D3b) allow for y_l and q_l to be in the same and different groupings, respectively, in the partition. Therefore, at any point in time, either (D3a) or (D3b) will hold.

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-q_l^{pI})\partial y_b^{pII}} = C_{y_b^{pII} q_l^{pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, \quad l \in S^{pI}, b \in S^{pII}; l \neq b \quad \text{(D5)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial q_l^{pI}\partial q_b^{pI}} = -C_{q_l^{pI} q_b^{pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, \quad l, b \in S^{pI};\ l \neq b \qquad \text{(D6)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial y_l^{pI}\partial x_k^{c,pI}} = \eta\pi_l\alpha\lambda_k u''(r_l) - C_{y_l^{pI} x_k^{c,pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0,\ l \in S^{pI};\ k \in K^{pI} \qquad \text{(D7)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial q_l^{pI}\partial x_k^{c,pI}} = \eta\pi_l\beta\lambda_k u''(r_l) - C_{q_l^{pI} x_k^{c,pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, l \in S^{pI}; k \in K^{pI} \qquad \text{(D8)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-x_k^{c,pI})\partial y_b^{pII}} = -\eta\pi_b\alpha\lambda_k u''(r_b) + C_{y_b^{pII} x_k^{c,pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0,\ b \in S^{pII};\ k \in K^{pI} \quad \text{(D9)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial x_i^{c,pI}\partial x_k^{c,pI}} = -C_{x_i^{pI} x_k^{pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, \quad i, k \in K^{pI}; \quad i \neq k \qquad \text{(D10)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-y_l^{pI})\partial\alpha} = -\eta\pi_l u'(r_l) - \eta\pi_l\alpha u''(r_l) y_l \geq 0, \quad l \in S^{pI} \qquad \text{(D11)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial y_b^{pII}\partial\alpha} = \eta\pi_b u'(r_b) + \eta\pi_b\alpha u''(r_b) y_b \geq 0, \quad b \in S^{pII} \qquad \text{(D12)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-q_l^{pI})\partial\alpha} = -\eta\pi_l\beta u''(r_l) y_l \geq 0, \quad l \in S^{pI} \qquad \text{(D13)}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-x_k^{c,pI})\partial\alpha} = -\eta\lambda_k \sum_s \pi_s u''(r_s) y_s \geq 0, \quad k \in K^{pI} \qquad \text{(D14)}$$

The sufficient conditions for the monotone comparative statics with respect to the set $[(-\mathbf{y}^{\beta I*}, -\mathbf{q}^{\beta I*}, -\mathbf{x}^{c,\beta I*} \vdots \mathbf{q}^{\beta II*});\ \beta]$ are given by (D1, with $m = \beta I$), (D4), (D7), (D8), (D10) with $pI = \beta I$ and $pII = \beta II$, and the conditions (D14) through (D22) below (with $pI = \beta I$ and $pII = \beta II$):

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(y_l^{pI})\partial q_l^{pI}} = \eta\pi_l\alpha\beta u''(r_l) - C_{y_l^{pI} q_l^{pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, \quad l \in S^{pI} \tag{D14a}$$

or[2],

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-y_l^{pI})\partial q_l^{pII}} = -\eta\pi_l\alpha\beta u''(r_l) + C_{y_l^{pI} q_l^{pII}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, \quad l \in \Omega \tag{D14b}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-y_l^{pI})\partial q_b^{pII}} = C_{y_l^{pI} q_b^{pII}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0,\; l \in S^{pI}, b \in S^{pII}; l \neq b \tag{D15}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial q_l^m \partial q_b^m} = -C_{q_l^m q_b^m}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, \quad l,b \in S^m;\; l \neq b;\; m = p1, pII \tag{D16}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-q_l^{pI})\partial q_b^{pII}} = C_{q_l^{pI} q_b^{pII}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0, \quad l \in S^{pI}, b \in S^{pII}, l \neq b \tag{D17}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-x_k^{c,pI})\partial q_b^{pII}} = -\eta\pi_l\beta\lambda_k u''(r_l) + C_{q_b^{pII} x_k^{c,pI}}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \geq 0,\; b \in S^{pII};\; k \in K^{pI} \tag{D18}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-y_l^{pI})\partial\beta} = -\eta\pi_l\alpha u''(r_l) q_l \geq 0, \quad l \in S^{pI} \tag{D19}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-q_l^{pI})\partial\beta} = -\eta\pi_l u'(r_l) - \eta\pi_l\beta u''(r_l) q_l \geq 0, \quad l \in S^{pI} \tag{D20}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial q_b^{pII}\partial\beta} = \eta\pi_l u'(r_b) + \eta\pi_b\beta u''(r_b) q_b \geq 0, \quad b \in S^{pII} \tag{D21}$$

[2] (D14a) and (D14b) allow for y_l and q_l to be in the same and different groupings, respectively, in the partition. Therefore, at any point in time, either (D14a) or (D14b) will hold.

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-x_k^{c,pI})\partial\beta} = -\eta\lambda_k \sum_s \pi_s u''(r_s) q_s \geq 0, \quad k \in K^{pI} \tag{D22}$$

The set of conditions under which $(-\mathbf{y}^{\lambda I*}, -\mathbf{q}^{\lambda I*}, -\mathbf{x}^{c,\lambda I*} \vdots \mathbf{x}^{c,\lambda II*})$ increases with λ_k is given by (D1, with $m = \lambda I$), (D3a), (D4), (D6), (D7), (D8), and the following (all conditions apply with $pI = \lambda I$ and $pII = \lambda II$):

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-y_l^{pI})\partial x_k^{c.pII}} = -\eta\pi_l\alpha\lambda_k u''(r_l) + C_{y_l^{pI} x_k^{c,pII}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0, \; l \in S^{PI}; \; k \in K^{PII} \tag{D23}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-q_l^{pI})\partial x_k^{c,pII}} = -\eta\pi_l\beta\lambda_k u''(r_l) + C_{q_l^{pI} x_k^{c,pII}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0, \; l \in S^{pI}; \; k \in K^{pII} \tag{D24}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial x_i^{c,m}\partial x_k^{c,m}} = -C_{x_i^m x_k^m}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0, \quad i,k \in K^m; \quad i \neq k; \; m = pI, pII \tag{D25}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-x_i^{c,pI})\partial x_k^{c,pII}} = C_{x_i^{pI} x_k^{pII}}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq 0, \quad i \in K^{pI}, k \in K^{pII} \tag{D26}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-y_l^{pI})\partial\lambda_k} = -\eta\pi_l\alpha u''(r_l) x_k^c \geq 0, \quad l \in S^{pI} \tag{D27}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-q_l^{pI})\partial\lambda_k} = -\eta\pi_l\beta u''(r_l) x_k^c \geq 0, \quad l \in S^{pI} \tag{D28}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(-x_k^{c,pI})\partial\lambda_k} = -\eta\sum_s \pi_s u'(r_s) - \eta\lambda_k \sum_s \pi_s u''(r_s) x_k^c \geq 0, \quad k \in K^{pI} \tag{D29}$$

$$\frac{\partial^2 F(\mathbf{a},\boldsymbol{\theta},\mathbf{h})}{\partial(x_k^{c,pII})\partial\lambda_k} = \eta\sum_s \pi_s u'(r_s) + \eta\lambda_k \sum_s \pi_s u''(r_s) x_k^c \geq 0, \quad k \in K^{pII} \tag{D30}$$

Appendix E

First Order Conditions for the Agent

The grower's optimal choices under a linear payment and CRA preferences are characterized by the following first order conditions:

$$y_l : \eta[\pi_l\alpha - \kappa T^{-1/2}\{\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)]\sum_{i\neq l}\pi_i\alpha + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)](-\pi_l\alpha)\}]$$

$$-C_{y_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad y_l \geq 0;\ i, l, s \in S \qquad \text{(E1)}$$

$$q_l : \eta[\pi_l\beta - \kappa T^{-1/2}\{\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)]\sum_{i\neq l}\pi_i\beta + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)](-\pi_l\beta)\}]$$

$$-C_{q_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad q_l \geq 0;\ i, l, s \in S \qquad \text{(E2)}$$

$$x_k^c : \eta\lambda_k - C_{x_k^c}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad x_k^c \geq 0, \qquad k = 1, 2, ...K \qquad \text{(E3)}$$

in the notation of complementary slackness.

The first order conditions $(E1) - (E3)$, in turn, can be written as:

$$y_l : \eta[\pi_l\alpha - \kappa T^{-1/2}\{\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)]\alpha + \pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)](-\pi_l\alpha) + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)](-\pi_l\alpha)\}]$$

$$-C_{y_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad y_l \geq 0;\ i, l, s \in S \qquad \text{(E4)}$$

$$q_l : \eta[\pi_l\beta - \kappa T^{-1/2}\{\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)]\beta + \pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)(-\pi_l\beta)] + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)](-\pi_l\beta)\}]$$

$$-C_{q_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad q_l \geq 0;\ i, l, s \in S \qquad \text{(E5)}$$

$$x_k^c : \eta\lambda_k - C_{x_k^c}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad x_k^c \geq 0, \qquad k = 1, 2, ...K \qquad \text{(E6)}$$

CLAIM: In (E4) and (E5) above, $\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)] + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)] = 0$

PROOF(by induction):

- Suppose $S = 2$; Let state l refer to state 1.

$$\begin{aligned}
& \pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)] + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)] \\
= \ & \pi_1[\pi_2(r_1 - r_2)] + \pi_2[\pi_1(r_2 - r_1)] = 0
\end{aligned}$$

- Suppose $S = 3$; Let state l refer to state 1.

$$\begin{aligned}
& \pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)] + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)] \\
= \ & \pi_1[\pi_2(r_1 - r_2) + \pi_3(r_1 - r_3)] + \pi_2[\pi_1(r_2 - r_1) + \pi_3(r_2 - r_3)] + \\
& +\pi_3[\pi_1(r_3 - r_1) + \pi_2(r_3 - r_2)] \\
= \ & 0
\end{aligned}$$

- S states

$$\begin{aligned}
& \pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)] + \sum_{s\neq l}\pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)] \\
= \ & \pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)] + \sum_{s\neq l}\pi_s[\pi_l(r_s - r_l) + \sum_{i\neq s\neq l}\pi_i(r_s - r_i)] \\
= \ & \sum_{s\neq l}\pi_s[\sum_{i\neq s\neq l}\pi_i(r_s - r_i)] \\
= \ & \pi_m[\sum_{i\neq l\neq m}\pi_i(r_m - r_i)] + \sum_{s\neq l\neq m}\pi_s[\pi_m(r_s - r_m) + \sum_{i\neq s\neq l\neq m}\pi_i(r_s - r_i)] \\
= \ & \sum_{s\neq l\neq m}\pi_s[\sum_{i\neq s\neq l\neq m}\pi_i(r_s - r_i)]
\end{aligned}$$

Continuing in this way $S - 1$ times gives the desired result. C.E.D.

Appendix F

Optimization Problem (General Payment Scheme)

For a more general payment scheme such as one in which $r_s = \delta + p_s$ (where δ is a fixed transfer and $p_s(y_{s,}q_s, \mathbf{x}^c)$ is a state-contingent incentive payment), the principal's maximization problem, assuming CRA preferences for the agent, is given by:

$$\max_{\alpha,\beta,\delta,\lambda,\mathbf{y},\mathbf{q},\mathbf{x}^{\mathbf{G}},\mathbf{x}^I} \quad \eta\sum_s \pi_s(y_s + Pq_s) - \eta(\delta + \sum_s \pi_s p_s) - \sum_k \upsilon_k x_k^c - g^I(\mathbf{x}^{Nc})$$

$$subject\ to:$$

$$\eta(\delta + \sum_s \pi_s p_s) - \kappa\eta T^{1/2} - C(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \geq \underline{u} \qquad (IR)$$

$$(\mathbf{y}, \mathbf{q}, \mathbf{x}^G, \mathbf{x}^c) \in \arg\max\{\eta E[\delta + \alpha y + \beta q] - \kappa\eta T^{1/2} + \eta\sum_k \lambda_k x_k^c - g^G(\mathbf{x}^G; \mathbf{x}^I)\} \qquad (IC)$$

$$: \mathbf{x} \in X(\mathbf{y}, \mathbf{q}, \mathbf{h})$$

The first order conditions for an agent having CRA preferences are given by:

$$y_l : \eta[\pi_l \frac{\partial p_l(y_{l,}q_l, \mathbf{x}^c)}{\partial y_l} - \kappa T^{-1/2}\{\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)]\frac{\partial p_l(y_{l,}q_l, \mathbf{x}^c)}{\partial y_l}\}] -$$

$$-C_{y_l}(\mathbf{x}^I, \mathbf{y}, \mathbf{q}, \mathbf{h}) \leq 0, \quad y_l \geq 0; \ i, l, s \in \Omega$$

$$q_l : \eta[\pi_l \frac{\partial p_l(y_{l,}q_l, \mathbf{x}^c)}{\partial q_l} - \kappa T^{-1/2}\{\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)]\frac{\partial p_l(y_{l,}q_l, \mathbf{x}^c)}{\partial q_l}\}] -$$

$$-C_{q_l}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \le 0, \quad q_l \ge 0;\ i,l,s \in \Omega$$

$$x_k^c : \eta[\sum_s \pi_s \frac{\partial p_s(y_s,q_s,\mathbf{x}^c)}{\partial x_k^c} - \kappa T^{-1/2}\{\sum_s \pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)]\}$$

$$\{\sum_s \pi_s[\sum_{i\neq s}\pi_i(\frac{\partial p_s(y_s,q_s,\mathbf{x}^c)}{\partial x_k^c} - \frac{\partial p_i(y_i,q_i,\mathbf{x}^c)}{\partial x_k^c})]\}] - C_{x_k^c}(\mathbf{x}^I,\mathbf{y},\mathbf{q},\mathbf{h}) \le 0,$$

$$x_k^c \ge 0, \qquad k = 1,2,....K$$

The corresponding first order conditions for the principal are given by:

$$r_l : \eta[\sum_s [\pi_s - C_{y_s}]\frac{\partial y_s}{\partial r_l} + \sum_s [P\pi_s - C_{q_s}]\frac{\partial q_s}{\partial r_l} - \kappa T^{-1/2}\pi_l[\sum_{i\neq l}\pi_i(r_l - r_i)]] -$$

$$-\sum_k \{v_k + C_{x_k^c}\}\frac{\partial x_k^c}{\partial r_l} \le 0, \qquad r_l \ge 0, l \in \Omega$$

$$x_j^{Nc} : \eta[\sum_s (\pi_s - C_{y_s})\frac{\partial y_s}{\partial x_j^{Nc}} + \sum_s (P\pi_s - C_{q_s})\frac{\partial q_s}{\partial x_j^{Nc}}]$$

$$-\kappa T^{-1/2}\{\sum_s \pi_s[\sum_{i\neq s}\pi_i(r_s - r_i)]\}\{\sum_s \pi_s[\sum_{i\neq s}\pi_i(\frac{\partial r_s(y_s,q_s,\mathbf{x}^c)}{\partial x_j^{Nc}} - \frac{\partial r_i(y_i,q_i,\mathbf{x}^c)}{\partial x_j^{Nc}})]\}]$$

$$-\sum_k (v_k + C_{x_k^c})\frac{\partial x_k^c}{\partial x_j^{Nc}} - C_{x_j^{Nc}} - \frac{\partial g^I(\mathbf{x}^{Nc})}{\partial x_j^{Nc}} \le 0,\ x_j^{Nc} \ge 0, \quad k = 1,2,....K,\ j = 1,2,....J$$

Appendix G

Determination of reservation utility - Cooperative Case

Suppose that, instead of deciding quantities noncooperatively, the two growers make their decisions cooperatively. The solution concept used in what follows is the Nash Bargaining Solution. Suppose, the bargaining strengths of the two growers are given by α and $1-\alpha$, respectively. Let the disagreement payoffs, in which case cooperation breaks down, be given by the outcome of the Cournot noncooperative game (Binmore, 1999). That is, the disagreement payoffs are given by E_1 for grower I and E_2 for grower II. In the bargaining program, the growers maximize:

$$\max_{\mathbf{z}_1,\mathbf{z}_2}[\Phi_1 - E_1]^{\alpha}[\Phi_2 - E_2]^{1-\alpha}$$

where $\Phi_i - E_i$ represents the surplus from cooperation for player i in excess of the disagreement payoff E_i. That is, the bargaining problem is given by:

$$\max_{\mathbf{z}_1,\mathbf{z}_2}\ [\pi_1(1-z_1^I-z_1^{II})z_1^I+\pi_2(1-z_2^I-z_2^{II})z_2^I-c_1z_1^I-c_2z_2^I-E_1]^{\alpha}$$

$$[(\pi_1-\kappa\sqrt{\pi_1\pi_2})(1-z_1^I-z_1^{II})z_1^{II}+(\pi_2+\kappa\sqrt{\pi_1\pi_2})(1-z_2^I-z_2^{II})z_2^{II}-d_1z_1^{II}-d_2z_2^{II}-E_2]^{1-\alpha} \qquad \text{(G1)}$$

The first-order conditions corresponding to the above maximization program are:

$$z_1^I : -(\pi_1 - \kappa\sqrt{\pi_1\pi_2})z_1^{II} + \frac{\Phi_2 - E_2}{\Phi_1 - E_1}\frac{\alpha}{1-\alpha}[\pi_1(1 - 2z_1^I - z_1^{II}) - c_1] \leq 0; \quad z_1^I \geq 0 \quad \text{(G2)}$$

$$z_2^I : -(\pi_2 + \kappa\sqrt{\pi_1\pi_2})z_2^{II} + \frac{\Phi_2 - E_2}{\Phi_1 - E_1}\frac{\alpha}{1-\alpha}[\pi_2(1 - 2z_2^I - z_2^{II}) - c_2] \leq 0; \quad z_2^I \geq 0 \quad \text{(G3)}$$

$$z_1^{II} : (\pi_1 - \kappa\sqrt{\pi_1\pi_2})(1 - z_1^I - 2z_1^{II}) - \frac{\Phi_2 - E_2}{\Phi_1 - E_1}\frac{\alpha}{1-\alpha}\pi_1 z_1^I - d_1 \leq 0; \quad z_1^{II} \geq 0 \quad \text{(G4)}$$

$$z_2^{II} : (\pi_2 + \kappa\sqrt{\pi_1\pi_2})(1 - z_2^I - 2z_2^{II}) - \frac{\Phi_2 - E_2}{\Phi_1 - E_1}\frac{\alpha}{1-\alpha}\pi_2 z_2^I - d_2 \leq 0; \quad z_2^{II} \geq 0 \quad \text{(G5)}$$

In order to simplify the problem, I assume that:

$$\frac{\Phi_2 - E_2}{\Phi_1 - E_1} = \frac{1-\alpha}{\alpha}$$

That is, the surplus over and above the disagreement payoff for each player is assumed to be divided among the players in the ratio of their bargaining strengths. The first order conditions (F2) - (F5) are therefore goven by:

$$z_1^I : -(\pi_1 - \kappa\sqrt{\pi_1\pi_2})z_1^{II} + \pi_1(1 - 2z_1^I - z_1^{II}) - c_1 \leq 0; \quad z_1^I \geq 0 \quad \text{(G6)}$$

$$z_2^I : -(\pi_2 + \kappa\sqrt{\pi_1\pi_2})z_2^{II} + \pi_2(1 - 2z_2^I - z_2^{II}) - c_2 \leq 0; \quad z_2^I \geq 0 \quad \text{(G7)}$$

$$z_1^{II} : (\pi_1 - \kappa\sqrt{\pi_1\pi_2})(1 - z_1^I - 2z_1^{II}) - \pi_1 z_1^I - d_1 \leq 0; \quad z_1^{II} \geq 0 \quad \text{(G8)}$$

$$z_2^{II} : (\pi_2 + \kappa\sqrt{\pi_1\pi_2})(1 - z_2^I - 2z_2^{II}) - \pi_2 z_2^I - d_2 \leq 0; \quad z_2^{II} \geq 0 \quad \text{(G9)}$$

These conditions simplify to give:

$$z_1^I = \frac{(\pi_1 - \kappa\sqrt{\pi_1\pi_2} - d_1)(2\pi_1 - \kappa\sqrt{\pi_1\pi_2}) - 2(\pi_1 - \kappa\sqrt{\pi_1\pi_2})(\pi_1 - c_1)}{\pi_1^2 + (\pi_1 - \kappa\sqrt{\pi_1\pi_2})^2}$$

$$z_1^{II} = \frac{(\pi_1 - c_1)(2\pi_1 - \kappa\sqrt{\pi_1\pi_2}) - 2\pi_1(\pi_1 - \kappa\sqrt{\pi_1\pi_2} - d_1)}{\pi_1^2 + (\pi_1 - \kappa\sqrt{\pi_1\pi_2})^2}$$

$$z_2^{I} = \frac{(\pi_2 - d_2)(2\pi_2 + \kappa\sqrt{\pi_1\pi_2}) - 2\pi_2(\pi_2 - c_2)}{(2\pi_2 + \kappa\sqrt{\pi_1\pi_2})^2 - 4\pi_2^2}$$

$$z_2^{II} = \frac{(\pi_2 - c_2)(2\pi_2 + \kappa\sqrt{\pi_1\pi_2}) - 2\pi_2(\pi_2 - d_2)}{(2\pi_2 + \kappa\sqrt{\pi_1\pi_2})^2 - 4\pi_2^2}$$

The above solutions for z_1^I, z_1^{II}, z_2^I, and z_2^{II} can then be plugged into Φ_2 to obtain the expression for the expected reservation utility that results from Nash bargaining.

Assumption: Suppose that grower I has all the bargaining power so that $\alpha = 1$.

If grower I has all the bargaining power, the maximization problem in (F1) becomes:

$$\max_{\mathbf{z}_1,\mathbf{z}_2} \pi_1(1 - z_1^I - z_1^{II})z_1^I + \pi_2(1 - z_2^I - z_2^{II})z_2^I - c_1 z_1^I - c_2 z_2^I - E_1$$

The corresponding first order conditions are:

$$z_1^I : \pi_1(1 - 2z_1^I - z_1^{II}) - c_1 \leq 0; \quad z_1^I \geq 0 \qquad \text{(G10)}$$

$$z_2^I : \pi_2(1 - 2z_2^I - z_2^{II}) - c_2 \leq 0; \quad z_2^I \geq 0 \qquad \text{(G11)}$$

$$z_1^{II} : -\pi_1 z_1^I \leq 0; \quad z_1^{II} \geq 0 \qquad \text{(G12)}$$

$$z_2^{II} : -\pi_2 z_2^I \leq 0; \quad z_2^{II} \geq 0 \qquad \text{(G13)}$$

Suppose $\mathbf{z}^{II} = 0$. Then , plugging $\mathbf{z}^{II} = 0$ in the first order conditions (G10)-(G13) gives:

$$z_1^I = \frac{1 - \frac{c_1}{\pi_1}}{2}$$

and,

$$z_2^I = \frac{1 - \frac{c_2}{\pi_2}}{2}$$

Thus, all production is carried out in the lower cost firm (firm I). In fact, this is excatly what would happen if this were a multi-plant monopoly where both firms were managed by grower I. Efficiency would dictate that all production be carried out in the lower cost plant. The corresponding equilibrium prices are:

$$P_1 = \frac{1}{2} + \frac{c_1}{2\pi_1}, \text{ and}$$

$$P_2 = \frac{1}{2} + \frac{c_2}{2\pi_2}$$

with grower I's expected profits given by:

$$\Phi_1^* = \pi_1\left(\frac{1}{4} - \frac{c_1^2}{4\pi_1^2}\right) + \pi_2\left(\frac{1}{4} - \frac{c_2^2}{4\pi_2^2}\right) \qquad \text{(G14)}$$

In this set-up, to facilitate cooperation, grower I would compensate grower II an amount in the interval $[E_2, \Phi_1^* - E_1]$, with E_2, E_1 given by expressions (4.9) and (4.10), respectively. That is, grower I must atleast assure grower II of his disagreement payoff in order to get the latter to agree to give up production. And, this compensation will not exceed the surplus $\Phi_1^* - E_1$ that grower I achieves out of the cooperative arrangement.

Clearly, if there is a fall in c_1 and/or c_2, the expected profits Φ_1^* and E_1 for grower I will rise, and E_2 will fall. Suppose $\frac{\partial(\Phi_1^* - E_1)}{\partial c_s} \leq 0, s = 1, 2$. This then implies that a fall in c_1 and/or c_2 will provide a stronger incentive for grower I to get grower II to shut down operations and enter into a cooperative arrangement, while paying out not more than the new reduced disagreement payoff to grower I.

As a matter of fact, the analysis under the assumption where grower I has all the bargaining power is a special case of a principal-agent problem where the principal contracts with the agent, assures him of his or her reservation utility, but requires him to put in zero effort (by shutting down his operation).

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