JOINT VENTURES AND BARGAINING

Prabal Ray Chaudhuri

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Planning Unit
Indian Statistical Institute
New Delhi - 110 016.

To my parents:

Parimal Ray Chaudhuri

Pampa Ray Chaudhuri

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Chapter 1

Introduction

1.1 Introduction

My dissertation deals with some problems in theoretical economics. The five essays in this thesis can be classified under the broad categories of industrial organization and game theory.

Part I of the thesis comprises three chapters. These deal with some issues in the area of joint ventures and technology transfer. Chapter 2 investigates the relationship between technological dissimilarity and joint venture success. The third chapter explores some policy issues related to joint product development. Chapter 4 examines the relative efficacy of centralized and decentralized bargaining schemes in technology transfer.

In part II I examine some issues in bargaining theory. The fifth chapter is concerned with the non-cooperative foundations of the Nash bargaining solution. The last chapter studies bargaining models with small reneging costs.

In the next section I present a brief literature survey on joint product development and technology transfer. Section 3 presents an overview of the chapters in part I. The two chapters in part II are described in section 4.

1.2 Literature Survey on Joint Product Development and Technology Transfer

Technological change is one of the prime movers in the process of economic growth. Perhaps the most influential study to highlight the fact was by Solow (1957). He studied the growth rate of nonfarm American economy over the period 1909-49 and came to the conclusion that almost 90% of the observed growth in output per man was attributable to the time factor.[1] Second generation studies which explicitly incorporate technological change as an input into the production process, attribute about 40% of the growth to technological change.[2] In fact the Schumpeterian school would argue that technological change is the *sine qua non* of economic growth without which the economy would stagnate in a state of unchanging equilibrium.[3] An examination of the

[1] Of course the whole of the time factor cannot be attributed to technological progress alone. Denison (1962) breaks down the residual into its constituent parts. He finds that about 40% of the changes can be attributed to technical change. Other studies have found effects of similar magnitude in other countries e.g. Matthews (1964) for the U.K.

[2] See Stoneman (1987) ch. 4.3 for a survey of these studies.

[3] See Nelson and Winter (1982) for an exposition of these views.

institutions under which R&D is carried out is thus of paramount importance.

Since the 80s there have been a significant change in the institutional framework of R&D activity. Due to various reasons there have been a shift away from the intrafirm method of doing research towards a more collaborative approach. International collaborative ventures, domestic joint ventures and university-industry research collaborations are the usual vehicles for such ventures.

Joint ventures are of course not a new phenomenon. They were common in the U.S. extractive industry such as mining and petroleum production.[4] The newer ventures however differ from the older ones in their emphasis on research, technological development and production for world markets. Not only has there been a drastic growth in the number of such ventures,[5] but they now also appear in a much wider range of industries. They include both mature industries such as steel and automobiles, as well as young industries like computers and biotechnology.

The joint ventures can be divided functionally into two categories- those pursuing product development and those pursuing process development. Pavitt (1984) conducted a firm level survey of the British industries analysing some 2000 significant industries in Britain from 1945 to 1979. Though there was considerable variation across industries, he found that 74% of the innovations represented product innovation. This trend was strongest in the

[4]See Stukey, 1983.

[5]Harrigan (1984) found that domestic joint ventures involving U.S. firms had grown over the seventies. Hladik (1985) also found significant growth from 1975-82 in the number of international joint ventures involving U.S. firms

manufacturing industries.

In this survey I organise the material around two themes- that of production of new knowledge and that of exchange of existing knowledge. The literature on research joint ventures is basically concerned with the generation of knowledge. The technology transfer literature on the other hand is concerned with the exchange of knowledge. Of course this classification is not watertight, an issue which I will elaborate later.

I start by considering the product development literature. In the next subsection I examine the reasons that led to the shift towards the collaborative form of joint ventures.

1.2.1 Reasons for the Emergence of Collaborative Ventures

The rapid growth of joint venture R&D can be attributed to the changes in the nature of R&D over the period. The trend was reinforced by an increase in competitive pressure in the industrialized countries.

There has been a drastic increase in the cost of performing R&D in most industries, especially the newer ones. This problem has been exacerbated by a phenomenon of technological convergence whereby there is a greater degree of technological interdependence among the industries. This implies that the innovating firms must now concentrate on a larger number of fields, thus pushing up costs further.[6]

[6] The most well known example of such interdependence are that between telecommunications and computers and that between biotechnology and pharmaceuticals and food-

Rapid fall in the duration of product cycles coupled with larger development periods also tend to push up the costs of doing R&D as there is an increasing threat of being upstaged by a 'fast second'.[7]

These cost pressures assumed a greater importance in view of the intensified competitive pressures arising out of the increased openness of the international economy and faster rates of international technology transfer. This transfer was aided by a number of powerful institutions like the MNCs.[8]

It has been argued that cooperative R&D can help mitigate the above problems in several ways. By spreading the costs among firms it lowers the cost to any firm of a failure in R&D. Moreover, if there are economies of scale in R&D, collaborations can help reduce the costs per unit of R&D.[9] Thus the firms can monitor developments in technology at a lower cost to themselves. Besides as observed by Bozeman, Link and Zardkoohi (1986), if research collaborations can lower the costs to any single firm of R&D and if the results are made available to the participants, cooperative research can reduce the appropriability problem.

It is however not obvious that an increase in the variable costs of research

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processing industries.

[7]One of the most dramatic demonstrations can be found in the commercial jet industry. Althought the first commercial jet Comet 1 was introduced by a British firm (DeHavilland) the benefits were reaped by U.S. firms who however introduced substantial improvements.

[8]See OECD 1979, Mansfield and Romeo 1980, Baumol 1986. Baumol among others infact attributes the convergence of the growth rates of the industrialized countries to this transfer.

[9]The existence of research economies of scale is however not well supported by evidence. Indicators to identify the industries characterised by R&D is also absent. See Fisher and Temin (1974) for a discussion of these issues.

would increase the incentives for joint research, as in this case there is no special advantage to be gained from joint ventures. The above argument must therefore rely on increases in the fixed costs. It would be interesting to enquire to what extent the cost increases were of the fixed cost type.

The above reasons apply equally to all forms of R&D collaborations. I next discuss some reasons which are specific to international collaborations and to industry-university ventures respectively.

One of the most important reasons for the prolifeartion of international ventures is the possibility of foreign market penetration. In view of the drastic increase in such costs and the more even distribution of demand across national frontiers, R&D would often be impossible without access to foreign markets. With the growth of non-tariff restrictions such international ventures are often the only possible means of such penetration. A greater degree of technogical equality among the firms of the industrialized nations makes technological collaboration easier.[10] The technological capabilities of firms from the newly industrialized countries like Brazil, Korea etc have also improved.

The industry-university joint ventures were motivated, apart from the above mentioned cost increase, by two factors. The possibility of absorption and utilisation by firms of research advances by academic scientists and

[10]Flamm (1988) suggests that robotics technology has been adopted more rapidly in countries like Sweden, West Germany and Japan. Clark et al. (1987) estimate that Japanese automobile firms require one-half as much time to bring a new model to market as U.S. automobile firms. Thus the above evidence, though impressionistic, seem to suggest that technological strength is now more evenly distributed among the industrial nations.

engineers was the first motivating factor. The second reason relates to the prospect of recruiting personnel from academia.[11]

1.2.2 The Structure of Collaborative Ventures

The analysis of the implications of various distortions in the nature of R&D on the scale of R&D have attracted much theoretical attention in the past decade. Limited appropriability of social returns (Arrow, 1962) and spill-overs of knowledge (Spence, 1984) tend to create under-investment relative to socially optimal levels. These create a rationale for the patent system with its winner-take-all feature: this may however lead to over investment as researchers care about who wins a race, but the society is only interested in any one unit succeeding (Loury, 1979; Dasgupta and Stiglitz, 1980). Another interesting question pertains to the effect of patent races on the risk choice of competitors. Bhattacharya and Mookherjee (1986) find that the outcome depends on the levels of risk aversion and on the distributional characteristics of the research strategies available. If society and the firm are not very risk-averse, it is socially optimal for the firms to choose the maximum risk. This is the unique Nash equlibrium for a large class of distributions over discovery size. If however the distribution is skewed in favour of small discoveries it is possible that the firms prefer smaller risks than is socially optimal. On the

[11] In OECD 1984 p. 47 a Xerox corporation research executive speaker talks about the firm's investment in the Center for Integrated Systems at Stanford: For little additional investment we enlarge our perspective by participating in a broad program of basic research. We envision oppurtunities for joint interaction with the university and with other companies, as well as the ablities to recruit students. On a per dollar basis it should be a good investment.

other hand society prefers intermediate levels of risk if the common level of risk aversion is high enough. With symmetric distributions over discovery size firms may then prefer excessive risk. Klette and De Meza (1986) reach results which are similar to these.

Given that competitive research have these intrinsic problems it is interesting to enquire to what extent joint ventures can succeed in mitigating them. I now briefly discuss the potential gains and losses from collaborative ventures from the point of view of the economy as a whole. The usual justification for joint ventures is their ability to internalize the spillover externality. In view of the public good nature of R&D, the joint ventures can also help avoid duplication of R&D effort. The potential synergies of research effort, when there are complementarities between the firms, are also important.

There are some limitations associated with joint ventures though which may prevent them from realising the above beneficial effects.

The first point to observe is that cooperative research is not a substitute for but a complement to inhouse research. This is because the results of cooperative research must be absorbed by the firm and and transformed into commercially viable knowledge.[12] Some duplication of inhouse research is thus inevitable.

Another problem is that participants in cooperative research may react to the high cost of exploiting collaborative basic research by shifting the research agenda away from basic research.[13] From a social point of view cooperative

[12]See Cohen and Levinthal 1987.

[13]This may have actually occurred in case of the Electric Power Research Institute which decided to reduce their commitment to basic research.

R&D may reduce the number of independent lines of enquiry thus reducing diversity in downstream research.

Cooperative ventures may also act as a vehicle to reduce competition in the product market as well as the intensity of research itself so as to reduce research costs and also enjoy the benefits of the established technology. Another worrying aspect is that the participants may engage in predatory research i.e. research which is aimed at increasing the costs of business for rival firms. An example would be when the joint venture seeks to increase the compatibiliy between the product of the participants so as to exclude others from the network. One can also site the recent IBM-Apple collaboration, aimed at developing new hardware\software standards to keep out the 'clones'.

Problems with the organisational aspects of joint research ventures have sparked theoretical interest in socially optimal incentive schemes under imperfect competition. Picard and Rey (1990) consider the problem of a public regulator who is in charge of coordinating a joint research project. It is assumed that the regulator does not precisely know how much money each firm will be able to make from the patents and other statutory rights for inventions conceived by contractors. When efforts are not verifiable it is shown that the outcome in the absence of hidden action can be implemented even in the presence of hidden action through a menu of compensation schemes which define the agent's reward as a function of realized outcome through fairly simple compensation schemes. The above chapter extends results by Laffont and Tirole (1986), McAfee and McMillan (1987) etc obtained in a single agent context. McAfee and McMillan (1986) examine a similar problem where the analysis is in terms of Bayesian implementation rather than posterior implementation. They also rule out correlation among the characteristics of the agents.

Gandal and Scotchmer (1991) investigate a similar problem. They show that a joint venture can implement the rates of investment that maximize joint profit when firms' research abilities are private information even though there is a budget constraint and there are participation constraints arising out of the non-cooperative alternative which is a patent race. The usual conflict between participation constraints and budget balance is absent as the firms' payoff can depend on ex post signal of abilities. The conflict between the two reappears if the rates of investment are unobservable as well.

There is also the issue whether technologically diverse firms are more likely to succeed in product development under joint ventures. Empirical evidence from the commercial aircraft industry seem to suggest that this is indeed the case. The ventures that ran into trouble were often those between technological equals, such as those between Rolls Royce and Pratt and Whitney in the JT10D jet engine project, Fokker and McDonnell Douglas in the MDF100 commercial aircraft project, and Saab and Fairchild in the SF340 commuter aircraft project. Collaborative ventures between a technologically dominant and subordinate firms, such as the CFM international venture between General Electric and SNECMA of France and the collaborative ventures between Boeing and the Japan Commercial Transport Development Corporation seem to be doing better. Success is also more likely when the venture spans several products so that one firms expertise in one product may be exchanged against that of another firm in another product.[14]

In chapter 2 I seek to explain this phenomenon through an analysis of the free-rider problem involved in joint research. I find that technological diversity decreases the possibility of a joint venture forming at all. If, however, a joint venture does form technological dissimilarity (mean-preserving spread of marginal costs) increases the probability of success. Thus our chapter suggest the following testable hypothesis that the proportion of observed successes among heterogenous firms would be higher.

1.2.3 Policy Questions in Joint Product Development

In this subsection I discuss some policy questions related to domestic collaborations. The basic concerns in international ventures seem to be quite different and will be taken up later.

As regards domestic collaborations the main issues seem to relate to efficiency and anticompetitive effects. Empirical studies in recent years suggest that the social returns from R&D are much higher than the private returns. Bernstein and Nadiri (1988) offers some startling results in this respect. In the scientific instruments industry for example the social rate of return was estimated to be ten times the private rate of return. Such divergences between the social and private rates are to some extent caused by the spillover effects and various bargaining problems which prevent an innovator from appropriating the whole value of his innovation. Thus an important question is whether the collaborative ventures would succeed in reducing this dispar-

[14]It appears that such effects aided the Motorola-Toshiba Venture, in which Toshiba's CMOS process expertise was exchanged for Motorola's micro-processor design capabilities.

ity. A collaborative venture can serve to internalize the externality arising from spillover effects.[15] It is often feared that allowing collaboration in R&D may facilitate collaboration in the product market as well leading to anti-competitive effects. Mowery (1989) however argues that such effects are not very important. Another problem in assessing the efficacy of joint ventures lies in deciding the apprppriate counterfactual. As pointed out by Katz and Ordover (1990) the alternative to collaboration may be ex post cooperation (through patent licensing) rather than competition. Even if there is competition it may involve only a subset of the firms interested in collaborative ventures doing R&D in the absence of collaboration.

The dynamic gains in the form of greater R&D may however outweigh the efficiency losses due to anticompetitive effects. Thus straightforward application of antitrust laws is not very sensible in case of joint research ventures, and each case should be judged individually according to the rule of reason.[16]

The treaty of Rome, concerned with the prohibition of collusion if it inhibits trade or distorts competition, explicitly takes such trade-offs between static efficiency losses and possible dynamic gains due to increased success probability, into account. Such exemptions are infact extended to joint venture product manufacture or licensing to third parties though not to marketing. The best known legislation in the U.S. is the National Cooperative Research Act of 1984 (NCRA). Under this act firms that notify the Federal Trade Commission and the U.S. Department of Justice of their intent to enter

[15]D'Aspremont and Jacquemin show that whether the amount of effective research increases or decreases depends crucially on the strength of the spillover effects.

[16]See Ordover and Willig, 1985 for an elaboration of the above views.

into a joint R&D agreement can reduce their exposure in private antitrust litigation. The coverage of the law however is not very wide. It excludes from the definition of "joint research and development venture" various important activities in which the coventurers might engage. [17]

It seems however that the U.S. firms did not avail of the facilities to any great extent. Only 159 registrations were made through the end of 1985.[18] It seems that the moderate decrease in risks coupled with the need to disclose the broad outlines to the public, discourage such registrations.

Ordover and Willig (1985) show that under some conditions joint product development is going to lead to increased R&D. Their model however do not take into account the free-riding effect inherent in joint research. D'Aspremont and Jacquemin (1988) consider a model in case of process innovation which does allow for free-riding effects. They show that in the absence of spill-overs joint ventures may invest less in R&D compared to competitive research. If, however, there is a high degree of spill-over joint ventures are shown to be superior in terms of R&D. In the product development context I find that (chapter 3 of this thesis) free-riding assumes an even serious form. Not only is the probability of success lower in a joint venture in the absence of spill-overs, even when there is complete spill-over joint ventures may have a lower probability of success. Katz (1986) examines whether allowing firms in a given industry to form cooperative R&D ventures can be an effective way of correcting the failure of R&D to reach socially optimum levels. He demon-

[17]Several new legislations designed to increase the scope of exemptios are however pending. Katz and Ordover (1990) catalogues the legislations which are pending.

[18]See Katz and Ordover, 1990.

strates that when the firms agree to share both the costs and the fruits of a research project, industry wide projects have socially beneficial effects when the degree of product market competition is low, there are R&D spillovers and the agreements concern basic research rather than product development.

Another interesting policy question relates to the optimal degree of indigenization of foreign firms. In chapter 3 I examine this question when the government seeks to maximize a weighted sum of the domestic firm's profit and the probability of success.

1.2.4 Technology Transfer and Licensing

In the earlier sub-secions I discussed the development of new knowledge, in the context of joint ventures. In the rest of this section the focus is on information exchange rather than information generation.

An alternative to doing R&D by themselves is to acquire technologies from other firms through licensing. However this has the disadvantage that the licensor firm bears the full cost of research. There are also contractual limitations and transactions costs associated with the licensing mode arising from the "small numbers problem".[19]

One can therefore expect licensing ventures to be more prevalent in situations where the technologies do not rely on user active innovation and are relatively simple, with well defined patents. If the technologies do rely on user active innovations then once a recipient firm invests in user specific capital the technology supplier has the possibility of exploiting the technology

[19] See Klein, Crawford and Alchian, 1978.

recipient. This perhaps explains why licensing is an important alternative to collaborative ventures in pharmaceuticals, while in microelectronics, robotics and biotechnology they complement each other.

In recent years the problem of licensing has received much attention from theoretical economists. Gallini (1984) demonstrates that licensing by the incumbent may deter R&D by a potential entrant, as obtaining an efficient technology reduces the gains to the entrant from further R&D. In this case licensing performs a strategic function. K.E. Rockett (1990) focuses on another strategic aspect of licensing. Licensing can act as a means of choosing competitors which a patentee monopolist will face in the period after the patent expires. By granting licenses to weak competitors the incumbent can prolong its dominant position in the market. In fact Contractor (1985) found that firms cite the choosing of opposition as an important element in their licensing calculations. Gallini and Wright (1990) analyze the licensing of innovation focusing on the problem of possible imitation by the potential licensee if too much information is released prior to licensing. They show that innovations with relatively low values can be fully exploited with an exclusive contract[20] and a fixed fee. When the innovations have a high valuation the following hold:

(a) The licensor will offer a contract with an output related royalty in equilibrium. For exclusive contracts the royalty will be non-linear in output

[20]An exclusive contract is where the licensor foregoes the right to license to others. other firms.

when the innovation is drastic[21] but may be linear for non-drastic innovations.

(b) For sufficiently low imitation costs the equilibrium contract may leave some rents with the licensee.

(c) For product or drastic process innovation both exclusive and non-exclusive contracts extract full monopoly rents when imitation costs are sufficiently large. For lower imitation costs and large rent differentials between innovation types only non-exclusive contracts would be offerred in equilibrium.

Katz and Shapiro (1985) study a three stage asymmetric duopoly game of R&D rivalry, where the stages are the development of an innovation, fixed fee licensing of the innovation and the sale of the final product. They find that major innovations would not be licensed but that equally efficient firms would tend to license minor innovations. It is also demonstrated that private incentives to license fall short of the social one, although licensing is not always welfare improving.

Another important question is whether licensing is going to encourage research or not. Gallini and Winter (1990) examine the above question in the context of process innovation in the presence of uncertainty. They find that licensing tends to encourage research when the existing production technologies of the firms are close in costs. Research is however discouraged if the technologies are far apart. This result can be explained in terms of two distinct incentives for licensing. First licensing yields rents from the replacement of relatively inefficient means of production by more efficient means.

[21] An innovation is drastic if adoption of the innovation by one of the firms make it unprofitable for some of the older firms to remain in the market.

This leads to increased research as each firm recognizes the benefits of being in the lowest cost position. This is weak when the costs are far apart. In this case licensing results from a strategic incentive. A licensing contract offerred by a firm with a very efficient production technology can provide a high cost firm with a production technology at its reservation cost, the maximum production cost this firm would tolerate before undertaking research, without any research expenditure at all. At the same time by decreasing the licensee's incentive to do research licensing in this case prevents the erosion of low cost firm's market position by its rivals' discovery of superior technology.

1.2.5 Some Policy Issues Regarding Licensing of Technology

Initially I examine the role of government intervention in technology licensing. I begin by comparing the Indian and the Japanese experience, as regards technology transfer.

The Indian industries have always relied on foreign firms for the supply of technology. Given the increase in costs of doing research such dependence is only likely to increase. The growth of a relatively large, consumerist, upper middleclass in the last few decades has led to an increase in demand for high technology consumer goods and consequently for foreign technology on the part of Indian industries. The demand for foreign technology has been reinforced by some additional considerations. Of these one can mention the facts that foreign technology is standardised, soft financing is often made available by the technology suppliers and that the Indian consumers have brand loyalty towards foreign goods.[22]

Technology transfer in India has mostly been under licensing schemes. Such licensing has tended to perpetuate the technological dependence of the Indian firms as demonstrated by the high incidence of renewals of foreign collaborations.[23] Such dependence was fostered through secrecy clauses,[24] packaged transfer of technology, appointment of technical director/plant manager by the technology supplier, restriction on expansion of capacity and sublicensing and regulatory clauses prohibiting freedom to change the original design, horizontal transfer of technology and export[25] etc. Such unfavourable arrangements have usually been explained by the relatively weaker bargaining power of the Indian firms. Evidence from the petrochemical industry seem to coroborate the bargaining power hypothesis. Such restrictions were much less in case of basic processes where the technology is much more commonly available.[26]

Such technological dependence is reflected in the fact that the annual R&D expenditure incurred by the technology partners is not significantly

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[22]See N. Kumar for a more detailed discussion.

[23]See Subhramanian, 1984.

[24]Kewal Ram, 1990 shows that in the petrochemical industry secrecy clauses often extend beyond even the period of agreements.

[25]72.3% of the purely technological collaborations agreements in the RBI's Fourth Survey of Foreign Collaborations had regulatory clauses.

[26]The above hypothesis have however been challanged by some studies which argue that many of the foreign firms were infact quite small and in terms of bargaining experience etc the Indian firms were often the equal of the foreign technology suppliers. See Bell and Scott-Kamiens (1985) for a forceful exposition of the above view.

higher than those incurred by the technology nonimporters.[27] Thus there is a serious lack of inhouse R&D among the technology importers. AsIargued before such in-house R&D is required to absorb the technology domestically and gives an indication of the degree of technology assimilation.

It is instructive to consider the case of Japan as a counterpoint. In Japan the firms would usually bargain via the mediation of MITI (Ministry for International Trade and Industry); the restrictive conditions on the technology recepient tended to be conspicuously absent. The greater degree of diffusion of foreign technology amongst Japanese firms is reflected in the positive correlation between the amounts of payment made for technology acquisition and the amount of in-house R&D expenditure incurred by Japanese firms.[28]

There are however ample reasons to doubt whether even in the absence of such restrictions the Indian firms would have performed the needed inhouse R&D. One reason for such scepticism is the lesser degree of competitiveness faced by the Indian firms compared to their Japanese counterpart. The greater competitiveness in the Japanese industry could be attributed to two factors, the relatively smaller size of the Japanese market (forcing the firms to depend on the export market) and the fact that MITI ensured that the technology was made available to a number of domestic firms.

In chapter 4 I examine the question of the relative efficacy of centralized versus decentralized bargaining mechanisms in technology transfer. Our basic finding is that government intervention is beneficial when the number of firms adopting the technology is no less under government intervention. Otherwise

[27]See Subhramanian, 1991.

[28]Goto and Wakasugi, 1987, p.271

intervention may reduce the net surplus in the economy.

For the less developed countries the problem can be broken up into two parts. The first point is to ensure that the imported technology should be diffused through out the industry and that the technology importing firm should perform an adequate amount of inhouse research to ensure that the acquired technology does not become outdated. The Japanese experience suggests the following two pronged policy. One the one hand the government should ensure that restrictions on inhouse research is not imposed by the technology supplier. On the other hand the government should strive to increase domestic competition so as to induce greater inhouse R&D. Ensuring that the technology is imported by a number of domestic firms can serve to increase domestic competition. Besides it also facilitates greater diffusion through spillover effects. The second point relates to the vintage and quality of the technology being imported. There is a widespread belief in India that the technology suppliers are dumping outdated technology on the Indian firms. The small size of the domestic market, the low demand profile, payments constraints imposed by the domestic government are some factors which lead to trade in second hand technologies.[29] Desai (1985) however suggests that usually the technology being supplied are the ones that the suppliers are themselves using. Whenever a technology of older vintage has been supplied it is usually because the Indian firm specifically asked for it on the basis of their assessment of the Indian market. The suppliers though usually do not sell technologies which they are in the process of developing and which they feel may yield them a potential monopoly power. Such an

[29] See Alam (1985) and Desai (1988) for an elaboration of the above views.

assessment is also substantiated by the fact that it was often the Indian firm which initiated the search for the new technology.[30]

This question has been subjected to theoretical scrutiny in recent years. Most of these examinations were however carried out in the context of process innovations. Kabiraj and Marjit (1992) suggests that an alternative cause could be threat of entry into the technology seller's market by the technology recipient. When the firms play a price game in the post entry phase they find that the severity of the competition implies that only partial transfer of technology would occur. Both in Rockett (1990b) and Kabiraj and Marjit (1990b) the output market is characterized by Cournot competition. Rockett examines the case where both the licensor and and the licensee operate in the same market. If imitation is possible, at least partially, the latest innovations will not be transferred. If imitation is not possible, royalty per unit and quality are substitute instruements and the best technology would be transferred. In Kabiraj and Marjit licensing creates competition in the seller's market whereas the buyer's market is perfectly protected by prohibitive tariff. They use an example to demonstrate that the best technology can be transferred by controlling upfront payments.

[30]See Cooper (1985) for a discussion of these issues in the context of collaborations between firms from the Benelux and firms from India.

1.2.6 Technology Generation and Technology Exchange

In this subsection I examine the interaction of technology generation and technology exchange.

In fact, in the context of international collaborative ventures the question that has attracted most attention concerns technology transfer. There seems to be widespread concern that technologies critical to a country's competitiveness may be exported.

In the United States there is an heated debate over the effect of technological collaboration with Japan. Mowery (1989) however cautions against restriction on technology transfer. His argument is twofold. Firstly such restrictions have historically been shown to be ineffective or have yielded perverse results.[31] Secondly, it is not possible to show in which direction the balance of technology transfer has gone. While in some industries it may have gone against the U.S., in industries like steel, automobiles, microelectronics etc collaborations can only have improved the competitiveness of the U.S. economy. Even if a technology is being exported, as long as the industry is located domestically, diffusion of such technologies is still possible through employee movement.

Even for less developed countries this question is of vital importance. In chapter 2 I examine whether, in a product development context, the foreign firm is going to opt for a efficient technology while collaborating with

[31]See Harris, 1986 or the COSEPUP Panel on the Impact of National Controls on International Technology Transfer, 1987.

a domestic firm. The somewhat counterintuitive answer is that it will do so provided the domestic technology is inefficient enough.

Killing (1983) suggests in a similar vein that collaborative ventures are more likely to succeed when they take place between technologically diverse firms, as the motive for technology transfer acts as a binding force. As technology transfer continues, however, the value of one firm's technological capabilities to its partner may decline and the collaboration may consequently break up.[32]

These considerations are of importance to the questions of organizational structure of joint ventures. Mowery (1989) suggests that in collaborations involving a senior and a junior firm, financial and organizational structure do not seem to matter as long as the technologically more advanced firm retains overall control of technological and management decisions. Why this should be so is not very clear. Presumably the junior firm's basic interest lies in technology acquisition whereas the senior firm is likely to be more interested in developing the product. Under such a setup the venture is more likely to succeed if the senior firm decides the governance structure. In collaborations involving technological equals however an autonomous management structure charged with a wide range of design, marketing, production and product support may be preferable even though it may be costly in terms of duplicated management structures. If however technology acquisition is the driving force behind joint ventures then such a conclusion makes sense only if majority of technological firms between equals involves firms with largely complementary assets. There does not seem to be any empirical work regarding this aspect

[32] See Phillips, 1989.

of collaborative ventures.

1.3 Overview of Part I

Chapter 2, entitled "Technological Asymmetry and Joint Product Development," was motivated by some empirical evidence, which suggested that, technologically dissimilar firms are more successful in developing a product when they undertake joint product development. I seek to explain this phenomenon by an analysis of the free-rider problem involved in joint research between two partners with varying degrees of technological asymmetry.

This chapter develops a model of two firms undertaking joint product development. I start with a static one period game where the two firms simultaneously decide on their espective effort levels.. The probability of success depends on the joint effort of the two firms. Efforts are unobservable and so cannot be contracted upon. Both the firms share equally in the resulting profits. The technological dissimilarity pertains to the marginal costs of putting in the effort. This model generates the result that an increase in dissimilarity (mean-preserving spread of marginal costs) increases the probability of success. What happens is that the more productive firm increases effort and the less productive firm decreases effort, but the increase in effort of the more productive firm more than compensates for the decrease in effort by the other firm. I identify sufficient conditions for this to happen. The result holds for a large class of cost functions e.g., for cost functions with concavity or constant elasticity of marginal cost. This result is independent of the nature of the return function.

I next investigate the case where the sharing rule is endogenously determined. I find that if the endogenously determined sharing rule obeys some reasonable conditions then the previous conditions are still sufficient to ensure that the effort stream increases for a mean preserving spread of the technology levels. I also identify some situations when the sharing rule would obey the stipulated restrictions. I find that such conditions may arise either when the sharing rule is determined through a Nash bargaining solution or when it is determined so as to maximise aggregate profits. This shows that conditions imposed are not empty.

I then examine how our results extend to a dynamic context where the two firms interact over two periods. The earlier sufficient conditions no longer ensure that the effort stream increases as technological dissimilarity between the firms increase. The reason is as follows. As a result of greater technological diversity the second period pay-off of the firms may increase. This would have a negative effect on the first period efforts because the consequences of failure in the first period is reduced. Hence the net effect on the effort stream could go either way.

The preceding result, however, is driven by the sharp asymmetry between the first and the second stages of the game. This asymmetry is somewhat artificial, and would disappear in an infinite horizon framework. I therefore subsequently examine a stationary Markov equilibrium in the infinite horizon formulation. I find that for a stationary Markov equilibrium and linear costs my results still hold. Thus it appears that for technological cooperation over a short span of time the impressionistic evidence can be supported theoretically. For longer time periods however, the effect is ambiguous.

Next I introduce uncertainty over the possible cost parameters of the two firms. I examine the case where the cost parameters of the firms are private information though drawn from the same distribution. For the case of symmetric equilibria I identify sufficient conditions for the joint effort stream to increase for a mean preserving spread of the realised levels of the technology parameters. The condition is that the marginal cost be concave and that the marginal return function be convex in the effort levels.

I also look at the case where the firms can indulge in basic research to determine the technology levels endogenously. Under the simplifying assumption of constant cost of basic research I show that for a certain class of cost functions at least one of the firms is going to go in for the most efficient level of technology. Here the problem is that reducing one's productivity may increase asymmetry and thus increase the likelihood of success because the other party puts in more effort. This may outweigh increased effort costs and so free-riding would increase.

Chapter 3, entitled "Joint Product Development: Some Policy Issues" deals with some policy issues pertaining to joint product development. It builds on the basic model developed in chapter 2.

The first issue is related to the financial control of joint ventures. This examines the case where the joint venture is going to form anyway. The government can however control the outcome through controlling the profit share of the two firms. This question is of special interest to less developed countries interested in fostering joint ventures with foreign firms. The second issue is concerned with whether the joint venture should be allowed at all. The important questions in this case relates to the probability of success under the two alternative form of R&D, cooperative R&D and competitive R&D, and the nature of the product market competition following success. This issue pertains to anti-trust policies as regards domestic joint ventures.

The first issue pertains to the financial regulation of joint ventures between a domestic and a foreign firm. Consider the case where the foreign firm is relatively more efficient and the government can optimally choose the profit sharing rule so as to maximize its objective function. In this context the profit share going to the domestic firm, being related to the proportion of domestic equity participation, can be interpreted as the degree of indigenization. The government's objective function is a weighted sum of the profits of the domestic firm and the probability of success, where the success probability is interpreted as a proxy for the consumers' surplus. I find that the optimal share of the foreign firm is a increasing function of the weight put on the probability of success as well as the relative inefficiency of the domestic firm. I also show (in an example) that the optimal share of the foreign firm is greater than half, provided that technologically the firms are sufficiently far apart. The same example also demonstrates that the share of the foreign firm would be bounded away from one, however great the disparity in the technology levels, provided the weight on the consumers' surplus is not too high. If the weight is however large enough then the share would approach one.

I next consider the case where the government, in addition to manipulating the sharing rule, can impose lumpsum transfers between the firms. I examine the case where the objective of the government is to maximise the payoff of the domestic firm. I find that for a linear return function and homogeneous cost functions, the profit shares of the foreign firm would be greater than one half. This result questions the wisdom of the importance placed in India on keeping the equity participation of foreign firms at less than fifty percent. Of course, this has to do with the issue of 'control' of joint ventures, an aspect I abstract from. Besides, the optimal policy may involve the domestic firm paying a transfer fee to the foreign firm. Another interesting question is whether the first best can be achieved through some scheme. I demonstrate that there does exist a scheme of the following type. The government charges some entry fee from both the firms. In return the government promises to subsidize the product if success does take place. It also specifies the share in which the profits are going to be shared. For appropriate values of the policy variables the first best can be implemented and the foreign firm held down to its participation level of payoffs.[33]

The second set of issues that I consider deal with joint product development among domestic firms. The focus is on efficiency and anticompetitive effects.

The standard argument justifying joint ventures claims that the dynamic gains in the form of greater R&D may outweigh the efficiency losses due to anticompetitive effects. The above argument has been put forward to claim that research joint ventures should be treated more leniently under anti-trust legislation compared to usual mergers etc.

This argument presumes that the R&D success is going to be higher under

[33]Of course these results depend critically on the assumption that the government possesses complete information about the foreign firm's technology and market oppurtunities elsewhere.

joint ventures. In the presence of free-riding problems in joint ventures this is not at all obvious.

I begin by examining the effect of joint venture formation on the probability of success. Various possible counterfactuals are considered. In contrast to the previous section product market considerations are introduced explicitly. Lastly I examine if joint ventures, even though individually rational, can reduce the expected surplus in the economy.

I first examine the case where in the absence of joint product development only one of the firms is going to opt for R&D. The result depends on whether it is the more efficient or the less efficient firm that is conducting the R&D. If it is the more efficient firm then the probability of success is lower under joint venture. If, however, it is the less efficient firm that is performing the R&D then a joint venture improves the probability of success. I then examine the case where in the absence of a joint venture, the two firms engage in competitive R&D. In the absence of spillover effects the probability of success is higher in case of competitive R&D. This result however depends on a sufficient condition on the return function. I use an example to demonstrate that if this condition is not satisfied then the probability of success may be higher under a joint venture. I then examine the case when there are spillover effects in the market. Even with complete spillovers competitive R&D may have a greater probability of success. Only when the return from joint venture is large enough compared to the competitive returns do I find that the probability of success under joint venture is greater.

Lastly I demonstrate that it may be possible that the formation of joint ventures, though individually rational, leads to a decline in the expected agggregate surplus. The intuition is simple. I use an earlier result to show that in this case the probability of success declines under a joint venture. Since in this case the surplus under a joint venture is always lower than that under competitive R&D, (since I consider the case where the firms cooperate in the product market as well, following joint venture success), irrespective of whether one or both firm succeeds under competitive R&D, the result follows.

Ordover and Willig (1985) show that under some conditions joint product development is going to lead to increased R&D. Their model however does not take into account the free-riding effects inherent in joint research. In order to facilitate comparison with their model I consider a variant where the effort level is verifiable. I find that in this case joint ventures indeed increase the probability of success. This corroborates the intuition that the Ordover and Willig results can be traced to their ignoring the free-riding effects.

D'Aspremont and Jacquemin (1988) consider a model in the case of process innovation which does allow for free-riding effects. They show that in the absence of spill-overs joint ventures may invest less in R&D compared to competitive research. When however there is a high degree of spill-over joint ventures are shown to be superior in terms of R&D. My model demonstrates however that no simple answers can be provided as regards the probability of success under these two alternative modes of R&D. The results may go either way depending on the return function.

The model I examine differs from d'Aspremont and Jacquemin (1988) by focusing on product development rather than process innovation. My results demonstrate that an important consideration in this respect is the nature of the return function, an issue that d'Aspremont and Jacquemin (1988) implicitly abstract from.

The motivation of the fourth chapter, entitled "The Role of Government Intervention in Technology Transfer," comes from the contrasting experiences of India and Japan as regards technology transfer. Whereas in India, the import of foreign technology did not lead to technological self sufficiency, in the case of Japan, the import of technology proved to be an unqualified success. Much of the high growth rate in the Japanese industry can be attributed to imported technology. The relevant question is the extent to which this success can be attributed to government intervention in technology transfer, specifically to the cenrtralized bargaining procedure adopted by MITI in Japan.

I set up a model where there are n identical domestic firms, facing a single foreign firm possessing a superior technology. Technology transfer may or may not involve government intervention. Government intervention, if it occurs, takes the following form. The government selects a group of firms, who are to acquire the foreign technology. It also imposes an all or nothing restriction on the bargaining process, so that if the foreign firm wants to sell the technology, it must sell it to all the firms in this group or to none of them. In the subsequent bargaining process, the government bargains on behalf of the selected firms transfering the technology to them if negotiations prove successful.

I find that the results depend on the ability of the foreign firm to impose restrictions on sublicensing. When the contracts involve restrictions on sublicensing, domestic surplus is higher if the number of firms adopting the technology increases due to the intervention. This follows as the payoff of the foreign firm is greater if the government does not intervene. The greater payoff of the foreign firm is the result of the greater bargaining power of the foreign firm in the absence of intervention, because in this case it can threaten to sell the technology to other firms in case agreement is not arrived at with the current firm. It is possible however that when the number of adopting firms decreases as a result of the intervention the domestic surplus may decline. This is likely to occur when the old technology is not too inefficient and the level of fixed costs is neither too high nor too low.

In this case the equilibrium when there is no intervention may involve the firms who bargain later acquiring the technology. The firms who enter the bargaining process earlier fail to acquire the technology. This may occur if the value of the marginal surplus declines too sharply as the number of firms acquiring the technology increases. The foreign firm now prefers to restrict the number of firms acquiring the technology so as to keep up the value of the surplus.

It is possible that the foreign firm's payoff increases under government intervention, when sublicensing restrictions cannot be imposed. This is the result of the reduced bargaining power of the foreign firm as the domestic firms can now purchase from other domestic firms who have acquired the technology. Without any intervention the domestic firms would have obtained the technology domestically. Under government intervention however they all have to purchase from the foreign firm. This compulsion may be sufficient to offset the advantage accruing from the all or nothing restriction. The condition that the number of firms does not decline under intervention is no longer sufficient to ensure that the domestic surplus increases. I show that in certain cases it may infact decline. Therefore government intervention appears less attractive when the foreign firm cannot impose restrictions on relicensing.

I also examine the impact of technology improvement on the aggregate surplus in the economy. I find that such improvements need not always lead to an increase in the aggregate surplus. If it is an inefficient firm which is undertaking the technology improvement and if the improvement is not too great, then it is possible that the surplus declines. If, however, the technology improvement is large enough the surplus is going to increase. In the context of my model, however, technology improvement is always welfare improving.

Therefore from the analysis it appears that while the intuition as regards the efficacy of centralized bargaining is vindicated in many cases, there are situations where it does not. It appears that the intuition is most likely to be vindicated when in case of no intervention, restrictions on résell can be imposed. If, however, restrictions on resale cannot be imposed caution seems to be called for. Infact it appears from the analysis that imposing legal sanctions against resale restrictions maybe a policy alternative worth looking into.

1.4 Overview of Part II

Chapter 5, entitled" The Outside Option and the Nash Bargaining Solution" can be treated as a contribution to the Nash programme aimed at providing non-cooperative foundations for cooperative solution concepts. There is some debate in the literature regarding the interpretation of the threat point in the

Nash bargaining solution. In applications of the Nash bargaining solution (especially in wage bargaining), the threat point is often identified with the outside option. Examinations of the non-cooperative foundations of the Nash bargaining solution, however, do not support such an identification. Binmore, Rubinstein and Wolinsky (1986) argue that the threat point ought to be identified with the impasse point[34] in case of the standard Rubinstein model and with the breakdown point in models with exogenous risks of breakdown. Both Binmore (1985) and Shaked and Sutton (1984) demonstrate that the outside options of players do not affect the outcome, if the value of the outside option lies below the perfect equilibrium payoff levels that would prevail in the absense of any outside options (the Outside Option Principle[35]). If the value of the outside option exceeds this critical level then the payoff of the concerned player equals the value of the outside option. Hence the outside option payoffs cannot be identified with the threat points in the Nash bargaining solution.

Dalmazzo (1992) provides a justification for treating the outside option vector as the threat point. He considers a model with decay in the size of the cake.[36] This essentially converts the model into a finite horizon one, which can be solved using backwards induction. He shows that in the limit when the time lag between successive offers goes towards zero, the outcome

[34]The impasse point refers to outcome that comes about when the players continue to bargain without reaching an agreement.

[35]See Shaked and Sutton (1984).

[36]Dalmazzo suggests several possible economic reasons to justify the decay; physical decay of production oppurtunities, loss of market due to customers defecting to other firms, increasing amount of interest maturing over time when there is a fixed debt to be repaid etc.

approaches the Nash bargaining solution, where the outside option is taken to be the threat point. In many cases however, the assumption of a decay in the size of the cake is not appropriate. Besides the value of the outside option may also be decreasing for precisely the same reasons that cause a decrease in the cake size. In this chapter I provide an alternative justification which does not rely on the assumption of a shrinking cake.

I consider a model of bilateral bargaining with outside options, where the move structure is probabilistic rather than deterministic. At the start of every period nature selects which player is to make the offer according to some probability distribution. Once a player is selected he makes an offer which the other player may either accept or reject. If he rejects then he may either opt out of the game, when the players immediately receive their outside option payoffs, or remain in the game when in the next period nature again selects which player is to make the offer. I find that the results depend on the nature of the parameter values. Irrespective of the values of the outside option an unique equilibrium exists. *When the value of the outside option is high, compared to the discounted values of the probability of being selected as the proposer, the outside option can be identified with the threat point of the Nash bargaining solution.* I find that the outcome leads to the asymmetric Nash solution, where the probability of any player being selected as the proposer, is interpreted as his bargaining power. However if the value of the outside option is relatively low then the outside option principle holds good in that the value of the outside option does not affect the outcome. In this case the relative payoffs of the players equal their relative probabilities of being selected as the proposer. For intermediate values of the outside option, the outcome depends on the outside option of the player with a relatively higher value of the outside option. It does not depend on the outside option of the other player.

Chapter 6, entitled "Bargaining Without Commitment but with Small Reneging Costs" is concerned with a problem in non-cooperative bargaining theory. Most standard models of bargaining, whether the alternating offers model or the one sided offers model generate a unique perfect equilibrium.

Muthoo (1989, 1990), however argues that a central feature of all these models is that, when an offer is accepted, the bargaining terminates with the implementation of that offer. He demonstrates that allowing the proposer to change his mind can lead to non-uniqueness of equilibria in both the alternating offers (Rubinstein) model as well as the one sided offers model.

In this chapter I introduce reneging costs into the model. This cost could arise through penalties imposed by the courts or by the society when some standadised procedures for bargaining exist. Alternatively, reputational loss following reneging could also lead to costs for the reneger.

I consider three forms of penalties for reneging: fixed costs, proportional costs and reputational costs. Suppose that a player reneges on his offer. In the fixed cost scheme a fixed slice of the remaining cake would be cut off and offered to the other player. When the costs are proportional the other player would be offered a given proportion of the cake. In the case of reputational costs there is a loss of reputation which is captured by the fact that the reneging player would have to incur a given cost whereas no compensatory benefit is earned by the other bargainer. In the last two cases I assume that for repeat offenses the penalty increases and that ultimately it is going to get very large. In the next period the bargaining would be carried out over the truncated cake.

I show that for all three specifications of the penalty a unique equilibrium exists for one sided offers bargaining. In the alternating offers bargaining model however the results are more complex. When the discount factor is small I find that I have a unique equilibrium for any positive level of costs. For fixed costs I find that for large values of the discount factor perfect equilibrium may not be unique. Uniqueness obtains when the size of the penalty is large relative to the size of the cake.

In the context of Muthoo's model I also provide a number of justifications for considering the Rubinstein solution more acceptable than the alternative equilibria proposed by Muthoo. For one, the Rubinstein solution is reached as the limit of the unique equilibrium of the truncated games. For another, restricting ourselves to Markov strategies in the infinite horizon game yield the Rubinstein solution as the unique equilibrium. I also demonstrate that in the Muthoo model there exist perfect equilibria with delay.

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Part I

Joint Ventures

Chapter 2

Technological Asymmetry and Joint Product Development

2.1 Introduction

In this chapter I pose the following question. Suppose there are two firms undertaking joint product development. What determines whether the firms will be successful in developing this product? I am specifically interested in the question whether technologically similar firms are more likely to succeed compared to technologically dissimilar firms when they collaborate.

Empirically the evidence is impressionistic rather than systematic. Even so, Mowery (1988) suggests that technologically dissimilar firms are usually more successful in developing the product. Product development between technological equals like that between Rolls Royce and Pratt and Whitney in the JT 10D jet engine, Fokker and Mcdonell Douglas in the MDF 100 commercial aircraft project, and Saab and Fairchild in the SF 340 commuter aircraft project has frequently failed to develop the product or market it. The AT & T-Phillips venture in telecommunications also ran into problems.[1] Product development ventures between dissimilar firms e.g. the CFM International venture between General Electric and SNECMA of France and that between Boeing and the Japan Commercial Transport Developement Corporation appeared to be doing better.[2]

I seek to explain this phenomenon through an analysis of the free-rider problem involved in joint research. In order to focus on the simplest possible model in which the free-rider problem can be posed, some of the usual questions addressed in the product development literature are abstracted from. These include the problem of market interaction following the product development stage as well as the spill-over effect. D'Aspremont and Jacquemin (1988) investigate the effects of extending cooperation from the R & D stage to the marketing stage. They show that some of the expected results of the product development literature (decrease in R & D expenditure, decrease in total production) may not hold if the analysis incorporates spill-over effects. Katz (1986) examines whether allowing firms in a given industry to form cooperative R & D ventures can be an effective way of correcting the failure of R & D levels to reach the socially optimum levels. Killing (1983) explains the greater success of the technologically divergent firms in terms of the greater incentive of the technologically inferior firm to make the cooperation work so as to benefit from the spillover effects.

[1] Business Week, 1/18/88p.62.

[2] See Mowery (1988) for a more detailed discussion of these issues.

In this chapter I examine a model of two firms undertaking joint product development. I start with a static one period game where the two firms simultaneously decide on their effort levels. The probability of success depends on the joint effort of the two firms. For any given level of efforts the probability of success is given by a function which I call the return function. Efforts are unobservable or nonverifiable by courts and so cannot be contracted upon. Both the firms are assumed to share equally in the resulting profits. The technological dissimilarity pertains to the marginal costs of putting in the effort. Initially I consider whether the firms would find it individually rational to opt for joint product development rather than going it alone. I find that joint product development is individually rational if the technology levels are not too dissimilar and the cost levels are not too high compared to the gross profits. However if the technology levels are too dissimilar then the efficient firm will not find it individually rational to opt for joint product development.

In the remainder of this chapter I consider the case where the joint venture has formed. In the one period setting the model generates the result that an increase in technological dissimilarity (mean-preserving spread of marginal costs) increases the probability of success. The reason is that the more productive firm increases effort and the less productive firm decreases effort, but the increase in effort of the more productive firm more than compensates for the decrease in effort by the other firm. I identify sufficient conditions for this to happen. The result holds for a large class of cost functions e.g. for cost functions with concavity or constant elasticity of marginal cost. This result is independent of the nature of the return function.

The above results pertain to the case where the sharing rule is exogenously given. I next investigate the case where the sharing rule is endogenously determined. I find that if the endogenously determined sharing rule obeys some reasonable conditions then the previous conditions are still sufficient to ensure that the effort stream increases for a mean preserving spread of the technology levels. I also identify some situations when the sharing rule would obey the stipulated restrictions. I find that such conditions may arise either when the sharing rule is determined through a Nash bargaining solution or when it is determined so as to maximise aggregate profits.

I then examine how the results extend to a dynamic context where the two firms are interacting over two periods. The earlier sufficient conditions no longer ensure that the effort stream increases as the firms become more technologically diverse. The reason is as follows. As a result of greater technological diversity the second period pay-off of the firms may increase. This would have a negative effect on the first period efforts because the consequences of failure in the first period is reduced. Hence the net effect on the effort stream could go either way.

The preceding result, however, is driven by the sharp asymmetry between the first and the second stages of the game. This asymmetry is somewhat artificial, and would disappear in an infinite horizon framework. I therefore subsequently examine a stationary Markov equilibrium in the infinite horizon formulation. I find that for if the costs are linear the results still hold. For more complex cost structures, however, the effect is ambiguous. Therefore it appears that for technological cooperation over a short span of time the impressionistic evidence can be supported theoretically. For longer time periods the effect is less certain. In the infinite horizon game however the result reemerges for some cost functions.

I next introduce uncertainty over the possible cost parameters of the two firms. I examine the case where the cost parameters of the firms are private information, though drawn from the same distribution. For the case of symmetric equilibria I identify sufficient conditions for the joint effort stream to increase for a mean preserving spread of the realised levels of the technology parameters. The condition is that the marginal cost should be concave and that the marginal return function should be convex in the effort levels.

I also look at the case where the firms can indulge in basic research to determine the technology levels endogenously. This introduces another level of free-riding into the problem. Under the simplifying assumption of constant cost of basic research I show that for a certain class of cost functions at least one of the firms is going to go in for the most efficient level of technology. Here the problem is that reducing one's productivity may increase asymmetry and thus increase the likelihood of success because the other party puts in more effort. This may outweigh increased effort costs and so free-riding would increase.

The rest of the chapter is organised as follows. The one period game is taken up in section 2. The case where the sharing rule is endogenously determined is considered in section 3. Section 4 briefly examines the two period game. Section 5 is concerned with the infinite horizon game. In section 6 I examine the case where the technology levels of the two firms are private information though drawn from the same distribution. Section 7 looks at the case when the firms can choose their level of technology simultaneously prior to choosing their levels of effort. Section 8 summarizes and concludes.

2.2 One Period Game

There are two firms, firm 1 and firm 2, jointly trying to develop a product denoted X. If they succeed they jointly receive a gross pay-off of R, which they split equally.[3] One way to interpret R is to think of the joint venture as a purely research venture which is going to sell the product to a third firm for a fixed fee R. Alternatively one can think of the joint venture as cooperating in the product market as well. In this case R can be interpreted as the payoff accruing to the firms from jointly marketing the product. If they fail to develop the product they receive nothing, despite incurring development costs.[4] The cost functions of the two firms are given by $C_i(e_i) = h_i \int_0^{e_i} c(\tilde{e}_i)d\tilde{e}_i$, $i = 1, 2$ where e_i is the amount of effort put in by the ith firm, $h_i c(e_i)$ is the marginal cost of effort of the ith firm and h_i^{-1} is a productivity index. I use h_1, h_2 as indices of technological similarity. If $h_1 < h_2$ then I say that firm 1 is technologically superior to firm 2. If $h_1 = h_2$ then I say that they are technologically identical. The probability of success is given by $\lambda(e_1 + e_2)$.[5]

[3] In the next section I relax this assumption to examine the case where the sharing rule is determined endogenously.

[4] As I argue below I can assume that in case of failure also they receive a positive payoff, which is smaller than what they would receive in case of success. This will not affect the analysis in any way.

[5] An equilivalent formulation of the same problem would be as follows. Let $\lambda(E_1, E_2) = \lambda(n_1 E_1 + n_2 E_2)$ and let $C(E_i) = \int_0^{E_i} c(e)de$ where $c(e)$ is the marginal cost of effort. One has to be careful about what a mean preserving spread of n_1 and n_2 denotes in this context. The equivalent formulation here would be a mean preserving spread of $\frac{1}{n_1}$ and $\frac{1}{n_2}$.

The profits of the two firms are therefore given by,

$$P_1(e_1, e_2) = \lambda(e_1 + e_2)\frac{R}{2} - h_1 \int_0^{e_1} c(\tilde{e_1})d\tilde{e_1} \quad (2.2.1)$$

$$P_2(e_1, e_2) = \lambda(e_1 + e_2)\frac{R}{2} - h_2 \int_0^{e_2} c(\tilde{e_2})d\tilde{e_2} \quad (2.2.2)$$

Though the analysis will be, for the most part, carried out in the context of product development, I point out that the framework can also handle the case of process innovation. Suppose there are two firms collaborating in order to develop a cheaper method of production. If success occurs then in the next period production is going to utilise the cheaper technology, otherwise production involves the old technology. I assume that the firms cooperate in the product market as well, and the share of the first firm is α. Let the joint profits in case of success be P and that in case of failure be P', with $P > P'$.

Therefore the profits in this case would be,

$$\begin{aligned} Q_1 &= \lambda(e_1 + e_2)P\alpha + (1 - \lambda)P'\alpha - h_1 \int c(e_1)de_1 \\ &= P'\alpha + \lambda(e_1 + e_2)(P - P')\alpha - h_1 \int c(e_1)de_1 \\ Q_2 &= P'(1 - \alpha) + \lambda(e_1 + e_2)(P - P')(1 - \alpha) - h_2 \int c(e_2)de_2 \quad (2.2.3) \end{aligned}$$

Observe that except for the constant term the profit expressions in this case are formally equivalent to that in case of joint product development. Notice that the above formulation also covers the case of product development with a positive profit in case of success. In this case I denote the payoff from success as P and the payoff from failure as P'.

I make the following assumptions on $c(e_i)$ and λ,

(A) c and λ are twice continuously differentiable.

(B) Marginal costs are positive and strictly increasing in effort level i.e. $c(e_i) \geq 0$ and $c'(e_i) > 0$, $\forall e_i$.

(C) Marginal productivity of effort is positive but strictly decreasing in the effort level i.e. $\lambda \in [0,1], \lambda' > 0, \lambda'' < 0$.

(D) $c(0) = 0$.

Since the pay-off functions P_i are strictly concave in e_i, I can use the first order condition to derive the two reaction functions, $R1$ of firm 1 and $R2$ of firm 2. (See Figure 1.) The reaction functions can be obtained by solving the following equations,

$$
\begin{aligned}
h_1 c(e_1) &= \lambda'(e_1 + e_2)\frac{R}{2} &\quad (2.2.4)\\
h_2 c(e_2) &= \lambda'(e_1 + e_2)\frac{R}{2} &\quad (2.2.5)
\end{aligned}
$$

Assumption D is a simplifying assumption which ensures that for all $h_1, h_2 \neq 0$ a strictly interior solution exists i.e. the equilibrium effort levels are strictly positive.[6]

First I examine whether the firms find it individually rational to go in for joint product development rather than pursue isolated research. Marjit (1991) also examines the individual rationality of pursuing joint research. His model however involves process innovation rather than product development and more importantly the probability of success is exogenous rather than endogenous. He also assumes that the firms cannot cooperate in the product

[6]Define e_1' by $\lambda'(e_1')\frac{R}{2} = h_1 c(e_1')$ and e_1'' by $\lambda'(e_1'')\frac{R}{2} = h_2 c(0) = 0$. Therefore for all h_1, h_2 it follows that $e_1' < e_1''$. One can similarly define e_2' for $R2$ and e_2'' for $R1$ and show that $e_2' < e_2''$ which proves my contention.

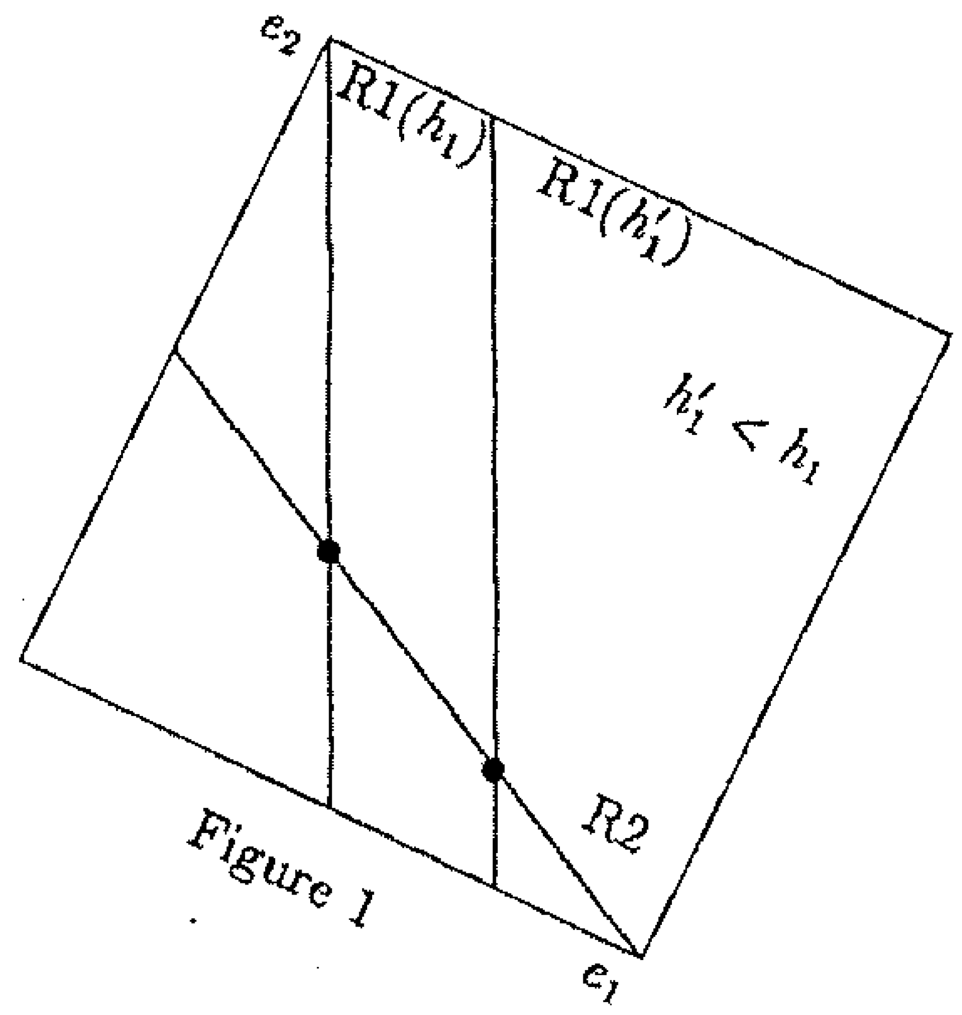

Figure 1

market. He finds that joint research is profitable provided the exogenous probability of success is either too high or too low.

I assume that the alternative to joint ventures is competitive R&D by the two firms. I also assume that if both the firms succeed in developing the product then the gross pay-offs are zero. This can be justified by assuming that the post discovery production involves price competition. Denoting the disagreement pay-offs by D_i,

$$D_1(e_1, e_2) = \lambda(e_1)(1-\lambda(e_2))R - h_1 \int c(e_1)de_1, \tag{2.2.6}$$

$$D_2(e_1, e_2) = \lambda(e_2)(1-\lambda(e_1))R - h_2 \int c(e_2)de_2 \tag{2.2.7}$$

The first order conditions would be,

$$\lambda'(e_1)(1-\lambda(e_2))R = h_1 c(e_1) \tag{2.2.8}$$

$$\lambda'(e_2)(1-\lambda(e_1))R = h_2 c(e_2) \tag{2.2.9}$$

The reaction functions of firm 1 and firm 2 are denoted by F1 and F2 respectively. It is easy to see that the reaction functions are negatively sloped. It can be demonstrated that if $\lambda(E) < 1, \ \forall E < \infty$ and $\lim_{E\to\infty} \lambda(E) = 1$, the equilibria will be interior.[7]

Proposition 1 demonstrates that, for a sufficient condition on the return function, if h_1 and h_2 are equal and the return R is high enough relative to the cost parameter, it is individually rational for both firms to opt for joint product development.

[7] Define e_1' by $\lambda'(e_1')(1-\lambda(0))R = h_1 c(e_1')$ and e_1'' by $(1-\lambda(e_1''))R\lambda'(0) = h_2 c(0) = 0$. Therefore $\lambda(e_1'') = 1$. Hence forall h_1, h_2 it follows that that $e_1' < e_1''$. One can similarly define e_2' for $F2$ and e_2'' for $F1$ and show that $e_2' < e_2''$ which proves my contention.

Proposition 1. *Assume that* $h_1 = h_2$ *and* $\lambda'(e_i)(1-\lambda(e_j)) \geq \lambda'(e_i + e_j), \forall e_i, e_j$. *I also assume that under competitive R&D a unique solution exists and there exists* e^* *such that* $\lambda(2e^*) \geq \frac{1}{2}$. *For a high enough* $\frac{R}{h}$ *the profit from joint product development exceeds that from competitive R&D.*

Proof. The first order conditions for the joint product development case simplify to, $\lambda'(e_1+e_2)R = 2hc(e_i)$ $i = 1, 2$. It is obvious that the equilibrium must be symmetric i.e. $e_1 = e_2$.

Next I examine the case where the firms indulge in competitive R&D. The first order conditions in this case becomes $R\lambda'(e_i)(1-\lambda(e_j)) = hc(e_i), i \neq j$. I have already shown that an interior solution exists. Since by assumption the equilibrium is unique, it must be symmetric. The first order conditions therefore reduce to $\lambda'(e)(1-\lambda(e))R = hc(e)$.

Let the solution in case of joint product development and competitive R&D be denoted by $\overline{e}$ and $\underline{e}$ respectively. Clearly for $\frac{R}{h}$ high enough[8] $\overline{e} > \frac{1}{2}$.

I next argue that $\underline{e} \geq \overline{e}$. Suppose not, then $\overline{e} > \underline{e}$. This implies that,

$$hc(\underline{e}) = \lambda'(\underline{e})(1-\lambda(\underline{e}))R \geq \lambda'(2\underline{e})R > \lambda'(2\overline{e})\frac{R}{2} = hc(\overline{e})$$

But this implies that $\overline{e} < \underline{e}$ which is a contradiction.

The pay-offs under the two cases would be,

$$P = \lambda(2\overline{e})\frac{R}{2} - h\int_0^{\overline{e}} c(e)de \tag{2.2.10}$$

$$D = \lambda(\underline{e})(1-\lambda(\underline{e}))R - h\int_0^{\underline{e}} c(e)de. \tag{2.2.11}$$

For $\lambda(2\overline{e}) > \frac{1}{2}$, $\lambda(2\overline{e})\frac{R}{2} > \lambda(\underline{e})(1-\lambda(\underline{e}))R$ and for $\underline{e} \geq \overline{e}$, $h\int_0^{\underline{e}} c(e)de \geq h\int_0^{\overline{e}} c(e)de$. ∎

[8] Take $\frac{R}{h}$ such that $\frac{R}{h} \geq \frac{2c(e^*)}{\lambda'(2e^*)}$.

The next example demonstrates that the condition on the return function is not necessary for the proof. I show that even in the case of a linear return function viz. $\lambda(e_1 + e_2) = \min(1, e_1 + e_2)$, where the condition is not satisfied, a similar result holds.

I demonstrate that if h_1 and h_2 are equal and the return R is high enough relative to the cost parameter, it is individually rational for both firms to opt for joint product development.

Assume that $\frac{R}{h} < \min\{2c(\frac{1}{2}), c(1), \min c'(e_i)\}$.[9]

The first order conditions for the joint product development case simplify to, $R = 2hc(e_i)\ i = 1, 2$. It is obvious that the equilibrium must be symmetric i.e. $e_1 = e_2$. For $\frac{R}{h} < 2c(\frac{1}{2})$, the joint effort stream would be less than 1, so that the first order condition becomes, $R = 2hc(e)$.

Next I examine the case where the firms indulge in competitive R&D. The first order conditions in this case becomes $R(1 - e_j) = hc(e_i), i \neq j$. It is easy to see that an interior solution exists.[10]

Next observe that the condition $\frac{R}{h} < c'(e_i)\forall e_i$ implies that the slope of F1 is less than -1 and the slope of F2 is greater than -1.[11] Therefore the equilibrium is unique and symmetric. The first order conditions therefore reduce to $(1 - e)R = hc(e)$.

---

[9] For a quadratic cost function of the form $\frac{h_i e_i^2}{2}$ this reduces to $h \geq R$.

[10] Define e_1' by $R = h_1 c(e_1')$ and e_1'' by $(1 - e_1'')R = h_2 c(0) = 0$. Therefore $e_1'' = 1$. Hence for all h_1, h_2 it follows that that $e_1' = c^{-1}(\frac{R}{h} < 1 = e_1''$. This follows from the condition that $\frac{R}{h} < c(1)$. One can similarly define e_2' for $F2$ and e_2'' for $F1$ and show that $e_2' > e_2''$ which proves my contention.

[11] $\frac{de_2}{de_1}|_{F1} = -\frac{h}{R}c'(e_1) < -1$ and $\frac{de_2}{de_1}|_{F2} = -\frac{R}{hc'(e_2)} > -1$.

Let the solution in case of joint product development and competitive R&D be denoted by $\overline{e}$ and $\underline{e}$ respectively. Clearly $\overline{e} = c^{-1}(\frac{R}{2h})$. Therefore for $\frac{R}{h}$ high enough $\overline{e} > \frac{1}{4}$.

I next argue that $\underline{e} \geq \overline{e}$. Suppose not, then $\overline{e} > \underline{e}$. This implies that $c(\overline{e}) > c(\underline{e})$ i.e. $\frac{R}{2h} > \frac{R}{h}(1-\underline{e})$. This implies that $\underline{e} > \frac{1}{2}$. But this implies that $2\overline{e} > 2\underline{e} > 1$ which is a contradiction.

The pay-offs under the two cases would be,

$$\begin{aligned} P &= \overline{e}R - h\int_0^{\overline{e}} c(e)de \\ D &= \underline{e}(1-\underline{e})R - h\int_0^{\underline{e}} c(e)de. \end{aligned}$$

For $\overline{e} > \frac{1}{4}$, $\overline{e}R > \underline{e}(1-\underline{e})R$ and for $\underline{e} \geq \overline{e}$, $h\int_0^{\underline{e}} c(e)de \geq h\int_0^{\overline{e}} c(e)de$.

In the next proposition I prove that the technology levels of the two firms cannot be too far apart if joint product development is to take place. Basically what happens is the following. As one of the firms becomes very inefficient the equilibrium effort level put in by the inefficient firm becomes negligible, however it would still obtain half of the profit shares if success occurs. Therefore it is better for the efficient firm to go it alone. This proposition does not require any conditions on the return function. This however does depend on the equal split of profits.[12]

Proposition 2. *Assume that $\lambda(0) < \frac{1}{2}$. For any given level of h_1, it is not individually rational for the first firm to opt for joint product development if the second firm is inefficient enough.*

[12] Actually the proof only requires that the profit share be independent of h_1 and h_2, rather than exactly one half for the two firms.

Proof. Define $\tilde{e_1}$ = argmax $R\lambda(e_1)(1-\lambda(0)) - h_1 \int c(e_1)de_1$ and define $\overline{e_1}$ = argmax $\frac{R}{2}\lambda(e_1) - h_1 \int c(e_1)de_1$. Let $\overline{D_1} = R\lambda(\tilde{e_1})(1-\lambda(0)) - h_1 \int^{\tilde{e_1}} c(e_1)de_1$ and $\overline{P_1} = \frac{R}{2}\lambda(\overline{e_1}) - h_1 \int^{\overline{e_1}} c(e_1)de_1$.

Now $R\lambda(\tilde{e_1})(1-\lambda(0)) - h_1 \int^{\tilde{e_1}} c(e_1)de_1 \geq R\lambda(\overline{e_1})(1-\lambda(0)) - h_1 \int^{\overline{e_1}} c(e_1)de_1$ [as $\tilde{e_1}$ = argmax $D_1(e_1, 0)$] $> \frac{R}{2}\lambda(\overline{e_1}) - h_1 \int^{\overline{e_1}} c(e_1)de_1$.

Next I show that for h_2 high enough P_1 approach $\overline{P_1}$ and D_1 approach $\tilde{D}_1$. First consider the case of joint product development.

Pick an (e_1', e_2') arbitrarily close to $(\overline{e_1}, 0)$. Take h_2' such that $R2(h_2')$ originates at $(0, e_2')$, $h_2' = \frac{R\lambda'(e_2')}{2c(e_2')}$. (See Figure 2). Therefore for this $R2$ the intersection would be below (e_1', e_2').

Next consider competitive R&D. Since F1 and F2 are negatively sloped and the intersection is unique and interior I can simply mimic the earlier argument. ∎

Propositions 1 and 2 are concerned with properties that hold in the limit. The spirit of the results however, seems to be, that joint product development is individually rational provided the technology levels are not too far apart. I show that in a simple example this is indeed true.

Consider the case where the return function is linear viz. $\lambda(e_1 + e_2) = \min(1, e_1 + e_2)$ and the cost function is quadratic viz. $C(e_i) = \frac{h_i e_i^2}{2}$.

In order to ensure that the solution in the joint product development case is interior I assume that the return from success is not too high compared to the R&D costs. Formally the condition is that $R < h_1, h_2$.

In this case the pay-offs from the two options can be calculated explicitly, $P_1 = \frac{R^2}{4}(\frac{1}{2h_1} + \frac{1}{h_2})$ and $D_1 = \frac{R^2 h_1 (h_2 - R)^2}{2(h_1 h_2 - R^2)^2}$.

I begin by showing that there exists h_2^* such that joint development is

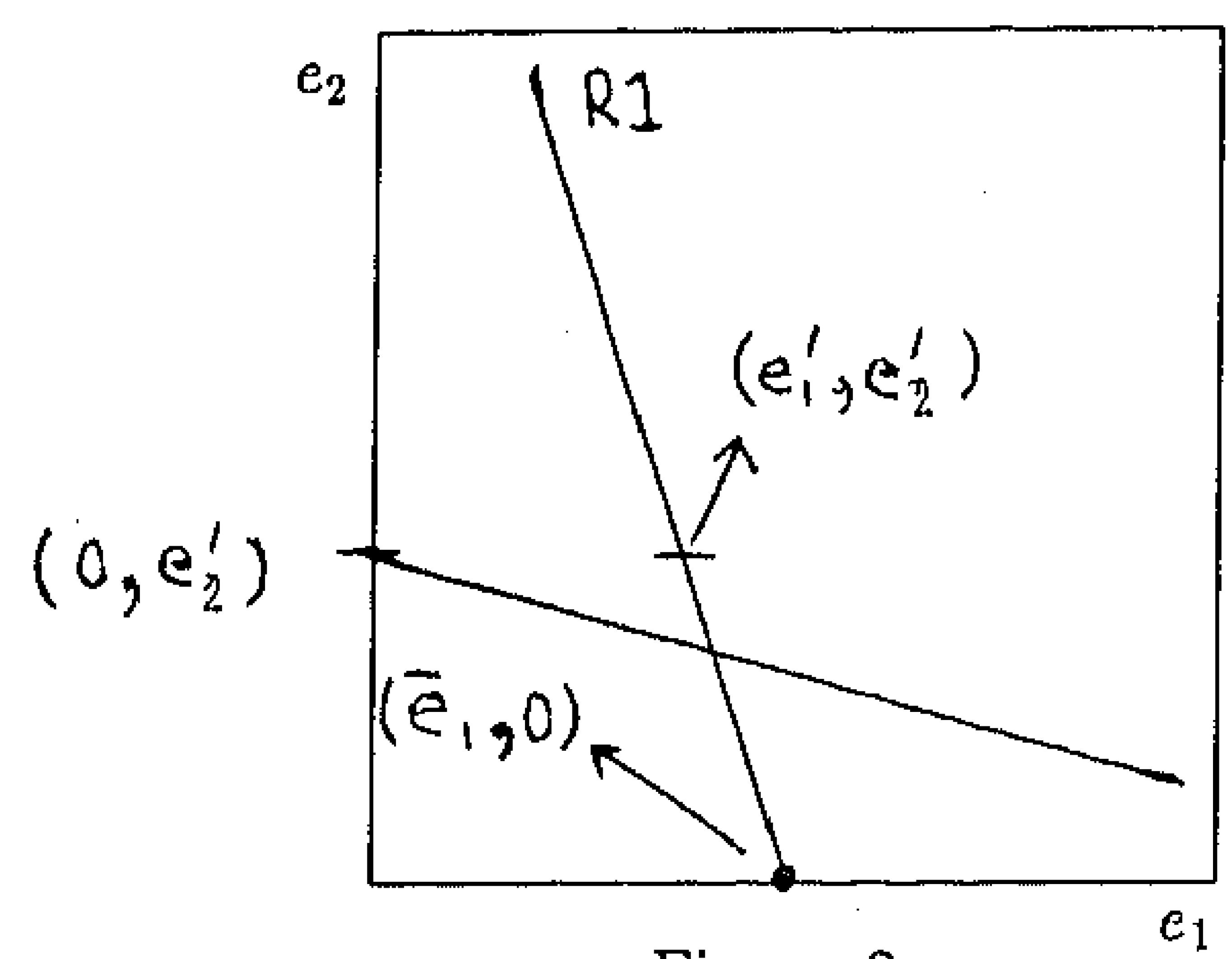

Figure 2

individually rational for the first firm iff the technology level of the other firm is atleast as efficient as h_2^*.

Clearly, $\lim_{h_2 \to \infty} D_1 = \frac{R^2}{2h_1} > \frac{R^2}{8h_1} = \lim_{h_2 \to \infty} P_1$

$D_1|_{h_2=R} = 0 < \frac{R^2}{4}(\frac{1}{R} + \frac{1}{2h_1}) = P_1|_{h_2=R}$.

Also $\frac{\partial P_1}{\partial h_2} < 0$ and $\frac{\partial D_1}{\partial h_2} = \frac{R^3 h_1(h_2-R)(h_1-R)}{(h_1h_2-R^2)^3} > 0$.

Therefore the result follows from the continuity of P_1 and D_1.

I next demonstrate that there exists h_1^* such that joint product development is not individually rational for the first firm if it is more efficient than h_1^*.

It can be shown that both P_1 and D_1 are negatively sloped in h_1.[13] It is easy to see that,

$$\lim_{h_1 \to \infty} P_1 = \frac{R^2}{4h_2} > 0 = \lim_{h_1 \to \infty} D_1$$

$$P_1|_{h_1=R} = \frac{R^2}{4}[\frac{1}{h_2} + \frac{1}{2R}] < \frac{R}{2} = D_1|_{h_1=R}$$

The result follows from the continuity of P_1 and D_1.

Lastly I show that for $h_1 = h_2$, joint product development will not be individually rational if the return R becomes very small.

When $h_1 = h_2 = h$, I find that $P = \frac{3R^2}{8h}$ and $D = \frac{hR^2}{2(h+R)^2}$. Clearly as R becomes very small, the disagreement pay-off comes to dominate the joint development pay-off.

$$(P - D) = \frac{R^2}{2}\{\frac{3}{4h} - \frac{h}{(h+R)^2}\}$$

$$\lim_{R \to 0}\{\frac{3}{4h} - \frac{h}{(h+R)^2}\} = -\frac{1}{4h}$$

Therefore $\lim_{R \to 0}(P - D) < 0$.

---

[13] $\frac{\partial D_1}{\partial h_1} = -\frac{R^2(h_2-R)^2(R^2+h_1h_2)}{2(h_1h_2-R^2)^3}$.

This example demonstrates that even if the profit share is endogenous, joint venture need not always be individually rational. Straightforward calculations yield that P_1 is maximized at $\alpha = 1$ and P_2 is maximized at $\alpha = 0$, where α denotes the profit share of the first firm. It is also easy to demonstrate that P_1 is decreasing and P_2 is increasing in α. It is obvious that for a joint venture to be individually rational $P(\alpha = \frac{1}{2}) > D$. Otherwise there do not exist any α for which a joint venture would be individually rational. The above example shows that for R small enough such is indeed the case.

I next investigate whether technological diversity is good for the success of joint product development ventures. The next proposition provides two sufficient conditions for the effort stream to increase for a mean preserving spread of the technology levels.

Proposition 3. *(A) There exists a unique and interior Nash equilibrium of this game.*

(B) Either of the following are sufficient conditions for the joint effort stream $(e_1 + e_2)$ to increase for a mean-preserving spread of h_1 and h_2:

(i) $c(e_i)$ should be concave,

(ii) c^{-1} be homogeneous of degree k, $k \geq 0$.

Proof. (A) Uniqueness follows from the fact that R1 and R2 are both negatively sloped and that R1 has a slope less than -1 and R2 has a slope greater than -1.[14]

(B) See Appendix.[15]

Diagrammatically it is easy to see what is going on. (See Figure 3.) First consider a quadratic cost function i.e. $C_i = \frac{h_i e_i^2}{2}$. The Nash conditions are

$$h_1 e_1 = \lambda'(e_1 + e_2)\frac{R}{2} \quad (2.2.12)$$
$$h_2 e_2 = \lambda'(e_1 + e_2)\frac{R}{2} \quad (2.2.13)$$

Suppose $(e_1 + e_2)$ decreases or stays the same. Initially (h_1, e_1) and (h_2, e_2) was on the same rectangular hyperbola. Now suppose to the contrary that the effort stream decreases then λ' increases and I should move to a higher rectangular hyperbola. Clearly from the diagram e_1 must increase by more which is a contradiction.

---

[14]Differentiating equations (4) and (5) I obtain that

$$\frac{de_2}{de_1}|_{R1} = -1 - \frac{h_1 c'(e_1)}{-\lambda'' \frac{R}{2}} < -1$$
$$\frac{de_2}{de_1}|_{R2} = -1 + \frac{h_2 c'(e_2)}{-\lambda'' \frac{R}{2} + h_2 c'(e_2)} > -1$$

[15]I briefly mention the case when the return function is multiplicative rather than additive in the effort levels of the two firms, viz. $\lambda = \lambda(e_1 e_2)$. Define $\mu = E\lambda'$, where $E = e_1 e_2$ and $d(e) = ec(e)$. I can provide two sets of sufficient conditions for the effort stream to increase for a mean preserving spread of h_1 and h_2,

(A) $d^{-1}(e)$ be homogenous of degree $k \geq 0$ and $\mu(E)$ be decreasing in E.

(B) $d(e)$ be concave and and $\mu(E)$ be decreasing in E.

The condition that $\mu(E)$ be decreasing in E is equivalent to the condition that $\frac{-\lambda'(E)}{\lambda''(E)} < E$ and the condition that $d(e)$ be concave is equivalent to the condition that $2c'(e) + ec''(e) < 0$.

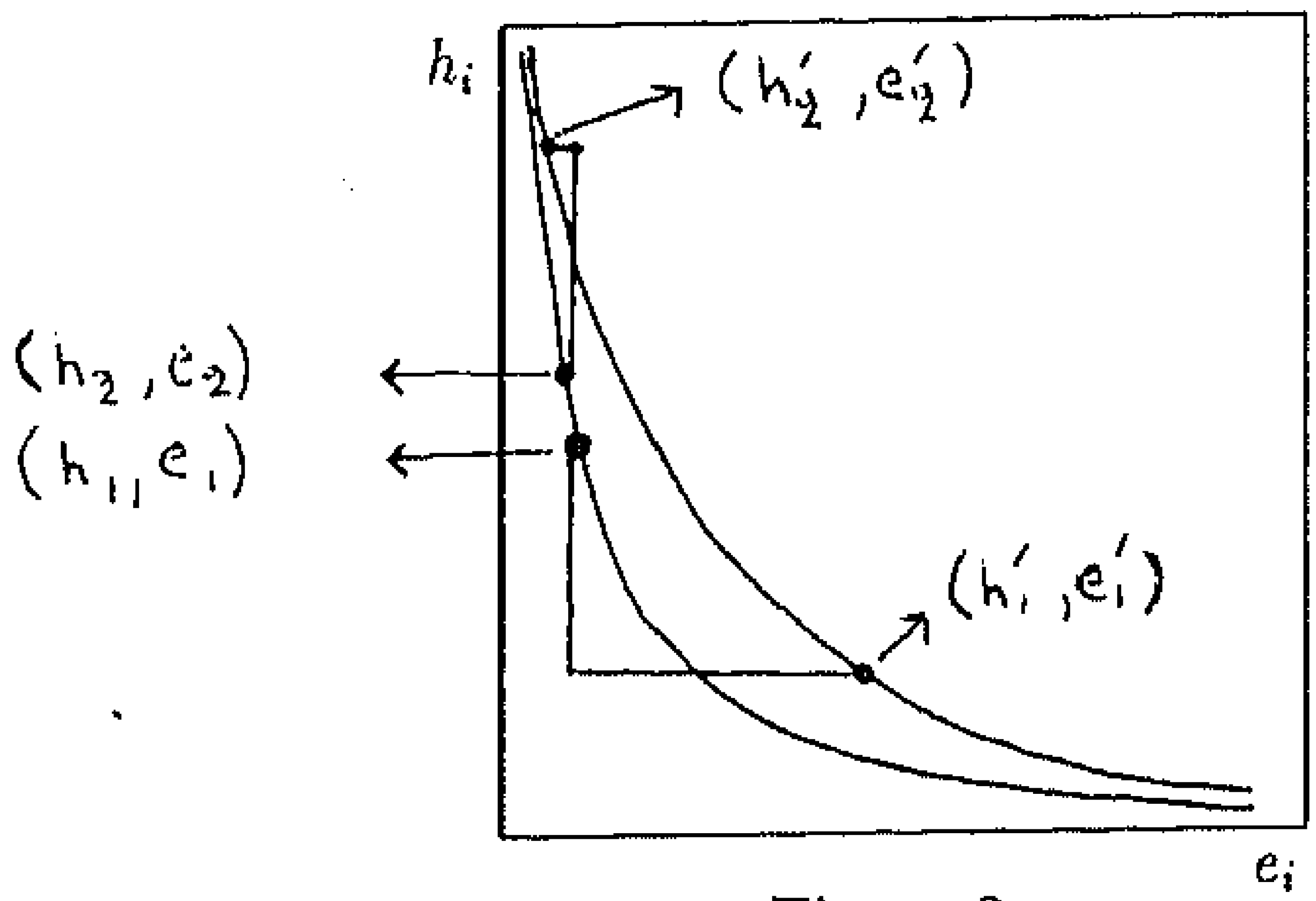

Figure 3

For the general case replace the e axis by $c(e)$ and by the same argument I see that $c(e_1)$ should increase much more. For a concave $c(e)$ function this again implies that e_1 should increase more.

Part B(ii) of proposition 4 enables me to give definite answer for some cost curves with convexity of marginal cost ($c'' > 0$) e.g: $C(e_1) = h_1 e_1^m, m > 2$.

Next I investigate the relation between the Nash and the efficient solution. The efficient effort pair (e_1, e_2) solves

$$\text{Max}_{e_1,e_2} \lambda(e_1 + e_2)R - C_1 - C_2$$

Let E1 and E2 be given by the solution to

$$h_1 c(e_1) = \lambda'(e_1 + e_2)R \tag{2.2.14}$$

$$h_2 c(e_2) = \lambda'(e_1 + e_2)R \tag{2.2.15}$$

Clearly an equivalent version of proposition 4 holds for the efficient solution as well. (See Figure 4.)

I can also show that the effort stream for the efficient case is higher than that for the Nash solution. This is essentially the well known free-rider problem.[16]

2.3 Endogenous Sharing Rule

So far in the analysis I have assumed that the sharing rule is exogenously given. I next consider the case where the sharing rule is determined endogenously following some criterion or through a bargaining process. First I show

[16]This is easy to see since E1 lies to the right of R1 and E2 lies to the right of R2. This coupled with the slope of the E and R curves yields this result.

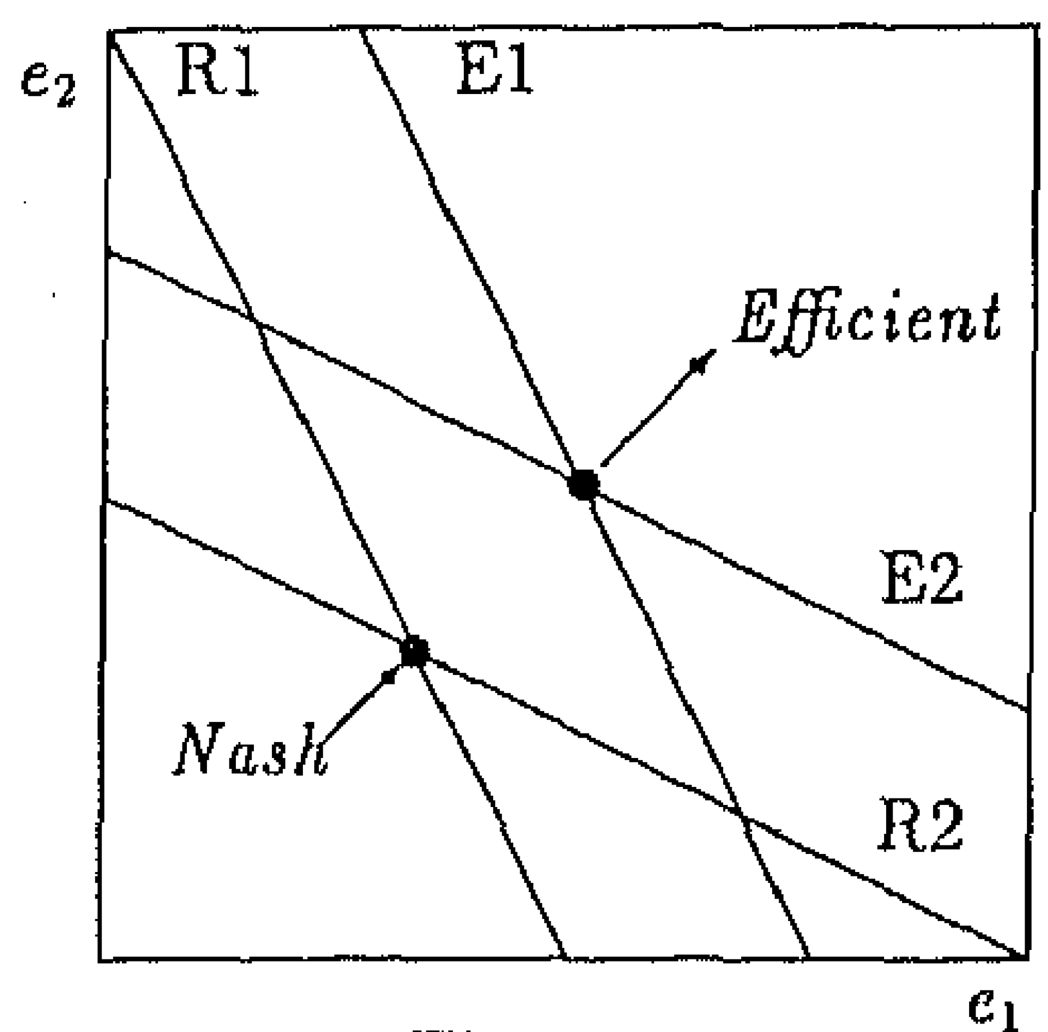

Figure 4

that for some quite reasonable restrictions on the endogenous sharing rule the effort level increases for a mean preserving spread of the technology levels. Next I identify some procedures for determining the sharing rule, which could generate sharing rules satisfying these restrictions.

Assumption E. The sharing rule $\alpha = \alpha(h_1, h_2)$ is differentiable in both the variables and obeys the following two restrictions:

(i) Symmetry: $\alpha = \frac{1}{2}$ for $h_1 = h_2$.

(ii) Monotonicity: α is increasing in h_2 and decreasing in h_1.

The first assumption states that if the firms are symmetric as regards the cost structure then they would share the profits equally. The second assumption relates the profit share to the relative efficiency of the two firms. It states that if a firm becomes relatively more efficient then its share would increase. Clearly taken together the assumptions imply that the more efficient firm would obtain a larger share of the profits.

The first order conditions in this case would be,

$$\lambda'(e_1 + e_2)R\alpha(h_1, h_2) = h_1 c(e_1) \qquad (2.3.16)$$

$$\lambda'(e_1 + e_2)R(1 - \alpha(h_1, h_2)) = h_2 c(e_2). \qquad (2.3.17)$$

Proposition 4 demonstrates that for sharing rules that obey some reasonable restrictions, the previous conditions are still sufficient to ensure that the effort level increases for a mean preseving spread of the technology levels.

Proposition 4. *For any sharing rule satisfying the symmetry and monotonicity conditions, either of the following is a sufficient condition for the* *joint effort stream to increase for a mean preserving spread of the technology levels h_1 and h_2:*

(i) The marginal cost c be concave.

(ii) The inverse of the marginal cost function c^{-1} be homogeneous of degree $k \geq 0$ and either

(a) $k \geq 1$, or

(b) $k < 1$ and in addition the sharing rule obeys the condition that $\alpha \leq \frac{h_2^{\frac{k}{1-k}}}{h_1^{\frac{k}{1-k}} + h_2^{\frac{k}{1-k}}}$.

Proof. See Appendix.

Condition (ii)(b) states that though the sharing rule should give a larger share to the more efficient firm it should not give it a share which is too large.

I next show that the restrictions placed on the endogenous sharing rule are not empty, i.e. there do exist procedures under which I can expect such restrictions to hold. To this end I examine two cases. The first is when the sharing rule is determined so as to maximise the aggregate profits $P_1 + P_2$ and the second is when the sharing rule is determined through the Nash bargaining process.

I simplify to the case where the return function is linear viz. $\lambda(e_1 + e_2) = \min(1, e_1 + e_2)$ and the cost functions are homogenous viz. $C(e_i) = \frac{h_i e_i^{k+1}}{k+1}$, where $k \geq 1$.

The first order conditions in this case are,

$$R\alpha = h_1 e_1^k \quad (2.3.18)$$

$$R(1-\alpha) = h_2 e_2^k \quad (2.3.19)$$

The case where the sharing rule is determined through a Nash bargaining process is examined under assumption that the disagreement payoffs are determined by the competitive R&D outcome. For the sake of computational convenience I simplify by considering the quadratic cost function viz. $C(e_i) = \frac{h_1 e_i^2}{2}$. In this case the disagreement pay-offs are given by the following equations,

$$D_1 = e_1(1 - e_2)R - \frac{h_1 e_1^2}{2} \tag{2.3.20}$$

$$D_2 = e_2(1 - e_1)R - \frac{h_2 e_2^2}{2} \tag{2.3.21}$$

where I assume that the pay-offs when both succeed in developing the product are zero.

Solving I obtain $D_1 = \frac{R^2 h_1 (h_2 - R)^2}{2(h_1 h_2 - R^2)^2}$ and $D_2 = \frac{R^2 h_2 (h_1 - R)^2}{2(h_1 h_2 - R^2)^2}$.

Proposition 5 shows that in all the above cases the sharing rule satisfy the symmetry and monotonicity condition. In addition, when the sharing rule is set so as to maximize aggregate profits then it also satisfies the condition that $\alpha \leq \frac{h_2^{\frac{z}{1-z}}}{h_1^{\frac{z}{1-z}} + h_2^{\frac{z}{1-z}}}$ where z is the degree of homogeneity of c^{-1}.

Proposition 5. *(i) The sharing rule determined so as to maximise joint profits satisfies the symmetry and the monotonicity conditions. It also satisfies* $\alpha \leq \frac{h_2^{\frac{z}{1-z}}}{h_1^{\frac{z}{1-z}} + h_2^{\frac{z}{1-z}}}$*, where z is the degree of homogeneity of c^{-1}.*

(ii) Consider the case where the sharing rule is determined through the Nash bargaining solution, the cost functions are quadratic and $\frac{1}{3} \leq \alpha \leq \frac{2}{3}$. The sharing rule satisfies the symmetry and the monotonicity conditions.

Proof. See Appendix.

2.4 Two Period Game

Joint product development ventures are, in reality, spread over many periods. If success is not achieved within a single period, it is hardly ever the case that a collaboration is terminated immediately. Therefore it is of interest to examine whether in a dynamic context, Proposition 3 continues to hold. That is whether the earlier conditions still ensure that a mean-preserving spread of the technological levels results in an increased effort stream. I find that for a two period model the previous conditions are no longer sufficient.

In this section I analyse a two period game. In both period 1 and period 2 the firms simultaneously decide on their effort levels. They have a one-shot pay-off of R which they split equally. Of course if they succeed in developing the product in period 1 then the game stops after period 1 itself. For simplicity, I assume that the players don't discount the future and that there is no 'learning' i.e. spill-overs of first period effort into the second period is absent. Therefore, the probability of success in period 2 depends on the effort level in that period only.

Let e_{ij} denote the amount of effort put in by firm i in period j. In general I use the first subscript to denote the firm and the second subscript to denote the period.

I calculate the subgame perfect equilibrium of this game. The period 2 game is identical to the game in the previous section and the analysis there is still applicable with a relabelling of the variables. I write down the first order Nash condition for future reference,

$$\lambda'(e_{12}+e_{22})\frac{R}{2} = h_1 c(e_{12}) \tag{2.4.22}$$

$$\lambda'(e_{12}+e_{22})\frac{R}{2} = h_2 c(e_{22}) \tag{2.4.23}$$

In period 1 the pay-off functions are strictly concave in their own effort levels and assuming interior solutions to the profit maximization condition the Nash equilibrium is given by the first order condition,

$$\frac{\partial P_{11}}{\partial e_{11}} = \lambda'(e_{11}+e_{21})(\frac{R}{2} - P_{12}) - h_1 c(e_{11}) = 0 \tag{2.4.24}$$

$$\frac{\partial P_{21}}{\partial e_{21}} = \lambda'(e_{11}+e_{21})(\frac{R}{2} - P_{22}) - h_2 c(e_{21}) = 0. \tag{2.4.25}$$

Here P_{12} and P_{22} denote *the second period pay-off of firm* 1 and firm 2 respectively at the Nash equilibrium of the second period game. As before it can be shown that the period 1 reaction functions R_{11} and R_{21} are negatively sloped and that a unique interior solution exists.

From observing the above equations it is clear that, for a mean-preserving spread of the technology levels (h_1, h_2), if P_{12} and P_{22} increase, that is going to have a negative effect on the first period efforts. The firms can expect a pay-off of P_{12} and P_{22} in the second period even if they do not succeed in period 1. If the expected profits in the second period increase they care less if success proves elusive in the first period i.e. the consequences of failure in the first period is reduced.

Even for the especially simple example of a linear cost function, where $C(e_{ij}) = h_i e_{ij}$, I find that the effect is ambiguous and the sign of $\frac{de_{11}}{dh_1}$ could go either way.

The period 2 reaction functions are given by,

$$\lambda'(e_{12} + e_{22})\frac{R}{2} = h_1 \quad (2.4.26)$$

$$\lambda'(e_{12} + e_{22})\frac{R}{2} = h_2. \quad (2.4.27)$$

Clearly for $h_1 = h_2$, the reaction functions coincide and unless I use some kind of selection criterion all points can be a Nash equilibrium. For $h_1 < h_2$, R_{12} lies above R_{22}. Consequently, it follows that in equilibrium $e_{22} = 0$ and $e_{12} = \overline{e_{12}}$ where $\lambda'(\overline{e_{12}}) = h_1$. Clearly, for a mean preserving spread of h_1 and h_2, e_{12} would increase and e_{22} would still remain at zero. Besides both P_{12} and P_{22} would increase. Infact $dP_{12} = -e_{12}dh_1 > 0$.

The period 1 reaction functions would be given by,

$$\lambda'(e_{11} + e_{21})[\frac{R}{2} - P_{12}] = h_1 \quad (2.4.28)$$

$$\lambda'(e_{11} + e_{21})[\frac{R}{2} - P_{22}] = h_2. \quad (2.4.29)$$

Since $P_{12} < P_{22}$ again R_{21} lies below R_{11} and the equilibrium occurs at $e_{21} = 0$ and $e_{11} = \overline{e_{11}}$ such that $\lambda'(\overline{e_{11}})(\frac{R}{2} - P_{12}) = h_1$.

Differentiating the above and taking into account the change in P_{12} I obtain,

$$\frac{de_{11}}{dh_1} = \frac{1 - \lambda''(\overline{e_{11}})e_{12}}{\lambda''(\overline{e_{11}})e_{12}(\frac{R}{2} - P_{12})} \quad (2.4.30)$$

and the sign of this is ambiguous. Therefore in this example its clearly seen that the problem stems from the fact that P_{12} increases.

2.5 Infinite Horizon Game

I next investigate whether the indeterminacy problem of the previous section could be due to the finite horizon formulation of the game. The dissimilarity between the first and the second period is artificial. If second period failure is followed by the possibility of going into another period then second period effort may not increase and consequently the first period effort may not decrease. So I set up an infinite horizon version of the above game where at each $t = 0, 1, 2, \cdots, \infty$ the firms simultaneously put in the effort. The infinite horizon formulation does not mean that the firms expect to live forever, but that, in any given period, the firms keep open the possibility of further collaboration, if success is not achieved in the current period. Again for simplicity I assume that the discount factor is one and that there is no memory.

In this section I introduce a fixed cost. So I can express the cost function as $C(e_i) = K + h_i \int_0^{e_i} c(\tilde{e}_i) d\tilde{e}_i$, where $K > 0$. Since there is no discounting and since assumption E (yet to be introduced) ensures that even with zero effort the venture will ultimately succeed, without this fixed cost there is no incentive for the firms to put in a positive level of effort. Note that this is different from the usual interpretation of fixed costs as this has to be met even when effort levels are zero. This is some kind of establishment cost which has to be met whenever the firms decide to set up a joint venture. Once they succeed in developing the product the joint venture can be dissolved and there is no need to incur the cost any more.

The assumption of no memory makes this a stochastic game with a state space which is a singleton. With positive memory I would have a stochastic game with an uncountable state and action space, which raises a number of technical difficulties.[17] In view of the diffilculties in even assuring existence

[17]Maitra and Parthasarathy (1970) proved the existence of stationary equilibrium for uncountable state space but only for zero sum games. There have been attempts at ap-

of equilibria in such games I don't try to explore the question with positive memory.

I restrict attention to Markov equilibrium which depend only on the state.

The technique followed is to approximate this game by considering a sequence of truncated games where the freedom of action of the players is taken away after a certain period. Define G_T to be the game truncated at T if for $t \geq T+1$, $e_{1t} = e_{1T}$ and $e_{2t} = e_{2T}$ where e_{ij} is the amount of effort put in by the ith firm in period j. Effectively after the Tth period the players freedom of action is taken away and they are forced to choose the same effort levels as in the Tth period.

Fortunately there exists a unique subgame perfect equilibrium for any truncation period. Besides, the same strategies are prescribed for all truncation periods. Next I let these games approximate the real game by postponing the truncation period to later periods indefinitely. I find that the limit of the equilibrium of these truncated games is an equilibrium of the untruncated game.[18]

Consider the game from period T onwards. Clearly, under the above

proximating games with uncountable state and action spaces through simpler games and to use these simpler games to locate ϵ−equilibrium for the original game. Nowak (1985) is one paper in the above vein. Mertens and Parthasarathy (1987) prove the existence of non-stationary equilibrium for discounted stochastic games with compact state space and finite action space. There have been other important papers in this field but the general problem of solving games with uncountable state and action spaces still awaits a solution.

[18]This technique draws heavily on Harris (1985).

truncation rules, it follows that,

$$P_1 = \lambda(e_1 + e_2)\frac{R}{2} - K \quad - \quad h_1 \int_0^{e_1} c(\tilde{e}_1)d\tilde{e}_1 \\ + \quad (1 - \lambda(e_1 + e_2))P_1 \qquad (2.5.31)$$

$$P_2 = \lambda(e_1 + e_2)\frac{R}{2} - K \quad - \quad h_2 \int_0^{e_2} c(\tilde{e}_2)d\tilde{e}_2 \\ + \quad (1 - \lambda(e_1 + e_2))P_2. \qquad (2.5.32)$$

Taking the Nash equilibrium of the above game I obtain the following first order conditions,

$$\frac{\lambda(e_1 + e_2)}{\lambda'(e_1 + e_2)} = \frac{K + h_1 \int_0^{e_1} c(\tilde{e}_1)d\tilde{e}_1}{h_1 c(e_1)} \qquad (2.5.33)$$

$$\frac{\lambda(e_1 + e_2)}{\lambda'(e_1 + e_2)} = \frac{K + h_2 \int_0^{e_2} c(\tilde{e}_2)d\tilde{e}_2}{h_2 c(e_2)}. \qquad (2.5.34)$$

In Proposition 6(ii) I show that the above equations have a unique solution. Denote it by (e_1^*, e_2^*).

From equations (31) and (32)[19] I see that,

$$P_1(e_1^*, e_2^*) = \frac{R}{2} - \frac{h_1 \int_0^{e_1^*} c(\tilde{e}_1)d\tilde{e}_1}{\lambda(e_1^*, e_1^*)} \qquad (2.5.35)$$

$$P_2(e_1^*, e_2^*) = \frac{R}{2} - \frac{h_2 \int_0^{e_2^*} c(\tilde{e}_2)d\tilde{e}_2}{\lambda(e_1^*, e_1^*)}. \qquad (2.5.36)$$

I next look at the game starting from period $T - 1$. The pay-offs in this case are,

$$\overline{P_1} = \lambda(e_1 + e_2)\frac{R}{2} \quad - \quad h_1 \int_0^{e_1} c(\tilde{e}_1)d\tilde{e}_1 \\ + \quad (1 - \lambda(e_1 + e_2))P_1(e_1^*, e_1^*) \qquad (2.5.37)$$

$$\overline{P_2} = \lambda(e_1 + e_2)\frac{R}{2} \quad - \quad h_2 \int_0^{e_2} c(\tilde{e}_2)d\tilde{e}_2 \\ + \quad (1 - \lambda(e_1 + e_2))P_2(e_1^*, e_1^*) \qquad (2.5.38)$$

[19]For the sake of notational simplicity I refer to the equations by the last number only, and drop the reference to chapter and section.

So the subgame perfect solution in this case is given by

$$\lambda'(e_1+e_2)[\frac{R}{2} - P_1(e_1^*, e_1^*)] - h_1 c(e_1) = 0 \quad (2.5.39)$$

$$\lambda'(e_1+e_2)[\frac{R}{2} - P_2(e_1^*, e_1^*)] - h_2 c(e_2) = 0 \quad (2.5.40)$$

From equations (35) and (36) it is easy to see that, e_1^*, e_2^* solves the above equation pair.

Since the equations have a unique solution[20] it must be (e_1^*, e_2^*). Therefore at $T-1$ also the equilibrium levels of effort will be (e_1^*, e_2^*). So F_T the equilibrium of the game truncated at T involves (e_1^*, e_2^*) at each period. Clearly this strategy is independent of the period of truncation and for all G_T the same unique strategy $F = F_T$ obtains for all T.

Next I identify a stationary equilibrium of the game. But before that I introduce some notations and assumptions.

Let g be some strategy pair of the infinite horizon game. Let (g, x) denote the continuation strategies prescribed by g following some subgame x. Let g/h_i denote the strategy pair where player i plays h_i instead of what is being prescribed by g. Let $\pi_s h_i$ denote a truncation of player i's strategy (h_i) at period s i.e. from period $s+1$ onwards player i will choose the same action as in period s.

Assumption F. $\lambda(0) > 0$.

Note that in this model the discount factor is 1. Instead $1 - \lambda$ plays the

[20]Uniqueness follows from the fact that in (35) $e_1 + e_2$ declines for an increase in e_1, and in (36) $e_1 + e_2$ declines for an increase in e_2.

role of a discount factor in this model. Though the discount factor here is endogenous rather than exogenous the above assumption ensures that it is always strictly less than 1.[21]

Assumption G. $e_i \in [0, \overline{e_i}]$.

Technically I need this assumption to put a bound on the one-shot pay-offs. This can be justified on the following grounds. Take $\overline{e_i}$ such that $\frac{R}{2} = h_i \int_0^{\overline{e_i}} c(\tilde{e}_i) d\tilde{e}_i$. Clearly firm i is never going to put in an effort level greater than $\overline{e_i}$ because for any higher effort level his pay-off is going to be negative. Clearly this implies that the deviations in one-shot pay-offs are bounded.

Observe that assumption F and the fact that the deviations in one-shot pay-offs are bounded implies that $P_j(g/\pi_s h_i) - P_j(g/h_i)$ goes towards zero as s goes towards infinity. These are what Harris calls continuous at infinity games.

I next introduce the following assumption which I need in part (ii) of the next proposition.

Define $g(e_1 + e_2) = \frac{\lambda(e_1+e_2)}{\lambda'(e_1+e_2)}$ and $y(e_i) = \frac{K + h_i \int^{e_i} c(\tilde{e}_i) d\tilde{e}_i}{h_i c(e_i)}$.

Assumption H. Either (i) $y(e_i)$ is decreasing in e_i or (ii) $y(e_i)$ is increasing in e_i and $\frac{\partial g(e_i+e_j)}{\partial e_i} > \frac{\partial y(e_i)}{\partial e_i}, \forall \ e_i, e_j$.

Proposition 6. *(i) F is a stationary equilibrium of the infinite horizon*

[21]This is the same assumption as that of Shapley (1985) that there is a positive stopping probability of the stochastic game.

game.

(ii) F is interior and unique in the class of stationary Markov equilibria.

(iii) For a linear cost function of the form $C_i = K + h_i e_i$ *the joint effort stream is increasing for a mean preserving spread of* h_1 *and* h_2.[22]

Proof. (i) I have to show that for any subgame x, (F, x) is a Nash equilibrium for the game after x.

$$\begin{aligned} P_i(F/h_i, x) &- P_i(F, x) \\ &= P_i(F/h_i, x) - P_i(F/\pi_s h_i, x) \\ &+ P_i(F_T/\pi_s h_i, x) - P_i(F_T, x) \end{aligned} \quad (2.5.41)$$

For $T \geq s$, the second difference is less than equal to zero, as $\pi_s h_i$ can be taken to be any strategy of the truncated game and F_T is optimal in the truncated game. Now keeping $T \geq s$ take T, s towards infinity. Clearly $\pi_s h_i \rightarrow h_i$ so the first difference goes towards zero. This follows as deviations in one shot payoff are bounded and assumption F. The second difference is less than equal to zero, therefore

$$P_i(F/h_i, x) - P_i(F, x) \leq 0.$$

(ii) First observe that assumption H implies that equations (33) and (34) are negatively sloped. Define e_1' by $\frac{\lambda(e_1')}{\lambda'(e_1')} = \frac{K + h_1 \int^{e_1'} c(e_1) de_1}{h_1 c(e_1')}$ and e_1'' by $\lambda'(e_1'') = 0$. Therefore, $e_1' < e_1''$. I can similarly define e_2' and e_2'' and show that $e_2' < e_2''$. Therefore it follows that the intersection is interior..

[22] In this case clearly $y'(e_i) = 1$. Assumption H is however satisfied for some λ functions e.g. $\lambda(E) = 1 - e^{-E}$.

From assumption H it also follows that in equation (33) as e_1 increases $e_1 + e_2$ decreases and symmetrically in equation (34) as e_2 increases $e_1 + e_2$ decreases. Therefore (33) and (34) have a unique intersection.

(iii) For $h_1 < h_2$, totally differentiating equations (39) and (40) and manipulating I obtain,

$$\frac{de_1 + de_2}{dh_2} = \frac{h_2^2 - h_1^2}{h_1 h_2 (2g' - 1)}$$

for $dh_2 = -dh_1 > 0$. For all λ such that $\lambda'' < 0$ it follows that $g' > \frac{1}{2}$[23] and therefore the effort stream will increase. ∎

For complex cost structures however the effect is ambiguous.

2.6 Uncertainty

In the previous sections I investigated the case where the efficiency parameter of both the firms were common knowledge. However this need not always be the case. In this section I assume that the efficiency parameters of the firms are private information though drawn from the same distribution. The actual realisation of h_i is, however, known to firm i alone. I investigate whether the joint effort stream is going to increase for a mean preserving spread of the *realised* levels of efficiency.

Suppose the cost parameter h_i is drawn from $[\underline{h}, \overline{h}]$ with distribution $F(h)$. I assume that the distribution has a continuous density function $f(h)$.

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[23] $g' = \frac{\lambda'^2 - \lambda\lambda''}{\lambda'^2} > 1$.

A strategy for the ith firm takes the form $e_i = x_i(h)$ for $h \in [\underline{h}, \overline{h}]$. The expected profit of the ith firm when the jth firm is following the strategy $x_j(h)$ can be written as follows,

$$\pi_i = \frac{R}{2}\int_{\underline{h}}^{\overline{h}} \lambda(e_i + x_j(h))f(h)dh - h_i \int c(e_i)de_i, \tag{2.6.42}$$

where π_i denotes the expected profit of the ith firm.

The first order condition can therefore be written as,

$$\frac{\partial \pi_i}{\partial e_i} = \frac{R}{2}\int_{\underline{h}}^{\overline{h}} \lambda'(e_i + x_j(h))f(h)dh - h_i c(e_i) = 0 \tag{2.6.43}$$

for $i, j = 1, 2$ and $i \neq j$.

Define $\tilde{e}$ as follows,

$$\frac{R}{2}\lambda'(\tilde{e}) = \underline{h}c(\tilde{e}).$$

Clearly the best response function x_i satisfy $x_i(h) \leq \tilde{e}$ for all h.

Proposition 7. *An equilibrium exists.*

Proof. I utilise the Tarski fixed point theorem to prove this result.[24]

I define the space X as the space of decreasing functions from $[\underline{h}, \overline{h}]$ to $[0, \tilde{e}]$.

I define the relation $\leq$ as follows. I say that $x \leq y$ iff $x(h) \leq y(h)$, $\forall h \in [\underline{h}, \overline{h}]$. Clearly $\mathcal{U}$ is a complete lattice as $x(h) = 0$ and $y(h) = \tilde{e}$ is the greatest lower and least upper element of X respectively.

[24] Tarski Fixed Point Theorem: Let $\mathcal{U} = (X, \leq)$ be a complete lattice and f be an increasing function from X to X, where $\leq$ is a partial order defined on X. Then f has a fixed point. See Theorem 1 in Tarski (1955).

Define an operator A such that A is the best response map obtained from the first order condition. From the definition of $\tilde{e}$ it is clear that A maps from X to X. Clearly an equilibrium is a pair of functions x, Ax such that $A^2x = x$. Therefore I have to demonstrate that the operator A^2 has a fixed point. It is easy to see that the operator A is monotone decreasing (as $\lambda'' < 0$ and $c' > 0$) and hence A^2 is monotone. Therefore by the Tarski theorem a fixed point exists. ∎

In the rest of this section I restrict attention to symmetric equilibria. I assume that a unique symmetric equilibrium exists.

Proposition 8. *For any symmetric equilibrium, a sufficient condition for the effort stream* $(e_1 + e_2)$ *to increase for a mean preserving spread of the realised* h_1, h_2 *is that the marginal cost function* $c(e)$ *be concave and the marginal probability function* $\lambda'(e_1 + e_2)$ *be convex.*

Proof. See Appendix.

Some return functions which satisfy the conditions of the proposition would be $\lambda = 1 - \frac{1}{E+1}$ and $\lambda = 1 - e^{-E}$.[25] For a linear return function i.e. $\lambda(e_1 + e_2) = \min(1, e_1 + e_2)$ the first order conditions reduce to

$$\frac{R}{2} = h_i c(e_i), \quad i = 1, 2. \tag{2.6.44}$$

Clearly, in this case the equilibrium is symmetric and so the condition

[25]For $\lambda = 1 - \frac{1}{E+1}$, $\lambda''' = 6(E+1)^{-4} > 0$ and for $\lambda = 1 - e^{-E}$ $\lambda''' = e^{-E}$.

just reduce to $c(e)$ being concave.

2.7 The model with Basic Research

In the previous sections I had considered exogenously determined technology levels for the two firms. In reality however technology levels are endogenously determined by the firms through basic research. Here I consider a very naive version of this basic research. I consider a scenario where technologies are available off the rack. The set of technologies available to different firms can be different. The firms can, however, choose any technology within that set without incurring any development costs.

In this section I consider the following game. At the first stage, the firms choose the technology levels h_1 and h_2 simultaneously. In the following stage they simultaneously choose the effort levels e_1, e_2. For simplicity I assume that the firms can choose any level of technology from a given set of feasible technologies i.e. they can choose any level of h_i from a set of available productivity parameters. I assume that the set of available parameters for both players is closed and bounded below. The firms cannot, however, choose a technology level which is outside their own technology set.

Under this set-up reducing one's productivity may increase asymmetry, and thus increase the chances of success as the other firm puts in more effort. This effect may outweigh the increased effort costs. Thus it seems that in this case there could be an increased scope for free-riding. It is our aim to identify conditions under which such reductions may or may not come about.

The stage two game is identical to the game in section 3. The stage 1 game is solved using the subgame perfectness concept.

Let $h_i c(e_i) = h_i[e_i^l + \cdots + e_i^k]$ where $l < \cdots < k$ and $l - 1 > \frac{k}{2}$. Clearly for any cost curves with a marginal cost curve of the form $h_i e_i^l$ where $l \geq 2$ would satisfy the above conditions.

Lemma 9. *If firm 1 is at least as efficient as the second firm, i.e. if $h_2 \geq h_1$, then firm 1's pay-off increases as it goes in for more efficient technologies, i.e.* $\frac{dP_1}{dh_1} < 0$.

Proof. See Appendix.

Proposition 10. *In any equilibrium at least one of the firms will choose the most efficient available technology level.*

Proof. If not then for atleast one firm $h_i > h_j$, then firm j can do better by going to the most efficient point according to lemma 9. ∎

Consider collaboration between a foreign firm and a firm belonging to a developing country. Let firm i be the foreign firm and let firm j be the domestic firm. An important question is whether the foreign firm is going to use an efficient technology. In this context it seems natural to consider a foreign firm which is more efficient than the domestic firm. There are two set-ups in which I consider this question. First, I consider the case where both the firms can choose their level of technology through basic research. Secondly, I consider the case where the level of technology in the domestic firm is given. The two cases can be taken to represent developing countries at various stages of their development, with the first case representing a country with a greater degree of technological dynamism. In the two cases the result is broadly similar. I find that if the domestic firm is inefficient enough compared to the foreign firm then the foreign firm opts for an efficient technology. In contrast to Proposition 10 these results pinpoints which of the firms is going to opt for the efficient technology. Suppose that the intervals from which firm i and firm j choose are $[h_i', h_i'']$ and $[h_j', h_j'']$ respectively. Let $h_i'' < h_j'$ i.e. the foreign firm's worst technology is better than the domestic firm's best technolgy. Then from lemma 9 it is apparent that any equilibrium must involve $h_i = h_i'$ i.e. the foreign firm will choose the best technology.[26] The idea is as follows. Given the nature of the technologies the foreign firm can increase asymmetry by choosing the most efficient technology. This also helps by reducing the cost of putting in the efforts. Thus from both angles it is best to choose the efficient technology.

Next I consider the case where the technology level in the domestic country is given and a foreign firm wants to enter into an R & D agreement with some domestic firm. The technology level of the domestic firm is h_j. As before the foreign firm can choose from the set $[h_i', h_i'']$. I make no assumption as regards whether the domestic firm's technology level is more efficient than the foreign firm's worst technology or not.

Proposition 11. *If λ'' is bounded below and if the domestic firm is*

[26] I need not assume that the feasible technology sets are intervals. All I need is that the best technology of the domestic firm be worse than the worst technology of the foreign firm.

inefficient enough, i.e. if h_2 is high enough then the foreign firm's pay-off increases as it goes in for more efficient technologies, i.e. $\frac{dP_1}{dh_1} < 0$.

Proof. Let the lower bound on λ'' be $-K$. A sufficient condition for $\frac{dP_1}{dh_1} < 0$ is that, $h_2 + \lambda''\frac{R}{2} > 0$, or $h_2 > \frac{KR}{2}$ using the bound. ∎

Thus in this case I find that the technology level of the foreign firm does not matter. Provided the domestic firm is very inefficient the foreign firm always selects its most efficient technology level.

Two examples which satisfy the above conditions are $\lambda(E) = 1 - e^{-E}$ for which λ'' is bounded below by -1 and $\lambda(E) = 1 - \frac{1}{E+1}$ for which λ'' is bounded below by -2.

Thus this result does not seem to agree with the general consensus that the foreign firms export inferior technology in case of joint product development. Infact in this model it is the domestic firm which may have an incentive to utilise an inefficient technology level so as to increase technological dissimilarity. However all that this say, is that, free-riding is not going to prevent the foreign firm from introducing its most efficient technology when collaborating with a domestic firm. There can be other reasons, ignored in this model, which lead the foreign firm to use less efficient technologies.

2.8 Conclusion

In this chapter I investigate the effects of free-riding in the context of joint product development. I find that technological diversity decreases the possibility of a joint venture forming at all. However, if a joint venture does form technological dissimilarity (mean-preserving spread of marginal costs) increases the probability of success. Therefore this essay suggest the following testable hypothesis that the proportion of observed successes among heterogenous firms would be higher.

2.9 Appendix 1

Proof of Proposition 3. B(i) Take $h_1 < h_2$.

Totally differentiating equations (4) and (5) and rearranging terms I obtain,

$$de_1(\lambda''\frac{R}{2} - h_1c'(e_1)) = dh_1c(e_1) - \lambda''\frac{R}{2}de_2 \tag{2.9.45}$$
$$de_2(\lambda''\frac{R}{2} - h_2c'(e_2)) = dh_2c(e_2) - \lambda''\frac{R}{2}de_1 \tag{2.9.46}$$

Substituting equation (45) into (46) and simplifying,

$$de_2[h_1h_2c'(e_1)c'(e_2) - \lambda''\frac{R}{2}(h_1c'(e_1) + h_2c'(e_2))]$$
$$= -\lambda''\frac{R}{2}c(e_1)dh_1 + \lambda''\frac{R}{2}c(e_2)dh_2 - h_1c'(e_1)c(e_2)dh_2 \tag{2.9.47}$$

Similarly one obtains,

$$de_1[h_1h_2c'(e_1)c'(e_2) - \lambda''\frac{R}{2}(h_1c'(e_1) + h_2c'(e_2))]$$
$$= -\lambda''\frac{R}{2}c(e_2)dh_2 + \lambda''\frac{R}{2}c(e_1)dh_1 - h_2c'(e_2)c(e_1)dh_1 \tag{2.9.48}$$

Adding up equations (47) and (48) and using the fact that $dh_2 = -dh_1 > 0$,

$$\frac{de_1 + de_2}{dh_2} = \frac{h_2c(e_1)c'(e_2) - h_1c(e_2)c'(e_1)}{h_1h_2c'(e_1)c'(e_2) - \lambda''\frac{R}{2}(h_1c'(e_1) + h_2c'(e_2))} \tag{2.9.49}$$

Clearly from equations (4) and (5), $h_1 < h_2 \Rightarrow e_1 > e_2$. Since c is concave, $e_1 > e_2$ implies that $\frac{de_1+de_2}{dh_2} > 0$. ■

B(ii) From equations (4) and (5) I obtain using the sufficient condition,

$$e_1 = c^{-1}(\lambda'(e_1+e_2)\frac{R}{2h_1}) = \left(\frac{R}{2h_1}\right)^k c^{-1}(\lambda'(e_1+e_2)) \quad (2.9.50)$$

$$e_2 = c^{-1}(\lambda'(e_1+e_2)\frac{R}{2h_2}) = \left(\frac{R}{2h_2}\right)^k c^{-1}(\lambda'(e_1+e_2)) \quad (2.9.51)$$

Adding and rearranging,

$$\frac{c^{-1}(\lambda'(e_1+e_2))}{e_1+e_2} = \left(\frac{2}{R}\right)^k \frac{h_1^k h_2^k}{h_1^k+h_2^k} \quad (2.9.52)$$

Define $f(E) = \frac{c^{-1}(\lambda'(E))}{E}$ where $E = e_1 + e_2$.[27]

It is easy to see that $f' < 0$ and that the R.H.S. decreases for a mean preserving spread of h_1 and h_2.[28] ■

Proof of Proposition 4. (i) Totally differentiating the first order con-

[27] For a quadratic cost function $f(E) = \frac{\lambda'(E)}{E}$ i.e. it can be interpreted as the marginal return to effort per unit of effort.

[28] Straightforward differentiation yields that,

$$f' = \frac{\lambda''}{Ec'(E)} - \frac{c^{-1}(\lambda'(e_1+e_2))}{E^2} < 0.$$

$$\text{Let } Z = \frac{(h_1-\delta)^k(h_2+\delta)^k}{(h_1-\delta)^k+(h_2+\delta)^k}$$

I want to evaluate $\frac{dZ}{d\delta}$. The numerator of this expression reduces to

$$k\frac{(h_1-\delta)^{1+k}-(h_2+\delta)^{1+k}}{(h_1-\delta)^{1-k}(h_2+\delta)^{1-k}} < 0.$$

ditions and manipulating,

$$de_1[h_1c'(e_1) - \lambda''R\alpha] = \lambda''R\alpha de_2 + \lambda'Rd\alpha - c(e_1)dh_1 \quad (2.9.53)$$

$$de_2[h_2c'(e_2) - \lambda''R(1-\alpha)] = \lambda''R(1-\alpha)de_1 - \lambda'Rd\alpha - c(e_2)dh_2 \quad (2.9.54)$$

Take $h_2 > h_1$ and $dh_2 = -dh_1 > 0$. Substituting in the above equations and solving,

$$(de_1 + de_2)[h_1h_2c'(e_1)c'(e_2) - \lambda''R\{(1-\alpha)h_1c'(e_1) + \alpha h_2c'(e_2)\}]$$

$$= \lambda'Rd\alpha(h_2c'(e_2) - h_1c'(e_1)) + dh_2(h_2c(e_1)c'(e_2) - h_1c(e_2)c'(e_1)).$$

For $h_2 > h_1$ and $\alpha > \frac{1}{2}$, $e_1 > e_2$. This together with the concavity of $c(e)$ imply that both the terms are positive as $d\alpha$ is also positive.[29]

(ii) Using the first order condition I find that,

$$e_1 = c^{-1}(\lambda'(e_1+e_2)\frac{R\alpha}{h_1}) = (\frac{R\alpha}{h_1})^k c^{-1}(\lambda'(e_1+e_2)) \quad (2.9.55)$$

$$e_2 = c^{-1}(\lambda'(e_1+e_2)\frac{R(1-\alpha)}{h_2}) = (\frac{R(1-\alpha)}{h_2})^k c^{-1}(\lambda'(e_1+e_2)) \quad (2.9.56)$$

Adding the two equations and rearranging I obtain,

$$f(E) = \frac{1}{R^k}\frac{h_1^k h_2^k}{(\alpha h_2)^k + (h_1(1-\alpha))^k},$$

where $E = e_1 + e_2$ and $f(E) = \frac{c^{-1}(\lambda'(E))}{E}$. It is easy to check that f is negatively sloped. Therefore it is sufficient to demonstrate that Z decreases for a mean preserving spread of h_1 and h_2.

Totally differentiating Z, I find that the numerator of dZ equals,

[29]That $d\alpha$ is positive follows from monotonicity.

$$dh_2kh_1^{k-1}h_2^{k-1}(h_1^{k+1}(1-\alpha)^k - \alpha^k h_2^{k+1}) + h_1^k h_2^k k d\alpha(h_1^k(1-\alpha)^{k-1} - h_2^k\alpha^{k-1}).$$

Clearly the first term is negative (as $\alpha > \frac{1}{2}$ and $h_2 > h_1$). The second term is also negative if either of the two conditions of the proposition is satisfied.■

Proof of Proposition 5. (i) The problem in this case is the following,

$$\begin{aligned} \text{Max}_\alpha \quad P_1 \ &+ \ P_2 \\ \text{s.t.} \quad R\alpha \ &= \ h_1 e_1^k \\ R(1-\alpha) \ &= \ h_2 e_2^k \end{aligned} \tag{2.9.57}$$

After substitution the problem reduces to maximizing,

$$R^{\frac{1+k}{k}}[h_1^{-\frac{1}{k}}\{\frac{k\alpha^{\frac{1+k}{k}}}{1+k} + \alpha^{\frac{1}{k}}(1-\alpha)\} + h_2^{-\frac{1}{k}}\{\frac{k(1-\alpha)^{\frac{1+k}{k}}}{1+k} + \alpha(1-\alpha)^{\frac{1}{k}}\}].$$

The first order condition yields, $\alpha = \frac{h_2^{\frac{1}{2k-1}}}{h_1^{\frac{1}{2k-1}} + h_2^{\frac{1}{2k-1}}}$

From the expression it is clear that α satisfies symmetry and monotonicity. It remains to show that

$$\alpha \leq \frac{h_2^{\frac{z}{1-z}}}{h_1^{\frac{z}{1-z}} + h_2^{\frac{z}{1-z}}},$$

where z is the degree of homogeneity of c^{-1}. Clearly in this case $z = \frac{1}{k}$. Substituting the condition reduces to, $\alpha \leq \frac{h_2^{\frac{k}{k-1}}}{h_1^{\frac{k}{k-1}} + h_2^{\frac{k}{k-1}}}$.

Clearly from the condition that $\alpha = \frac{h_2^{\frac{1}{2k-1}}}{h_1^{\frac{1}{2k-1}} + h_2^{\frac{1}{2k-1}}}$ the above condition is satisfied. This follows as $\frac{h_2^a}{h_1^a + h_2^a}$ is increasing in a and $\frac{k}{k-1} > \frac{1}{2k-1}$.

(ii) The Nash bargaining solution in this case involves, $P_1 - D_1 = P_2 - D_2$. Solving the equation yields,

$$h_1(1-\alpha)(3\alpha - 1) = h_2\alpha(2-3\alpha) + \frac{h_1h_2(h_2 - h_1)}{(h_1h_2 - R^2)}$$

The equation can be written as follows,

$$h_1 A(\alpha) = h_2 B(\alpha) + Q$$

where $A(\alpha) = (1-\alpha)(3\alpha - 1)$, $B(\alpha) = \alpha(2-3\alpha)$ and $Q = \frac{h_1 h_2 (h_2 - h_1)}{(h_1 h_2 - R^2)}$.

I begin by showing that the intersection of $Q + h_2 B(\alpha)$ and $h_1 A(\alpha)$ have an interior intersection. This follows since, $h_2 B(0) + \frac{h_1 h_2 (h_2 - h_1)}{(h_1 h_2 - R^2)} = \frac{h_1 h_2 (h_2 - h_1)}{(h_1 h_2 - R^2)} > -h_1 = h_1 A(0)$ and $h_2 B(1) + \frac{h_1 h_2 (h_2 - h_1)}{(h_1 h_2 - R^2)} = h_2 \frac{R^2 - h_1^2}{h_1 h_2 - R^2} < 0 = h_1 A(1)$. Clearly they have a unique intersection since $\frac{\partial B}{\partial \alpha} = 2 - 6\alpha < 4 - 6\alpha = \frac{\partial A}{\partial \alpha}$. It is also obvious that $Q + h_2 B(\alpha)$ would intersect $h_1 A(\alpha)$ from above. Also observe that Q increases for a mean preserving spread of h_1 and h_2.[30] Therefore for a mean preserving spread of h_1 and h_2, $h_1 A(\alpha)$ shifts downwards and $Q + B(\alpha)$ shifts up. This implies that monotonicity is satisfied. It is obvious that for $h_1 = h_2$, $\alpha = \frac{1}{2}$ satisfies the equation. Since the intersection is unique symmetry follows. ∎

Proof of Proposition 8. Let $x : [\underline{h}, \overline{h}] \to [0, \tilde{e}]$ be the symmetric equilibrium.

The first order condition in this case can be written as,

$$\frac{R}{2} \int_{\underline{h}}^{\overline{h}} \lambda'(e_i + x(\tilde{h})) f(\tilde{h}) d\tilde{h} = h_i c(e_i) \qquad (2.9.58)$$

for $i = 1, 2$.

From the above it is easy to see that $h_2 > h_1$ implies that $e_1 > e_2$. Next

[30] Denote $Q = \frac{h_1 h_2 (h_2 - h_1)}{(h_1 h_2 - R^2)}$. Totally differentiating I find that the numerator of dQ equals $[(h_1 h_2 - R^2)\{4h_1 h_2 - h_1^2 - h_2^2\} + h_1 h_2 (h_2 - h_1)^2] dh_2$. Clearly for $4h_1 h_2 - h_1^2 - h_2^2 > 0$, $dQ > 0$. For $4h_1 h_2 - h_1^2 - h_2^2 \leq 0$ the numerator equals, $2h_1^2 h_2^2 - R^2(4h_1 h_2 - h_1^2 - h_2^2) > 0$.

differentiating and manipulating the first order conditions I obtain,

$$\frac{de_1}{dh_1} = \frac{c(e_1)}{\frac{R}{2}\int \lambda''(e_1 + x(\tilde{h}))f(\tilde{h})d\tilde{h} - h_1 c'(e_1)} \tag{2.9.59}$$

$$\frac{de_2}{dh_2} = \frac{c(e_2)}{\frac{R}{2}\int \lambda''(e_2 + x(\tilde{h}))f(\tilde{h})d\tilde{h} - h_2 c'(e_2)} \tag{2.9.60}$$

Calculate $\frac{de_1+de_2}{dh_2}$ for the case when $h_2 > h_1$ and $dh_2 = -dh_1 > 0$. Clearly the denominator is positive. The numerator equals,

$$\begin{aligned}[h_2 c(e_1)c'(e_2) &- h_1 c(e_2)c'(e_1)] \\ &+ \frac{R}{2}\int [c(e_2)\lambda''(e_1 + x(\tilde{h})) - c(e_1)\lambda''(e_2 + x(\tilde{h}))]f(\tilde{h})d\tilde{h}.\end{aligned}$$

It is clear that for $c(e)$ concave the first term is positive and for $\lambda'(e_1 + e_2)$ convex the term within square brackets in the second term is also positive. ■

Proof of Lemma 9. $dP_1 = \lambda''\frac{R}{2}de_2 - dh_1\int_0^{e_1} c(e_1)de_1$ using the Nash equilibrium condition for the second stage game. Using equation (47) to substitute for de_2 I obtain,

$$\frac{dP_1}{dh_1} = \lambda''\frac{\lambda''\frac{R}{2}c(e_1)}{h_1 h_2 c'(e_1)c'(e_2) - \lambda''\frac{R}{2}(h_1 c'(e_1 + h_2 c'(e_2))} - \int_0^{e_1} c(e_1)de_1 \tag{2.9.61}$$

For the class of cost functions considered it follows that,

$$\lambda'\frac{R}{2} = h_1[le_1^{l-1} + \cdots + ke_1^{k-1}] \tag{2.9.62}$$

$$\lambda'\frac{R}{2} = h_2[le_2^{l-1} + \cdots + ke_2^{k-1}] \tag{2.9.63}$$

So

$$\begin{aligned}\frac{dP_1}{dh_1} &= -\frac{\lambda'\lambda''\frac{R^2}{4}[le_1^{l-1} + \cdots + ke_1^{k-1}]}{D} - e_l - \cdots - e_k \\ &\leq -\frac{\lambda'\lambda''\frac{R^2}{4}[ke_1^{l-1} + \cdots + ke_1^{k-1}]}{D} - e_1^l - \cdots - e_1^k \\ &= -[le_1^{l-1} + \cdots + ke_1^{k-1}][\frac{\lambda'\lambda''\frac{R^2}{4}k}{D} + e_1]\end{aligned} \tag{2.9.64}$$

Where $D = h_1h_2c'(e_1)c'(e_2) - \lambda''\frac{R}{2}[h_1[l(l-1)e_1^{l-2} + \cdots + k(k-1)e_1^{k-2}] + h_2[l(l-1)e_1^{l-2} + \cdots + k(k-1)e_1^{k-2}]]$.

Let $Y = [\frac{\lambda'\lambda''\frac{R^2}{4}k}{D} + e_1]$.

Taking the numerator of Y say Z,

$$\begin{aligned}
Z &= \lambda'\lambda''\frac{R^2}{4}k + De_1 \\
&= \lambda'\lambda''\frac{R^2}{4}k + h_1h_2e_1c'(e_1)c'(e_2) - \lambda''\frac{R}{2}e_1[h_1[l(l-1)e_1^{l-2} + \cdots + k(k-1)e_1^{k-2}] \\
&+ h_2[l(l-1)e_1^{l-2} + \cdots + k(k-1)e_1^{k-2}]] \\
&> \lambda'\lambda''\frac{R^2}{4}k + h_1h_2e_1c'(e_1)c'(e_2) - \lambda''\frac{R}{2}e_1(l-1)[h_1[le_1^{l-2} + \cdots + ke_1^{k-2}] \\
&+ h_2[l(l-1)e_1^{l-2} + \cdots + k(k-1)e_1^{k-2}]] \\
&[\text{ as } l \leq k] \\
&> \lambda'\lambda''\frac{R^2}{4}k + h_1h_2e_1c'(e_1)c'(e_2) \\
&- \lambda''\frac{R}{2}(l-1)[h_1[le_1^{l-1} + \cdots + ke_1^{k-1}] + h_2[l(l-1)e_1^{l-1} + \cdots + k(k-1)e_1^{k-1}]] \\
&[\text{ as } e_2 < e_1] \\
&= \lambda'\lambda''\frac{R^2}{4}k + h_1h_2e_1c'(e_1)c'(e_2) - \lambda''\frac{R}{2}(l-1)\lambda'R \\
&= h_1h_2e_1c'(e_1)c'(e_2) - \lambda''\frac{R}{2}(l-1) - \lambda'\lambda''\frac{R^2}{4}[2(l-1) - k] > 0 \qquad (2.9.65)
\end{aligned}$$

under my hypothesis. ∎

2.10 Appendix 2

I investigate in an one period framework what happens to the gap between the efficient and the Nash solution for a mean-preserving spread of the cost levels. Here success is interpreted in terms of getting as close as possible to the efficient level. Define $f(E) = \frac{c^{-1}(\lambda'(E))}{E}$ where $E = e_1 + e_2$.

Proposition 12. *For the class of cost functions for which c^{-1} is homogeneous of degree $k \geq 0$, a sufficient condition for $E_E - E_N$ to decrease for a mean preserving spread of h_1 and h_2 is that $f(E)$ is a concave function of E and a necessary condition for it to increase is that $f(E)$ be a convex function of E.*

Proof. Exploiting the homogeneity of c^{-1} it can be shown that,

$$f(E_N) = \left(\frac{2}{R}\right)^k \frac{h_1^k h_2^k}{h_1^k + h_2^k} \qquad (2.10.66)$$

$$f(E_E) = \left(\frac{1}{R}\right)^k \frac{h_1^k h_2^k}{h_1^k + h_2^k} \qquad (2.10.67)$$

It is easy to see that $f' < 0$, which implies that $E_E > E_N$.

For the proposition it is enough to note that $\frac{h_1^k h_2^k}{h_1^k + h_2^k}$ decreases for a mean preserving spread of h_1, h_2 and hence $\left(\frac{2}{R}\right)^k \frac{h_1^k h_2^k}{h_1^k + h_2^k} - \left(\frac{1}{R}\right)^k \frac{h_1^k h_2^k}{h_1^k + h_2^k}$ also decreases.

■

2.11 Reference

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Chapter 3

Joint Product Development: Some Policy Issues.

3.1 Introduction

In this chapter I look at some policy issues pertaining to joint product development. The first issue is related to the financial control of joint ventures. This examines the case where the joint venture is going to form anyway. The government can however control the outcome through controlling the profit share of the two firms. This question is of special interest to less developed countries interested in fostering joint ventures with foreign firms. The second issue is concerned with whether the joint venture should be allowed at all. The important questions in this case relates to the probability of success under the two alternative form of R&D, cooperative R&D and competitive R&D, and the nature of the product market competition following success.

This issue pertains to anti-trust policies as regards domestic joint ventures.

The basic model is identical to that in chapter 2. I start with a static one period game where the two firms simultaneously decide on their effort levels. The probability of success depends on the joint effort of the two firms. For given levels of effort the probability of success is defined by a function which I call the return function. Efforts are unobservable and so cannot be contracted upon. The technological dissimilarity pertains to the marginal costs of putting in the effort.

The first issue pertains to joint ventures between a domestic and a foreign firm. Consider the case where the foreign firm is relatively more efficient and the government can optimally choose the profit sharing rule so as to maximize its objective function. In this context the profit share going to the domestic firm, being related to the proportion of domestic equity participation, can be interpreted as the degree of indigenization. The government's objective function is a weighted sum of the profits of the domestic firm and the probability of success, where the success probability is interpreted as a proxy for the consumers' surplus. I find that the optimal share of the foreign firm is a increasing function of the weight put on the probability of success as well as the relative inefficiency of the domestic firm. I also show (in an example) that the optimal share of the foreign firm is greater than half, provided that technologically the firms are sufficiently far apart. The same example also demonstrates that the share of the foreign firm would be bounded away from one, however great the disparity in the technology levels, provided the weight on the consumers' surplus is not too high. If, however, the weight is large enough then the share would approach one.

I next consider the case where the government, in addition to manipulating the sharing rule, can impose lumpsum transfers between the firms. I examine the case where the objective of the government is to maximise the payoff of the domestic firm. I find that for a linear return function and homogeneous cost functions, the profit shares of the foreign firm would be greater than one half. This result questions the wisdom of the importance placed in India on keeping the equity participation of foreign firms at less than fifty percent. Of course, this has to do with the issue of 'control' of joint ventures, an aspect I abstract from. Besides, the optimal policy may involve the domestic firm paying a transfer fee to the foreign firm. Another interesting question is whether the first best can be achieved through some scheme. I demonstrate that there does exist a scheme of the following type. The government charges some entry fee from both the firms. In return the government promises to subsidize the product if success does take place. It also specifies the share in which the profits are going to be shared. For appropriate values of the policy variables the first best can be implemented and the foreign firm held down to its participation level of payoffs.[1]

The second set of issues that I consider deal with joint product development among domestic firms. The focus is on efficiency and anticompetitive effects. Empirical studies in recent years suggest that the social returns from R&D are much higher than the private returns.[2] Such divergences between

[1]Of course these results depend critically on the assumption that the government possesses complete information about the foreign firm's technology and market oppurtunities elsewhere.

[2]Bernstein and Nadiri (1988) offers some startling results in this respect. In the scientific instruments industry for example the social rate of return was ten times the private rate of

the social and private rates are to some extent caused by the spillover effects and various bargaining problems which prevent an innovator from appropriating the whole value of his innovation. An important question is whether the collaborative ventures would succeed in reducing this disparity. A collaborative venture can serve to internalize the externality arising from spillover effects.[3] It is often feared that allowing collaboration in R&D may facilitate collaboration in the product market as well, leading to anticompetitive effects. There is however another problem associated with joint ventures which has received less attention. This has to do with the free-riding problems inherent in joint ventures.

The standard argument justifying joint ventures claims that the dynamic gains in the form of greater R&D may outweigh the efficiency losses due to anticompetitive effects. The above argument has been put forward to claim that research joint ventures should be treated more leniently under anti-trust legislation compared to usual mergers etc. The treaty of Rome, concerned with the prohibition of collusion if it inhibits trade or distorts competition, explicitly takes such trade-offs between static efficiency losses and possible dynamic gains due to increased success probability, into account. Such exemptions are infact extended to joint venture product manufacture or licensing to third parties, though not to marketing.

This argument presumes that the R&D success is going to be higher under joint ventures. In the presence of free-riding problems in joint ventures this

return.

[3]D'Aspremont and Jacquemin (1988) show that whether the amount of effective research increases or decreases depends crucially on the strength of the spillover effects.

is not at all obvious.

I begin by examining the effect of joint venture formation on the probability of success. Various possible counterfactuals are considered. In contrast to the previous section product market considerations are introduced explicitly.

I first examine the case where in the absence of joint product development only one of the firms is going to opt for R&D. The result depends on whether it is the more efficient or the less efficient firm that is conducting the R&D. If it is the more efficient firm then the probability of success is lower under joint venture. If, however, it is the less efficient firm that is performing the R&D then a joint venture improves the probability of success. I then examine the case where in the absence of a joint venture, the two firms engage in competitive R&D. In the absence of spillover effects the probability of success is higher in case of competitive R&D. This result however depends on a sufficient condition on the return function. I use an example to demonstrate that if this condition is not satisfied then the probability of success may be higher under a joint venture. I then examine the case when there are spillover effects in the market. Even with complete spillovers competitive R&D may have a greater probability of success. Only when the return from joint venture is large enough compared to the competitive returns do I find that the probability of success under joint venture is greater.

Lastly I demonstrate that it may be possible that the formation of joint ventures, though individually rational, leads to a decline in the expected aggregate surplus. The intuition is simple. I use an earlier result to show that in this case the probability of success declines under a joint venture. Since in this case the surplus under a joint venture is always lower than that under competitive R&D, (since I consider the case where the firms cooperate in the product market as well, following joint venture success), irrespective of whether one or both firm succeeds under competitive R&D, the result follows.

Ordover and Willig (1985) show that under some conditions joint product development is going to lead to increased R&D. Their model however does not take into account the free-riding effects inherent in joint research. In order to facilitate comparison with their model I consider a variant where the effort level is verifiable. I find that in this case joint ventures indeed increase the probability of success. This corroborates the intuition that the Ordover and Willig results can be traced to their ignoring the free-riding effects.

D'Aspremont and Jacquemin (1988) consider a model in the case of process innovation which does allow for free-riding effects. They show that in the absence of spill-overs joint ventures may invest less in R&D compared to competitive research. When however there is a high degree of spill-over joint ventures are shown to be superior in terms of R&D. My model demonstrates however that no simple answers can be provided as regards the probability of success under these two alternative modes of R&D. The results may go either way depending on the return function.

The model I examine differs from d'Aspremont and Jacquemin (1988) by focusing on product development rather than process innovation. My results demonstrate that an important consideration in this respect is the nature of the return function, an issue that d'Aspremont and Jacquemin (1988) implicitly abstract from.

The rest of the chapter is organised as follows. In section 2 I briefly recapitulate the basic model. Section 3 is concerned with the problem of finding the optimal profit sharing rule. In section 4 I examine whether joint ventures are likely to increase the probability of success.

3.2 The Basic Model

In this section I briefly set down the basic model which is identical to that of chapter 2 of this thesis. There are two firms, firm 1 and firm 2, jointly trying to develop a product denoted X. If they succeed they jointly receive a gross pay-off of R. They either sell their product to a third firm for a fixed price R, or this could represent the discounted sum of pay-offs accruing to the firms from jointly marketing the product. The sharing rule is given by α, where α denotes the share of the first firm. If they fail to develop the product they receive nothing, despite incurring development costs. The cost functions of the two firms are given by $C_i(e_i) = h_i \int_0^{e_i} c(\tilde{e}_i)d\tilde{e}_i$, $i = 1, 2$ where e_i is the amount of effort put in by the ith firm, $h_i c(e_i)$ is the marginal cost of effort of the ith firm and h_i^{-1} is a productivity index. If $h_1 < h_2$ then I say that firm 1 is technologically superior to firm 2. If $h_1 = h_2$ then I say that they are technologically identical. The probability of success is given by $\lambda(e_1 + e_2)$.

I make the following assumptions on $c(e_i)$ and λ,

(A) c and λ are twice continuously differentiable.

(B) Marginal costs are positive and strictly increasing in effort level i.e. $c(e_i) \geq 0$ and $c'(e_i) > 0$, $\forall e_i > 0$.

(C) Marginal productivity of effort is positive but strictly decreasing in the effort level i.e. $\lambda \in [0, 1], \lambda' > 0, \lambda'' < 0$.

(D) $c(0) = 0$.

The profits of the two firms are given by,

$$\lambda(e_1 + e_2)R\alpha \quad - \quad h_1 \int_0^{e_1} c(\tilde{e}_1)d\tilde{e}_1 \tag{3.2.1}$$

$$\lambda(e_1 + e_2)R(1-\alpha) \quad - \quad h_2 \int_0^{e_2} c(\tilde{e}_2)d\tilde{e}_2 \tag{3.2.2}$$

Since the pay-off functions are strictly concave in e_i, I can use the first order condition to derive the two reaction functions, $R1$ of firm 1 and $R2$ of firm 2. The reaction functions can be obtained by solving the following equations,

$$h_1 c(e_1) \quad = \quad \lambda'(e_1 + e_2)R\alpha \tag{3.2.3}$$

$$h_2 c(e_2) \quad = \quad \lambda'(e_1 + e_2)R(1-\alpha) \tag{3.2.4}$$

Assumption D is a simplifying assumption which ensures that for all $h_1, h_2 \neq 0$ I have a strictly interior solution i.e. the equilibrium effort levels are strictly positive.[4]

Proposition 0. *There exists a unique and interior Nash equilibrium of this game.*

The proof of this is similar to that of Proposition 3(i) in the second chapter of this thesis.

[4]Define e_1' by $\lambda'(e_1')R\alpha = h_1 c(e_1')$ and e_1'' by $\lambda'(e_1'')R(1-\alpha) = h_2 c(0) = 0$. Therefore forall h_1, h_2 it follows that $e_1' < e_1''$. One can similarly define e_2' for $R1$ and e_2'' for $R2$ and show that $e_2' > e_2''$ which proves my contention.

I next consider the case of competitive R&D by the two firms. I assume that if both the firms succeed in developing the product then the gross pay-offs are zero. This can be justified by assuming that the post discovery production involves price competition. The disagreement pay-offs of firm 1 and 2 will be,

$$\lambda(e_1)(1-\lambda(e_2))R \;-\; h_1\int c(e_1)de_1, \tag{3.2.5}$$

$$\lambda(e_2)(1-\lambda(e_1))R \;-\; h_2\int c(e_2)de_2 \tag{3.2.6}$$

The first order conditions would be,

$$\lambda'(e_1)(1-\lambda(e_2))R \;=\; h_1c(e_1) \tag{3.2.7}$$

$$\lambda'(e_2)(1-\lambda(e_1))R \;=\; h_2c(e_2) \tag{3.2.8}$$

The reaction functions of firm 1 and firm 2 are denoted by F1 and F2 respectively. It is easy to see that the reaction functions are *negatively sloped*. It can be demonstrated that if $\lambda(E) < 1,\ \forall E < \infty$ and $\lim_{E\to\infty}\lambda(E) = 1$, the equilibria will be *interior*.[5]

I then impose the following simplifying assumption as regards the competitive equilibrium.

Assumption E. *Competitive R&D have a unique equilibrium.*

In section 4, I will be considering a model where the payoff structures are more complex.

[5]Define e_1' by $\lambda'(e_1')(1-\lambda(0))R = h_1c(e_1')$ and e_1'' by $(1-\lambda(e_1''))R\lambda'(0) = h_2c(0) = 0$. Therefore $\lambda(e_1'') = 1$. Hence forall h_1, h_2 it follows that that $e_1' < e_1''$. One can similarly define e_2' for $F2$ and e_2'' for $F1$ and show that $e_2' < e_2''$ which proves my contention.

3.3 Choosing the Optimal Profit Sharing Rule

Consider joint product development between a foreign firm (firm 1) and a domestic firm (firm 2). I assume that the foreign firm is relatively more efficient i.e. $h_1 < h_2$, and that the government can manipulate the profit sharing rule so as to maximize its objective function (a weighted sum of domestic profits and the consumers' surplus). I am interested in the properties of the optimum profit sharing rule. This question is of policy interest to developing countries interested in fostering joint ventures with foreign firms. In this section I abstract from the question of whether the joint venture should be allowed to form or not. It is possible that under a joint venture the probability of success is lower, thus the government, intersested in consumers' surpus, may have a reason for not allowing the joint venture to form. Such issues are addressed in the following section.

The share of profits accruing to the domestic firm is related to the degree of indigenization of a joint venture which again is equated to the extent of equity participation by the domestic firm. There are several policy tools available to the government for controlling the degree of indigenization. These include announcing a maximum allowable limit for foreign equity participation, restricting the debt equity ratio etc. I, however, abstract from the question of exactly how α is to be controlled.

Observe that the government can not choose the optimal profit sharing rule in an unconstrained manner. The α that the government selects must respect the participation constraints of the two firms, otherwise the joint venture will not form at all. I examine the case where the participation constraints are given by competitive R&D payoffs of the two firms. Let me denote the joint venture payoffs of the two firms by $P_i(\alpha)$, and the competitive payoffs by D_i, where these payoffs are evaluated at the equilibrium effort levels.

It is obvious that $P_1(1) > P_2(1) = 0$ and $P_2(0) > P_1(0) = 0$. Therefore there exists α^* such that $P_1(\alpha^*) = P_2(\alpha^*)$. I make the following simplifying assumption,

Assumption F. $P_1(\alpha)$ and $P_2(\alpha)$ possess a unique intersection.

Clearly for concave P_i, a sufficient condition for the assumption to hold is that, $\frac{\partial P_2}{\partial \alpha} < 0$ and $\frac{\partial P_1}{\partial \alpha} > 0$.

Next observe that $P_1(1) > D_1$ and $P_2(0) > D_2$. Let $\tilde{e}_1 = \text{argmax } P_1(1)$ and $\tilde{e}_2 = \text{argmax } P_2(0)$. Also let $\hat{e}_1, \hat{e}_2$ solve the competitive R&D game.

Clearly, $\lambda(\tilde{e}_1)R - h_1 \int^{\tilde{e}_1} c(e_1)de_1 \geq \lambda(\hat{e}_1)R - h_1 \int^{\hat{e}_1} c(e_1)de_1 > \lambda(\hat{e}_1)(1 - \lambda(\hat{e}_2))R - h_1 \int^{\hat{e}_1} c(e_1)de_1$. Similarly for the other case.

It is also obvious that $D_1 > P_1(0) = 0$ and $D_2 > P_2(1) = 0$.

Clearly a sufficient condition for there to exist some α for which a joint venture is individually rational is $P_i(\alpha^*) > \max\ (D_1, D_2)$.

Clearly if $h_1 = h_2$ then $\alpha^* = \frac{1}{2}$ and $D_1 = D_2 = D$. In this case $P_i(\frac{1}{2}) > D$ is a necessary and sufficient condition for there to exist α for which a joint venture is individually rational. Proposition 1 in the second chapter of this thesis provides a sufficient condition for this to occur.

Define α', α'' as follows. Let α' solve, $P_1(\alpha') = D_1$ and let α'' solve $P_2(\alpha'') = D_2$. For P_i concave, α' and α'' are unique. (Proposition 1 provides two different sufficient conditions for P_i to be concave.)

It is clear that if $P_i(\alpha^*) > \max \ (D_1, D_2)$, then $\alpha' < \alpha''$. Clearly for $D_1, D_2 > 0$, $0 < \alpha', \alpha'' < 1$. (See Figure 1.)

Therefore for the joint venture to form the optimal profit sharing rule must lie between α' and α''.

The objective function of the government is as follows,

$$G = P_2 + \beta\lambda(e_1 + e_2) = \lambda(e_1 + e_2)[R(1-\alpha) + \beta] - h_2 \int c(e_2) de_2, \quad (3.3.9)$$

where β denotes the weightage given to the probability of success. The objective function of the government can be interpreted as an weighted sum of the producers' surplus and the consumers' surplus where the probability of success can be taken as a proxy for consumers' surplus. Let α equal argmax $G(\alpha)$ and let $\hat{\alpha} =$ argmax $G(\alpha)$ such that $\alpha \in [\alpha', \alpha'']$.

Proposition 1 examines some implications of the choice of profit sharing rule. Part (i) of the proposition identifies sufficient conditions for α to be unique and interior. It shows that the optimal profit sharing rule α lies between 0 and 100% provided the weight β is not too high or too low. There are two effects operating on α. As far as maximising the domestic profits are concerned it is better if α is relatively small, but as far as maximising the effort stream is concerned it is better if α is relatively high. For β too small the domestic profit effect dominates and α would be small, where as for β too large the effect of consumer surplus dominates. Part (ii) shows that for marginal costs concave the probability of success is increasing in the share going to the more efficient foreign firm. As the foreign firm's share of the total revenue increases, its incentive to put in effort increases as it can appropriate a greater share of the pay-offs. For α high enough, the foreign

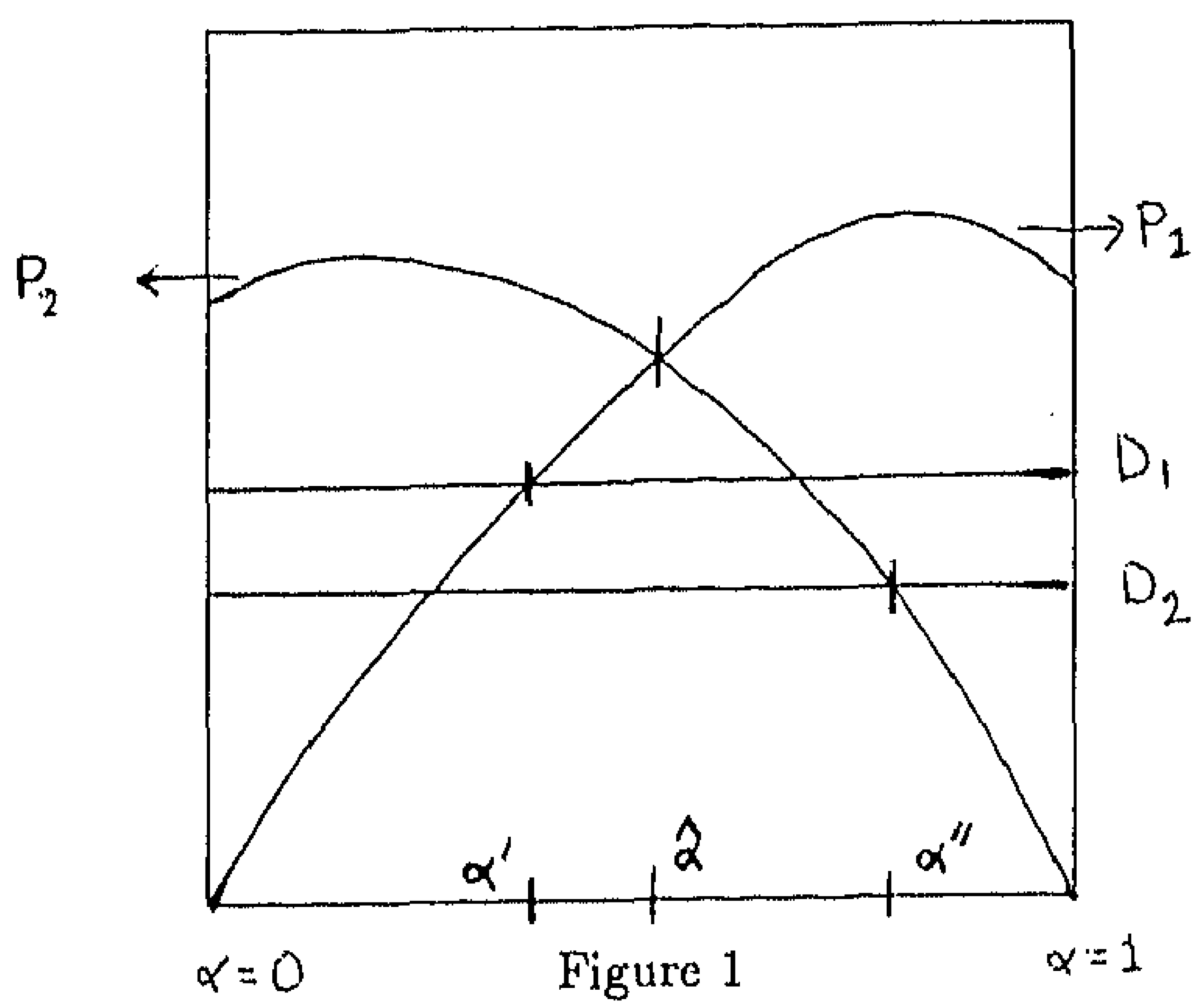

Figure 1

firm's effort comes to dominate the effort stream and the increase in this more than compensates for the decrease in the domestic firm's effort, so that the joint effort increases. This suggests that if the weight on consumer surplus is sufficiently high, it makes sense to give a dominant share of profits to the foreign firm.

Next I examine some comparative static properties of the optimal sharing rule. In this case I take into account the participation constraint of the two firms. i.e. I am concerned with the properties of $\hat{\alpha}$. Part (iii) examines the following question. Suppose β increases i.e. the government puts greater emphasis on the domestic consumer surplus. What is the effect on the optimum profit sharing rule $\hat{\alpha}$? Under some conditions I find that the share of the foreign firm would increase. This obviously holds if the optimal α lies between α' and α''. Otherwise the optimal $\hat{\alpha}$ will not be affected for a small change in β.

In the last part I consider the following question. Suppose that the domestic firm becomes more efficient. Should the profit share be adjusted in favour of the domestic firm or not? When the return function is linear, I find that the answer is yes, provided that α is not very high to begin with, and α lies between α' and α''. The reason is that as the domestic firm becomes more and more inefficient the second effect on α comes to dominate. If, however, $\alpha \geq \alpha''$ then clearly $\hat{\alpha} = \alpha''$. In this case as h_2 increases both P_2 and D_2 decrease. The effect on α'' is thus ambiguous.

Proposition 1. *(i) Assume that the cost functions are quadratic and the marginal return function is concave in effort. Then the optimal profit share*

α of the foreign firm is unique. There exist weights β^* and β^{**} such that if $\beta \in (\beta^*, \beta^{**})$, then the optimal profit share of the foreign firm lies strictly between 0 and 100%.

(ii) Consider $\alpha \geq \frac{1}{2}$, where α is the share of the pay-offs going to the foreign firm. A sufficient condition for the effort stream to increase, as α increases, is that the marginal cost $h_i c(e_i)$ be concave.

(iii) Assume that α lies between α' and α''. If cost functions are quadratic and the marginal return function concave in effort then the share of the payoff going to the foreign firm increases if the weight put on the probability of success increases. If, however, $\alpha \notin [\alpha', \alpha'']$, then it is not affected by a change in β.

(iv) Assume that α lies between α' and α''. Consider the case where the government is only interested in maximizing the payoff of the domestic firm. If the marginal cost function is convex, the return function is linear and $\alpha < \frac{h_1}{h_1+h_2}$, then as h_2 decreases α decreases. If, however, $\alpha \geq \alpha''$, then the effect of an increase in h_2 on the optimal sharing rule $\hat{\alpha}$ is ambiguous.

Proof. (i) Let $\beta^* = \max(0, \tilde{\beta})$, $\tilde{\beta}$ solve $\frac{\partial G}{\partial \alpha}(\tilde{\beta})|_{\alpha=0} = 0$ and β^{**} solve $\frac{\partial G}{\partial \alpha}(\beta^{**})|_{\alpha=1} = 0$.

One can solve the equilibrium effort levels as a function of the sharing rule α, $e_1 = e_1(\alpha)$ and $e_2 = e_2(\alpha)$. The first order condition for the government's maximization problem now yields,

$$\frac{\partial G}{\partial \alpha} = -R\lambda(e_1+e_2)+\lambda'(e_1+e_2)[(e_1'(\alpha)+e_2'(\alpha))\beta+R(1-\alpha)e_1'(\alpha)] = 0 \quad (3.3.10)$$

It can be shown that G is concave in α. (See Appendix). Therefore the optimal α is unique. Hence it is enough to show that β^* and β^{**} exist and

$\beta^* < \beta^{**}$. That β^* and β^{**} exist follow from the continuity of $\frac{\partial G}{\partial \alpha}$ and the fact that for large enough β, for both $\alpha = 0$ and $\alpha = 1$, $\frac{\partial G}{\partial \alpha}$ is positive and it is negative for a small enough β. For $\alpha = 1$ observe that $\frac{\partial G}{\partial \alpha} < 0$ for $\beta = 0$.

Next I show that $\tilde{\beta} < \beta^{**}$.[6] Observe that,

$$\tilde{\beta} = \frac{R\lambda(\overline{e_2}) - \lambda'(\overline{e_2})Re_1'(0)}{\lambda'(\overline{e_2})[e_1'(0) + e_2'(0)]}$$

$$\beta^{**} = \frac{R\lambda(\overline{e_1})}{\lambda'(\overline{e_1})[e_1'(1) + e_2'(1)]}$$

The contention follows since $\overline{e_1} > \overline{e_2}$, λ is concave and $e_1'(\alpha) + e_2'(\alpha)$ is decreasing in α. (See appendix for the proof.)

(ii) See Appendix.

(iii) Since from part (i) it follows that G is concave in α, it is immediate from the first order condition of the government that if β increases, α increases as well.

(iv) The first order condition of the government simplifies to,

$$\frac{\partial G}{\partial \alpha} = -R(e_1 + e_2) + R(1-\alpha)e_1'(\alpha) = 0 \qquad (3.3.11)$$

Since G is concave in α,[7] it follows that as h_2 decreases, α decreases.

For the last part of the proposition I concentrate on a simple example. Consider the case where $\lambda(e) = \min(e, 1)$ and $C = \frac{h_i e_i^2}{2}$. Assume that $R \leq h_1, h_2$. (This rules out corner solutions under a joint venture.) Let $h_1 < h_2$. Explicitly solving, I obtain $D_1 = \frac{R^2 h_1 (h_2 - R)^2}{2(h_1 h_2 - R^2)^2}$ and $D_2 = \frac{R^2 h_2 (h_1 - R)^2}{2(h_1 h_2 - R^2)^2}$. It is easy to see that $D_1 > D_2$. Straightforward calculations yield,

$$P_1 = R\alpha[\frac{R\alpha}{2h_1} + \frac{R(1-\alpha)}{h_2}]$$

---

[6] The case when $\beta^* = 0$ is trivial.

[7] See Appendix.

$$P_2 = R(1-\alpha)[\frac{R\alpha}{h_1} + \frac{R(1-\alpha)}{2h_2}]$$

Besides it can also be shown that, P_1 is increasing and P_2 is decreasing in α. It is obvious that both D_2 and P_2 is decreasing in h_2. The effect on α'' is therefore ambiguous. ■

The condition that the marginal return function be concave is not necessary for part (iii) of the proposition. Consider the function $\lambda(E) = 1 - e^{-E}$. In this case $\lambda''' > 0$. Even in this case however it can be demonstrated that α would increase for an increase in β.[8]

Another interesting policy question is whether the share of the foreign firm should be more or less than half. This question relates to the Indian emphasis on keeping the equity participation by the foreign firm less than half. Of course this emphasis has to do with the question of 'control' of the joint ventures. In this essay I abstract from such considerations. Even so, it is interesting to examine whether this emphasis can be justified if such issues of control are abstracted from. I examine this question when the return function is linear $\lambda(e_1 + e_2) = \min(e_1 + e_2, 1)$ and the cost functions are quadratic i.e. $C(e_i) = \frac{h_1 e_i^2}{2}$, $i = 1, 2$, $h_1, h_2 \geq R$. It is easy to see that for any $\beta > 0$, the

[8] Observe that in this case $\lambda'(E) = -\lambda''(E)$. Using this I obtain that

$$e_1' + e_2' = \frac{R\lambda'(h_2 - h_1)}{h_1 h_2 + R\lambda'\{h_1(1-\alpha) + h_2\alpha\}}$$

Observe that the numerator of $\frac{\partial(e_1'+e_2')}{\partial\lambda'} = R(h_2 - h_1)h_1 h_2 > 0$. Besides $e_1'(\alpha) = \frac{R[\lambda' h_2 + R\lambda'^2]}{h_1 h_2 + R\lambda'\{h_1(1-\alpha)+h_2\alpha\}}$. The numerator of $\frac{1}{R}\frac{\partial e_1'(\alpha)}{\partial\lambda'} = h_1 h_2^2 + 2R\lambda' h_1 h_2 + R^2\lambda' h_1 h_2 + R^2\lambda'^2\{h_1(1-\alpha) + h_2\alpha\} > 0$. Therefore in this case G is concave and for an increase in β α would increase.

share of the foreign firm would be greater than half if the domestic firm is inefficient enough.

One can substitute the first order conditions in the government maximand to obtain,

$$P_2 + \beta(e_1 + e_2) = \frac{R\alpha(1-\alpha)}{h_1} + \frac{R(1-\alpha)^2}{2h_2} + \beta[\frac{R\alpha}{h_1} + \frac{R(1-\alpha)}{h_2}]$$

Solving for the first order condition I obtain that, $\alpha = \frac{(\beta+R)(h_2-h_1)}{R(2h_2-h_1)}$. Therefore when $\frac{h_2}{h_1} \geq 1 + \frac{R}{2\beta}$, $\alpha \geq \frac{1}{2}$. It is also immediate that α is increasing in both β and h_2. The above example also demonstrates that as the relative disparity in the technology levels increase the profit share of the foreign firm may remain bounded away from 1 if the emphasis put on the success probability is not too large. In this case clearly,

$$\lim_{h_2 \to \infty} \alpha = \frac{\beta + R}{2R}$$

Obviously for β small enough α would be bounded away from 1.

In this case the optimal α is increasing in the weight put on consumers' surplus β. Let $\tilde{\alpha}$ be the profit share that the two firms would agree upon in the absence of government intervention. A priori there is no reason why $\tilde{\alpha}$ should equal the optimal $\hat{\alpha}$. Let $\tilde{\beta}$ be the the weight on consumers' surplus for which the optimal $\hat{\alpha}$ takes the value $\tilde{\alpha}$. Obviously, for $\beta < \tilde{\beta}$ the optimal $\hat{\alpha}$ would be less than the laissez faire $\tilde{\alpha}$, though greater than α'. For, $\beta \geq \tilde{\beta}$ the optimal $\hat{\alpha}$ would lie between $\tilde{\alpha}$ and α''. (See Figure 2.)

I next consider the case where the government, in addition to manipulating the α, can impose a transfer payment T from the foreign firm to the domestic firm. Therefore in this case the problem takes the following form,

$$\text{Max}_{\alpha,T} \quad P_2(e_1, e_2) + T$$

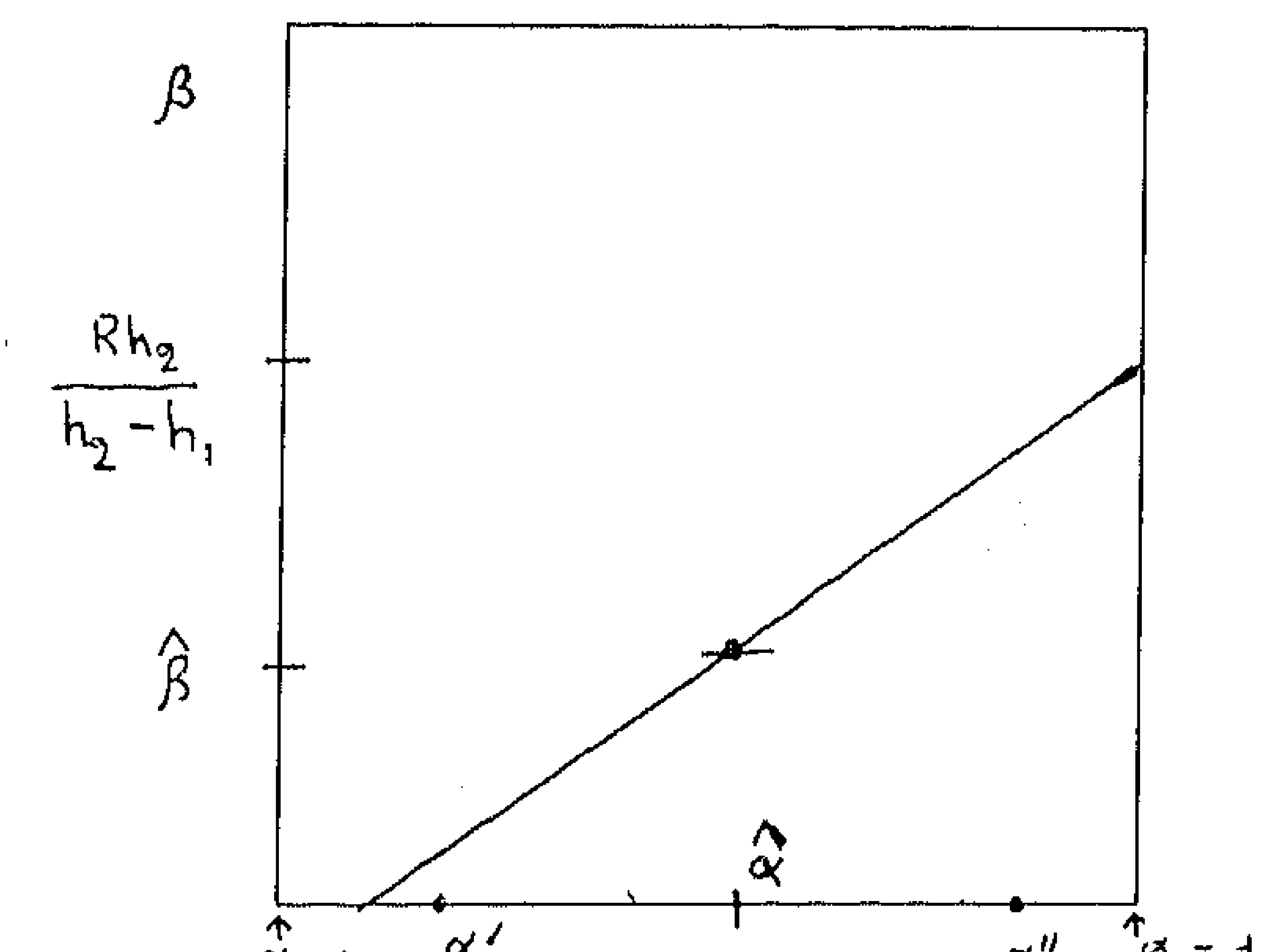

Figure 2

$$
\begin{aligned}
\text{s.t.}\quad P_1(e_1, e_2) - T &\geq D_1 \\
\text{s.t.}\quad P_2(e_1, e_2) + T &\geq D_2 \\
\text{where}\quad e_1, e_2 &\quad \text{solves} \\
\lambda' R\alpha &= h_1 c(e_1) \\
\lambda' R(1-\alpha) &= h_2 c(e_2)
\end{aligned}
\tag{3.3.12}
$$

where D_1 and D_2 (the competitive R&D payoffs of the two firms) represent the outside option of the foreign and the domestic firm respectively. Observe that in this case the government puts zero weight on the success probability. This neglect of the consumer's surplus can be justified for example in the case when the good is meant for export alone.

Clearly T solves $P_1(e_1 + e_2) - D_1 = T$, thus the problem reduces to maximizing the aggregate profit knowing that the firms are going to play non-cooperatively in the next stage. The optimal solution may not however satisfy the particiaption constraint of the second firm. In that case observe that no solution exists. Clearly if $P_i(\alpha^*) > \max\ (D_1, D_2)$ then the participation constraint will be satisfied. However, observe that it is possible that the participation constraint will be met even though the above condition is not satisfied. The government can however impose lumpsum taxes on the foreign firm if it pursues individual research, thus bringing down the value of D_1. An extreme form of this would be where the government does not allow the foreign firm to compete in the R&D market.

In case when the return function is linear and cost function is of the form $C(e_i) = \frac{h_i e_i^k}{k}, k \geq 2$ it can be shown that the optimum α takes the form, $\alpha = \frac{h_2^{\frac{1}{2k-1}}}{h_1^{\frac{1}{2k-1}} + h_2^{\frac{1}{2k-1}}}$.

Besides for a high enough D_1, T may be negative. Therefore the solution may involve the foreign firm obtaining a greater share of the payoff, as well as receiving some kind of fee from the domestic firm. Proposition 2 follows from the above discussion and from observing the form of the optimal α in this case.

Proposition 2. *Assume that the return function is linear and the cost function is homogeneous. When the government can impose a transfer on the two firms as well as set the optimal α then it is in the interests of the domestic firm that the share of the foreign firm be greater than half. In addition the optimum may involve the domestic firm paying a transfer fee to the foreign firm. The optimal α is increasing in h_2 and decreasing in h_1. Clearly as h_2 tends towards infinity or h_1 tends towards zero the optimal α goes towards 1.*

In this case the transfer payment can be used to restrict the foreign firm's payoff to the participation level. Therefore the profit sharing rule can be used to maximise the aggregate payoff. For the special case considered this involves the foreign firm obtaining a larger share of the payoffs.

Next I enquire whether the first best solution can be implemented i.e. whether I can have a solution where the outcome is (e_1', e_2') where (e_1', e_2') maximizes the joint profits in an unconstrained fashion.

Consider the following scheme. The government purchases the product from the joint venture at a price of R'. It also determines the licensing fee L_1, L_2 that the two firms must pay to the government and the surplus sharing rule β at which the R' is to be shared between the two firms. I show that for an appropriate choice of R', β, L_1 and L_2 the above scheme implements the first best.

The intuition is similar to that of the incentive schemes used in McAfee and McMillan (1986). The subsidy rate and β is set so as to induce $(e_1' + e_2')$. Then the lumpsum taxes L_1, L_2 are used to finance the scheme.

The problem can be written as follows,

$$
\begin{aligned}
\text{Max}_{R',\beta,L_1,L_2} \quad & P_2 - L_2 \\
\text{s.t.} \quad P_1(e_1, e_2) - L_1 \quad & \geq D_1 \\
\text{s.t.} \quad P_2(e_1, e_2) - L_2 \quad & \geq D_2 \\
\lambda(e_1 + e_2)(R' - R) \quad & = L_1 + L_2 \\
\text{where} \quad e_1, e_2 \quad & \text{solves} \\
\lambda' R' \beta \quad & = h_1 c(e_1) \\
\lambda' R'(1 - \beta) \quad & = h_2 c(e_2)
\end{aligned}
\tag{3.3.13}
$$

where the third constraint is the ex ante budget balance condition for the government and $P_i = \lambda(e_1 + e_2)R'\beta - h_i \int_0^{e_i} c(e_i)de_i$.

From the participation constraint for the foreign firm $L_1 = P_1(e_1, e_2) - D_1$. Substituting in the budget balance condition I obtain, $\lambda(e_1 + e_2)(R' - R) = L_2 + P_1(e_1, e_2) - D_1$. After substitution I find that the objective function becomes, $P_1(e_1, e_2) + P_2(e_1, e_2) - D_1$. The problem therefore reduces to,

$$
\begin{aligned}
\text{Max}_{R',\beta} \ \lambda(e_1 + e_2)R \quad & -h_1 \int_0^{e_1} c(\tilde{e}_1)d\tilde{e}_1 - h_2 \int_0^{e_2} c(\tilde{e}_2)d\tilde{e}_2 \\
\text{s.t.} \quad P_2(e_1, e_2) - L_2 \quad & \geq D_2 \\
\text{where} \quad e_1, e_2 \quad & \text{solves} \\
\lambda' R' \beta \quad & = h_1 c(e_1)
\end{aligned}
$$

$$\lambda' R'(1-\beta) \qquad = h_2 c(e_2) \tag{3.3.14}$$

Clearly $R' = 2R$ and $\beta = \frac{1}{2}$ implements the first best. Therefore,

$$\begin{aligned} L_1 &= P_1(e_1', e_2') - D_1 \\ L_2 &= \lambda(e_1' + e_2')R - P_1(e_1', e_2') + D_1 \\ &= h_1 \int_0^{e_1'} c(e_1) de_1 + D_1. \end{aligned} \tag{3.3.15}$$

Since the solution implements the first best the aggregate profit in this case would be greater than the aggregate profit under competitive R&D i.e. $D_1 + D_2$. Therefore the participation constraint of the domestic firm will not bind. Clearly the first best always involves the domestic firm paying a positive licensing fee. The fee charged from the foreign firm however, can be positive or negative. Summarising the preceeding discussion I obtain Proposition 3.

Proposition 3. *The first best solution can be implemented through the following mechanism. The government buys the discovery from the corporation at a price* $2R$ *to be shared equally by the two firms. The firms also have to pay licensing fees* L_1, L_2 *where,*

$$L_1 = P_1(e_1', e_2') - D_1$$

$$L_2 = h_2 \int_0^{e_2'} c(e_2) de_2 + D_1.$$

Next I consider the case where both the firms are domestic firms. The government objective function in this case can be written as $P_1 + P_2 + \gamma\lambda(e_1 +$

e_2). It can be demonstrated that the above mechanism still implements the first best. In this case after substitution the problem simplifies to,

$$\text{Max}_{R',\beta} \quad \lambda(e_1+e_2)R - h_1\int_0^{e_1} c(\tilde{e_1})d\tilde{e_1} - h_2\int_0^{e_2} c(\tilde{e_2})d\tilde{e_2} + \gamma\lambda(e_1+e_2)$$

where e_1, e_2 solves

$$\begin{aligned} \lambda' R'\beta &= h_1 c(e_1) \\ \lambda' R'(1-\beta) &= h_2 c(e_2) \end{aligned} \tag{3.3.16}$$

Let e_1^F, e_2^F denote the first best solution where the first best solves,

$$\begin{aligned} \lambda'(e_1+e_2)(R+\gamma) &= h_1 c(e_1) \\ \lambda'(e_1+e_2)(R+\gamma) &= h_2 c(e_2). \end{aligned} \tag{3.3.17}$$

Clearly the solution involves $\beta = \frac{1}{2}$ and $R' = 2(R+\gamma)$. It is obvious that greater is γ greater is the first best effort stream.

The above formulation ignores the participation constraints of the two firms. However there always exist a feasible solution as implementing the solution in Proposition 3 is feasible in this case. The unconstrained optimum may not however satisfy the participation constraints.

3.4 Anti-trust Analysis

In this section I examine the following question. Is the amount of R&D going to increase under joint research as compared to cooperative research? Much of the argument in favour of joint ventures is justified on the grounds that the dynamic benefits of an increase in R&D is going to outweigh the harm that may be caused by a reduction in competition due to the formation of joint ventures. Therefore it is important to examine the extent, to which the assertion of an increase in R&D under joint ventures, holds good.

I show that such an assertion is not always justified. I provide sufficient conditions for the probability of success to be higher under competitive R&D. The results however depend on the nature of the return function. For some return functions the probability of success may be higher under a joint venture. Even when there is complete spill-over the probability of success can be higher under competitive R&D. Besides I demonstrate that the expected surplus may also decline under a joint venture.

In contrast to the previous section I abstract from the questions of financial control in this section. The government, once it decides to allow a joint venture to form, does not intervene in the financial aspects of the joint venture. The government only decides whether to allow the joint venture to form or not. I consider the case where the firms have current market power. By market power I mean that the firms have already established products in the market so that even if they are not successful in developing the new product they can still sell the older product. I assume that under competitive R&D the firms never cooperate in the product market. Under joint product development however the firms may or may not cooperate in the product market.[9] Initially I consider the case where under a joint venture the firms

[9]An example where the firms cooperate in the R&D stage but not in the product market the European Strategic Program for R&D in Information Technologies. The EUREKA project meant for common European Research with concrete objectives and leading to the joint exploitation of the results is an example where the cooperation extends to the product market as well.

do not cooperate in the product market.

First I introduce some notation,[10] in the case where the two firms do not cooperate in the product market.

P_{i1} denotes the ith firm's payoff when firm i succeeds and firm j do not.

P_{i2} denotes the ith firm's payoff when both firm i and j succeed.

P_{i3} denotes the ith firm's payoff when both firm i and j fails.

P_{i4} denotes ith firm's payoff when firm i fails and firm j succeeds.

Clearly it is better for a firm if it innovates rather than if it does not. It is also better for the firm if it faces less competition in the market. Therefore the payoffs can be ordered in the following manner,

$$P_{i1} \geq P_{i2} \geq P_{i3}, P_{i4}$$

It is difficult to order P_{i3} and P_{i4} because if the rival innovates then it may move to a different market thus reducing competition in the market.

I now consider two examples to check whether the above ranking holds. First consider the case where the firms possess current market power. Let the new and the old product be denoted by q_o and q_n respectively. The demand functions take the form, $p_n = A - 2q_n - q_o$ and $p_o = A - q_n - 3q_o$. This is the case of Cournot competition in differentiated products. Here p denotes the market price. The cost functions are identical for the old and the new product i.e. $C = cq$, where $c(< A)$ is the common marginal cost for both the old and the new product. Straightforward calculations show that, $P_{i1} = \frac{50(A-c)^2}{529}$, $P_{i2} = \frac{(A-c)^2}{18}$, $P_{i3} = \frac{(A-c)^2}{27}$ and $P_{i4} = \frac{27(A-c)^2}{529}$. Clearly the ranking holds.

[10]These are borrowed from Ordover and Willig (1985).

Next consider the case where the firms do not possess an existing product. In this case the demand function can be written as $p = A - aq$, where $a > 0$. It is obvious that, $P_{i1} = \frac{(A-c)^2}{4a}$, $P_{i2} = \frac{(A-c)^2}{9a}$ and $P_{i3} = P_{i4} = 0$. Clearly, the ranking holds.

Now consider joint venture payoffs when the firms do not cooperate in the product market. In this case either both the firms fail to develop the product, or both succeed. Therefore the joint venture payoff in case of success would be P_{i2} and that in case of failure would be P_{i3}. I denote the effort levels of firm 1 and firm 2 in this case by e_1' and e_2' respectively. The net payoff of the ith firm would therefore be

$$\lambda(e_1' + e_2')P_{i2} + (1 - \lambda(e_1' + e_2'))P_{i3} - h_i \int_0^{e_i'} c(e_i)de_i$$

Let $g(e) \equiv 1 - \lambda(e)$ denote the probability of failure. Then the first order condition in this case can be written as,

$$\begin{aligned} \lambda'(e_1' + e_2')[P_{i2} - P_{i3}] &= h_i c(e_i'), \ \ i = 1, 2 \\ \text{i.e. } -g'(e_1' + e_2')[P_{i2} - P_{i3}] &= h_i c(e_i'), \ \ i = 1, 2 \qquad (3.4.18) \end{aligned}$$

Following Ordover and Willig (1985) I consider two cases while constructing the counterfactual. In the first case only one of the firms pursue R&D in the absence of a joint venture. In the other case the firms do competitive R&D. I assume that the firms need an expensive research laboratory to perform the R&D. When both the firms have already sunk the costs of installing a laboratory then under competitve R&D both the firms can pursue R&D. If however only one of the firms possess the laboratory then in the absence of a joint venture only the firm that possess the laboratory can pursue R&D. The firm with the laboratory can however invite the other firm to pursue joint research if it so desires.[11]

To begin with I consider the case where only *one* of the firms pursue R&D in the absence of joint research. First consider the case where the firms behave non-cooperatively in the product market following agreements to do joint research. The first order condition of the firm pursuing R&D would be,

$$\begin{aligned} \lambda'(e_i)[P_{i1} - P_{i3}] &= h_i c(e_i), \quad i = 1,2 \\ \text{i.e.} \ -g'(e_i)[P_{i1} - P_{i3}] &= h_i c(e_i), \quad i = 1,2 \end{aligned} \tag{3.4.19}$$

I first briefly examine the individual rationality of pursuing joint research in this context. The firms endogenously decide whether to undertake joint research or not, and in case of joint research what should be the profit sharing rule. In order to simplify the analysis I assume that the firms do not possess an existing product. Besides, assume that under a joint venture the firms collaborate in the product market and that $P_{i1} = P_{i2} = R$.

First consider the case where it is the efficient firm i.e. firm 1 that does R&D alone in the absence of a joint venture. Clearly, $D_2 = 0$ and $P_1(1) = D_1$ where $P_1(1)$ and D_1 are evalued at the equilibrium effort levels. Therefore it is enough to look at the participation constraint of the first firm. Clearly a necessary and sufficient condition for a joint venture to be individually rational is that $\frac{\partial P_1}{\partial \alpha}(1) < 0$ i.e. $\lambda'(\underline{e_1})e_2'(1) + \lambda(\underline{e_1}) < 0$, where $\underline{e_1}$ satisfies $R\lambda'(e_1) - h_1 c(e_1) = 0$. (See Figure 3).

The condition, when the inefficient firm performs the R&D in the absence of a joint venture, is symmetrical. The above analysis is concerned with

[11] It would be interesting to pursue a *model* where these decisions are endogenous rather than exogenous.

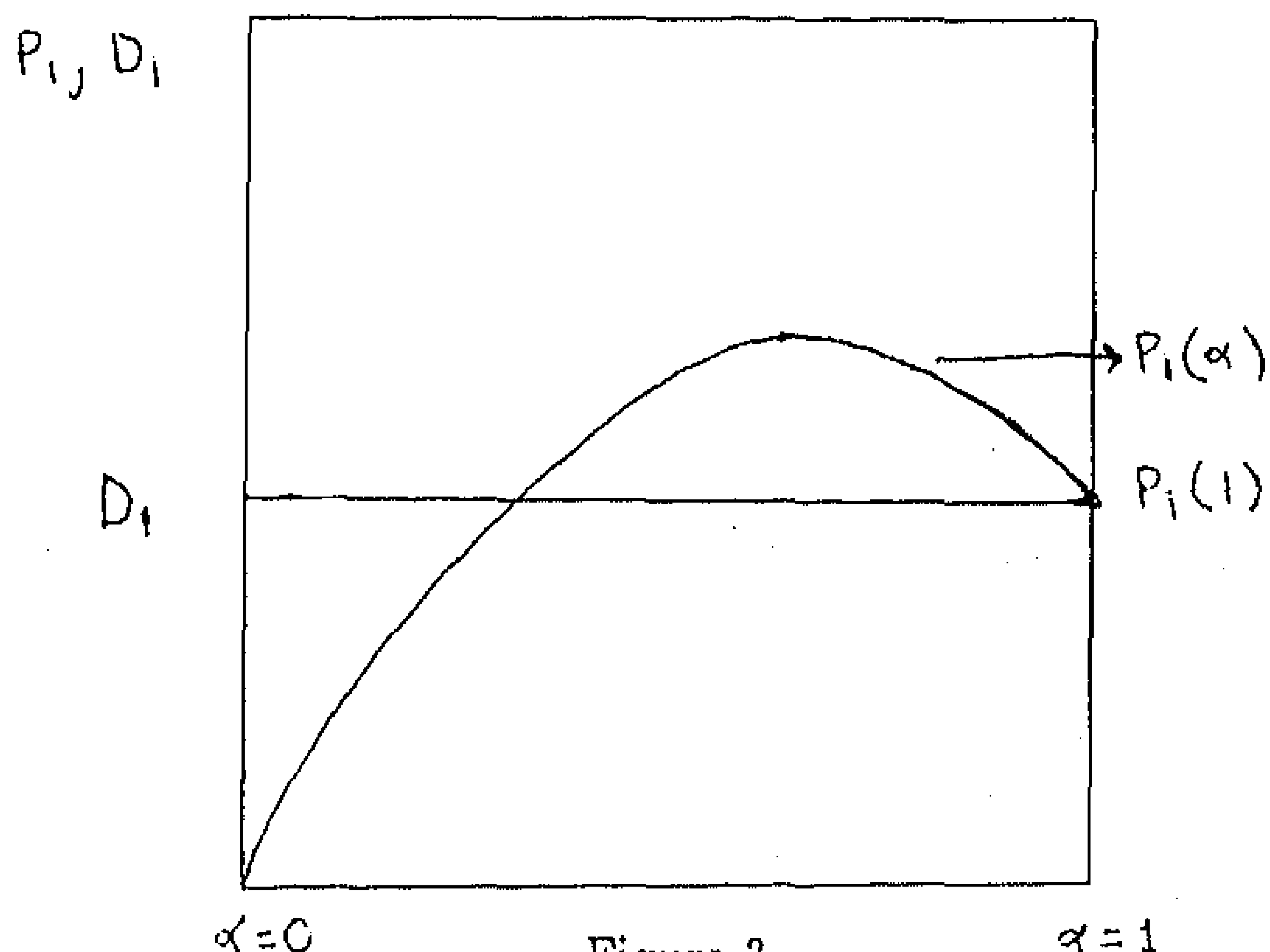

Figure 3

the case where under a joint venture the firms cooperate in the product market. In case the firms compete in the product market following joint venture success the incentive to form a joint venture would be lower.

I do not examine the nature of the profit sharing rule. None of my results depend on the nature of the profit sharing rule.

I now examine whether the probability of success is higher under joint research compared to when the firms do research alone. I find that the result depends on whether it is the efficient firm or the inefficent firm which owns a research lab. It can be demonstrated that the more efficient firm pursuing R&D alone has a greater probability of success compared to that under the joint venture and the less efficient firm has a lower probability of success.

Proposition 4. *Suppose that the firms do not cooperate in the product market irrespective of whether or not a joint venture has formed.*
(i) Assume that $c(e)$ is concave and $P_{11} - P_{12} \geq P_{22} - P_{23}$. Then the efficient firm pursuing R&D alone has a greater probability of success compared to a joint venture.

(ii) If $c(e)$ is convex and $P_{21} - P_{22} \leq P_{12} - P_{13}$ then the less efficient firm pursuing R&D alone has a lower probability of success compared to a joint venture.

Proof. (i) Adding up the first order conditions for the joint venture I obtain,

$$\begin{aligned} \lambda'(e_1' + e_2')[(P_{12} - P_{13}) + (P_{22} - P_{23})] &= h_1 c(e_1') + h_2 c(e_2') \\ &> h_1[c(e_1') + c(e_2')] \end{aligned}$$

$$> \; h_1 c(e_1' + e_2') \qquad (3.4.20)$$

The last line follows as $c(e)$ is concave and $c(0) = 0$. From the first order condition of firm 1 and using the condition on payoff I obtain that

$$\lambda'(e_1)[(P_{12} - P_{13}) + (P_{22} - P_{23})] < h_1 c(e_1) \qquad (3.4.21)$$

From equations (20) and (21) it follows that, $e_1 > e_1' + e_2'$.

(ii) The proof is similar to that in the first part of the proposition. ■

The sufficient condition for Proposition 4(i) states that the value to the first firm of the second firm not succeeding when the first firm does, is greater than the value to the second firm of the joint venture succeeding. Part (ii) of the proposition shows that under the converse condition the second firm has a lower probability of success compared to the joint venture. The intuition is as follows. Reward for succeeding alone is the motivation for isolated R&D. Reward from joint success is the motivation for R&D in case of joint venture. Depending on which of the effects outweigh the other the result can go either way.

Consider the first example where the firms possess an existing product. In this case $P_{i1} - P_{i2} \simeq 0.039(A-c)^2 > 0.0184(A-c)^2 \simeq P_{j2} - P_{j3}$. Therefore in this case the sufficient condition for Proposition 4(i) is being satisfied. The condition for Proposition 4(ii) is, however, not being satisfied. In the example where the firms do not have an existing product also, the inequalities go the same way. In this case $P_{i1} - P_{i2} = \frac{5}{36}\frac{(A-c)^2}{a} > \frac{(A-c)^2}{9a} = P_{j2} - P_{j3}$.

Next consider the case where the firms cooperate in both the R&D and the product market stage. Let the joint payoff in case of success be denoted

R and that in case of failure be denoted R', where $R > R'$. Let the sharing rule be given by α where α denotes the share of the first firm. I assume that the sharing rule is identical in case of both success and failure. Therefore the first order condition for firm 1 in this case yields,

$$\begin{aligned} \lambda'(e_1' + e_2')[R - R']\alpha &= h_1 c(e_1') \\ \text{thus } \lambda'(e_1' + e_2')[R - R'] &> h_1 c(e_1') \end{aligned} \quad (3.4.22)$$

The condition for the second firm would be symmetrical. This makes no qualitative difference to the results. As before I find that the more efficient firm pursuing R&D alone has a greater probability of success compared to the joint venture and the less efficient firm has a lower probability of success.

Proposition 5. *(i) When $c(e)$ is concave and $P_{11} - P_{13} \geq R - R'$ the more efficient firm doing R&D alone has a higher probability of success compared to the joint venture.*

(ii) When $c(e)$ is convex and $P_{21} - P_{23} \leq R - R'$ the less efficient firm doing R&D alone has a lower probability of success compared to the joint venture.

Proof. Similar to that of Proposition 4.

First consider the case where the firms possess current market power. In this case $R = \frac{(A-c)^2}{8}$ and $R' = \frac{(A-c)^2}{12}$. Clearly $R - R' \simeq 0.042(A-c)^2 < 0.057(A-c)^2 \simeq P_{i1} - P_{i3}$. Therefore in this case the sufficient conditions for Proposition 5(i) will be satisfied while that for Proposition 5(ii) will not be.

If, however, the firms do not possess an existing product then the conditions hold with equality i.e. $P_{i1} - P_{i3} = R - R'$.

I next consider the case where the alternative to joint venture is competitive R&D by the firms.

I first briefly examine the individual rationality of pursuing joint research in this context. The firms endogenously decide whether to undertake joint research or not, and in case of joint research what should be the profit sharing rule. In order to simplify the analysis I assume that the firms do not possess an existing product. Besides, assume that under a joint venture the firms collaborate in the product market and that $P_{i1} = P_{i2} = R$.

In the previous section I demonstrated that provided $P_i(\alpha^*) > \max\ (D_1, D_2)$, there exists α for which a joint venture is individually rational. I do not examine the case where following joint venture success the firms compete in the product market. Clearly the incentive to form a joint venture would be lower in this case. I also abstract from the question of exactly at what level is α to be determined as my results do not depend on the precise level of α.

Consider the payoff of the ith firm when the firms are competing in the R&D market. The payoff of the first firm can be written as follows,

$$\begin{aligned}[1 - g(e_2)][g(e_1)P_{14} \ &+ \ \{1 - g(e_1)\}P_{12}] \\ &+ \ g(e_2)[g(e_1)P_{13} + \{1 - g(e_1)\}P_{11}] - h_1 \int_0^{e_1} c(\tilde{e_1})d\tilde{e_1}\end{aligned}$$

The first order condition of firm 1 would be,

$$-g'(e_1)g(e_2)[P_{11} - P_{13}] - g'(e_1)(1 - g(e_2))[P_{12} - P_{14}] = h_1c(e_1) \quad (3.4.23)$$

The first order condition for firm 2 would be symmetric.

Proposition 6 demonstrates that for a class of return functions, the probability of success is likely to be less in the case of joint product development, compared to the case when the firms compete in the R&D market. The two parts of this proposition successively examine the case when under a joint venture, the firms do not and do cooperate in the product market. However, note that in the case where the firms cooperate in the R&D stage but not in the product market, joint ventures have an advantage as far as the surplus is concerned. Under a joint venture any success is joint success, whereas under a competitive R&D it is possible that only one firm succeeds. Consumers' surplus is higher when both the firms succeed, because success by only one of the firms would lead to monopoly. In this case therefore, it would be interesting to examine the relative probability of joint vis a vis solitary success under competitive R&D. However, I do not address this question in this essay.

Proposition 6. *(i) Assume that* $\lambda'(e_i)(1-\lambda(e_j)) \geq \lambda'(e_i+e_j), \forall e_i, e_j$ *and that the joint venture firms do not cooperate in the product market. The probability of success is greater when the firms compete in the R&D stage rather than when they cooperate in the R&D stage.*

(ii) Assume that $\lambda'(e_i)(1-\lambda(e_j)) \geq \lambda'(e_i+e_j), \forall e_i, e_j$ *and that the joint venture firms cooperate in the product market. A sufficient condition that the probability of success be greater when the firms compete in the R&D stage is that* $P_{i1} - P_{i3} \geq R - R'$ *for* $i = 1, 2$.

Proof. (i) Observe that the probability of failure is lower under joint product development if and only if,

$$g(e_1)g(e_2) > g(e_1' + e_2').$$

Next observe that $\lambda'(e_i)(1 - \lambda(e_j)) \geq \lambda'(e_i + e_j), \forall e_i, e_j$ i.e. $g'(e_i)g(e_j) \leq g'(e_i + e_j)$ for all e_i, e_j is a sufficient condition for $g(e_i)g(e_j) \leq g(e_i + e_j)$.[12]

It is sufficient to show that $(e_1 + e_2) > (e_1' + e_2')$. This implies that $g(e_1' + e_2') > g(e_1 + e_2) \geq g(e_i)g(e_j)$ where the second inequality follows from the condition in the proposition.

From equation (23) it follows that,

$$\begin{aligned} -g'(e_1)g(e_2)[P_{i1} - P_{i3}] &< h_i c(e_i) \\ \text{or } - g'(e_1 + e_2)[P_{i1} - P_{i3}] &< h_i c(e_i) \end{aligned} \qquad (3.4.24)$$

where the first line follows as $-g'(e_1)(1 - g(e_2)) \geq 0$ and the second line follows from the condition in the proposition.

Now suppose to the contrary that $e_1 + e_2 \leq e_1' + e_2'$. This implies that,

$$\begin{aligned} -g'(e_1 + e_2) &\geq -g'(e_1' + e_2') \\ \text{or } - g'(e_1 + e_2)[P_{i1} - P_{i3}] &> -g'(e_1' + e_2')[P_{i2} - P_{i3}] \end{aligned} \qquad (3.4.25)$$

where the first line follows from the concavity of $\lambda(e)$ and the second line follows from the fact that $P_{i1} > P_{i2}$.

Now equations (18), (24) and (25) together imply that,

$$h_i c(e_i) > -g'(e_1 + e_2)[P_{i1} - P_{i3}] > -g'(e_1' + e_2')[P_{i2} - P_{i3}] = h_i c(e_i') \quad (3.4.26)$$

[12] Integrating both sides of the first equation from 0 to e_i I obtain,

$$g(e_i)g(e_j) + g(e_j)(1 - g(0)) \leq g(e_i + e_j).$$

Since $g(0) \leq 1$ the result is immediate.

which implies that $e_i > e_i'$. Therefore it follows that $e_1 + e_2 > e_1' + e_2'$ which is a contradiction.

(ii) The proof would be similar to that of proposition (i). ∎

The sufficient condition on payoffs for Proposition 6(ii) to hold will be satisfied in both the examples. It will, however be satisfied with an equality in the example where the firms do not possess an existing product.

A return function that satisfies the condition of Proposition 6 would be $\lambda(E) = 1 - e^{-\delta E}$, where $\delta > 0$. Next I show that the condition on the return function is necessary in the sense that if it does not hold, then the result of Proposition 6(ii) may be overturned. This condition essentially implies that there is no bias against competitive R&D, because for identical effort levels, this implies that the probability of success is atleast as much under competitve R&D as under a joint venture. This condition however breaks down for very simple return functions. I consider the case of linear return functions i.e. $\lambda(e) = \min(e, 1)$. Assume that the firms do not possess current market power, joint venture firms cooperate in the product market as well and the return to the firms under competitive R&D, if both succeed, is zero. Also assume that $h_1 = h_2 = h$ and that $h \geq R$. In the example following Proposition 1 in chapter 2 of this thesis, I demonstrate that there exists a unique interior solution in this case under competitive as well as cooperative R&D.

Denote the effort levels under joint venture and competitive R&D by $\overline{e}$ and $\underline{e}$ respectively. Explicitly solving I obtain, $\overline{e} = \frac{R}{2h}$ and $\underline{e} = \frac{R}{h+R}$. It is easy to see that joint venture success probability is higher if and only if,

$$h(h-R) \leq R^2$$

For $h \geq R$ the L.H.S. is increasing in h. Therefore there exists an h^* such that the condition is satisfied for any $R \leq h \leq h^*$.

Next I consider the case where the effort level is verifiable. I assume that the joint venture firms are going to cooperate in the product market as well. Clearly under a joint venture the firms can contract to implement the first best. This case corresponds to the Ordover and Willig (1985) case. Not surprisingly I also find that the probability of success is likely to be greater under cooperative research. I assume that the firms do not possess an existing product and the payoff, when both the firms succeed and compete in the product market, is zero. This implies that $P_{i2} = P_{i3} = P_{i4} = R' = 0$.

Denote the effort level of the ith firm under a joint venture by e_i''. The joint venture first order condition in this case yields,

$$-g'(e_1'' + e_2'')R = h_i c(e_i'') \tag{3.4.27}$$

Proposition 7. *Assume that* $\lambda'(e_i)(1-\lambda(e_j)) \leq \lambda'(e_i+e_j), \forall e_i, e_j$ *and* $g(0) = 1$. *A sufficient condition that the probability of success be less when the firms compete in the R&D stage is that* $P_{i1} < R$ *for* $i = 1, 2$.

Proof. Observe that $g'(e_i)g(e_j) \geq g'(e_i + e_j)$ for all e_i, e_j and $g(0) = 1$ is a sufficient condition for $g(e_i)g(e_j) \geq g(e_i + e_j)$.[13]

[13]Integrating both sides of the first equation from 0 to e_i I obtain,

$$g(e_i)g(e_j) + g(e_j)(1 - g(0)) \geq g(e_i + e_j).$$

Therefore I have to show that $e_1'' + e_2'' \geq e_1 + e_2$. Suppose not. Then $-g'(e_1'' + e_2'') > -g'(e_1 + e_2)$. This implies that,

$$-g'(e_1'' + e_2'')R > -g'(e_1 + e_2)P_{i1} \tag{3.4.28}$$

I can argue (mimicing the proof in Proposition 6) that,

$$h_i c(e_i'') > h_i c(e_i)$$

This implies that $e_i'' > e_i$ which is a contradiction. ∎

The condition on the payoffs is satisfied in both the examples. $\lambda(e) = \min(e, 1)$ satisfies the condition on the return function.

I next introduce spill-over effects into the model. One of the major findings of D'Aspremont and Jacquemin (1988) was that in the presence of spill-over effects the joint venture form of research becomes more attractive as regards the probability of success. The reason is simple. In the presence of spill-over effects, appropriating the returns from individual research becomes more difficult. Therefore there is less incentive for the firms to invest in case of individual research. D'Aspremont and Jacquemin (1988) found that when spill-over is complete the probability of success is greater under joint venture. It is of interest to examine whether the same holds true in the context of product development. In the context of this chapter spill-overs can be represented as an increase in the effective effort stream of the two players. If, under competitive R&D, the effort levels of the two firms are e_1 and e_2 respectively, then the probability of success of the ith player will be

Now for $g(0) = 1$ the result is immediate.

$\lambda(e_i+\beta e_j)$ where $0 < \beta < 1$ is the coefficient of spill-over. If there is complete spill-over, the probability of success of both the firms will be $\lambda(e_1 + e_2)$.

I explore the question in a simplified framework. I assume that the cost function $c(e)$ is concave and the return function is of the form $\lambda(E) = 1-e^{-E}$. I also assume that the under a joint venture the firms cooperate in the product market as well, that the firms have no current market power and that the payoff when both the firms succeed and compete in the product market is zero. This implies that $P_{i2} = P_{i3} = P_{i4} = R' = 0$. For simplicity denote $P_{i1} = P$.

To further simplify matters I assume that the two firms possess identical level of technologies, i.e. $h_1 = h_2 = h$, the sharing rule involves $\alpha = \frac{1}{2}$ and there is complete spill-over so that the probability of success of any firm depends on the joint effort stream, i.e. the probability of success of any firm is $\lambda(e_1 + e_2)$. The first order condition for the joint venture is given by,

$$e^{-2e'}\frac{R}{2} = hc(e') \qquad (3.4.29)$$

The first order condition in case of competitive R&D would be,

$$e^{-4e}(2 - e^{2e})2P = 2hc(e) > hc(2e) \qquad (3.4.30)$$

where the last line follows as $c(e)$ is concave and $c(0) = 0$.

The next proposition demonstrates that with complete spill-over the probability of success under joint research would be higher provided the return from joint venture is high enough.

Proposition 8. *If $R > 4P$ then the probability of success under joint venture exceeds that under competitive research.*

Proof. The probability of success under the joint venture is $1 - e^{-2e'}$ and the success probability under competitive research is $1 - e^{-4e}$. Clearly the probability of success under joint research is greater iff $e' > 2e$.

From equation (30) it follows that ,

$$e^{-4e}\frac{R}{2} > hc(2e) \tag{3.4.31}$$

Now from equation (29) and (31) the conclusion follows. ∎

Observe that in neither of the examples the condition that $R > 4P$ is going to be satisfied. Only if the firms compete in prices rather than quantity is this likely to be satisfied.

I next show that contrary to the result in D'Aspremont and Jacquemin (1988) even with complete spill-over the probability of success may be greater under competitive research. I use a simple example for this exercise. Assume that $\lambda(e) = \min(e, 1)$ and that costs are quadratic.[14] Solving the respective first order conditions I obtain that,

$$e' = \frac{R}{2h} \text{ and } e = \frac{P}{h + 4P}$$

Using these relations it is easy to see that the probability of success is higher under competitive research iff,

$$4hP(h + 3P) > R(h^2 + 16P^2 + 8hP)$$

For $R = \beta h$, where $\beta < 1$ the condition reduces to,

$$R^2 + P^2\beta(16\beta - 12) + RP(8\beta - 4) < 0$$

[14]In order to rule out corner solutions I assume that $R \leq h$.

It is easy to see that there exists a β^* such that the competitive probability of success is greater if and only if $\beta < \beta^*$.[15] Therefore for a cooperative return which is low enough compared to the costs and the competitive return competitive R&D is better than joint research as regards the probability of success.

Lastly I consider the impact of joint ventures on the aggregate surplus in the economy. Specifically I address the following question. Is it possible that the firms find it individually rational to opt for a joint venture, though allowing joint ventures to form is not beneficial from the social point of view? I address this question for the case where there is no spill-over. Let the equilibrium effort levels in case of joint ventures and competitive R&D be denoted by (e'_1, e'_2) and (e_1, e_2) respectively. I consider the case where, under joint product development the firms cooperate in the product market as well.

I introduce the following notation for the surplus under various possible outcomes. For simplicity consider the case when the firms are identical. Let B denote the surplus when both the firms are successful in developing the product and they compete in the product market. Let C denote the surplus when both the firms are successful and they cooperate in the product market. Let D denote the surplus when only one of the firms succeed. Finally let E denote the surplus when both the firms fail to innovate. One can impose the

[15] Let

$$Z(\beta) = R^2 + P^2\beta(16\beta - 12) + RP(8\beta - 4) < 0.$$

It is easy to see that $Z(0) = R^2 - 4RP$ and $Z(1) = R^2 + 4P^2 + 4RP > 0$. Besides $\frac{1}{4}\frac{\partial Z}{\partial \beta} = P^2(8\beta - 3) + 2RP \geq P^2(8\beta - 3) + 4P^2 = P^2(8\beta + 1) > 0$. Clearly for $R < 4P$ it follows that $Z(0) < 0$. Therefore there exist β^* such that $Z(\beta) < 0$ iff $\beta < \beta^*$.

following natural ranking on the surplus, $B > D > C > E$.

The surplus in case of joint ventures is therefore,

$$\lambda(e_1' + e_2')C + (1 - \lambda(e_1' + e_2'))E$$

The surplus in case of competitive R&D can be expressed as,

$$\lambda(e_1)\lambda(e_2)B + 2\lambda(e_i)(1 - \lambda(e_j))D + (1 - \lambda(e_1))(1 - \lambda(e_2))E$$

Assume that the firms do not possess any current market power. Clearly, given the ranking on the surplus, a sufficient condition for the surplus to be greater under competitive R&D is that the probability of success be greater under competitive R&D.

The last proposition demonstrates that it is possible, that even though the firms find it individually rational to opt for a joint venture, the social surplus declines as a result.

Assume that the firms do not possess current market power, joint venture firms cooperate in the product market as well and the return to the firms under competitive R&D if both succeed is zero. Also assume that $h_1 = h_2 = h$.

Proposition 9. *Assume that $\lambda'(e_1)(1 - \lambda(e_2)) \geq \lambda'(e_1 + e_2)$ and there exists e^* such that $\lambda(2e^*) \geq \frac{1}{2}$. For a high enough $\frac{R}{h}$ the firms will find it individually rational to opt for a joint venture and the social surplus would be lower under the joint venture.*

Proof. The first part of the proof follows from Proposition 1 in the second chapter of this thesis. The next part follows from Proposition 6(ii) and the preceding observation. ■

3.5 Appendix

Proof of Proposition 1. (i) From the Nash conditions of the two firms it follows that,

$$e_1'(\alpha) = \frac{R\lambda' h_2 - R^2\lambda'\lambda''}{h_1h_2 - R\lambda''\{h_1(1-\alpha) + h_2\alpha\}} > 0 \quad (3.5.32)$$

$$e_2'(\alpha) = \frac{-R\lambda' h_1 + R^2\lambda'\lambda''}{h_1h_2 - R\lambda''\{h_1(1-\alpha) + h_2\alpha\}} < 0 \quad (3.5.33)$$

$$e_1'(\alpha) + e_2'(\alpha) = \frac{R\lambda'(h_2 - h_1)}{h_1h_2 - R\lambda''\{h_1(1-\alpha) + h_2\alpha\}} > 0 \quad (3.5.34)$$

$$(3.5.35)$$

Next I show that G is concave in α. Clearly as α increases e_1+e_2 increases. Therefore $\lambda(e_1+e_2)$ increases, and $\lambda'(e_1+e_2)$ decreases. Hence it is enough to demonstrate that $e_1'(\alpha)+e_2'(\alpha)$ and $e_1'(\alpha)$ is decreasing in α.

First I check for the sign of $\frac{d}{d\alpha}\{e_1'(\alpha)+e_2'(\alpha)\}$. Clearly as α increases $\lambda'(e_1+e_2)$ decreases and $h_1(1-\alpha)+h_2\alpha\}$ increases. Since $\lambda''' < 0$, it follows that $\lambda''(e_1+e_2)$ is decreasing in α. Therefore $\frac{d}{d\alpha}\{e_1'(\alpha)+e_2'(\alpha)\} < 0$.

Next I check for the sign of $\frac{d}{d\alpha}e_1'(\alpha)$. Clearly the sign is negative provided $\frac{\partial}{\partial\lambda''}e_1'(\alpha) > 0$. Numerator of $\frac{\partial}{\partial\lambda''}e_1'(\alpha) = R^2\lambda' h_2\alpha(h_2-h_1) > 0$.

(ii) If α is the share of firm 1 then the Nash equilibrium conditions are given by,

$$\lambda'(e_1+e_2)R\alpha = h_1c(e_1) \quad (3.5.36)$$

$$\lambda'(e_1+e_2)R(1-\alpha) = h_2c(e_2) \quad (3.5.37)$$

Algebraic manipulations similar to those undertaken before yields,

$$\frac{(de_1 + de_2)}{d\alpha} = \frac{\lambda'(e_1 + e_2)R[h_2c'(e_1) - h_1c'(e_2)]}{h_1h_2c'(e_1)c'(e_2) - \lambda''R(\alpha h_2h_2c'(e_2) + (1-\alpha)h_1c'(e_1))} \tag{3.5.38}$$

For $e_1 > e_2$, $c'(e_1) > c'(e_2)$. To complete the proof I note that for $\alpha \geq \frac{1}{2}$ from equations (28) and (29) it follows that $e_1 > e_2$.

(iv) In this case,

$$e_1 = c^{-1}(\frac{R\alpha}{h_1}) \tag{3.5.39}$$

$$e_2 = c^{-1}(\frac{R(1-\alpha)}{h_2}) \tag{3.5.40}$$

Therefore,

$$e_1'(\alpha) = \frac{1}{c'(e_1)}\frac{R}{h_1} \text{ and } e_2'(\alpha) = -\frac{1}{c'(e_2)}\frac{R}{h_2}.$$

Clearly

$$\frac{\partial^2 G}{\partial \alpha^2} = -R(2e_1'(\alpha) + e_2'(\alpha)) - \frac{R^2}{h_1}(1-\alpha)e_1'(\alpha)\frac{c''(e_1)}{(c'(e_1))^2}$$

Therefore a sufficient condition for G to be concave is that $2e_1'(\alpha) + e_2'(\alpha) > 0$. It is easy to show that, for $\alpha < \frac{h_1}{h_1+h_2}$ the above holds.[16] ∎

[16] Substituting the values of $e_1'(\alpha)$ and $e_2'(\alpha)$ I find that this is equivalent to showing $2c'(e_2)h_2 - c'(e_1)h_1 > 0$. Therefore from the convexity of $c(e)$ a sufficient condition is that $c'(e_2) > c'(e_1)$ i.e. $e_2 > e_1$. From equation (35) and (36) this reduces to $\alpha < \frac{h_1}{h_1+h_2}$.

3.6 Reference

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Chapter 4

The Role of Government Intervention in Technology Transfer

4.1 Introduction

In this chapter I examine the role of government intervention in transnational technology transfer. The motivation comes from the contrasting experiences of India and Japan. In the case of Japan, technology imports proved to be an unqualified success. Much of the high growth rate in the Japanese industry can be attributed to imported technology (except in a few cases like the shipbuilding and the optical industry). The Indian experience, however, was not as satisfactory. In case of India, the import of foreign technology did not lead to technological self sufficiency.[1] The question is, to what extent can one attribute the Japanese success to government intervention in technology transfer.

In India, the domestic firms are usually dependent on the foreign firms for access to modern technology. Such transfer, mostly taking place under licensing schemes, have been associated with various restrictive practices in the form of secrecy clauses, restrictions on sublicensing, exclusive right of patent, trademark and knowhow etc. In fact, 72.3% of the purely technological collaborations agreements in the RBI's Fourth Survey of Foreign Collaborations, involved regulatory clauses.[2]

[1]K.K. Subrahmanian points out that "Nor has the expected diffusion of industrial know how and skills taken place on an impressive scale. ··· the terms and conditions of imports hindered the choice of technology, their effective adaptation, assimilation and the effective utilisation even at too high a price.···(and) constrained the Indian industry to remain continuously dependent on the scaffolding of borrowed technologies."

[2]Kewalram (1990) found widespread evidence of such restrictions in the petrochemical industries. One commonly adopted method was to impose secrecy clauses on the Indian firms. Often the duration of these clauses would be longer than that of the agreement itself. In case of the vinyl chloride and ethylene dichloride project the duration of the agreement is for seven years but the secrecy clause holds for fifteen years. Besides there are restrictions on exclusive right of patent, trademark and know-how. Of the eleven projects for which information on patents, trade-marks and know-how was made available, only two projects were granted exclusive rights. Only in the case of three projects were the Indian partner granted the right to sublicense the technology, and even then the consent of the foreign partner was required in two of these three cases. Often the right to use the patent after the expiry of the agreement was also restricted. Besides there were restrictions on exports and capacity expansion as

The restrictive conditions so prevalent in India are, however, almost totally absent in Japan. In Japan the bargaining process was usually carried out via the mediation of the Ministry for International Trade and Industry (MITI). It is usually argued that MITI, using its monopsony power, was able to obtain relatively more favourable terms for the domestic firms than would have been the case otherwise. As an (perhaps extreme) example one can mention that " royalty payments on import of the oxidation (basic oxygen furnace) process for steel production from Austria were held down to under 1 cent per ton for Japan through an agreement between MITI and the industry, while the U.S. firms paid upto 35 cents per ton for the import of the same technology." (Goto and Wakasugi, 1988, pp. 189-190.)[3]

Based on the above stylized facts, it has been argued, that the Japanese success owes a great deal to the centralized bargaining procedure adopted in Japan. The empirical evidence however, is suggestive rather than conclusive. It is therefore of interest, to pose the question analytically and examine whether the intuition regarding the benefits of a centralized bargaining procedure is vindicated.

well. One explanation common in the Indian literature is the weak bargaining power of the Indian firms vis-a-vis foreign firms. Evidence from the petrochemical industry corroborates the above hypothesis as it appears that such restrictions are comparatively less in the basic processes where technology is much more commonly available.

[3]Of course the preferential treatment accorded to the industries selected as part of the "national team" as regards finance, tax exemptions etc also played vital roles in the development of these industries. However I abstract from these aspects to concentrate on the bargaining angle alone.

I set up a model where there are n identical domestic firms, facing a single foreign firm possessing a superior technology. Technology transfer may or may not involve government intervention. Government intervention, if it occurs, takes the following form. The government selects a group of firms, who are to acquire the foreign technology. It also imposes an all or nothing restriction on the bargaining process, so that if the foreign firm wants to sell the technology, it must sell it to all the firms in this group or to none of them. In the subsequent bargaining process, the government bargains on behalf of the selected firms transfering the technology to them if negotiations prove successful.

I find that the results depend on the ability of the foreign firm to impose restrictions on sublicensing. When the contracts involve restrictions on sublicensing, domestic surplus is higher if the number of firms adopting the technology increases due to the intervention. This follows as the payoff of the foreign firm is greater if the government does not intervene. The greater payoff of the foreign firm is the result of the greater bargaining power of the foreign firm in the absence of intervention, because in this case it can threaten to sell the technology to other firms in case agreement is not arrived at with the current firm. It is possible however that when the number of adopting firms decreases as a result of the intervention the domestic surplus may decline. This is likely to occur when the old technology is not too inefficient and the level of fixed costs is neither too high nor too low.

In this case the equilibrium, when there is no intervention, may involve the firms who bargain later acquiring the technology. The firms who enter the bargaining process earlier fail to acquire the technology. This may occur if the value of the marginal surplus declines too sharply as the number of firms acquiring the technology increases. The foreign firm now prefers to restrict the number of firms acquiring the technology so as to keep up the value of the surplus.

It is possible that the foreign firm's payoff increases under government intervention, when sublicensing restrictions cannot be imposed. This is the result of the reduced bargaining power of the foreign firm, since the domestic firms can now purchase from other domestic firms who have acquired the technology. Without any intervention the domestic firms would have obtained the technology domestically. Under government intervention however, they all have to purchase from the foreign firm. This compulsion may be sufficient to offset the advantage accruing from the all or nothing restriction. The condition, that the number of firms does not decline under intervention, is no longer sufficient to ensure that the domestic surplus increases. I show that in certain cases it may, infact, decline. Therefore government intervention appears less attractive when the foreign firm cannot impose restrictions on relicensing.

I also examine the impact of technology improvement on the aggregate surplus in the economy. I find that such improvements need not always lead to an increase in the aggregate surplus. If it is an inefficient firm which is undertaking the technology improvement, and if the improvement is not too great, then it is possible that the surplus declines. If, however, the technology improvement is large enough the surplus is going to increase. In the context of my model, however, technology improvement is always welfare improving.

Therefore from the analysis it appears that while the intuition as regards the efficacy of centralized bargaining is vindicated in many cases, there are situations where it does not. It appears that the intuition is most likely to be vindicated when in case of no intervention, restrictions on resell can be imposed. If, however, restrictions on resale cannot be imposed caution seems to be called for. Infact it appears from the analysis that imposing legal sanctions against resale restrictions maybe a policy alternative worth looking into.

The rest of the chapter is organised as follows. Section 2 describes the basic model. The effect of technological improvement on the aggregate surplus is examined in section 3. The model where the foreign firm imposes a restriction on the relicensing of the acquired technology is taken up in section 4. Section 5 considers the model when restrictions on relicensing are not allowed.

4.2 The Model

The model consists of n identical domestic firms ($n \geq 2$) and one foreign firm. Let the domestic firms be numbered consecutively from 1 to n, the firm in the ith position being denoted f_i. Compared to the domestic firms the foreign firm is technologically more advanced. The only role of the foreign firm is as a supplier of the advanced technology; it cannot participate in the domestic market. I consider two kinds of contracts under which technology transfer can take place. In section 4 I assume that the contracts prohibit the domestic firms from relicensing the technology. The case where relicensing is allowed is taken up in section 5.

Next I introduce some basic notations. Consider the case where k of the domestic firms have already acquired the foreign technology. Let π'_k and π_k denote the gross payoff of the firms which do and do not possess the new technology respectively. If F denotes the fixed cost of adopting the new technology, then the net profit of a firm which has acquired the new technology is $\pi'_k - F$.

I make the following assumptions regarding the payoff structure of the game:

(A) If there are no fixed costs of technology acquisition then it is always profitable for one single firm to do so, assuming that the other firms are not going to acquire the technology i.e. $\pi'_k > \pi_{k-1}$.

(B) If the number of firms possessing the new technology increases then the profits of the other firms decline, i.e. π'_k and π_k are decreasing in k.

(C) Consider the case where the foreign firm is selling the advanced technology to some domestic firm. The net gain to the domestic firm from acquiring the technology is decreasing in the number of firms already possessing the new technology, i.e. $\pi'_k - \pi_{k-1}$ is decreasing in k.

These assumptions will be satisfied in the case when the competition in the product market is of the Cournot type and demand and cost curves are linear. Let the demand function be $p = A - bq$ and the cost function be $C_i = hq_i$, with $A, b, h > 0$ and $A - h > 0$. Here p denotes the price level and q_i denotes the output of the ith firm.

The payoffs of the firms can be obtained by straightforward calculation,

$$\pi'_k = \frac{[A + h(n-k) - h'(n-k+1)]^2}{b(1+n)^2}$$
$$\pi_k = \frac{[A + h'k - h(k+1)]^2}{b(1+n)^2}$$

It is easy to verify that assumptions (A)-(C) hold in this case.[4]

The payoffs to two negotiating firms, is written in the form (x, y), where x denotes the payoff of the firm which do not possess the efficient technology, and y denotes the payoff of the firm that possesses the new technology.

I first describe the structure of the game where the government does not intervene in the bargaining process. To begin with I consider the game where the domestic firms are not allowed to resell the technology. In stage 1, f_1 and the foreign firm bargain. First the foreign firm decides whether to transfer the technology or not. If the foreign firm decides not to transfer, then the game moves on to stage 2, without any technology transfer having taken place. If the foreign firm agrees, then the firms use the Nash bargaining solution to decide how the surplus should be shared. The licensing fee is then paid out, f_1 acquires the technology and the game moves to the next stage. In the next stage the process is repeated between the foreign firm and f_2. This process goes on until the foreign firm and f_n complete their bargaining. (See Figure

[4]First consider assumption (A). Assuming that the firms produce a positive amount, $\pi'_k - \pi_{k-1} > 0$ if and only if $[A + h(n-k) - h'(n-k+1)] > [A + h'(k-1) - hk)]$ which reduces to $h > h'$. Next consider assumption (B). Straightforward differentiation yields that $\frac{\partial \pi'_k}{\partial k} = -2\frac{[A+h(n-k)-h'(n-k+1)]}{b(1+n)^2}(h - h') < 0$ and $\frac{\partial \pi_k}{\partial k} = -2\frac{[A+h'k-h(k+1)]}{b(1+n)^2}(h-h') < 0$. Lastly consider assumption (C). It is obvious that $\frac{\pi'_k - \pi_{k-1}}{\partial k} = -\frac{2(h-h')^2}{bn(1+n)^2} < 0$.

1.)

I next describe the game when relicensing of technology is allowed. Consider the case when it is f_j's turn to bargain and the foreign technology have already been acquired by the firms $f_{n_1}, \cdots, f_{n_k}$, where $n_k < j$. In the first step f_j decides whether to bargain with the foreign firm or with f_{n_1}. The bargaining process following the selection of partner is as before i.e. f_j's partner decides whether to transfer the technology or not. If it decides to transfer the technology, then they use the Nash bargaining solution, otherwise the game moves to the next step. First consider the continuation game where f_j selects the foreign firm as partner but they fail to reach an agreement. In the next stage f_j bargains with f_{n_1}. If they also fail to reach an agreement then f_j bargains with f_{n_2}. This process continues until an agreement is reached or f_j runs out of partners. Next consider the continuation game when f_j chooses f_{n_1} but they fail to reach an agreement. In the next step f_j can again choose whether to bargain with the foreign firm or with f_{n_2}. If f_j opts for f_{n_2} but they fail to reach an agreement then in the next step f_j can again choose between f_3 and the foreign firm. If f_j chooses the foreign firm but they fail to agree then in the next stage f_j approaches f_{n_3}. If there is disagreement then in the next stage the bargaining occurs between f_j and f_{n_3}, etc. The game proceeds in this manner until an agreement is reached or f_j runs out of partners. Then it is f_{j+1}'s turn to bargain. (See Figure 2.)

Now consider the case where the government intervenes in the bargaining process. The government selects a group of firms who are to acquire the foreign technology. It imposes the restriction that if the foreign firm is to sell the technology then it must sell to all the firms in this group or to none of

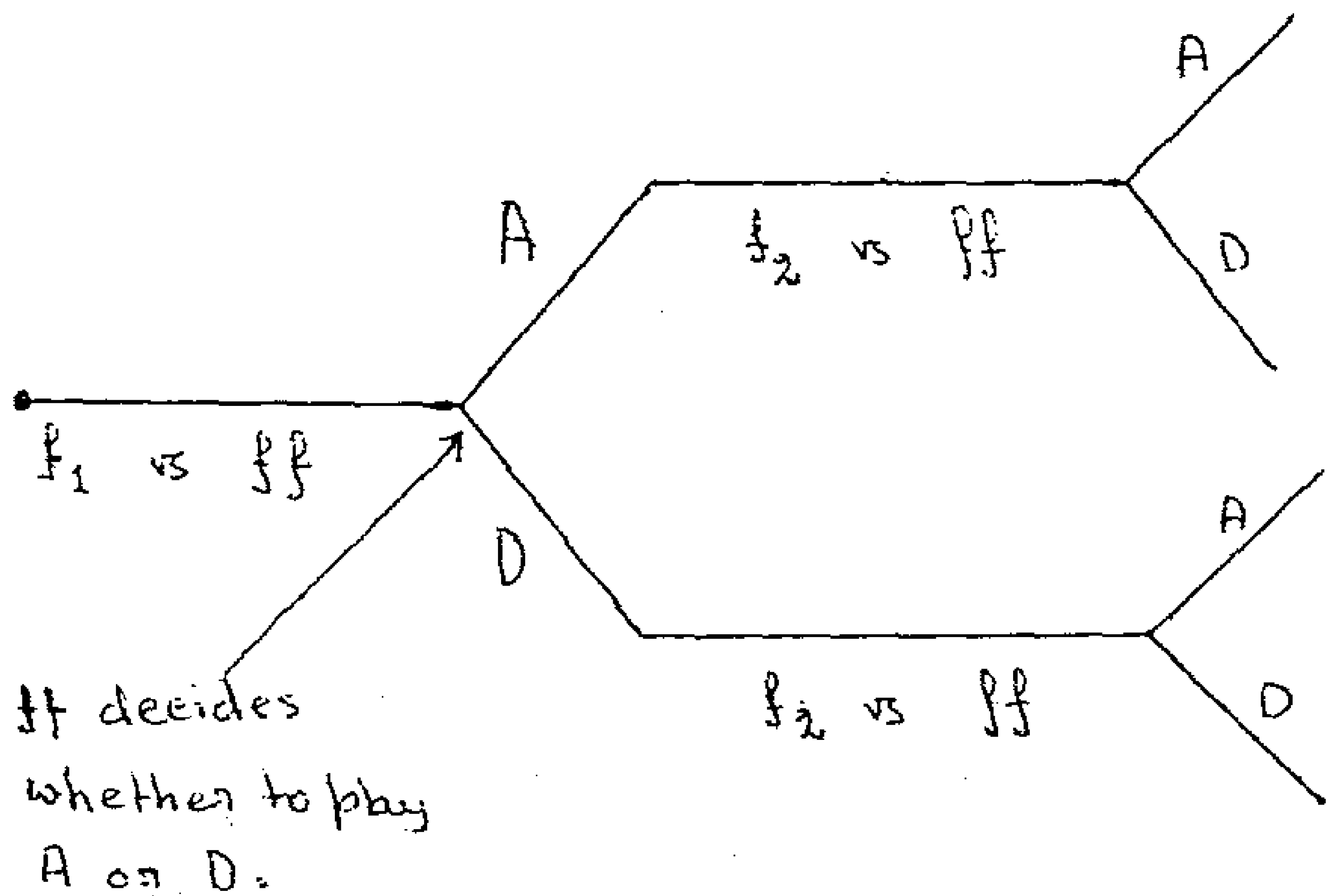

Figure 1.

A: Agree to transfer the technology.

D: Disagree to transfer the technology.

ff: Foreign Firm.

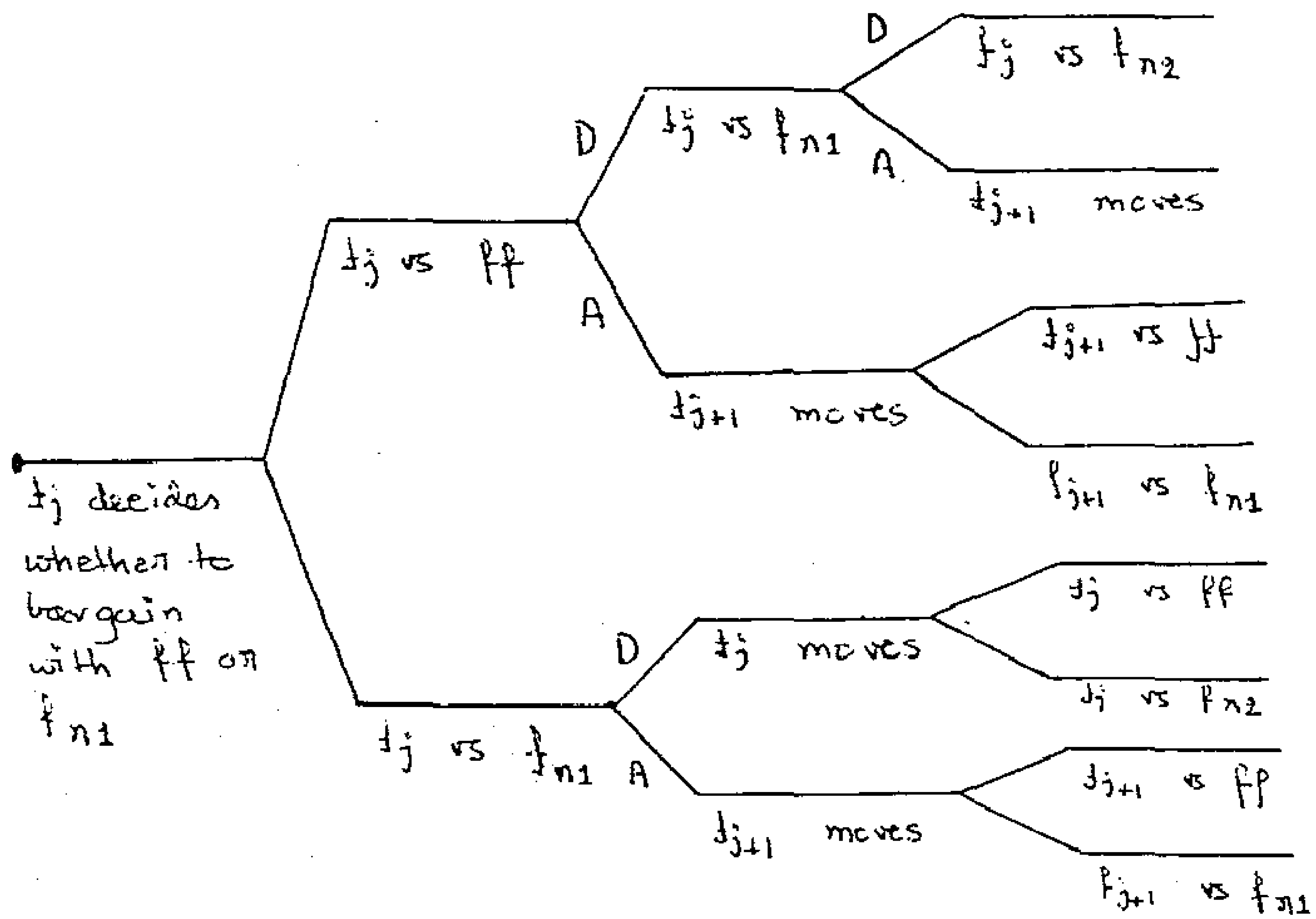
fj decides whether to bargain with ff or fn1
fj vs ff
D
A
fj vs fn1
D
A
fj vs fn2
fj+1 moves
fj+1 moves
fj+1 vs ff
fj+1 vs fn1
fj vs fn1
D
A
fj moves
fj vs ff
fj vs fn2
fj+1 moves
fj+1 vs ff
fj+1 vs fn1

Figure 2

them. Besides the government itself bargains with the foreign firm on behalf of the selected firms and transfers the technology to the selected domestic firms, if negotiations succeed.

I assume that the objective of the government is to maximise the net aggregate surplus i.e. the sum of net producers' surplus plus the consumers' surplus. Let k be such that $\pi'_k - \pi_0 - F \geq 0$ and $\pi'_{k+1} - \pi_0 - F < 0$. Clearly, under government intervention, at most k of the firms can acquire the technology. Therefore the government selects $j(\leq k)$ firms to bargain with the foreign firm, so as to maximise the surplus, taking into account the bargaining game which is to follow.

Suppose the government selects j firms to bargain with the foreign firm. Observe that for a fixed j the gross surplus in the economy has been fixed, so that the government would only be interested in minimizing the amount to be paid to the foreign firm. In this case clearly the agreement payoff involves $j(\pi'_j - F)$ and the disagreement payoff involves $j\pi_0$. Applying the Nash solution I find that the payoff of the foreign firm is $\frac{j}{2}(\pi'_j - \pi_0 - F)$. The payoff of the domestic firms would be $\frac{1}{2}(\pi'_j + \pi_0 - F)$ (assuming that the payoff would be equally divided among the domestic firms).

The bargaining process does not involve a time lag. I use the symmetric Nash bargaining solution to solve this game. Here the disagreement payoffs are determined by solving the continuation game in case of disagreement. There is some discussion in the literature concerning the appropriateness of identifying the outside option with the disagreement point in the Nash solution. Shaked and Sutton (1984) for example point out that in a sequential alternating offers model with an outside option, the presence of an outside option has no effect on the outcome if it lies below some critical value. If the value of the outside option exceeds this critical level then the player in question simply receives the value of the outside option. Dalmazzo (1992) however demonstrates that when the cake decays in size over time it is possible to provide a non-cooperative justification for treating the outside option as the threat point. Chapter 5 of this thesis provides an alternative justification in the context of a bargaining game with a probabilistic move structure.

4.3 Impact of Technological Progress on the Aggregate Surplus

In this section I examine the impact of technological improvement on the aggregate surplus in the economy. The implicit assumption in the literature is that technological improvement is always beneficial for the economy. However, this need not necessarily be true. The intuition holds if the technological improvement is large enough. If the improvement is small, and the improvement is carried out by a relatively inefficient firm, then the aggregate surplus may as well fall. I am going to use these results in the next section, in proposition 4. Besides these results are also of interest by themselves. They suggest that the government should be wary of granting permission to import technology if the improvement is minor.

In order to examine this question I need to impose some structure on the market game following technology acquisition. Assume that the firms produce identical homogeneous goods and they are Cournot competitors in the market. Let the inverse demand function be denoted by $p = f(\sum q_i)$, where p denotes market price and q_i denotes the quantity produced by the ith firm. I assume that the inverse demand function is negatively sloped and concave in aggregate quantity. Let the cost function of the ith firm be denoted by

$$C_i(q_i, h_i) = \int_0^{q_i} c_i(\tilde{q}_i, h_i) d\tilde{q}_i$$

where the marginal cost c_i is increasing (weakly) in the quantity and increasing in h_i.[5] Technological advance takes the form of a cost reducing innovation, captured by a decrease in h_i. In order to simplify the analysis, we assume that the fixed costs of adoption of technology involves the use of assets with no alternative uses. Therefore it only involves transfer from one section of the population to another and can be ignored in calculating the welfare effects.

First I use an example to demonstrate that technological advance may actually lead to a decline in the surplus. Consider the case where there are two firms in the market and demand and cost curves are linear. Let the demand function be $p = A - bq$ and the cost function be $C_i = hq_i$, where $A, b, h > 0$ and $A - h > 0$.

Consider the case when the first firm possess the old technology h_2 and the second firm has the efficient technology h_1, where $h_2 < h_1$.

Solving the first order conditions I obtain,

$$q_1 = \frac{A - 2h_1 + h_2}{3b},$$

[5]In this section I allow for the domestic firms to be different so as to explore the question more generally. In the rest of the chapter I revert to my assumption of identical domestic firms.

$$q_2 = \frac{A - 2h_2 + h_1}{3b}.$$

The aggregate surplus (denoted S) can be written as $\int(A - bq)dq - h_1 q_1 - h_2 q_2$. After substituting the values for q_1 and q_2 this reduces to, $\frac{1}{3b}\{A(A - h_1 - h_2) - \frac{(A-h_1-h_2)^2}{6} - h_1(A - 2h_1 + h_2) - h_2(A - 2h_2 + h_1)\}$. Differentiating with respect to h_2 I find that

$$\frac{\partial S}{\partial h_2} > 0 \text{ iff } 11h_2 > 5A + 7h_1.$$

Hence, if the relatively inefficient firm makes a small technological improvement, then the economy is worse off, provided the inefficient firm is inefficient enough. The intuition is quite straightforward. As a firm gets more efficient, the output of that firm increases and that of the other firm decreases. If, however, the inefficient firm acquires the new technology, there is a substitution against the more efficient firm. If it was inefficient enough to start with, then this increase in costs may outweigh the benefits from increased output.

Next I demonstrate, that when the technology improvement is large enough, the economy would be better off. Proposition 2 makes formal the idea of a large enough technological improvement.

I assume, that there exists a unique interior Cournot equilibrium, which can be characterised using the first order conditions. I also assume that the innovation is non-drastic i.e. none of the firms leave the industry in consequence.

The first order condition would be given by,

$$f(\sum q_i) + f'(\sum q_i)q_j = c_j(q_j, h_j), \quad j = 1, \cdots, n \qquad (4.3.1)$$

First I prove the following lemma which is used in the proof of proposition 2.

Lemma 1. *If h_i decreases then q_i increases and $q_1, \cdots . q_{i-1}, q_{i+1}, \cdots, q_n$ decreases. The total quantity $\sum q_i$ also increases.*

Proof. W.l.o.g. assume that $i = 1$. Denote the new output configuration by $q'_1, \cdots, q'_n$. First I show that $\sum q'_i > \sum q_i$. Suppose not i.e. $\sum q_i \geq \sum q'_i$. From equation (1) and the concavity of the demand function I obtain $q'_i \geq q_i$, for all $i \neq 1$. This in turn implies that $q_1 \geq q'_1$ as $\sum q_i \geq \sum q'_i$. This, however, implies that $f(\sum q'_i) + f'(\sum q'_i)q'_1 > c_1(q'_1, h'_1)$, which is a contradiction. Next since $\sum q'_i > \sum q_i$ it follows from equation 1 and the concavity of the demand function that $q'_i < q_i, \quad \forall i \neq 1$. This in turn implies that $q'_1 > q_1$, since $\sum q'_i > \sum q_i$. ∎

Proposition 2. *If h_1 decreases to h'_1 such that $c_1(q, h'_1) \leq c_i(q, h_i)$, $\forall i, q$ then the aggregate surplus in the economy increases.*

Proof. First I show that $q'_1 \geq q'_i$ for all i. Suppose not. Let $q'_1 < q'_i$ for some i. This implies that $f(\sum q'_i) + f'(\sum q'_i)q'_1 = c_1(q'_1, h'_1) \leq c_i(q'_1, h_i) < c_i(q'_i, h_i) = f(\sum q'_i) + f'(\sum q'_i)q'_i$ which is a contradiction.

Clearly, from equation (1), $q'_i \geq q'_i$ implies that $c_1(q'_1, h'_1) \leq c_i(q'_i, h_i)$ which in turn implies that

$$c_1(\sum q_i - \sum_2 q'_i, h'_1) < c_i(q'_i, h_i) \tag{4.3.2}$$

where from lemma (1) it follows that $0 < \sum q_i - \sum_2 q'_i \leq q'_1$.

I have to show that,

$$\int_0^{\sum q_i} f(q)dq - \sum_{i=1}^{n}\int_0^{q_i} c_i(\tilde{q}_i, h_i)d\tilde{q}_i \;<\; \int_0^{\sum q_i'} f(q)dq \;-\; \int_0^{q_1'} c_1(q_1)dq_1 - \sum_{i=2}^{n}\int_0^{q_i'} c_i(q_i, h_i)dq_i$$

I can break up the R.H.S. into $A + B$ such that

$$\begin{aligned} A &= \int_0^{\sum q_i} f(q)dq - \int_0^{\sum q_i - \sum_2 q_i'} c_1(q_1, h_1')dq_1 - \sum_2^{n}\int_0^{q_i'} c_i(q_i, h_i)dq_i, \\ B &= \int_{\sum q_i}^{\sum q_i'} f(q)dq - \int_{\sum q_i - \sum_2 q_i'}^{q_1'} c_1(q_1)dq_1. \end{aligned}$$

Observe that writing the R.H.S. in this manner is possible as lemma 1 holds. I show that A is greater than the left hand side (denoted S) and B is positive. To prove that $A > S$, I have to show that,

$$\int_0^{\sum q_i - \sum_2 q_i'} c_1(q_1, h_1')dq_1 < \int_0^{q_1} c_1(q_1, h_1)dq_1 + \sum_2^{n}\int_{q_i'}^{q_i} c_i(q_i, h_i)dq_i$$

Clearly it is sufficient to show that,

$$\int_{q_1}^{\sum q_i - \sum_2 q_i'} c_1(q_1, h_1')dq_1 < \sum_2^{n}\int_{q_i'}^{q_i} c_i(q_i, h_i)dq_i$$

I can use equation (2) and the fact that marginal cost is increasing in q_i to show that the above is indeed true.

Clearly a sufficient condition for B to be positive is that $f(\sum q_i') > c_1(q_1', h_1)$. That the condition is true follows because, $f(\sum q_i') + f'(\sum q_i')q_1' = c_1(q_1', h_1')$ and $f(\sum q_i)$ is negatively sloped. ∎

The proof essentially involves breaking up the surplus into two parts A and B such that A corresponds to the surplus if one tries to produce the pre-transfer output with the new technology configuration and B corresponds to the surplus from the increased output. I demonstrate that A exceeds the pre-transfer level of surplus and that B is positive.

Observe, that if the domestic firms are identical and there is only one foreign technology in contention, then the marginal cost of the adopting firm always lies below the marginal costs of the other firms in the economy. Therefore in the context of my model technological improvement is welfare improving.

4.4 The Model With Restriction on Relicensing

In this section I consider the case where the foreign firm imposes a restriction on the relicensing of technology by the domestic firm.

I begin by exploring the equilibrium pattern of technology acquisition. The next proposition provides sufficient conditions under which we can explicitly determine the equilibrium structure. The proposition shows that for some parameter configurations the equilibrium will involve only the firms $f_j, \cdots, f_n$ acquiring the technology and the first $f_1, \cdots, f_{j-1}$ firms will not acquire the technology. Intuitively such patterns would occur if the net gains from technology acquisition declines too sharply. In that case the foreign firm would prefer to restrict the sale of technology and keep up the value of the surplus. The proposition identifies conditions for this to occur.

First I make an assumption which is required in Proposition 3.

Assumption D: The net gain from adopting the new technology when no other firm is going to adopt it, is concave in the number of firms already possessing the technology i.e. $\pi'_i - \pi_{i-1} - F$ is concave in $i-1$.[6]

I also introduce the following notations. Let $a_{i1} = \frac{1}{2^i}$, $a_{ii} = \frac{2^i-1}{2^i}$, $a_{ik} = \frac{a_{i-1,k}+a_{i-1,k-1}}{2}$, and $Z_i = \pi'_i - \pi_{i-1} - F$.

Proposition 3. *Let j satisfy $(a_{jj}+1)Z_{j+1} < (a_{jj} - a_{j,j-1})Z_j + \cdots + a_{j1}Z_1$ and $(a_{j-1,j-1}+1)Z_j > (a_{j-1,j-1} - a_{j-1,j-2})Z_{j-1} + \cdots + a_{j-1,1}Z_1$[7] and assume that $(2^j - 1)(\pi'_n - \pi_{n-1} - F) > (2^{j-1} - 1)(\pi'_1 - \pi_0 - F)$. Then $f_1, \cdots, f_{n-j}$ would not acquire the technology while the rest of the firms would. The foreign firm's payoff is $\sum_1^j a_{ik}Z_k$.*

The proof can be found in the appendix. Basically the second condition ensures, that the last j firms would acquire the technology, irrespective of how many firms had done so earlier. The first condition ensures that the first $n-j$ firms will not acquire the technology. It is easy to see what is going on in the case when there are two domestic firms in the market i.e. $n = 2$. Consider the case where $j = 1$. Therefore the conditions in Proposition 3 reduce to $\pi'_2 - \pi_1 - F > 0$ and $3(\pi'_2 - \pi_1 - F) < \pi'_1 - \pi_0 - F$. Then the foreign firm will transfer the technology to f_2 irrespective of whether f_1 had acquired

[6]In the example with linear cost and demand functions it is easy to see that this holds, infact $\frac{\partial^2 \pi'_i - \pi_{i-1}}{\partial k^2} = 0$.

[7]In the proof of the proposition I demonstrate that there exists a unique j satisfying this property.

it or not. Next consider the bargaining between the foreign firm and f_1. If it sells to f_1 then the payoff vector will be $(\pi_2' - F, \frac{\pi_2' - \pi_1 - F}{2})$ and if it does not then the payoff vector would be $(\pi_1, \frac{\pi_1' - \pi_0 - F}{2})$. From the second condition it follows that agreement with f_1 cannot occur as it will not be individually rational.

Next I examine whether government intervention is desirable in this case. I find that the result depends on the number of firms acquiring the technology under government intervention, compared to the case when the government does not intervene. If the number is no less under government intervention then intervention is desirable. In view of Proposition (2), it is enough to show that the payoff of the foreign firm is lower under government intervention. This is proved in the next proposition.

Proposition 4. *(i) The payoff of the foreign firm, when there is no government intervention, is higher than under government intervention, irrespective of the the number of firms chosen by the government.*

(ii) Government intervention increases the net surplus, provided the number of firms adopting the foreign technology, does not decline under government intervention.

Proof. (i) Consider the case where $\pi_k' - \pi_0 - F > 0$ and $\pi_{k+1}' - \pi_0 - F < 0$. Suppose the government select j firms to bargain with the foreign firm where $j \leq k$. Clearly the payoff of the foreign firm when the government intervenes equals $\frac{j}{2}(\pi_j' - \pi_0 - F)$.

Consider the case where the government does not intervene and the subgame where the foreign firm refuses to sell the technology to the first $n-j$ domestic firms. It is sufficient to show that the foreign firm's payoff in this case exceeds that under government restriction i.e. $\frac{i}{2}(\pi'_j - \pi_0 - F)$.

I consider the case where $j \geq 2$. For $j = 1$ the proof is immediate. In this subgame consider the the case where the foreign firm is bargaining with f_n and $l \leq k-1$ of the domestic firms have already acquired the new technology. It is easy to see that f_n and the foreign firm would agree to the technology transfer as $\pi'_{l+1} - \pi_l - F \geq \pi'_j - \pi_{j-1} - F > \pi'_j - \pi_0 - F > 0$. Therefore the payoff of the foreign firm is $\frac{\pi'_{l+1}-\pi_l-F}{2}$ which is strictly greater than $\frac{\pi'_j-\pi_0-F}{2}$.

Next I consider the game where the foreign firm is bargaining with f_{n-i} where $i \leq j$. Let the payoff from agreeing to the transfer be $(\pi'_a - F, X)$ and the payoff from disagreeing to the transfer be (π_b, Y). Clearly $a, b \leq j$. I make the inductive hypothesis that $X, Y > \frac{i}{2}(\pi'_j - \pi_0 - F)$. In case of agreement the payoff of the foreign firm is

$$\begin{aligned}\frac{\pi'_a - \pi_b - F}{2} + \frac{X+Y}{2} &> \frac{\pi'_j - \pi_0 - F}{2} + \frac{X+Y}{2} \\ &> \frac{\pi'_j - \pi_0 - F}{2} + \frac{i}{2}(\pi'_j - \pi_0 - F) \\ &= \frac{i+1}{2}(\pi'_j - \pi_0 - F).\end{aligned}$$

The first inequality follows since $0 \geq a, b \leq j$ and Assumption C together imply that $\pi'_a \geq \pi'_j$ and $\pi_0 \geq \pi_b$.

If there is disagreement then the payoff is even higher.

(ii) Follows from Proposition (2) and part (i) of this proposition. ∎

The proof basically follows from the fact that without government intervention the foreign firm has a stronger bargaining position as it can threaten to bargain with the other firms. Thus at each step it can extract a larger surplus from the domestic firms, compared to what it obtains under government intervention.

I next examine the case where government intervention causes a decline in the number of firms acquiring the foreign technology. Is it possible that in that case the economy becomes strictly worse off? I address this question in the simplified context of two firms and linear demand and cost functions i.e. $p = A - bq$ and $C_i = hq_i$, where $A, b, h > 0$ and $A > h$.

I write down the following expressions for future reference,

$$\pi_1' - \pi_0 = \frac{4}{9b}(A - h_1)(h_2 - h_1) \tag{4.4.3}$$

$$\pi_2' - \pi_1 = \frac{4}{9b}(A - h_2)(h_2 - h_1) \tag{4.4.4}$$

$$\pi_2' - \pi_0 = \frac{(h_2 - h_1)(2A - h_2 - h_1)}{9b} \tag{4.4.5}$$

In order to simplify the analysis I assume that the technology improvement is not drastic. In this context this implies that,

$$A + h_1 > 2h_2 \tag{4.4.6}$$

i.e. the domestic technology should not be too inefficient compared to the demand level and the foreign technology.

First consider the case where $\pi_2' - \pi_1 - F > 0$. It is obvious, that f_2 and the foreign firm would always reach an agreement, irrespective of whether the first firm reached an agreement or not. Clearly the foreign firm and f_1 would reach an agreement provided $F < \frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi)$. Otherwise the foreign firm would sell to f_2 alone. Observe that $\frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi) = \frac{2}{9b}(h_2 - h_1)(2A - 3h_2 + h_1) > 0$ where the positive sign of the expression follows from equation (6).

Next observe that,

$$\frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi) \gtrless \pi_2' - \pi \qquad (4.4.7)$$

$$\Leftrightarrow 2A \gtrless 5h_2 - 3h_1 \qquad (4.4.8)$$

There are two cases to consider,

Case 1. $2A < 5h_2 - 3h_1$.

Case 2. $2A > 5h_2 - 3h_1$.

Proposition (5) demonstrates that in case 1 government intervention can never make the economy worse off. In case 2 however, for some parameter values, intervention may reduce the net surplus. In case 1, the number of firms who adopt the technology does not decline under government intervention. In case 2 however, such a decline may occur. In that case straightforward calculations show that intervention may, infact, be harmful.

Proposition 5. *(i) In case 1, government intervention can never reduce the net aggregate surplus, and for some values of F, the net surplus strictly increases.*

(ii) In case 2, when $\frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi) > F > \pi_2' - \pi$, government intervention reduces the net agrregate surplus for F close enough to $\frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi)$. For other parameter values however, the net surplus is never reduced and may be increased.

Proof. (i) First observe that,

$$\pi_1' - \pi_0 > \pi_2' - \pi_1 > \pi_2' - \pi_0 > \frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi_0) > 0. \qquad (4.4.9)$$

Clearly if $\frac{3}{2}(\pi_2'-\pi_1)-\frac{1}{2}(\pi_1'-\pi_0) > F$ then both the firms adopt the technology if there is no intervention. In case of government intervention also both the firms can adopt the foreign technology. If $\pi_2' - \pi_0 > F > \frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi_0)$ then under government intervention both the firms can adopt the technology whereas if there is no intervention then only f_2 will adopt the new technology. Therefore in the above two cases government intervention leads to a *strict improvement in the net surplus* (from Proposition 4). Of course in this case the government may select only one of the firms to acquire the foreign technology. In that case however the surplus would be even higher compared to the case when the government selects both the firms. Next consider the case where $\pi_2' - \pi_1 > F > \pi_2' - \pi_0$. Irrespective of whether the government intervenes or not only one firm (f_2 in case of no intervention) adopts the technology and the payoff is identical in both cases. If, however, $\pi_1' - \pi_0 > F > \pi_2' - \pi_1$ then, if the government does not intervene, the foreign firm would sell to f_1 only and its payoff would be $\frac{1}{4}(\pi_1' - \pi_0 - F) + \frac{\pi_1' - \pi_1 - F}{2}$ which is strictly greater than the foreign firm's payoff under no intervention. In this case also government intervention increases the net surplus.

(ii) In this case observe that,

$$\pi_1' - \pi_0 > \pi_2' - \pi_1 > \frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi_0) > \pi_2' - \pi_0 > 0 \qquad (4.4.10)$$

I only analyse the case where $\frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi_0) > F > \pi_2' - \pi_0$. The rest can be analyzed in a manner similar to that above. It is easy to see that, under government intervention only one of the firms adopts the foreign technology, whereas if there is no intervention, then both the firms do so. In case of no intervention the net surplus equals

$$\int (A - bq)dq - h_1 q_1 - h_2 q_2 - \frac{3}{4}(\pi_2' - \pi_1 - F) - \frac{1}{4}(\pi_1' - \pi_0 - F),$$

where $q_1 = q_2 = \frac{A-h_1}{3b}$. The surplus in this case equals $\frac{4(A-h_1)^2}{9b} - \frac{3}{4}(\pi_2' - \pi_1) - \frac{1}{4}(\pi_1' - \pi_0) + F$.

One can similarly calculate the surplus in case of government intervention. This equals

$$\int (A - bq)dq - h_1 q_1 - h_2 q_2 - \frac{1}{2}(\pi_1' - \pi_0 - F),$$

where $q_1 = \frac{A-2h_1+h_2}{3b}$ and $q_2 = \frac{A-2h_2+h_1}{3b}$. The surplus in this case equals $\frac{1}{18b}[8A^2 - 8A(h_1 + h_2) + 11(h_1^2 + h_2^2) - 14h_1 h_2] - \frac{\pi_1' - \pi_0 - F}{2}$.

Substituting $F = \frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi_0)$ and simplifying, I find, that the net surplus in case of no intervention is greater, provided

$$\frac{4(A - h_1)^2}{9b} > \frac{1}{18b}[8A^2 - 8A(h_1 + h_2) + 11(h_1^2 + h_2^2) - 14h_1 h_2]$$

This reduces to,

$$(h_2 - h_1)(8A - 11h_2 + 3h_1) > 0$$

which from the condition that $2A > 5h_2 - 3h_1$ is always satisfied. ∎

Therefore, when the domestic technology is not too inefficient, and the fixed costs are at an intermediate level, government intervention may make the economy strictly worse off. If, however, either the domestic technology is inefficient enough or the fixed cost has an extreme value then government intervention is advisable.

It is easy to see that the results in this section hold for other bargaining schemes as well. All I need for the results to go through is that once two firms bargain and fail to reach an agreement they cannot bargain again. In fact I can replace the deterministic bargaining procedure by one where the domestic firms are randomly selected according to some random selection procedure as long as it satisfies the above mentioned condition. This is so because at any stage the results only depend on the payoff of the foreign firm and the currently selected domestic firm which is independent of the order in which the firms are going to be selected in the future.

4.5 The Model With No Restriction On Re-licensing

In this section I examine contracts which do not involve restrictions on relicensing. It is clear, that in this situation, the bargaining power of the foreign firm is reduced, because once a domestic firm acquires the technology, other domestic firms have the option of purchasing from the domestic firm rather than the foreign firm. In view of this a natural question is whether there is still scope for government intervention.

The question arises why such restrictions cannot be imposed. One possible reason could be the presence of legal sanctions against such restrictions. Another reason could be the difficulty of monitoring the actions of the domestic firms. This however raises the question that in that case how can the government prevent the resale of technology to firms outside those selected by the government. It can be argued that since the foreign firm does not participate in the domestic market it has greater problems in monitoring as compared to the government. I will however abstract from these questions by adopting the first interpretation.

First I introduce one more notation. Assume that n of the firms can acquire the technology if there is no intervention i.e. $\pi'_n - F > \pi_{n-1}$. Now consider the case where f_1 has acquired the technology. The continuation game following the agreement is denoted by $G(n)$. Next consider the case where f_1 failed to acquire the technology, but f_2 acquired it. The continuation game following an agreement is denoted by $G(n-1)$. Thus generally the continuation game following an agreement between f_{n-j+1} and the foreign firm, when $f_1, \cdots, f_{n-j}$ failed to acquire the technology, is denoted by $G(j)$. Thus j denotes that in the continuation game $j-1$ of the firms remain and can acquire the technology. The next proposition examines the structure of the equilibrium in the game $G(n)$.

Suppose that, $\pi'_n - \pi_{n-1} - F > 0$. The proposition shows, that in equilibrium, only the first firm to acquire the technology would purchase from the foreign firm. The other firms would prefer to acquire the technology domestically.

Proposition 6. *(i) Consider the game $G(j)$. In equilibrium, all the domestic firms will acquire the technology from f_{n-j+1} whose payoff would be $\pi'_j - F + (\pi'_j - \pi_{j-1} - F)(\frac{1}{2^2} + \cdots + \frac{1}{2^j})$.*

(ii) The payoff of the foreign firm in the game $G(n)$, assuming that it sells

to f_1 *is,*

$$\frac{J(n)-\pi_k}{2}+\frac{J(n-1)-\pi_k}{2^2}+\cdots+\frac{J(1)-\pi}{2^n},$$

where $J(k)$ *denotes the payoff of* f_{n-k+1} *in the game* $G(k)$.

Proof. (i) See Appendix.

(ii) Working backwards the payoff of the foreign firm in the game $G(n)$ turns out to be, $\frac{J(n)-\pi_k}{2}+\frac{J(n-1)-\pi_k}{2^2}+\cdots+\frac{J(1)-\pi}{2^n}$. Clearly $J(i)-\pi_{i-1} = \frac{2^i+2^{i-1}-1}{2^i}(\pi_i'-\pi_{i-1}-F)$. Of course, whether it sells to f_1, or some other domestic firm, will be endogenously determined by the foreign firm. ∎

In the next proposition I show that the payoff of the foreign firm may increase if the government intervenes. I make the simplifying assumption that demand and cost curves are linear and that the competition is of the Cournot type. Let the demand function be $p = A - bq$ and the cost function be $C_i = hq_i$, with $A, b, h > 0$ and $A - h > 0$.

Proposition 7. *Consider the case, where under government intervention, all the domestic firms are going to acquire the foreign technology. If* $F = 0$, $A = h$ *and* $h' \geq \frac{h}{2}$ *then the payoff of the foreign firm is greater under government intervention compared to the case where there is no intervention.*

Proof. Clearly, from proposition 6, the payoff of the foreign firm is

$$\frac{J(k)-\pi_{k-1}}{2}+\frac{J(k-1)-\pi_{k-2}}{2^2}+\cdots+\frac{J(1)-\pi}{2^k},$$

where $k(\leq n)$ is chosen by the foreign firm so as to maximise its payoff.

Observe that $J(k) - \pi_{k-1} = (\pi'_k - \pi_{k-1} - F)(1 + \frac{2^{k-1}-1}{2^k}) < 2(\pi'_1 - \pi_0 - F)$. Therefore , $\frac{J(k)-\pi_{k-1}}{2} + \frac{J(k-1)-\pi_{k-2}}{2^2} + \cdots + \frac{J(1)-\pi}{2^k} < 2(\pi'_1 - \pi_0 - F)[\frac{1}{2} + \cdots + \frac{1}{2^k}] < 2(\pi'_1 - \pi_0 - F)$. The payoff of the foreign firm under government intervention is $\frac{n}{2}(\pi'_n - \pi_0 - F)$. Therefore it is enough to show that,

$$\frac{n}{2}(\pi'_n - \pi_0 - F) > 2(\pi'_1 - \pi_0 - F).$$

Substituting $h' = \alpha h$ and the expressions for the variable profits the condition reduces to,

$$2h^2\alpha(8n - 1) > h^2(4n + 6).$$

This always holds for any $\alpha \geq \frac{1}{2}$ and $n > 1$. ■

Therefore whenever the initial technology is inefficient enough and the new technology not too efficient compared to the old one, government interevention may infact increase the bargaining power of the foreign firm. This demonstrates, that even if the number of firms do not decline as a result of government intervention, this is no longer sufficient to ensure that intervention is beneficial. Without any intervention the domestic firms would have obtained the technology domestically. Under government intervention however they all have to purchase from the foreign firm. This compulsion may be sufficient to offset the advantage accruing from the all or nothing restriction.

As in section 4, I simplify to the case of two firms and linear cost and demand functions. I show that in this case government intervention may reduce the net surplus even if the number of firms adopting the technology do not decline. First observe that when $\pi'_2 - \pi_1 - F > 0$, f_2 prefers to bargain with f_1 rather than the foreign firm. Clearly, from Proposition (6), the foreign firm would sell the technology to the foreign firm provided

$$F < \frac{5}{3}(\pi_2' - \pi_1) - \frac{2}{3}(\pi_1 - \pi_0).$$

Clearly $\frac{5}{3}(\pi_2' - \pi_1) - \frac{2}{3}(\pi_1 - \pi_0) = \frac{4}{27}(h_2 - h_1)(3A - 5h_2 + 2h_1) > 0.$

I can use equation (6) to show that the expression is positive.

Now consider the case where $\pi_2' - \pi_0 - F > 0$ and $\frac{5}{3}(\pi_2' - \pi_1) - \frac{2}{3}(\pi_1 - \pi_0) - F > 0$. Clearly both the firms are going to adopt the technology irrespective of whether the governement intervenes or not. Therefore the net surplus depends on the payoff of the foreign firm. In case of government intervention the foreign firm's payoff is $\pi_2' - \pi_0 - F$ and in case of no intervention it is $\frac{5}{8}(\pi_2' - \pi_1) + \frac{1}{4}(\pi_1' - \pi_0 - F)$. The payoff under government intervention is greater provided $3(\pi_2' - \pi_1 - F) > 2(\pi_1' - \pi_0 - F)$. If $F = 0$ this reduces to $A > 3h_2 - 2h_1$.

Lastly, I examine the case, when the decision to to impose restrictions on relicensing, is a choice variable to be determined by the foreign firm. First observe that,

$$\pi_1' - \pi > \pi_2' - \pi_1 > \frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi) > \frac{5}{3}(\pi_2' - \pi_1) - \frac{2}{3}(\pi_1' - \pi).$$

Denote $X = \frac{3}{2}(\pi_2' - \pi_1) - \frac{1}{2}(\pi_1' - \pi)$ and $Y = \frac{5}{3}(\pi_2' - \pi_1) - \frac{2}{3}(\pi_1' - \pi)$.

It is clear that, when $F > X$, the foreign firm's payoff is the same for both kinds of contracts and the foreign firm would be indifferent. Next, I consider the case where $X > F > Y$. When relicensing is not allowed, the payoff of the foreign firm is $\frac{3}{4}(\pi_2' - \pi_1 - F) + \frac{1}{4}(\pi_1' - \pi_0 - F) > \frac{1}{2}(\pi_1' - \pi_0 - F)$ the payoff of the foreign firm when relicensing is allowed. Therefore, in this case, the foreign firm would strictly prefer to impose restrictions on relicensing. If

$Y > F$, then both the firms are going to adopt the technology and again the foreign firm would prefer to impose relicensing restrictions.

Therfore, it appears that if restrictions on relicensing cannot be imposed, greater caution need to be exercised before the government intervenes in the bargaining process.

4.6 Appendix

Proof of Proposition 3. I begin by showing that there exists a unique j such that, $(a_{jj}+1)Z_{j+1} < (a_{jj}-a_{j,j-1})Z_j + \cdots + a_{j1}Z_1$ and $(a_{j-1,j-1}+1)Z_j > (a_{j-1,j-1} - a_{j-1,j-2})Z_{j-1} + \cdots + a_{j-1,1}Z_1$.

Observe that $(a_{jj}+1)Z_{j+1} \lesseqgtr (a_{jj} - a_{j,j-1})Z_j + \cdots + a_{j1}Z_1$ if and only if $Z_{j+1} \lesseqgtr (a_{jj} - a_{j,j-1})(Z_j - Z_{j+1}) + \cdots + a_{j1}(Z_1 - Z_{j+1})$. It is enough to observe that the L.H.S. is decreasing in j and the R.H.S. is increasing in j. That the R.H.S. is increasing follows since $(a_{jj} - a_{j,j-1}) + \cdots + a_{j1} = a_{jj}$ is increasing in j and the terms within brackets increase e.g. $Z_k - Z_{j+1}$ is increasing from Assumption C.

To start with I consider the case where $f_1, f_2, \cdots, f_{n-j}$ has not acquired the foreign technology. From Assumption C the second condition in the proposition implies that $(2^j-1)(\pi_j' - \pi_{j-1} - F) > (2^{j-1}-1)(\pi_1' - \pi_0 - F)$ (call this condition $(*)$). I show, that in that case, $f_{n-j+1}, \cdots, f_n$ would acquire the technology. I also demonstrate, that the aggregate payoff of the foreign firm, in the game with $f_{n-i+1}, \cdots, f_n$, when l of the firms have already acquired the technology, is $\sum_{j=1}^{i} a_{ij} Z_{l+j}$.

First observe that condition $(*)$ implies that $\pi_1' - \pi_0 - F > 0$. If not then $0 > \pi'_1 - \pi_0 - F > \pi'_j - \pi_{j-1} - F$ from assumption C, and thus $(2^j - 1)(\pi'_j - \pi_{j-1} - F) < (2^{j-1} - 1)(\pi'_1 - \pi_0 - F)$ which contradicts $(*)$. Next I observe that $(*)$ implies that $\pi'_j - \pi_{j-1} - F > 0$ which in turn implies that $\pi'_i - \pi_{i-1} - F > 0$ for $i \leq j$ (from assumption C). Therefore f_n and the foreign firm would always agree to the technology transfer and the foreign firm's payoff would be $\frac{\pi'_k - \pi_{k-1} - F}{2}$ where $k - 1$ of the firms have already agreed to the transfer.

Next consider the bargaining between f_{n-i} and the foreign firm when l of the domestic firms have already acquired the foreign technology. In this case I argue inductively. Assume, that in case of agreement between f_{n-i} and the foreign firm, all the subsequent firms agree and that the foreign firm's payoff is $\sum_{j=1}^{i} a_{i,j} Z_{l+j+1}$. Similarly in case of disagreement I assume that all the subsequent firms agree. In this case the foreign firm's payoff is $\sum_{j=1}^{i} a_{i,j} Z_{l+j}$.

It is easy to see that provided $(a_{ii} + 1)Z_{l+i+1} > (a_{ii} - a_{i,i-1})Z_{l+i} + \cdots + a_{i1} Z_{l+1}$, agreement would occur. Now, $\frac{2^{i+1}-1}{2^i-1} Z_{l+i+1} > Z_1$ which follows from the fact that $\frac{2^k-1}{2^{k-1}-1}$ is decreasing in k, assumption C and the second condition in the proposition. Therefore,

$$(a_{ii} + 1)Z_{l+i+1} > \frac{(2^i - 1)}{2^i}(\pi'_1 - \pi_0 - F) > (a_{ii} - a_{i,i-1})Z_{l+i} + \cdots + a_{i1} Z_{l+1}.$$

The last inequality follows from assumption C and the fact that $a_{i,k} < a_{i,l}$ for $k < l$. The foreign firm's payoff in this case can be defined recursively according to the recursive formula in the proposition.

Mimicing the above argument it can be demonstrated, that $f_{n-j+1}, \cdots, f_n$ are always going to adopt the new technology, irrespective of how many firms had done so earlier.

Next I show that $f_1, \cdots, f_{n-j}$ will not adopt the new technology. From

$(a_{jj}+1)Z_{j+1} < (a_{jj}-a_{j,j-1})(\pi'_j - \pi_{j-1} - F) + \cdots + a_{j1}Z_1$ (call this condition $(**)$) it follows that f_{n-j} is not going to agree to the technology transfer. That it would not do so in the case where none of the previous firms have acquired the technology follows directly from $(**)$. When l of the firms have already acquired the technology then I need to show that, $(a_{jj}+1)Z_{l+j+1} < (a_{jj} - a_{j,j-1})Z_{l+j} + \cdots + a_{j1}Z_1$. From $(**)$ it follows that $Z_{j+1} < (a_{jj} - a_{j,j-1})(Z_j - Z_{j+1}) + \cdots + a_{j1}(Z_1 - Z_{j+1})$. From the above it follows, using assumption C and D that, $Z_{l+j+1} < (a_{jj} - a_{j,j-1})(Z_{l+j} - Z_{l+j+1}) + \cdots + a_{j1}(Z_{l+1} - Z_{l+j+1})$.[8]

I can next argue inductively to show, that none of the firms $f_1, \cdots, f_{n-j}$, will adopt the foreign technology. ∎

Proof of Proposition 6. (i) For the sake of simplicity of exposition we only cansider the firms $f_{n-j+1}, \cdots, f_n$ and relabel them $f_1, \cdots, f_j$, so that f_{n-j+1} is relabelled f_1, f_{n-j+k} is relabelled f_k etc. Consider the case where $f_1, \cdots, f_{j-1}$ has already acquired the technology and f_j has bargained with $f_1, \cdots, f_{j-2}$ and failed to obtain the technology from them. So that at this point f_j can either acquire the technology from the foreign firm or from f_{j-1}. So that in case of a disagreement with the foreign firm f_j would bargain with f_{j-1} and in case of a disagreement with f_{j-1} it can bargain with the foreign firm.

In the bargaining between f_j and f_{j-1} the agreement payoff is $(\pi'_j - F, \pi'_j - F)$ and the disagreement payoff is $(\frac{\pi'_j + \pi_{j-1} - F}{2}, \pi'_j - F)$ because f_j and the foreign firm would agree in the next stage. Therefore f_j's payoff would be $\frac{3}{4}(\pi'_j - F) + \frac{\pi_{j-1}}{4}$.

[8]This follows since concavity of Z_i implies that $Z_{l+a} - Z_{l+b}$ is increasing in l, for $a < b$.

In the bargaining between f_j and the foreign firm the agreement payoff would be $(\pi'_j - F, 0)$. The disagreement payoff depends on whether $2\pi'_j - F \gtrless \pi'_{j-1} + \pi_{j-1}$. If $2\pi'_j - F > \pi'_{j-1} + \pi_{j-1}$ then f_j and f_{j-1} would reach an agreement in the next stage and the disagreement payoff would be $(\frac{\pi'_j+\pi_{j-1}-F}{2} + \frac{\pi'_j-\pi'_{j-1}}{2}, 0)$. In this case f_j's payoff would be $\frac{3}{4}(\pi'_j - F) + \frac{\pi_{j-1}}{4} + \frac{\pi'_j-\pi'_{j-1}}{4}$. Whereas if $2\pi'_j - F < \pi'_{j-1} + \pi_{j-1}$ then in the continuation game f_j and f_{j-1} would not agree and the disagreement payoff would be $(\pi_{j-1}, 0)$. f_j's payoff in this case would be $\frac{\pi'_j+\pi_{j-1}-F}{2}$. It is clear that f_j would prefer to bargain with f_{j-1} rather than with the foreign firm.

Next working backwards consider the case where f_j has already failed to reach an agreement with $f_1, \cdots, f_{j-k-1}$. First consider the case where f_j decides to bargain with the foreign firm first. The payoff vector in case of agreement is $(\pi'_j - F, 0)$. In case of a disagreement the continuation game involves bargaining sequentially with $f_{j-k}, \cdots, f_{j-1}$. I start by considering the case where $2\pi'_j - F > \pi'_{j-1} + \pi_{j-1}$. Make the induction hypothesis that in case of disagreement f_j would reach an agreement with f_{j-k+1} and the payoff vector would be $((\pi'_j - F)\frac{2^{k-1}-1}{2^{k-1}} + \frac{\pi_{j-1}}{2^{k-1}} + \frac{\pi'_j-\pi'_{j-1}}{2^{k-1}}, \pi'_j - F)$. Clearly f_j and f_{j-k} would agree (as the net surplus equals $\frac{\pi'_j-\pi_{j-1}-F}{2^{k-1}} + \frac{\pi'_j-\pi'_{j-1}}{2^{k-1}} > 0$). In this case f_j's payoff would be $(\pi'_j - F)\frac{2^k-1}{2^k} + \frac{\pi_{j-1}}{2^k} + \frac{\pi'_j-\pi'_{j-1}}{2^k}$.

Next I consider the case where $2\pi'_j - F < \pi'_{j-1} + \pi_{j-1}$. Here make the induction hypothesis that in case of disagreement with f_{j-k}, f_j would not reach an agreement with any of the $f_{j-k-1}, \cdots, f_j$. The disagreement payoff would therefore be $(\pi_{j-1}, \pi'_{j-1} - F)$. Clearly f_j and f_{j-k} also will not reach an agreement. Therefore the payoff of f_j would be $\frac{\pi'_j+\pi_{j-1}-F}{2}$.

Next consider the case where f_j decides to bargain with f_{j-k}. Make the induction hypothesis that at each step f_j decides to bargain with the domestic firm rather than the foreign firm and that f_j's payoff in the disagreement game with f_{j-k} is $(\pi'_j - F)\frac{2^{k-1}-1}{2^{k-1}} + \frac{\pi_{j-1}}{2^{k-1}}$. Clearly the agreement payoff is $(\pi'_j - F, \pi'_j - F)$. It is easy to see that f_j and f_{j-k} would reach an agreement as the net surplus equals $\frac{\pi'_j - \pi_{j-1} - F}{2^{k-1}} > 0$. Therefore the agreement payoff of f_j when bargaining with f_{j-k} would be $(\pi'_j - F)\frac{2^k-1}{2^k} + \frac{\pi_{j-1}}{2^k}$. Comparing the payoffs in the two cases it is obvious that f_j would prefer to bargain with the domestic firm rather than the foreign firm. In case where $2\pi'_j - F > \pi'_{j-1} + \pi_{j-1}$ the proof is immediate. In the other case it is enough to observe that $(\pi'_j - F)\frac{2^k-1}{2^k} + \frac{\pi_{j-1}}{2^k}$ is increasing in k.[9] Working backwards it can be demonstrated that f_1's payoff from bargaining with f_j is $\pi'_j - F + \frac{\pi'_j - \pi_{j-1} - F}{2^j}$. It can be argued similarly that f_j would always bargain with f_1 irrespective of how many firms had previously acquired the technology.

Next I consider the subgame where $f_1, \cdots, f_{j-2}$ has acquired the technology and it is f_{j-1}'s turn to bargain. Clearly, irrespective of whether f_{j-1} acquires the technology or not, f_j is going to acquire the technology. Mimicing the previous steps it can be seen that f_j would prefer to bargain with the domestic firm at every step. Now consider the case where f_{j-1} and f_1 bargain. Clearly the agreement payoff would be $(\pi'_j - F, \pi'_j - F + \frac{\pi'_j - \pi_{j-1} - F}{2^j})$ and the disagreement payoff would be $((\pi'_j - F)\frac{2^{j-2}-1}{2^{j-2}} + \frac{\pi_{j-1}}{2^{j-2}}, \pi'_j - F + \frac{\pi'_j - \pi_{j-1} - F}{2^j})$. Therefore the payoff of firm 1 in this subgame would be $\pi'_j - F + \frac{\pi'_j - \pi_{j-1} - F}{2^j + 2^{j-1}}$. I can use an inductive argument to prove this.

I can similarly work backwards to demonstrate that f_1's payoff would be

[9]Observe that $(\pi'_j - F)\frac{2^k-1}{2^k} + \frac{\pi_{j-1}}{2^k} > (\pi'_j - F)\frac{2^{k-1}-1}{2^{k-1}} + \frac{\pi_{j-1}}{2^{k-1}}$ if and only if $\frac{\pi'_j - \pi_{j-1} - F}{2} > 0$ which is true.

$\pi_j' - F + \frac{\pi_j' - \pi_{j-1} - F}{2^j + 2^{j-1} + \cdots + 2^2}$. ∎

4.7 References

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Part II

Bargaining

Chapter 5

The Outside Option and the Nash Bargaining Solution: A Probabilistic Bargaining Framework

5.1 Introduction

There is some debate in the literature regarding the interpretation of the threat point in the Nash bargaining solution. In applications of the Nash bargaining solution (especially in wage bargaining), the threat point is often identified with the outside option. Examinations of the non-cooperative foundations of the Nash bargaining solution, however, do not support such an identification. Binmore, Rubinstein and Wolinsky (1986) argue that the threat point ought to be identified with the impasse point[1] in case of the standard Rubinstein model and with the breakdown point in models with exogenous risks of breakdown. Both Binmore (1985) and Shaked and Sutton (1984) demonstrate that the outside options of players do not affect the outcome, if the value of the outside option lies below the perfect equilibrium payoff levels that would prevail in the absense of any outside options (the Outside Option Principle[2]). If the value of the outside option exceeds this critical level then the payoff of the concerned player equals the value of the outside option. Hence the outside option payoffs cannot be identified with the threat points in the Nash bargaining solution.

Dalmazzo (1992) provides a justification for treating the outside option vector as the threat point. He considers a model with decay in the size of the cake.[3] This essentially converts the model into a finite horizon one, which can be solved using backwards induction. He shows that in the limit when the time lag between successive offers goes towards zero, the outcome approaches the Nash bargaining solution, where the outside option is taken to be the threat point. In many cases however, the assumption of a decay in the size of the cake is not appropriate. Besides the value of the outside option

[1]The impasse point refers to outcome that comes about when the players continue to bargain without reaching an agreement.

[2]See Shaked and Sutton (1984).

[3]Dalmazzo suggests several possible economic reasons to justify the decay; physical decay of production oppurtunities, loss of market due to customers defecting to other firms, increasing amount of interest maturing over time when there is a fixed debt to be repaid etc.

may also be decreasing for precisely the same reasons that cause a decrease in the cake size. In this chapter I provide an alternative justification which does not rely on the assumption of a shrinking cake.

I consider a model of bilateral bargaining with outside options, where the move structure is probabilistic rather than deterministic. At the start of every period nature selects which player is to make the offer according to some probability distribution. Once a player is selected he makes an offer which the other player may either accept or reject. If he rejects then he may either opt out of the game, when the players immediately receive their outside option payoffs, or remain in the game when in the next period nature again selects which player is to make the offer. I find that the results depend on the nature of the parameter values. Irrespective of the values of the outside option an unique equilibrium exists. *When the value of the outside option is high, compared to the discounted values of the probability of being selected as the proposer, the outside option can be identified with the threat point of the Nash bargaining solution.* I find that the outcome leads to the asymmetric Nash solution, where the probability of any player being selected as the proposer, is interpreted as his bargaining power. However if the value of the outside option is relatively low then the outside option principle holds good in that the value of the outside option does not affect the outcome. In this case the relative payoffs of the players equal their relative probabilities of being selected as the proposer. For intermediate values of the outside option, the outcome depends on the outside option of the player with a relatively higher value of the outside option. It does not depend on the outside option of the other player.

In the next section I set down the model and establish the main theorem, that for high values of the outside option, it is legitimate to treat the outside option as the threat point. I also characterise the equilibrium for other values of the outside option. Section 3 concludes.

5.2 The Model

The game involves two players, player 1 and player 2, bargaining over a cake of size 1. Time is discrete and continues forever. Periods are indexed by $t = 0, 1, 2, \cdots$. Let the common discount factor of the two players be δ,[4] where $1 > \delta > 0$. The outside option vector is denoted by (d_1, d_2) where d_i refers to the payoff of the ith player if either of the players leave the game.[5] I assume that $1 > d_1, d_2 > 0$ and $d_1 + d_2 < 1$ (i.e. mutual gains from agreement is possible).

The move structure in this game is probabilistic rather than deterministic. At every time period nature selects player i as the proposer with probability p_i. Subsequently, the ith player makes an offer. An offer is a vector of the form $(x, 1 - x)$ where x and $1 - x$ denote the shares of the first and the second player repectively. An offer of x by the first player corresponds to the

[4]One can consider the case where the discount factors of the two players are different. This will not affect the qualitative results in any way.

[5]A more general formulation would be where the payoff of the ith player also depends on who decides to opt out of the game. In this case one can interpret d_i as the outside option of the ith player when the ith player decides to leave the game. The subsequent analysis won't be affected in any way.

vector $(1-x, x)$. Coming from the second player it corresponds to the vector $(x, 1-x)$. Acceptance or rejectance of the offer is instantaneous. If player j accepts the offer then the game terminates with the implementation of that offer. If he rejects then he can either opt out of the bargaining process, when the players receive their outside option payoffs, or he can stay in the game when at the next time period nature again selects one of the players as the proposer. The game continues in the above manner until an agreement is reached or one of the players opt for the outside option. One can interpret the probability p_i as reflecting the bargaining power of the ith individual. The bargaining power in this case arises from the bargaining skills of the players i.e. their ability to fast talk and make an offer before the other player makes his offer. This is in contrast to the Rubinstein (1982) formulation where the bargaining power arises out of the players' ability to wait.

The technique used in this chapter is based on Shaked and Sutton (1984). I employ the standard subgame perfectness concept to solve this game. To begin with I introduce the following notations. Let X_i^S denote the supremum of the ith player's payoff in any perfect equilibrium and X_i^I denote the infimum of such payoffs. If the equilibrium payoff of the ith player is unique it is denoted by X_i.

Consider player one's move when it is his turn to make an offer. Player 1 must make an offer of atleast max $\{\delta X_2^I, d_2\}$ if the second player is to accept. His payoff is therefore atmost $1-$ max $\{\delta X_2^I, d_2\}$. Similarly, his payoff when it is the second player's turn to make an offer, is atmost max $\{\delta X_1^S, d_1\}$. Hence, the expected payoff of the first player is atmost $p_1[1-$ max $\{\delta X_2^I, d_2\}] +$ p_2 max $\{\delta X_1^S, d_1\}$. Obviously, X_1^S can atmost be $p_1[1-$ max $\{\delta X_2^I, d_2\}] +$

$p_2 \max \{\delta X_1^S, d_1\}$.

Arguing similarly I obtain the following inequalities,

$$X_1^S \leq p_1[1 - \max \{\delta X_2^I, d_2\}] + p_2 \max \{\delta X_1^S, d_1\} \quad (5.2.1)$$

$$X_1^I \geq p_1[1 - \max \{\delta X_2^S, d_2\}] + p_2 \max \{\delta X_1^I, d_1\} \quad (5.2.2)$$

$$X_2^S \leq p_1 \max \{\delta X_2^S, d_2\} + p_2[1 - \max \{\delta X_1^I, d_1\}] \quad (5.2.3)$$

$$X_2^I \geq p_1 \max \{\delta X_2^I, d_2\} + p_2[1 - \max \{\delta X_1^S, d_1\}] \quad (5.2.4)$$

I first show that this game has a unique equilibrium. Lemma 1 demonstrates, that if the set of equilibrium payoffs of any player is a singleton, then that of the other player must be a singleton as well.

Lemma 1. *$X_i^S = X_i^I$ implies that $X_j^S = X_j^I$.*

Proof. W.l.o.g. assume that $X_2^S = X_2^I = X_2$. I have to show that $X_1^S = X_1^I$. Suppose to the contrary that $X_1^S > X_1^I$. First consider the case where $d_1 \geq \delta X_1^S > \delta X_1^I$. It is easy to see that in this case inequalities (1) and (2) reduce to,

$$X_1^S \leq p_1[1 - \max \{\delta X_2, d_2\}] + p_2 d_1 \quad (5.2.5)$$

$$X_1^I \geq p_1[1 - \max \{\delta X_2, d_2\}] + p_2 d_1 \quad (5.2.6)$$

Since by definition $X_1^S \geq X_1^I$, the above inequalities imply that,

$$X_1^S = X_1^I = p_1[1 - \max \{\delta X_2, d_2\}] + p_2 d_1 \quad (5.2.7)$$

One can therefore restrict attention to the following four cases,

(a) $\delta X_1^S > d_1 \geq \delta X_1^I$ and $d_2 \geq \delta X_2^S = \delta X_2^I$,

(b) $\delta X_1^S > d_1 \geq \delta X_1^I$ and $\delta X_2^S = \delta X_2^I > d_2$,

(c) $\delta X_1^S > \delta X_1^I > d_1$ and $d_2 \geq \delta X_2^S = \delta X_2^I$,

(d) $\delta X_1^S > \delta X_1^I > d_1$ and $\delta X_2^S = \delta X_2^I > d_2$.

I start by considering case (a). From inequalities (1) and (2) it follows that,

$$X_1^S \leq p_1(1-d_2) + \delta p_2 X_1^S \quad (5.2.8)$$

$$X_1^I \geq p_1(1-d_2) + p_2 d_1 \quad (5.2.9)$$

Clearly, $X_1^S \leq \frac{p_1(1-d_2)}{1-\delta p_2}$. Substituting for X_1^S and X_1^I in the inequality $\delta X_1^S > d_1 \geq \delta X_1^I$, I obtain,

$$\frac{\delta p_1(1-d_2)}{1-\delta p_2} > d_1 \geq \delta p_1(1-d_2) + \delta p_2 d_1.$$

It is enough to observe that $\frac{\delta p_1(1-d_2)}{1-\delta p_2} > d_1$ yields $\delta p_1(1-d_2) > d_1(1-\delta p_2)$, whereas $d_1 \geq \delta p_1(1-d_2) + \delta p_2 d_1$ yields $\delta p_1(1-d_2) \leq d_1(1-\delta p_2)$.

Next consider case (b). In this case inequalities (1) to (4) reduce to,

$$X_1^S \leq p_1(1-\delta X_2^I) + \delta p_2 X_1^S \quad (5.2.10)$$

$$X_1^I \geq p_1(1-\delta X_2^S) + p_2 d_1 \quad (5.2.11)$$

$$X_2^S \leq \delta p_1 X_2^S + p_2(1-d_1) \quad (5.2.12)$$

$$X_2^I \geq \delta p_1 X_2^I + p_2(1-\delta X_1^S) \quad (5.2.13)$$

Straightforward substitutions yield,

$$X_1^S \leq p_1 \quad (5.2.14)$$

$$X_1^I \geq p_1[1 - \frac{\delta p_2(1-d_1)}{1-\delta p_1}] + p_2 d_1 \quad (5.2.15)$$

$$X_2^S \leq \frac{p_2(1-d_1)}{1-\delta p_1} \quad (5.2.16)$$

$$X_2^I \geq p_2 \quad (5.2.17)$$

Since $\delta X_1^S > d_1$, it follows that $\delta p_1 > d_1$. However, from the condition that $d_1 \geq \delta X_1^I$, one obtains that $d_1 \geq \delta p_1$, which contradicts the previous statement.

Next consider case (c). In this case it is clear that,

$$X_1^S \leq p_1(1-d_2) + \delta p_2 X_1^S \qquad (5.2.18)$$

$$X_1^I \geq p_1(1-d_2) + \delta p_2 X_1^I \qquad (5.2.19)$$

It is obvious that, $X_1^S > X_1^I$ implies $\frac{p_1(1-d_2)}{1-\delta p_2} \geq X_1^S > X_1^I \geq \frac{p_1(1-d_2)}{1-\delta p_2}$, which is a contradiction.

Lastly I examine case (d). It is easy to see that the inequalities (1) and (2) imply $X_1^S \leq p_1$ and $X_1^I \geq p_1$, which in turn implies (since $X_1^S \geq X_1^I$) that $X_1^S = X_1^I = p_1$. ∎

Proposition 2 proves that the equilibrium is unique. In view of lemma 1, it is sufficient to demonstrate that $X_1^S > X_1^I$ and $X_2^S > X_2^I$ cannot hold.

Proposition 2. *This game has a unique perfect equilibrium.*

The proof can be found in the appendix. The argument is similar to that in lemma 1. Strictly speaking Proposition 2 demonstrates that the perfect equilibrium, if it exists is unique. Later however I prove existence for all possible parameter values.

Proposition 2 implies that the equations reduce to the following two,

$$X_1 = p_1[1 - \max\{d_2, \delta X_2\}] + p_2 \max\{d_1, \delta X_1\} \qquad (5.2.20)$$

$$X_2 = p_1 \max\{d_2, \delta X_2\} + p_2[1 - \max\{d_1, \delta X_1\}] \qquad (5.2.21)$$

I distinguish four cases,

(A) $d_1 \geq \delta X_1$ and $d_2 \geq \delta X_2$,

(B) $d_1 < \delta X_2$ and $d_2 < \delta X_2$,

(C) $d_1 < \delta X_1$ and $d_2 \geq \delta X_2$,

(D) $d_1 \geq \delta X_1$ and $d_2 < \delta X_2$.

In case (A) it follow from equations (20) and (21) that,

$$X_1 = p_1 - p_1 d_2 + p_2 d_1 \quad (5.2.22)$$

$$X_2 = p_2 - p_2 d_1 + p_1 d_2. \quad (5.2.23)$$

In case (B) equations (20) and (21) simplify to,

$$X_1 = p_1[1 - \delta X_2] + p_2 \delta X_1 \quad (5.2.24)$$

$$X_2 = p_1 \delta X_2 + p_2[1 - \delta X_1] \quad (5.2.25)$$

Straightforward substitution yields, $X_1 = p_1$ and $X_2 = p_2$. Next consider case (C). It is obvious that the following hold,

$$X_1 = p_1(1 - d_2) + \delta p_2 X_1 \quad (5.2.26)$$

$$X_2 = p_1 d_2 + p_2(1 - \delta X_1) \quad (5.2.27)$$

Solving one obtains,

$$X_1 = \frac{p_1(1 - d_2)}{1 - \delta p_2} \quad (5.2.28)$$

$$X_2 = p_1 d_2 + p_2[1 - \frac{\delta p_1(1 - d_2)}{1 - \delta p_2}]. \quad (5.2.29)$$

Case (D) would be symmetric. The outcome involves,

$$X_1 = p_2 d_1 + p_1[1 - \frac{\delta p_2(1 - d_1)}{1 - \delta p_1}] \quad (5.2.30)$$

$$X_2 = \frac{p_2(1 - d_1)}{1 - \delta p_1}. \quad (5.2.31)$$

The next proposition examines the equilibrium outcome for low values of the outside option payoffs. It is demonstrated that the relative payoff of the ith player equals the relative probability of his being selected as the proposer.

Proposition 3. *If $d_1 < \delta p_1$ and $d_2 < \delta p_2$, the unique equilibrium involves the outcome $X_1 = p_1$ and $X_2 = p_2$.*

Proof. First consider case (A). Since $d_1 \geq \delta X_1$ it follows that $d_1(1 - \delta p_2) \geq \delta p_1(1 - d_2)$. This implies that $d_i > \delta p_i$ for atleast one i. But this contradicts the hypothesis of the proposition.

In case (B) there is nothing to prove since $X_1 = p_1$ and $X_2 = p_2$. Next consider case (C). (Case (D) can be treated symmetrically). In this case $X_2 = p_1 d_2 + p_2[1 - \frac{\delta p_1(1-d_2)}{1-\delta p_2}]$. Substituting for X_2 in $d_2 \geq \delta X_2$, one obtains that $d_2 \geq \delta p_2$, which contradicts the hypothesis of the proposition. ∎

The equilibrium strategies involve player i offering δp_j to the other player whenever it is the ith player's turn to make an offer and accepting any offer which yields him a payoff of atleast δp_i.

In the next proposition I characterise the equilibrium for intermediate values of the outside option. I find that the outcome depends only on the outside option value of the player with the relatively higher value of the outside option. It does not depend on the outside option payoff of the other player.

Proposition 4. *(i) If $d_1(1-\delta p_2) < \delta p_1(1-d_2)$ and $d_2 \geq \delta p_2$,*[6] *then the outcome is,*

$$X_1 = \frac{p_1(1-d_2)}{1-\delta p_2} \qquad (5.2.32)$$

$$X_2 = p_1 d_2 + p_2[1 - \frac{\delta p_1(1-d_2)}{1-\delta p_2}]. \qquad (5.2.33)$$

(ii) If $d_1 \geq \delta p_1$ and $d_2(1-\delta p_1) < \delta p_2(1-d_1)$,[7] *then the outcome is,*

$$X_1 = p_2 d_1 + p_1[1 - \frac{\delta p_2(1-d_1)}{1-\delta p_1}] \qquad (5.2.34)$$

$$X_2 = \frac{p_2(1-d_1)}{1-\delta p_1}. \qquad (5.2.35)$$

Proof. (i) In case (A), the condition that $d_1 \geq \delta X_1$ implies $d_1(1-\delta p_2) \geq \delta p_1(1-d_2)$, which contradicts the hypothesis of the proposition.

Next consider case (B). In this case $X_1 = p_1$ and $X_2 = p_2$. But then $d_2 < \delta X_2$ implies that $d_2 < \delta p_2$ which contradicts the hypothesis of the proposition. If (C) hold then there is nothing to prove. Lastly consider case (D). In this case $X_1 = p_1[1 - \frac{\delta p_2(1-d_1)}{1-\delta p_1}] + p_2 d_1$. Substituting for X_1 in the condition $d_1 \geq \delta X_1$ one obtains that $d_1 \geq \delta p_1$, which contradicts the hypothesis of the proposition.

(ii) The proof in this case would be similar to that of part (i). ∎

In case (i) the equilibrium strategies involve player 1 offering d_2 whenever it is his turn to make an offer and the second player offering $\frac{\delta p_1(1-d_2)}{1-\delta p_2}$ whenever

[6] Observe that the conditions together imply that $d_1 < \delta p_1$.

[7] Observe that the conditions together imply that $d_2 < \delta p_2$.

it is his turn. Player 1 would accept any offer which yields him atleast $\frac{\delta p_1(1-d_2)}{1-\delta p_2}$ and player 2 would accept any offer which yields him atleast d_2.

The strategies in case (ii) would be symmetric.

Proposition 5 is the main result of this chapter and proves that for high values of the outside option, it is legitimate to identify the outside option with the threat point in the Nash bargaining solution.

Proposition 5. *If either (i) $d_1 \geq \delta p_1$ and $d_2 \geq \delta p_2$, or (ii) $d_1(1-\delta p_2) \geq \delta p_1(1-d_2)$ and $d_2(1-\delta p_1) \geq \delta p_2(1-d_1)$, then the unique equilibrium outcome involves the payoffs,*

$$X_1 = p_1 - p_1 d_2 + p_2 d_1 \tag{5.2.36}$$

$$X_2 = p_2 - p_2 d_1 + p_1 d_2. \tag{5.2.37}$$

Proof. (i) Clearly if (A) hold then there is nothing to prove. If (B) hold then $X_1 = p_1$ and $X_2 = p_2$. But this implies that $d_i < \delta p_i$, for $i = 1, 2$ which contradicts the hypothesis of the proposition. Next consider case (C). (The proof in case (D) would be symmetrical). Clearly $X_1 = \frac{p_1(1-d_2)}{1-\delta p_2}$. From $d_1 < \delta X_1$ it follows that $d_1 < \frac{\delta p_1(1-d_2)}{1-\delta p_2}$. Since $d_1 \geq \delta p_1$, the above implies that $d_2 < \delta p_2$, which contradicts the hypothesis of the proposition.

(ii) As in the proof of part (i), it is enough show that case (C) cannot occur.

As before $X_1 = \frac{p_1(1-d_2)}{1-\delta p_2}$. From condition (C) this implies that, $d_1(1-\delta p_2) < \delta p_1(1-d_2)$. But this contradicts the hypothesis of part (ii). ∎

The equilibrium strategies involve player i offering d_j whenever it is his turn to make an offer and accepting any offer which yields him atleast d_i.

It is easy to see that this solution corresponds to the Nash solution where p_i is interpreted as the weight of the ith player in the Nash maximization problem,

$$\text{Max}_{X_1}(X_1 - d_1)^{p_1}(1 - X_1 - d_2)^{p_2}.$$

For $p_1 = \frac{1}{2}$, the symmetric Nash bargaining solution obtains.

5.3 Conclusion

In this chapter I provide a justification for treating the outside option as the threat point in Nash bargaining. Unlike Dalmazzo (1992) this does not depend on a reduction in the size of the cake. My analysis suggests however that such an identification is legitimate only when the value of the outside option is relatively large. Whether such an assumption is legitimate is a matter of empirical reality and can not be decided a priori.

Binmore, Shaked and Sutton (1989) perform a bargaining experiment which corroborates their thesis that outside options do not matter. However the bargaining structure they use for their experiment is deterministic. In the light of this essay it would be of interest to perform an experiment with a probabilistic move structure and compare the results with that of Binmore, Shaked and Sutton.

5.4 Appendix

Proof of Proposition 2. For simplicity of notation I denote the solutions of the equations by X_1^I etc and do not introduce any new notation. Consider the case where $X_i^S > X_i^I$ for $i = 1, 2$. If $X_i^S = X_i^I$ for some i, then from lemma 1 there is nothing to prove.

I distinguish 9 cases.

(a) $d_1 \geq \delta X_1^S > \delta X_1^I$ and $d_2 \geq \delta X_2^S > \delta X_2^I$,

(b) $\delta X_1^S > \delta X_1^I > d_1$ and $d_2 \geq \delta X_2^S > \delta X_2^I$,

(c) $\delta X_1^S > d_1 \geq \delta X_1^I$ and $d_2 \geq \delta X_2^S > \delta X_2^I$,

(d) $d_1 \geq \delta X_1^S > \delta X_1^I$ and $\delta X_2^S > \delta X_2^I > d_2$,

(e) $\delta X_1^S > \delta X_1^I > d_1$ and $\delta X_2^S > \delta X_2^I > d_2$,

(f) $\delta X_1^S > d_1 \geq \delta X_1^I$ and $\delta X_2^S > \delta X_2^I > d_2$,

(g) $d_1 \geq \delta X_1^S > \delta X_1^I$ and $\delta X_2^S > d_2 \geq \delta X_2^I$,

(h) $\delta X_1^S > \delta X_1^I > d_1$ and $\delta X_2^S > d_2 \geq \delta X_2^I$,

(i) $\delta X_1^S > d_1 \geq \delta X_1^I$ and $\delta X_2^S > d_2 \geq \delta X_2^I$.

I show that all 9 cases lead to contradictions.

First consider case (a). From inequalities (1) and (2) it follows that,

$$X_1^S \leq p_1(1 - d_2) + p_2 d_1 \tag{5.4.38}$$

$$X_1^I \geq p_1(1 - d_2) + p_2 d_1. \tag{5.4.39}$$

This implies that (since $X_1^S \geq X_1^I$)

$$X_1^S = X_2^S = p_1(1 - d_2) + p_2 d_1,$$

when the proof follows from lemma 1.

Next consider case (b). (The argument would be similar in case (d)). Clearly in this case,

$$X_1^S \leq p_1(1-d_2) + \delta p_2 X_1^S \tag{5.4.40}$$

$$X_1^I \geq p_1(1-d_2) + \delta p_2 X_1^I \tag{5.4.41}$$

Clearly $X_1^S > X_1^I$ implies that $\frac{p_1(1-d_2)}{1-\delta p_2} \geq X_1^S > X_1^I \geq \frac{p_1(1-d_2)}{1-\delta p_2}$, which is a contradiction.

Next I take up case (c). (Case (g) can be treated symmetrically). In this case inequalities (1) and (2) simplify to,

$$X_1^S \leq p_1(1-d_2) + \delta p_2 X_1^S \tag{5.4.42}$$

$$X_1^I \geq p_1(1-d_2) + p_2 d_1 \tag{5.4.43}$$

Solving, $X_1^S \leq \frac{p_1(1-d_2)}{1-\delta p_2}$. Substituting for X_1^S and X_1^I in the inequality $\delta X_1^S > d_1 \geq \delta X_1^I$, I obtain,

$$\frac{\delta p_1(1-d_2)}{1-\delta p_2} > d_1 \geq \delta p_1(1-d_2) + \delta p_2 d_1.$$

It is enough to observe that $\frac{\delta p_1(1-d_2)}{1-\delta p_2} > d_1$ yields $\delta p_1(1-d_2) > d_1(1-\delta p_2)$, whereas $d_1 \geq \delta p_1(1-d_2) + \delta p_2 d_1$ yields $\delta p_1(1-d_2) \leq d_1(1-\delta p_2)$.

Next I examine the case where (e) holds. It is obvious, that the inequalities (1) and (2) imply $X_1^S \leq p_1$ and $X_1^I \geq p_1$, which in turn implies that $X_1^S = X_1^I = p_1$. Again the proof follows from lemma 1.

Penultimately, consider case (f). (The proof for case (h) would be similar). In this case inequalities (1) to (4) reduce to,

$$X_1^S \leq p_1(1-\delta X_2^I) + \delta p_2 X_1^S \tag{5.4.44}$$

$$X_1^I \geq p_1(1-\delta X_2^S) + p_2 d_1 \tag{5.4.45}$$

$$X_2^S \leq \delta p_1 X_2^S + p_2(1-d_1) \tag{5.4.46}$$

$$X_2^I \geq \delta p_1 X_2^I + p_2(1-\delta X_1^S) \tag{5.4.47}$$

Solving one finds,

$$X_1^S \leq p_1 \tag{5.4.48}$$

$$X_1^I \geq p_1[1-\frac{\delta p_2(1-d_1)}{1-\delta p_1}] + p_2 d_1 \tag{5.4.49}$$

$$X_2^S \leq \frac{p_2(1-d_1)}{1-\delta p_1} \tag{5.4.50}$$

$$X_2^I \geq p_2 \tag{5.4.51}$$

Since $\delta X_1^S > d_1$, it follows that, $\delta p_1 > d_1$. However $d_1 \geq \delta X_1^I$ implies that $d_1 \geq \delta p_1$, which is a contradiction.

Lastly consider case (i). In this case, the inequalities simplify to,

$$X_1^S \leq p_1(1-d_2) + \delta p_2 X_1^S \tag{5.4.52}$$

$$X_1^I \geq p_1(1-\delta X_2^S) + p_2 d_1 \tag{5.4.53}$$

$$X_2^S \leq \delta p_1 X_2^S + p_2(1-d_1) \tag{5.4.54}$$

$$X_2^I \geq p_1 d_2 + p_2(1-\delta X_1^S) \tag{5.4.55}$$

It is obvious that the solution involves,

$$X_1^S \leq \frac{p_1(1-d_2)}{1-\delta p_2} \tag{5.4.56}$$

$$X_1^I \geq p_1[1-\frac{\delta p_2(1-d_1)}{1-\delta p_1}] + p_2 d_1 \tag{5.4.57}$$

$$X_2^S \leq \frac{p_2(1-d_1)}{1-\delta p_1} \tag{5.4.58}$$

$$X_2^I \geq p_1 d_2 + p_2[1-\frac{\delta p_1(1-d_2)}{1-\delta p_2}] \tag{5.4.59}$$

Since $\delta X_1^S > d_1$, it follows that $\delta p_1(1-d_2) > d_1(1-\delta p_2)$. But this implies that either $\delta p_1 > d_1$ and/or $\delta p_2 > d_2$. However $d_1 \geq \delta X_1^I$ implies that $d_1 \geq \delta p_1$ and $d_2 \geq \delta X_2^I$ implies that $d_2 \geq \delta p_2$. ∎

5.5 References

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Chapter 6

Bargaining Without Commitment But With Small Reneging Costs

6.1 Introduction

Muthoo (1989, 1990) has recently argued that both the alternating-offer bargaining and the one-sided offer bargaining models share the central feature that when an offer is accepted, the bargaining terminates with the implementation of that offer. He contends that it is this possibility to commit that drives the uniqueness of equilibrium results in these models.[1] He points

[1] Rubinstein, 1982 proves that the alternating offer model has a unique subgame perfect equilibrium.

out that *"there is no sacred rule (or law) which says that if a proposal is accepted, then it must be implemented"*[2] and that allowing the proposer to change his mind can lead to non-uniqueness of equilibria in both the Rubinstein (Muthoo 1990) as well as in the one sided offers bargaining model (Muthoo 1989). These strategies use a hierarchy of punishments where if a proposer deviates then the responder rejects that offer and punishes him for the deviation, because otherwise the proposer will punish the responder for not punishing him. Thus uniqueness of perfect equilibrium, one of the main reasons for the interest commanded by the bargaining literature, is then lost.

In this chapter I argue that Muthoo's model misses out on an important aspect of the bargaining process. Muthoo considers reneging on an offer to be costless. But unless the bargaining is carried out verbally in the absense of any witness there would usually be some costs for reneging on an offer. This cost could arise through penalties imposed by the courts or when the parties belong to an organization with standardised negotiation procedures.

Alternatively, reputational loss following reneging could also lead to costs for the reneger.

I consider three forms of penalties for reneging: fixed costs, proportional costs and reputational costs. Suppose that a player reneges on his offer. In the fixed costs scheme a fixed slice of the remaining cake would be cut off and offered to the other player. When the costs are proportional the other player would be offered a given proportion of the cake. In the next period the bargaining would be carried out over the truncated cake. In the case of reputational costs there is a loss of reputation which is captured by the fact

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[2]Muthoo, 1990 pg. 291

that the reneging player would have to incur a given cost. While the first two cost schemes involves costs which are transfers, the reputational cost scheme involves deadweight losses. In the last two cases I assume that for repeat offenses the penalty increases and that if the offense is repeated for a large enough number of times then the penalty becomes very high. More specifically the penalty approaches the cake in magnitude.

I show that for all three specifications of the penalty a unique equilibrium exists for one sided offer bargaining games. This result holds for any strictly positive reneging costs, however small. However, in the alternating offers bargaining case the results are more complex. When the discount factor is small I show that there exists a unique perfect equilibrium for any positive level of cost. Muthoo's (1990) analysis was silent regarding this zone of values for the discount factor, and the suspicion remained, that even in this zone the multiplicity of equilibria may persist. Our result suggests that at least in this zone the Rubinstein results can be applied directly.

For the case of fixed costs I find that in the alternating offer game, for large values of the discount factor, perfect equilibrium may not be unique. Uniqueness obtains when the size of the penalty is large relative to the size of the cake.

The introduction of reneging costs thereby provides a unification of the two forms of bargaining. For different parameter values, the commitment and the non-commitment forms emerge as special cases. In the fixed cost case, I demonstrate the existance of an intermediate regime, where many, though not all, splits can be supported as perfect equilibria. This regime does not emerge in either the pure commitment or the pure non-commitment case.

In the context of Muthoo's model, I also provide a number of justifications for considering the Rubinstein solution more acceptable than the alternative equilibria proposed by Muthoo. For one, I show that the Rubinstein solution is reached as the limit of the unique equilibrium of the truncated games. By truncated games I refer to finite horizon formulations of the Rubinstein game where the game ends after a given number of periods, even if no agreement can be reached. For another, restricting ourselves to Markov strategies yields the Rubinstein solution as the unique equilibrium. I also demonstrate that in the Muthoo model there exist perfect equilibria involving delay. Moreover I show that Muthoo's results do not depend on the fact that only the proposer can change his mind, i.e. the results are not affected if the responder is also allowed to change his mind.

The rest of the chapter is organised as follows. Section 2 sets down Muthoo's model, summarises his results and also presents some additional results concerning Muthoo's model. The model with reneging costs is introduced in section 3. It also presents the main results of the chapter. Section 4 summarizes the results and discusses possible research directions for the future.

6.2 Muthoo's Model

There are two players, player one and player two (denoted P1 and P2 respectively) bargaining over the split of a cake of size one. I consider both the one sided offer bargaining model and the alternating offer bargaining model, both modified to allow a proposer to change his mind costlessly. Following acceptance ("A") of an offer by a responder, the proposer can either accept the responder's acceptance ("AA"), or reject it ("RA"). The modified one sided offers model game can thus be described as follows. In each period one of the players makes an offer. The responder either accepts the offer or rejects it. If the proposer accepts the acceptance by the responder, the game ends with the implementation of that offer. If the proposer rejects the acceptance or if the responder rejects his offer, then the proposer makes another offer in the following period. The modified alternating offers model game differs only so far as the players alternate in making the offers.

I assume that in either version of the model P1 is the first mover.

Let the length of a single bargaining period be normalised to unity. For simplicity I assume that P1 and P2 have a common discount factor δ, where $0 < \delta < 1$.

Whenever I refer to any spilt $(x, M - x)$, where M is the size of the cake, x denotes the share of P1 and $M - x$ denotes the share of P2.

If the players agree on a split of α at time n, then the utility pay-offs are for P1:$U_1(\alpha, n) = \alpha\delta^n$ and for P2: $U_2(\alpha, n) = (1 - \alpha)\delta^n$.

As usual I concentrate on the subgame perfect equilibrium[3] of the various models that I consider. I use the term subgame perfect equilibrium and perfect equilibrium interchangeably.

In the standard alternating offers game Rubinstein (1982) showed that the unique equilibrium of that game is the split $(\frac{1}{1+\delta}, \frac{\delta}{1+\delta})$. The one sided offer game has the unique outcome $(1, 0)$.

I summarise Muthoo's results in proposition 1.

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[3]See Selten (1975) for the definition of subgame perfectness.

Proposition 1. *(a) For any $\delta \geq \frac{1}{2}$, any split $(\alpha, 1-\alpha)$, where $\alpha \in [0,1]$, can be sustained as a perfect equilibrium of the modified one sided offers game.*[4]

(b) For any $\delta > \frac{1}{\sqrt{2}}$, any split $(\alpha, 1-\alpha)$, where $\alpha \in [0,1]$, can be sustained as a perfect equilibrium of the modified alternating offers game.[5]

The outline of the proof is as follows. First Muthoo demonstrates that irrespective of whether P1 is the first mover or P2 is the first mover, the splits $(1,0)$ and $(0,1)$ can be sustained as subgame perfect equilibrium outcomes. Next he uses these outcomes as threat outcomes to sustain the other splits.

These strategies use a hierarchy of punishments where if a proposer deviates then the responder rejects that offer and punishes him for the deviation, because otherwise the proposer will punish the responder for not punishing him. Such strategies are obviously not possible in the commitment game, as the proposer cannot punish a responder for accepting the wrong offer.

It is natural to inquire how crucially the multiplicity of equilibria depend on punishment strategies. To this end I examine two setups where punishment strategies are ruled out. First, I consider equilibrium of the truncated bargining games and observe what happens when the truncation period is taken to infinity. A bargaining game truncated after T periods is where the game ends after T periods if no agreements are reached, with both the players obtaining a zero pay-off. I also examine what happens if only Markov strategies are allowed. Markov strategies are defined as strategies which are

[4] Muthoo 1989.

[5] Muthoo 1990.

independent of the history of the game and the date. Hence the strategies are allowed to depend only on what has already happened in the present period. The offers must thus be the same in each period and the A/R and the AA/RA decision can only depend on the offer made. Proposition 2 shows that in both the above cases I obtain a unique solution. However, I need the following assumption to prove it (this is also needed for subsequent propositions).

Assumption 1. If a player is indifferent between accepting an offer and rejecting it, he accepts the offer.

This is a standard assumption in most bargaining problems.

Proposition 2. *(a) As the truncation period $T \to \infty$ the unique subgame perfect equilibrium of the truncated modified one sided offers model and the modified alternating offers model approach the* $(1, 0)$ *and the Rubinstein solution respectively.*

(b) The unique Markov equilibrium of the modified alternating offers game is the Rubinstein solution.

Proof. (a) For the one sided offer game it is clear that the unique perfect equilibriun involves the outcome $(1, 0)$ for any finite truncation period. I next consider the alternating offer game. Clearly for a game truncated after one period the unique equilibrium is $(1, 0)$ as the outcome following R or RA is $(0, 0)$. For a game truncated after 2 periods the unique outcome is $(\delta, 1 - \delta)$

because if P2 offers that split then P1 is going to accept knowing that by rejecting he can not do better and that P2 is going to accept. Thus after T periods where T is odd we have a unique equilibrium where P1's pay-off is $1-\delta+\cdots-\delta^T$ and P2's pay-off is $\delta[1-\delta+\cdots+\delta^{T-1}]$. As T is taken towards infinity clearly the pay-offs tend towards the Rubinstein pay-offs.

(b) From proposition 1 of Muthoo 1990 I can see that a Markov equilibrium exists.

Clearly a Markov equilibrium involves acceptance in either period one or period two. First I demonstrate that I can not have an equilibrium with acceptance in period 2. Suppose to the contrary that I have a Markov equilibrium where whenever it is P2's turn to make a move P2 offers y, P1 accepts and P2 accepts the acceptance.

From assumption 1 in any perfect equilibrium P2 must accept an offer s iff $1-s \geq \delta(1-y)$. Suppose P1 offers s where $1-s \geq \delta(1-y)$. From the Markov nature of the strategies P1 is always going to offer s. Thus irrespective of whether P1 is going to play AA or RA it is best to accept, as punishment is not allowed in this case. For $1-s = \delta(1-y)$ I need assumption 1. Thus P1 can offer $\delta(1-y)$ and gain, and I have a contradiction.

Next I consider the case where P1 offers x at each period, P2 accepts and P1 accepts the acceptance whenever it is P1's turn to make a move.

Consider P2's offer. From assumption 1 P1 will accept an offer s such that $s \geq \delta x$. So it must be that P2 offers δx with himself obtaining $1-\delta x$.

Now coming back to P1's move, from assumption 1 P2 accepts any offer s provided $1-s \geq \delta(1-\delta x)$. So in any perfect equilibrium P1 must be offering $\delta(1-\delta x)$.

By assumption $1 - x = \delta(1 - \delta x)$ or $x = \frac{1}{1+\delta}$. ∎

The next proposition shows that I can support delay in this game even though this is a complete informations game.[6] I demonstrate that any amount of delay can be sustained as a perfect equilibrium, for some splits, provided the discount factor is large enough.[7]

Proposition 3. *For any $N \in \{1, 2, \cdots, \infty\}$, there exists $\delta(N)$, such that for any $\delta \geq \delta(N)$, perfect equilibria with a delay of N periods can be sustained in the alternating offer game.*

Proof. See appendix.

The equilibria have the following form. When N is even, the equilibria involves PI offering $(1 - x, x)$ in period $N + 1$ when it is implemented, where $1 - \frac{1-\delta}{\delta^N} \geq x > \frac{1-\delta}{\delta^N}$. If N is odd, the game ends in the $N + 1$th period with the implementation of P2's offer of $(x, 1 - x)$, where $x > \frac{1-\delta}{\delta^N}$.

Here I just provide a sketch of the proof. First, I show that a delay of one period can be sustained. In the first period PI makes an unacceptably high offer, which is rejected, and an agreement is reached in the second period. He does not make a lower offer because it would be rejected and in the next period he would obtain a zero pay-off. Next I show that a two period delay

[6] Fernandez and Glazer, 1991 demonstrates that one can support delay in a complete information context of bargaining between a firm and an union.

[7] I would like to thank V. Bhaskar for encouraging me to look whether all possible delays can be supported.

can be sustained. Again in the first period PI makes an unacceptably high offer which is rejected. In the next period, they play the equilibrium with one period delay, but with P2 as the first mover.

A natural question to ask is what happens if we allow one more round of acceptance rejectance i.e. after the proposer says AA the responder can either accept it ("AAA") or reject it ("RAA"). I can show that this does not affect the result in any way i.e. proposition 1 is still valid. The proof merely consists in observing that the Muthoo strategies, with slight modifications, still constitute equilibrium strategies in this altered context. The reason is that I can take the Muthoo strategy supporting that particular equilibrium and then make the following changes for the enlarged strategy space: Let the responder accept all AA by the proposer, and let the continuation strategies for both players be the same as that for rejectance by the acceptor.

6.3 The Model With Reneging Costs

In this section I introduce costs of reneging. The game is as considered in section 2, with the difference that if a proposer reneges on his offer then some kind of penalty would accrue. Three specifications of the penalty are considered.

6.3.1 Fixed Costs

The cost structure is as follows. If a proposer reneges on his offer then immediately ϵ of the cake is offered to the responder and next period the bargaining is carried out over a cake of size $M - \epsilon$ (assuming that the cake was of size M in the previous round). If the size of the cake is less than ϵ then the whole of the cake is offered to the responder.

I call the two models the modified one sided offers model with costs and the modified alternating offers model with costs.

Proposition 4. *For any $\epsilon > 0$, the unique subgame perfect equilibrium of the modified one sided offers game with costs is $(M, 0)$.*

Proof. See appendix.

The basic idea of this proposition as well as later ones is as follows. Consider a stage of the game where one party has reneged often enough that the size of the remaining cake is less than the penelty for reneging once more. Then uniqueness of continuation outcomes is straightforward because reneging on an offer means that the proposer is going to end up with a zero pay-off. At the previous stage also the outcome is determined; and an inductive argument shows the outcome to be determined at all previous stages.

Next I show that in the modified alternating offers model with fixed positive reneging costs, for a low enough discount factor the Rubinstein equilibrium is still obtained as the unique equilibrium for any positive levels of penalty.

Proposition 5. *For $\delta < \frac{1}{\sqrt{2}}$ and reneging costs ϵ positive, the modified alternating offers model game with costs has a unique equilibrium which is the Rubinstein outcome.*

Proof. Suppose that $M \leq \epsilon$. I claim that the Rubinstein solution is still the unique equilibrium of this game.

Clearly if P1 reneges then the outcome is $(0, M)$.

Suppose it is P1's move and he offers $(M(1-\delta), \delta M)$. P2 would accept if he knew that P1 was going to accept. P1 accepts provided his pay-off from accepting exceeds what he can get by rejecting i.e. provided $M(1-\delta) > 0$. This implies that for any subgame perfect equilibrium P1 gets atleast $M(1-\delta)$ when it is his turn to move.

So when P2 is the first mover his pay-off is atmost $M(1-\delta(1-\delta))$.

Again consider P1's move . If he offers $M\delta(1-\delta(1-\delta))$ to P2 then he would accept if could be certain that P1 would accept his acceptance.

Since P1's pay-off $M(1-\delta(1-\delta(1-\delta))) > 0$, I am through.

I can repeat the argument *ad infinitum* to show that, when P1 is the first mover, his pay-off in any perfect equilibrium, is atmost $\frac{M}{1+\delta}$. Next I consider what is the least that P2 must offer to P1 when P2 is the first mover. Arguing along similar lines I can show that in any perfect equilibrium P1's pay-off is atleast $\frac{M}{1+\delta}$. Thus in any perfect equilibrium P1's pay-off can only be $\frac{M}{1+\delta}$. Similarly I can show that in any perfect equilibrium P2's pay-off can only be $\frac{\delta M}{1+\delta}$.

This also means that there is going to be no delay in the equilibrium. Thus the unique equilibrium involves P1 offering $\frac{M}{1+\delta}$ and P2 accepting it.

This allows me to frame the induction hypothesis that if the size of the cake is $M - \epsilon$ then I have the Rubinstein solution as the unique outcome of this model.

So if at any step P1 reneges then the pay-offs are, $\frac{\delta^2(M-\epsilon)}{1+\delta}$ and $\epsilon + \frac{\delta(M-\epsilon)}{1+\delta} =$

$\frac{\epsilon+\delta M}{1+\delta}$ respectively for P1 and P2.

Suppose it is P1's move and he offers $(M(1-\delta), \delta M)$. P2 would accept if he knew that P1 was going to accept. P1 accepts provided his pay-off from accepting exceeds what he can get by rejecting i.e. provided

$$M(1-\delta) > \frac{(M-\epsilon)\delta^2}{1+\delta}$$

or

$$\epsilon\delta^2 > M(2\delta^2 - 1).$$

Since for $\delta < \frac{1}{\sqrt{2}}$ the R.H.S. is negative we are through. This implies that for any subgame perfect equilibrium P1 gets atleast $M(1-\delta)$ when it is his turn to move.

Repeating the earlier argument I can show that the unique equilibrium involves P1 offering $\frac{M}{1+\delta}$ and P2 accepting it.

The strategies supporting this perfect equilibrium are the following. P1 offers $\frac{M}{1+\delta}$ and accepts an acceptance s iff $s \geq \frac{\delta^2(M-\epsilon)}{1+\delta}$. P2 accepts any offer which yields him a pay-off greater than equal to $\frac{\delta M}{1+\delta}$.

The strategies when it is P2's turn to offer are symmetric. ∎

The next proposition deals with the case when the discount factor is high. In this zone the answer depends on the size of the penalty relative to the size of the cake. When the size of the penalty is high enough there is a unique perfect equilibrium. When the size of the penalty is smaller but not arbitrarily small, I show that though a continuum of splits can be supported as an equilibrium, not every split can be thus supported. For penalty sizes which are still smaller I obtain the Muthoo result that all splits can be supported as equilibrium.

Proposition 6. *Consider the modified alternating offers game with initial cake size M and with fixed reneging costs ϵ. Assume that $\delta \geq \frac{1}{\sqrt{2}}$. Then:*

(a) For $\frac{M}{\epsilon} \leq \frac{\delta^2}{2\delta^2 - 1}$ *there is a unique equilibrium which is the Rubinstein outcome.*

(b) For $\frac{\delta^2}{2\delta^2 - 1} < \frac{M}{\epsilon} \leq \frac{\delta^2}{2\delta^2 - 1} + 1$, *any split* $(s, M - s)$ *can be supported where* $s \in [\frac{(M-\epsilon)\delta^2}{1+\delta}, 1]$.

(c) For $\frac{M}{\epsilon} > \frac{\delta^2}{2\delta^2 - 1} + 1$, *any split* $(s, M - s)$ *can be supported as a subgame perfect equilibrium.*

Proof. (a) The proof of this is similar to that of the earlier proposition. It is enough to check that if P1 offers $M(1 - \delta)$ then P2 is going to accept. Here P1's pay-off from not accepting is $\frac{(M-\epsilon)\delta^2}{1+\delta}$ thus P1 will accept an acceptance by P2 provided,

$$M(1 - \delta) \geq \frac{(M - \epsilon)\delta^2}{1 + \delta}$$

or

$$\frac{\epsilon\delta^2}{2\delta^2 - 1} \geq M,$$

which is satisfied in this case.

(b) See appendix.

(c) See appendix. ∎

The sketch of 6(b) is as follows. I use the inductive step to establish that $(M, 0)$ and $(\delta M, 0)$ can be supported as subgame perfect equilibria when P1 is the first mover and $(0, M)$ and $(0, \delta M)$ when P2 is the first mover. I then use these as threat equilibria to support the other equilibria. Clearly such an equilibrium cannot be supported for $s < \frac{(M-c)\delta^2}{1+\delta}$ as P1 can always reject such an acceptance and get $\frac{(M-c)\delta^2}{1+\delta}$. The proof of 6(c) is similar to that of (b).

Proposition 7. *If the responder is allowed to reject AA by the proposer without incurring any costs, then the results of propositions 3, 4 and 5 still hold.*

Proof. For all the earlier propositions where I reached a unique equilibrium I can still apply the earlier arguments because if the responder was accepting an offer earlier he must be accepting the AA now.

In the steps where I constructed equilibria explicitly I make the following changes. Let the responder AAA all AA by the proposer. Also let the continuation strategies for RAA be the same as for rejectance by the acceptor. ∎

I next consider the game where a finite number of such reneging is possible i.e. after a responder replies AAA, the proposer can either accept the AAA or reject it and so on.

Corollary. *For any game with finitely many rounds of reneging proposition 7 still hold.*

6.3.2 Proportional Costs

In this subsection I consider an alternative formulation of reneging cost which is proportional to the size of the remaining cake.[8] If a player reneges on his offer, then a proportion (say α), of the cake is cut off and offered to the responder. In the next period the game is continued over a cake of size $M(1-\alpha)$. The costs increase in severity for repeated offenses. Define $\alpha_i, 1 \geq \alpha_i \geq 0$ as the proportional penalty for the i-th offense by a player. So I assume that $\alpha_i \geq \alpha_j$ for any $i > j$. However it is the following assumption which really drives the results for this case.

Assumption 2. $\lim_{n\to\infty} \alpha_n = 1$.

This says that *ultimately* the penalty is going to get very high. No assumption is made however, about the speed which the penalties increase. In particular, α_i may equal zero for any finite number of stages in the beginning.

In the next proposition the one sided offers game with proportional costs is examined. It is demonstrated that a unique equilibrium exists.

Proposition 8. *The modified one sided offers game has a unique outcome* $(M, 0)$ *for any proportional cost scheme satisfying assumption 2.*

Proof. See appendix.

The basic idea of the proof is similar to that of proposition 4 above.

[8]I would like to thank Arunava Sen for encouraging me to look into the proportional form of penalties.

Next I show that if the discount factor is not too high then the alternating offers game also has a unique solution.

Proposition 9. *For $\delta < \frac{1}{\sqrt{2}}$ and for any proportional cost scheme satisfying assumption 2, the modified alternating offers game with costs has a unique equilibrium which is the Rubinstein outcome.*

Proof. See appendix.

The proof in this case uses the same ideas as those in proposition 6. The details are a little more tricky, though.

The next proposition identifies conditions under which a unique solution exists even when the discount factor is high. The condition being that the penalty should be high enough to start with.

Proposition 10. *For $\delta \geq \frac{1}{\sqrt{2}}$ and for any proportional cost scheme with $\alpha_1 \geq \frac{2\delta^2-1}{\delta^2}$, the modified alternating offers game with costs has a unique equilibrium which is the Rubinstein outcome.*

The proof of this is similar to that of proposition 9.

6.3.3 Reputational Costs

In this section the penalties do not involve any cutting of the cake nor does it involve handing the penalty over to the other player. In case of reneging the concerned player incurs a cost of $\epsilon_n > 0$, which I interpret as the monetary equivalent of the reputational loss suffered by the reneging player when he reneges for the nth time.[9] As in the proportional cost case I assume that the severity of the reputational loss increases for repeat offenses i.e. $\epsilon_i \geq \epsilon_j$ for $i > j$. The results in this section are driven by the next assumption which says that *ultimately* the reputational loss becomes very high. It could, however, be very low for any finite number of times at the start of the game.

Assumption 3. $\lim_{n\to\infty} \epsilon_n = M$.

The next proposition demonstrates that under Assumption 3 the one sided offers game has a unique solution. That the same is true for the alternating offers game, when the discount factor is not too high, is shown in the proposition that follows.

Proposition 11. *The modified one sided offers model with reputational costs satisfying assumption 3 has a unique outcome* $(M, 0)$.

Proposition 12. *For* $\delta < \frac{1}{\sqrt{2}}$ *and reputational costs satisfying assumption 3, the modified alternating offers game with costs has a unique equilibrium which is the Rubinstein outcome.*

The proofs of proposition 11 and 12 are similar to those of the previous propositions 8 and 9 respectively and has been left out.

In the next proposition it is shown that, provided the penalty rate is large enough to start with, a unique solution exists even when the discount factor

[9] I would like to thank Dilip Mookherjee for encouraging me to look into the reputational cost case.

is high.

Proposition 13. *For $\delta \geq \frac{1}{\sqrt{2}}$ and for any reputational cost scheme with $\epsilon_1 \geq \frac{M(2\delta^2-1)}{1+\delta}$, the modified alternating offers game with costs has a unique equilibrium which is the Rubinstein outcome.*

The proof of this is similar to that of proposition 12.

6.4 Conclusion

The analysis in this chapter is aimed at showing that for some reasonable modifications of the Muthoo model, I can regain the uniqueness of the perfect equilibrium provided the discount factor is not very high. The basic feature common to all these schemes, and which drives the results is that ultimately the costs are going to become high compared to size of the cake. However, for discount factors which are high I find that Muthoo's criticism still applies in that there is a multiplicity of perfect equilibria. Thus the message of this essay can be briefly summarized as follows:

For penalty schemes where the penalty is ultimately going to become high enough compared to the size of the cake, I obtain a unique perfect equilibrium in the one sided offers game. If the discount factor is not very high then the alternating offers game also has a unique equiliubrium.

In both Muthoo's papers as well as mine the multiplicity of equilibria is sustained by using as threats the equilibria where one of the players obtain the whole of the cake. Such equilibria however involves using dominated strategies as accepting such an offer is a dominated strategy for the player who obtains nothing. It might be of interest to examine whether a multiplicity of equilibria for the high values of the discount factor can be sustained when I restrict attention to undominated strategies.

6.5 Appendix

Proof of Proposition 3. I write down strategies supporting a subgame perfect outcome where P1's first offer is rejected and P2's offer of $x > \frac{1-\delta}{\delta}$ is accepted in period 2. [10]

In period 1, P1 makes an offer y where $1 - y < \delta(1 - x)$ and accepts all acceptances by P2. P2 accepts an offer s iff $1 - s \geq \delta$.

If in period 1, P1 makes an offer $\overline{y}$ such that $1-\overline{y} \geq \delta(1-x)$ and either P2 rejects it or P2 accepts and P1 responds with RA, then in period 2 both play strategies supporting the $(0, 1)$ equilibrium (the strategies are as according to Muthoo). Otherwise in period 2, P1 and P2 play strategies supporting $(x, 1 - x)$ (the strategies are as according to Muthoo).

Next I demonstrate that a two period delay can be sustained. In period 1, P1 makes an offer z where $1 - z < \delta(1 - x)$ and accepts all acceptances by P2. P2 accepts an offer s iff $1 - s \geq \delta$.

If in period 1, P1 makes an offer $\overline{z}$ such that $1 - \overline{z} \geq \delta^2 x$ and either P2 rejects it or P2 accepts and P1 responds with RA, then in period 2 both play strategies supporting the $(0, 1)$ equilibrium (the strategies are as according to Muthoo). Otherwise in period 2, P1 and P2 play strategies supporting the

[10]for $\delta > \frac{1}{\sqrt{2}}$, $\frac{1-\delta}{\delta} < 1$.

equilibrium where $(x, 1-x)$, $1 - \frac{1-\delta}{\delta^2} \geq x > \frac{1-\delta}{\delta}$, is reached after a delay of one period.

I can next use an inductive step to show that any delay can be supported.

The restriction on $\delta(N)$ and x is needed in the following step. We just consider the case of one period delay, the other cases are similar. Consider PI's offer. If he makes an offer $\overline{y}$ where $1 - \overline{y} \geq \delta$ then P2 would accept. In order that P1 does not gain from this deviation, his pay-off from this deviation which is atmost $1 - \delta$ should be less than his equilibrium pay-off δx, i.e. $\delta x \geq 1 - \delta$ or $x \geq \frac{1-\delta}{\delta}$. The restriction on δ arises from the fact that for such an x to exist it must be that $\frac{1-\delta}{\delta} < 1$. ∎

Proof of Proposition 4. Suppose that the size of the cake $M \leq \epsilon$. I claim that then the unique subgame perfect outcome is $(M, 0)$. The strategies supporting the above equilibrium are the following. P1 offers M at every period and accepts all acceptances by P2. P2 accepts all offers by P1.

Clearly if P1 reneges then the outcome is $(0, M)$.

Next suppose that the supremum of P2's pay-off in a subgame perfect equilibrium is z and that $z > 0$.

Next I consider two cases depending on whether the supremum is actually being reached or not.

Case 1. Suppose that the supremum is actually being reached.

(a) Suppose it is reached after P1 plays RA. This implies that $z = M$ and that there exists an equilibrium where P1's pay-off is 0 and P2's pay-off is M.

Suppose that as a deviating strategy P1 offers q such that

$$M - q > \delta M \tag{6.5.1}$$

$$q > 0. \tag{6.5.2}$$

Clearly from (2) and the induction hypothesis P1 is going to accept if P2 accepts. So P2 will accept and P1 gains. Thus I have a contradiction.

(b) Suppose it does not involve a RA.

Then there exists a perfect equilibrium where P1 obtains $M - z$ and P2 obtains z.

Again I can find a deviating strategy for P1 offering q such that

$$M - q > \delta z \tag{6.5.3}$$

$$q > M - z \geq 0 \tag{6.5.4}$$

Again P2 will accept and P1 is going to gain.

Case 2. Suppose the supremum is not being reached.

In that case I can always find an equilibrium where there is no delay and no RA and where P2's pay-off s is close enough to z (by close enough I mean that $s > \delta z$) so that I can again apply the arguement of case 1(b).

Thus I reach a contradiction. Therefore $z = 0$. Now by assumption 1 if P1 offers $(M, 0)$ P2 is going to accept.

The strategies supporting the above equilibrium are the following. P1 offers M at every period and accepts all acceptances by P2. P2 accepts all offers by P1.

The proof uses an inductive step.

Induction hypothesis: If the cake is of size $M - \epsilon$ then the unique subgame perfect outcome is $(M-\epsilon, 0)$. Next suppose that the supremum of P2's pay-off in a subgame perfect equilibrium is z and that $z > 0$.

Next I consider two cases depending on whether the supremium is actually being reached or not.

Case 1. Suppose that the supremum is actually being reached.

(a) Suppose it is reached after RA. This implies that $z = \epsilon$ and that there exists an equilibrium where P1's pay-off is $\delta(M-\epsilon)$ and P2's pay-off is ϵ.

Suppose that as a deviating strategy P1 offers q such that

$$M - q \;>\; z = \epsilon \tag{6.5.5}$$

$$q \;>\; \delta(M-\epsilon). \tag{6.5.6}$$

Clearly from (2) and the induction hypothesis P1 is going to accept if P2 accepts. So P2 will accept and P1 gains. Thus I have a contradiction.

(b) Suppose it does not involve a RA.

Then there exists a perfect equilibrium where P1 obtains $M - z$ and P2 obtains z. By the inductive hypothesis $M - z \geq \delta(M-\epsilon)$.

Again I can find a deviating strategy for P1 offering q such that

$$M - q \;>\; \delta z \tag{6.5.7}$$

$$q \;>\; M - z \geq \delta(M-\epsilon) \tag{6.5.8}$$

Again P2 will accept and P1 is going to gain.

Case 2. Suppose the supremum is not being reached.

In that case I can always find an equilibrium where there is no delay and no RA and where P2's pay-off s is close enough to z (by close enough I mean that $s > \delta z$) so that I can again apply the arguement of case 1(b).

Thus I have a contradiction. Therefore $z = 0$. Now by assumption 1 if P1 offers $(M, 0)$ P2 is going to accept. ∎

Proof of Proposition 6(b). From proposition 5(a) for a cake of size $M - \epsilon$ the unique equilibrium outcome is $\frac{(M-\epsilon)}{1+\delta}, \frac{\delta(M-\epsilon)}{1+\delta}$. Hence following a RA the pay-offs are $\frac{\delta^2(M-\epsilon)}{1+\delta}$ and $\frac{\epsilon+\delta M}{1+\delta}$ for the proposer and the responder respectively.

First I show that $(M, 0)$ can be supported when P1 is the first mover and $(\delta M, 0)$ can be supported when P2 is the first mover.

The strategies. When it's P1's move he offers $(M, 0)$ and he AA all offers s such that $s \geq \frac{\delta^2(M-\epsilon)}{1+\delta}$. P2 accepts all offers.

When it's P2's move he offers $(M, 0)$ and he AA all offers s such that $M - s \geq \frac{\delta^2(M-\epsilon)}{1+\delta}$. P1 rejects all offers.

Here I just check that P1's acceptance rejectance decision is optimal. If P1 accepts some offer then $s \geq \delta M \Rightarrow M - s \leq M(1-\delta)$. Since $M(1-\delta) < \frac{\delta^2(M-\epsilon)}{1+\delta}$ P2 will reject and P1's pay-off is $\frac{\epsilon+\delta M}{1+\delta}$. Whereas by rejecting he gets δM. Since $\delta^2 M \geq \epsilon$ it is best to reject.

Similarly one can show that $(0, M)$ can be supported when P2 is the first mover and $(0, \delta M)$ can be supported when P1 is the first mover.

Next I show that $(\hat{s}, M - \hat{s})$, where $\hat{s} \geq \frac{\delta^2(M-\epsilon)}{1+\delta}$, can be supported as equilibrium outcomes using the above equilibria as threat strategies.

The strategies. At time 0, P1 offers $\hat{s}$ and he plays AA iff $s \geq \frac{\delta^2(M-\epsilon)}{1+\delta}$. P2 accepts an offer iff $s \leq \hat{s}$.

If at time 0, P1 offers $s > \hat{s}$ and P2 rejects then next period they play $(0, M)$.

If at time 0, P1 offers $s \leq \hat{s}$ and P2 rejects then next period they play $(\delta M, 0)$.

Here I check P2's acceptance rejectance decision. P2 by rejecting $s > \hat{s}$ gets δM, whereas by accepting he gets $M - s$. Since $\delta M \geq M - \frac{\delta^2(M-\epsilon)}{1+\delta} \geq M - s$ I am through.

P2 by rejecting $s \leq \hat{s}$ gets a pay-off of 0. So it's best for him to accept. ∎

Proof of Proposition 6(c). First consider the case where $\frac{\delta^2(M-\epsilon)}{1+\delta} + \epsilon < M \leq \frac{\delta^2(M-\epsilon)}{1+\delta} + 2\epsilon$ So from proposition 5(b) for a cake of size $M - \epsilon$ I can support $(M - \epsilon, 0)$ and $(0, \delta(M - \epsilon))$ with P1 the first mover. With P2 the first mover we can support $(0, M - \epsilon)$ and $(\delta(M - \epsilon), 0)$. Besides I can support the Rubinstein outcome as well.

First I establish that with P1 the first mover I can support $(M, 0)$ and and with P2 the first mover I can support $(\delta M, 0)$.

The strategies. If either player plays RA then the next period they revert to the Rubinstein equilibrium.

Otherwise when it's P1's turn to move he offers $(M, 0)$ and he plays AA to some offer s iff $s \geq \frac{\delta^2(M-\epsilon)}{1+\delta}$. P2 accepts all offers.

When it's P2's turn to move he offers $(M, 0)$ and he plays RA iff $M - \epsilon < \frac{\delta^2(M-\epsilon)}{1+\delta}$. P1 rejects all offers by P2.

Here I check that P1's acceptance rejectance decision is optimal the same way I did in proposition 6(b).

Similarly I can show that with P2 the first mover I can support $(0, M)$ and $(\delta M, 0)$.

Next I use these to show that any split can be supported as an equilibrium.

First I show that I can support $(\hat{s}, M-\hat{s})$ as equilibrium where $\delta^2(M-\epsilon) \leq \hat{s} < 1$.

The strategies. In time 0, P1 offers $\hat{s}$ and plays AA iff $s > \delta^2(M-\epsilon)$. P2 accepts iff $s \leq \hat{s}$.

If in time 0, P1 offers $s \leq \hat{s}$ and P2 rejects then next period they play the $(\delta M, 0)$ equilibrium.

If in time 0, P1 offers $s > \hat{s}$ and P2 rejects then next period they play the $(0, M)$ equilibrium.

If in time 0, P1 offers $s \leq \delta^2(M-\epsilon)$ and P2 accepts and P1 rejects then next period they play the $(\delta(M-\epsilon), 0)$ equilibrium.

If in time 0, P1 offers $s > \delta^2(M-\epsilon)$ and P2 accepts and P1 rejects then next period they play the $(0, M-\epsilon)$ equilibrium.

Here I check P2's acceptance rejectance decision. P2 by rejecting $s > \hat{s}$ gets δM. By accepting P2 obtains a pay-off of less than $M - \hat{s}$. I have to show that $\delta M > M - \delta^2(M-\epsilon)$ i.e. $M(\delta + \delta^2 - 1) > \epsilon\delta^2$. Even for $M = \frac{\epsilon\delta^2}{2\delta^2+1}$ I find that this holds for any $\delta < 1$.

For $s \leq \hat{s}$, P2 by rejecting gets a pay-off of 0 so by accepting he can't lose.

Next I consider the case where $\hat{s} < \delta^2(M-\epsilon)$.

The strategies.

At time 0, P1 offers $\hat{s}$ and P1 plays AA if $s > \delta^2(M-\epsilon)$ or if $s = \hat{s}$. P2 accepts an offer s iff $s \geq \hat{s}$.

If in time 0, P1 offers $s > \hat{s}$ and P2 rejects then next period they play the $(0, M)$ equilibrium.

If in time 0, P1 offers $s \leq \delta^2(M-\epsilon)$ or $s \neq \hat{s}$ P2 accepts and P1 RA then next period they play the $(\delta(M-\epsilon), 0)$ equilibrium.

If in time 0, $s \leq \hat{s}$ and P2 rejects then next period they play the $(\delta M, 0)$ equilibrium.

If in time 0, $s > \delta^s(M - \epsilon)$ or $s = \hat{s}$ and P2 accepts and P1 RA then the next period they play $(0, M - \epsilon)$ the equilibrium.

Next I check P2's acceptance rejectance decision. If P2 rejects an offer such that $s > \hat{s}$ his pay-off is δM. If he accepts his pay-off is atmost $\text{Max}\{\epsilon, M - \delta^2(M - \epsilon)\}$.

Since $\delta M > \frac{\epsilon}{\delta} > \epsilon$ and $M(\delta + \delta^2 - 1) > \epsilon\delta^2$ I am through.

If he rejects an offer such that $s \leq \hat{s}$ then his pay-off is 0, therefore by accepting he cannot lose.

Thus I have proved my contention for $\frac{\delta^2(M-\epsilon)}{1+\delta} + \epsilon < M \leq \frac{\delta^2(M-\epsilon)}{1+\delta} + 2\epsilon$. Ican next consider the case where $\frac{\delta^2(M-\epsilon)}{1+\delta} + 2\epsilon < M \leq \frac{\delta^2(M-\epsilon)}{1+\delta} + 3\epsilon$ and repeat the same arguement and continue doing so for any higher M. ■

Proof of Proposition 8. Suppose that P1 has already reneged $i - 1$ times and that $\alpha_i > \delta$. I claim that the unique perfect equilibrium in that subgame must be $(M, 0)$. Suppose to the contrary that the supremum of P2's pay-off in this game be z where $z > 0$.

Case 1. Suppose that the supremum is being reached. Then there exists some equilibrium where P2's pay-off is z and P1's pay-off is less than equal to $M - z$.

Suppose that as a deviating strategy P1 offers q such that

$$M - q > \delta z \tag{6.5.9}$$

$$q > M - z. \tag{6.5.10}$$

Since P2 gains irrespective of whether PI accepts the acceptance or not (if P1 plays RA then P2's pay-off is $\alpha_i z > \delta z$) P2 accepts and P1 gains. Thus I reach a contradiction.

Case 2. When the supremum is not being reached I can take an equilibrium pay-off for P2 s where s is close enough to z and carry through the same argument.

Induction hypothesis. In the subgame following a RA the pay-offs are $(1-\alpha_i)M < \alpha_i M$.

Next simply mimicking the steps of proposition 2 but with this induction hypothesis I can show that the unique equilibrium in this case is $(M, 0)$. ∎

Proof of Proposition 9. Let i be such that $\alpha_i \geq 2 - \frac{1}{\sqrt{2}}$ and $\alpha_{i-1} < 2 - \frac{1}{\sqrt{2}}$.

Clearly when the state is (a, b) with $a, b \geq i-1$ I have a unique equilibrium. I can use the earlier technique to prove this. It is enough to note that if P1 offers $((1-\delta)M, \delta M)$ then P2 would accept since $(1-\delta)M \geq (1-\alpha_i)\delta M$ and thus P1 cannot play RA if this offer is accepted.

Induction hypothesis 1. For any state (a, b) where $a, b \geq j$, and $j < i-1$ we have a unique equilibrium where I obtain the Rubinstein outcome.

First I show that for $(j-1, j)$ I obtain the Rubinstein outcome. I use an inductive argument to prove this.

To start with I show that for $(j-1, i-1)$ I obtain the Rubinstein outcome. Clearly if P1 offers $(1-\delta)M, \delta M$ then P2 would accept if P1 is going to play AA. P1 is going to play AA as by playing RA he obtains $\frac{\delta^2 M(1-\alpha_j)}{1+\delta} \leq (1-\delta)M$.

Similarly if P2 offers $\delta M, (1-\delta)M$ then P1 would accept if P2 is going to play AA, since by playing RA P2 obtains atmost $\delta(1-\alpha_i)M \leq (1-\delta)M$.

Next I can use my earlier technique to show that a unique Rubinstein equilibrium exists.

Induction hypothesis 2. For $(j-1, k)$ where $i-1 > k > j$ there exists a unique perfect equilibrium where I obtain the Rubinstein outcome.

I show that for $(j-1, k-1)$ a unique equilibrium exists.

Using the first inductive hypothesis I can show that P1's pay-off when he is the first mover is atleast $\frac{M}{1+\delta}$. Similarly I can use the second inductive hypothesis to prove that P1's pay-off when he is the first mover is atmost $\frac{M}{1+\delta}$. It is enough to observe that if P2 offers $\delta M, (1-\delta)M$ then P2 would AA (as by the second inductive hypothesis he cannot do better by playing RA) and P1 would accept.

Thus I have established that for $(j-1, j)$ there exists a unique Rubinstein equilibrium. Similarly it can be shown that for $(j, j-1)$ a unique Rubinstein equilibrium exists. Using the above two results one can show that for (j, j) a unique Rubinstein equilibrium exists. ∎

6.6 References

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