TITLE LICENSING AND DIFFUSION IN OPEN ASYMMETRIC ECONOMIES

AUTHOR FRANCISCO CABALLERO SANZ

DEGREE

AWARDING BODY UNIVERSITY OF WARWICK
DATE 1991

THESIS
NUMBER

LICENSING AND DIFFUSION IN OPEN ASYMMETRIC ECONOMIES

FRANCISCO CABALLERO SANZ

Thesis realized by Francisco Caballero Sanz under the supervision of Professor Paul Stoneman and presented in partial fulfilment of the requirements for the degree of Ph.D. in Economics at the University of Warwick.

December, 1991.

Acknowledgements

Over the years, I have accumulated many debts of gratitude in the preparation of this thesis. First of all, I have to thank my supervisor Professor Paul Stoneman whose guidance, helpful comments and encouragement have been abundant from the early days of this research. Without his generous support this thesis would have never been completed.

I have also benefited from the advise of the Professors K. Roberts, R. Kanbur and particularly N. Ireland who acted as second supervisors.

In the Department of Economic Analysis of the Universitat de Valencia, A. Urbano provided not just analytical insights but moral support too, for the development of some models and chapter V in particular. M.L. Moltó, R. Moner, A. Ortí, V. Orts, J. Sempere and E. Uriel also contributed in someway to this work. More recently, Frank Mather helped me to make more readable some of material presented below.

But greatest one of my debts is with family, María, Ana and José María, to whom I owe many hours of dedication which I am looking forward to paying back as soon as possible.

Summary

The main objective of this thesis is to provide some simple theoretic insights that could help to design a technology policy for a "latecomer" country such as Spain. The thesis focuses on two major topics that can be considered as central for these countries: the acquisition of foreign technology through licensing and other contractual means and the adoption and diffusion of new process technologies.

The thesis is divided in four major parts. The introductory part is dedicated to the discussion of the main characteristics and technological profile of these kinds of countries. This is done in order to provide stylized facts which can help to build up the most suitable analytical framework for the study of these countries.

The second part of the thesis is dedicated to the study of two major issues concerning the licensing of innovations in an international context. It examines questions relative to the impact of ex-ante licensing on the incentives for technologically different firms to carry out R&D and on the rate and direction of technological change. Particular attention is paid to the consequences derived from differences between the private and the social value of the licenses. The study of these questions reveals the existence of important market failures that arise in the international transfer of technology.

The third part deals with the relative incentives for the introduction of a process innovation in countries with asymmetric cost structures. The impact of different directions of technological change, sequences of innovations and different forms of market competition is taken into account. This part includes some consideration of international trade and supply-side issues.

The conclusions of the analytical chapters are discussed in chapter IX.

Contents

Part I: Preliminaries

Chapter I: Introduction

I.1. Aims and motivation of the thesis 11
I.2. Late industrialisation and technology: Some stylized facts from the Spanish case 17
I.2.1. Late industrialisation 17
I.2.2. Some basic facts about the technological evolution of Spain in the last decades 25
I.2.3. Plan of the thesis 35
Statistical Annex 38
References 40

Chapter II: Assumptions and methodological considerations

II.1. Introduction 42
II.2. Assumption 1: Differences in production costs 43
II.2.1. Differences in factor prices 49
II.2.1.1. The cost of capital 50
II.2.1.2. The cost of labour 53
II.2.2. Differences in costs structures 56
II.3. Assumption 2: World demand function 58
II.4. Boundaries to the study 62
II.4.1. Process innovation versus product innovation 62
II.4.2. Market relationships: Multinational corporations as vehicles of technological change, joint ventures, international technological cooperation and strategic alliances 64
References 67

PART II: LICENSING

Chapter III: International licensing Versus domestic R&D and the rate and direction of technological change

III.1. Introduction 70

III.2. A Model of licensing vs. domestic generation of R&D 72

III.2.1. The case of "perfectly different" countries 80

III.2.1.1. Nash equilibria for the entire game: existence, unicity and characterization 85

III.2.1.2.- Analysis of results: Differences in R&D efforts between the two countries 85

III.2.1.3. Analysis of results: Dominance of strategies and subgame Nash perfect equilibrium 88

III.2.1.4.- Analysis of results: the rate and direction of technological progress in the licensing solution 90

III.2.2. Generalization to non-perfectly different countries 94

III.3. Conclusions 96

Appendix 98

References 101

Chapter IV: The impact of the international licensing of process innovations on domestic social welfare.

IV.1.- Introduction 103

IV.2.- International licensing of a non-drastic innovation by means of a fixed fee only: the non-drastic innovation 105

IV.2.1.- The market outcome 107

IV.2.2.- The social optimum 112

IV.2.2.1. The social demand for licenses. 112
IV.2.2.2.- Social-welfare properties of the private demand for licenses. 116
IV.2.2.3.- The socially-optimal equilibrium in the market for licenses. 119
IV.3.- Market value and social value of the patent. 122
IV.4.- Licensing of an innovation by means of a fixed fee only: the case of drastic innovations in Arrow's sense. 124
IV.5-.- Caveats and conclusions 125
Appendix 129
References 135

PART III: DIFFUSION, ADOPTION AND TRADE

Chapter V: Sequential models of innovation and market evolution in asymmetric economies
V.1. Introduction 137
V.2. The model and preliminary results. 140
V.3. Necessary and sufficient conditions for each kind of equilibrium 147
V.4. Direct and induced effects and the Vickers assumption. 149
V.5. Discussion of equilibria. 153
V.6. Joint profits and firms' costs 156
V.7. Sequential innovations with free diffusion. 159
V.8. Sequential innovation with non-reversible R&D costs 161
V.9. Differences in the ability to adopt new technologies. ("History Matters"). 164
V.10. Conclusion. 166
Appendix 169
References 171

Chapter VI: International diffusion of new process technologies with asymmetric duopolists

VI.1. Introduction 173

VI.2. The "world-market model" with Cournot-Nash conjectures. 176

VI.3. The "world demand function" with Bertrand conjectures 183

VI.4. Some supply-side considerations. 186

VI.4.1. Independent R&D producer with sequential innovations. 187

VI.4.2. Independent R&D producer and small innovations. 188

VI.5. The two-market model. 194

VI.5.1. Demand asymmetries. 194

VI.5.2. Comparative statics. 197

VI.5.3. The impact of trade policies on adoption. 199

VI.5.4. Diffusion and trade flows 199

VI.5.5. The impact of market size on diffusion 200

VI.6. Conclusions 201

Appendix 203

References 207

Chapter VII: International trade, endogenous innovation and dynamic efficiency

VII.1. Introduction 210

VII.2. The model. 211

VII.3. The impact of opening to trade on factor shares within each industry. 215

VII.4. The induced effect of trade policies on the direction of technical change and on domestic welfare: the small country case 219

VII.5. Some final comments 227

Appendix 232

References 235

Appendix to part III

Chapter VIII : A note on the adoption of new technologies under collusive behaviour:

A case of supply-side induced diffusion.

VIII.1. Introduction 237

VIII.2. The original formulation of the problem. 239

VIII.3. A framework for supply-side induced diffusion 241

VIII.4. Conclusion. 248

References 249

PART IV: CONCLUSIONS

Chapter IX: Conclusions

IX.1. Introduction 252

IX.2. Licensing of foreign technology as a means to acquire technology 253

IX.2.1. R&D vs. licensing: private incentives 256

IX.2.2. R&D vs licensing: differences between private and social incentives 257

IX.2.3. The impact of ex-ante licensing on the rate and direction of technological change 262

IX.2.3.1. Implications for the technologically less developed country: the appropriateness of the technology transferred 263

IX.2.3.2. Implications for technologically more developed countries. 265

IX.3. The international diffusion of new process technologies. 266

IX.3.1. Incentives to adopt, market competition and the direction of technological change. 269

IX.3.2. Technological leadership and sequences of innovations. 270

IX.3.3. The influence of supply side considerations. 271

IX.3.4. Some trade considerations. 273

Appendix 275

References 279

Part I Preliminaries

Chapter I: Introduction

I.1. Aims and Motivation of The Thesis

The main objective of this thesis is to provide some simple theoretic insights that could help to design a technology policy for a "latecomer" country, i.e. a country that has reached a certain stage of development in its process of industrialisation. It is common knowledge that technological competition is a major element determining the privileged economic position of countries such as Japan, the USA or Germany. But for the long list of countries such as South Korea, Spain, Brazil or Mexico, which have achieved a certain degree of industrial development, but lag still behind the levels of the world leading countries, technology is also of the greatest importance to maintain and consolidate their processes of industrialisation.

This research is limited to just a few selected issues that, in my personal opinion, are relevant for these kinds of situations. The ultimate objective of designing a global technology policy for one of these latecomer countries is a complex endeavour which is not within reach of the isolated effort of one doctoral dissertation. Consequently, a choice had to be made at the outset of this research about the methodological approach to follow. One possible alternative was to imitate some previous exercises that, based on empirical observations, have produced fairly detailed recipes about how to tackle such a complex undertaking. Excellent examples of these kinds of exercises are the periodical innovation surveys carried out by the OECD for various countries. The utility of these studies is out of question. Nonetheless, I think that little essentially new can be added along those lines.

Instead, it was considered that this thesis could make a more fruitful contribution by providing a better understanding of the theoretical basis required to guide in a sensible and rational way public policy interventions in such situations. This second alternative implies limiting the scope of the thesis to just a selection of theoretic problems, which are relevant for the design of technology policy in those countries that are still completing their industrialisation processes.

Technology policy can be defined as a "set of policies involving government intervention in the economy with the intent of affecting the process of technological innovation"[1]. But in order to obtain normative rules, one must have detailed knowledge of what are the positive aspects of the problem that justify public policy intervention. This observation, which was already present in the thesis proposal prepared a long time ago, has been decisive in the definition of the objectives and contents of this research.

Contrary to what happens in the case of countries at the leading edge of technological development, the study of market failures and market imperfections that may arise in the process of technological development of the so-called latecomer countries, has seldom been the subject of analytical research of the type presented here. In the late seventies and early eighties, several complex models were developed with the purpose of determining which is the best market structure to produce the optimal rate of technological change. However, even today there are only a few models that can help us to answer the most simple questions concerning technology policy for latecomer countries in an open international context.

Fortunately, and probably spurred by events such as the debate on intellectual property rights in the Uruguay Round and the solid economic progress of countries like South Korea and Taiwan, the second half of the eighties has produced several interesting

---

1 See Stoneman (1987), chapter 1, page 2.

pieces of research that have opened new horizons. Nevertheless, very simple but non-trivial questions such as what kinds of innovations would be pursued more intensively by certain countries or whether imperfect markets will produce too much or too little international licensing from a socially optimal perspective, remain unanswered.[2]

For these reasons, by concentrating on such questions, this study can perhaps make a more fruitful contribution to the understanding of these economic processes, and in that way, provide a better foundation for the definition of the basic guide-lines for public policy intervention.

Nevertheless, it is important to point out that this decision in favour of tackling the more basic theoretical questions, did not imply a change of direction in the aims of the research. It is true that this thesis does not include a detailed outline for technology policy intervention, but it is also true (or at least so I hope), that it provides some basic and robust propositions that give better theoretical support to some policies already implemented in such countries. It is my contention that when the nature of market failures occurring in these situations and the basic strategic responses of firms facing them are better known, technology policy can be designed in a more secure way.

Of course, this does not imply that this kind of research should be considered as a guarantee of success for technology policy. One must be conscious of the limitations of the theoretic models presented here below, but one must also be aware of the pressures that urge policy makers to take decisions concerning technology matters. Technology issues are acquiring an ever increasing importance in public policy and policy decisions require both rational foundations and a good understanding of what can be expected to be the result of the free action of market forces when they are left to work on their own. For these

2 At least to the best of my knowledge, at the time when the agenda for this research was closed in of 1990

reasons, propositions like those included in this thesis can be of potential utility for public policy. Perhaps an example can help to clarify this point.

Since 1973, industrial regulations in Spain compelled companies to submit any contractual form of technology acquisition from abroad for government approval. This regulation required that the companies involved should provide quite a detailed amount of information to public authorities who could, in principle, control the process of technology transfer, either by rejecting the deal or by requiring some modifications. In 1984, an interesting study[3] on the economic impact of this procedure was carried out in the context of a revision of this regulation by the Spanish Government. This study recommended the relaxation of the very strict and complex norms, which had permitted a high level of intervention for the Spanish authorities until then.

According to the authors of that report, the "quasi-policing" approach adopted in the regulation was based on the implicit assumption that the acquisition of technology implied "higher social than private costs".[4] This resulted in a complex series of bureaucratic controls, which after more than ten years of the enforcement of the regulation, had very seldom resulted in the rejection of contracts submitted for approval. This paradoxical outcome is not explored in detail in the report, but some comments included in it such as the disregard by the Directorate General for Industrial Innovation of this powerful instrument for intervention and the priority given in the process to "purely and almost police-like bureaucratic obsession", seem to indicate the simple truth of the matter: the administrative authorities in charge of a very powerful instrument for technology policy did not have much information about the best way to use it. Whenever the authorities actually

---

3 Martín González, C. and Rodríguez Romero, L. "La Transferencia Contractual de Tecnología en la Economía Española", Programa de Investigaciones Económicas, Fundación Empresa Pública, Documento de Trabajo 8401

4 Martín C. and Rodríguez L., (1984) page 10 and 11.

raised some objection to a given contract, it always concerned its ancillary clauses, and even in such cases, the decisions did not seem to be based on any solid economic rational.

In its conclusions, the final report recommended the simplification of the administrative procedures on the grounds that they resulted just in a waste of time and effort for the companies without any economic policy rational to justify them. However, the report did not inquire at all into what was, in the opinion of the authors, the implicit assumption behind the regulation: the difference between social and private costs in the process of international technology transfer.

This is the subject of a good part of the first half of this thesis. There, some insights into the kinds of effects acting upon the private and social costs and benefits of technology transfer are provided. As it was said before, one must be fully aware of the limitations of the results presented here, which have been obtained in a highly simplified context. It is probably true that, in the light of these results, the proposals contained in the above mentioned report are still the appropriate ones. However, some analysis like the one presented below, could have been of some utility for the preparation of a report of this nature: firstly, because it could have helped to produce a more precise evaluation of the application of this instrument of technology policy in the past; and secondly, because it could have helped to devise more useful regulations for the future. It is with this conviction, but also with this hope, that the research which is the subject of this thesis has been undertaken.

As it was said before, only a selection of theoretic issues will be dealt with in the thesis. They have been chosen after an examination of the main characteristics that are present in the Spanish case. This choice has also been influenced by a series of assumptions and boundaries of the research defined and discussed in chapter two. On the basis of all these elements, two main themes are addressed in the thesis:

1.- The first one is licensing of a new process technology in the context of asymmetric oligopolistic competition. Latecomer countries often have to obtain their technology through contractual means from foreign countries. But the market for technology is a complex one, with important information asymmetries. In the context of an asymmetric cost structure, both in the production of goods and new technologies, two basic topics concerning licensing will be analysed. The first one will be the impact of the possibility of ex-ante licensing on the incentives for the latecomer country to develop technology independently or to acquire it from abroad. As we will see later on, this possibility will have an important induced effect on the general rate and direction of technological progress. The second basic topic concerning licensing will be the analysis of the impact that licensing from abroad can have on social welfare when the industry using the new technology has an oligopolistic structure.

2.- The second main topic of the dissertation is the study of the relative incentives that firms located in two different countries and with different cost structures have to introduce a new process innovation. This analysis is carried out in a general framework in which firms bid for getting the new technology (or a sequence of them), in competition with their rivals in the market of a final good produced with the new technology. Although this type of analysis has often been used to analyse patent race situations, the lack of endogenous consideration of the conditions under which the new technology is produced makes them more suitable for the study of adoption decisions. In my opinion, the analysis of innovation decisions could give useful insights about the structural conditions affecting technological change in these kinds of economies in process of development. Special emphasis is given here to the competitive conditions prevailing in the markets for the final good and their influence on the incentives to innovate. Finally, some trade issues are also considered.

This introductory part of the thesis is dedicated to discussion of the type of situation that will be modelled later on. This is done in order to provide an analytical framework that suits the reality that will be studied here in the best possible manner. For that purpose, the next section will deal very briefly with the characteristics of a "latecomer" country that has reached a certain level of economic development and faces some important choices as regards to its technology policy. In order to provide a more specific description of this problem, a brief account of the main elements, from the technology policy point of view, that are present in the Spanish case is given later in this chapter. In the next one, the two main assumptions that are made almost throughout almost all the chapters of this thesis will be examined and their degree of realism assessed. Finally, in order to complete the presentation of methodological approach of the thesis, some of main boundaries defining its contents are discussed before presenting the theoretic models that are the core of the research.

1.2. LATE INDUSTRIALISATION AND TECHNOLOGY: SOME STYLIZED FACTS FROM THE SPANISH CASE.

1.2.1. Late industrialisation

The concept of "latecomer" industrialisation has been present in the Economic History literature for a long time. It has often been used to identify countries which, after experiencing a certain process of economic development, still maintain a relative economic backwardness with respect to the leading industrialised countries in the world. This term was applied to countries such as the USA , Germany and Russia at the end of the last century. Later on, it was used to designate Japan, Italy or Spain. Nowadays, the term Newly Industrialised Countries or NIC, has become more popular, but it still applies to countries experiencing similar economic transformations to those of the countries mentioned before. Although the economic environment and the prevailing technological paradigm has been changing over the years, some patterns have been common to all these cases.

In spite of some criticisms, Balassa's "stages theory of comparative advantage"[5] remains a useful theoretic framework to explain the process of transformation that these countries have undergone. This theory views the shifting industrial structure of countries at different stages of economic development as a reflection of their comparative advantages. In its basic structure, the theory has an undeniable appeal: countries start producing relatively primary commodities in the earlier stages of their process of economic development, as these do not require skilled labour and they are not capital-intensive goods; when unskilled labour becomes relatively scarce, continuation in the process of development requires moving into more capital-intensive economic activities requiring more skilled labour.

Alongside this fairly simple description of economic development, the technological basis of countries undergoing processes of economic development experiences substantial modifications which are essential for the sustainability of the process: if the technological basis needed for the next stage of economic development is not readily available, the whole process can be aborted. Only if technology is constantly upgraded, will the productivity gains that are essential to maintain growth and international competitiveness be achieved.

But technological change is important for economic growth not just for maintaining high levels of productivity. Technological change is essential to avoid increases in wage costs strangling the growth process. There is a wide-spread but simplistic belief about the

---

5 See Balassa, B. (1977) "A Stages Approach to Comparative Advantage", World Bank Staff Working Paper, n 256, Washington D.C., The World Bank

negative impact of labour costs upon the international competitiveness of countries. As economic development progresses in a country, wages and salaries tend to increase. If this were all that happened, other countries with still low wages could become more competitive and growth could be stopped. However, empirical evidence shows that those countries enjoying the highest rates of growth of their GDP and exports are those that have experienced the highest increases in their unit labour costs. This phenomenon, which is known in the literature as the Kaldor paradox, has been explained recently by Fagerberg (1988). His research has shown that despite the negative impact of labour costs on international competitiveness, technological knowledge and the country's capacity to deliver (in which technology is an important factor too), are capable of more than offsetting this negative impact. Therefore, technological innovation seems to be crucial not just to achieve international competitiveness but also to maintain external market shares and, at the same, relatively increase payments accruing to labour.

One of the commonalities that appears in all cases of latecomer industrialisation is the reliance on imported technological knowledge. This has been presented as an advantage by many authors[6], because borrowing technologies from more developed countries allows countries undergoing industrialisation to economise on resources needed for other investment purposes. Dependence on foreign technology can save costs in terms of:

1. the uncertainty associated with innovation, because the purchased technologies have already been tested elsewhere, hence reducing although not eliminating completely the uncertainty about their performance, real costs, etc;

2. rivalry in R&D processes often results in excessive social costs as the companies taking part in the R&D race duplicate efforts in their search

6 See for instance Krugman (1979) and its follow-ups by Dollar and several contributions by Thursby and Jensen

for the new technology. If already available technology is acquired from abroad and there is no R&D race, the country will avoid the inefficiencies due to such duplication of efforts.

However, as countries progress in their process of economic development, they require a more sophisticated technological basis which is harder to obtain by means of technology transfer. The USA in the early decades of this century, Italy in the fifties and sixties and Spain in the seventies and early eighties are just some examples of this sort of technological transition. Currently, countries like South Korea and Taiwan are facing the same type of experience[7]. However, there are reasons to believe that in recent years, it has become increasingly more difficult for all countries, whatever their stage of development, to rely on foreign technology. The following reasons have contributed to reduce the profitability of using foreign technology:

1. The most industrialised countries in the OECD area have started to tighten up the international enforcement of intellectual property right protection. The Uruguay Round has provided the scenario for this. The position of the G7 countries can be best summarised in the statement of a former US negotiator in this Round who stated that "the negotiations on trade-related intellectual property rights is the one area of the Uruguay Round in which protection is the solution, not the problem"[8]. The creation in the UK of the Federation Against Software Theft (FAST) and the already historical rulings in the patent cases in favour of Texas Instruments and Mr. G. Hyatt after twenty years in court are just some reflections of this trend.[9]

---

7 See for instance Ernst D. and O'Connor D. (1989)

8 Schott J.J. (1990), page 32.

9 "The Point of Patents", The Economist, September 15, p. 17

2. Nowadays, technological change presents some new characteristics that make it more difficult for countries to obtain new technologies from abroad. In first place, the rate of technological change in some key enabling technologies such as information technologies, is much higher today than ever before. Furthermore, the life cycle of new products is getting shorter at an increasingly faster pace. The case of DRAM generations epitomises this phenomenon.[10]

3. It is becoming increasingly apparent that technological progress is heading towards a greater integration of technologies. As the cases of telematics and facilities management show, the frontier of innovation has reached a certain point where many of the future advances will require the combination of different sorts of technological knowledge. The present upsurge in the number of international strategic alliances between companies coming from many different countries and industrial sectors is, to a certain extent, the result of these firms' search for firm specific technological knowledge, which is hard to transfer.[11] The diffusion of these types of innovations on an international scale will probably prove to be more difficult than in the past.

All these phenomena pose new problems for countries in the 'catching-up' process, for they can no longer proceed along the traditional routes. Nevertheless, this new situation may also open new opportunities to advance more rapidly in the process.

a) Firstly, shorter life cycles can make it possible for these countries to jump stages in the process, hence by-passing earlier starters. DRAM production in Korea is a good example of this possibility. However, this will require a change in the strategy that these countries have used in the past to acquire technological knowledge.

---

10 See Ernst and O'Connor (1991)

11 See Jorde T.M. and Teece D.J. (1990).

b) Secondly, at the present time, the number of potential sources of foreign technology for a developing country are more diverse than several decades ago. Countries in intermediate stages of economic growth can benefit from the present competition among the three technological leaders of the world, i.e. Japan, the USA and the European Community. The less developed country will be in a better situation to benefit from competition among the alternative suppliers of foreign technology if:

- it is relatively big,
- it has reached a relatively high level of economic development and its domestic market represents an important stake for these competitors, and/or
- the country has a strategic position that could be used as a spearhead to enter certain major economic markets. This could be the case of Portugal or Spain with respect to the European Community or Mexico and the Dominican Republic with respect to the USA.[12]

c) In the past few years, we have witnessed the proliferation of new forms of acquisition of foreign technology. Direct investment from abroad, the import of capital goods incorporating technological knowledge and the acquisition of licenses over patents or know-how no longer exhaust the possibilities of having access to new technologies. Under the form of joint ventures, strategic alliances or trans-national projects of cooperative R&D, countries can now overcome the existing technological barriers to entry into new markets. The most interesting characteristic of this new possibility is that it allows countries to have access not just to already existing technologies but also to conducting R&D projects. In this way,

---

12 A more sophisticated example of this has been the strategy of the Canadian telephone company, Northern Telecom, that has exploited its presence in the USA to benefit from Japanese concessions to the US in their bilateral trade disputes and consequent agreements.

firms entering these agreements can, not only learn new technologies, but they can "learn to learn" too.[13]

d) Finally, the high current rate of technological change has raised the costs necessary to enter an R&D race. But it has also created some new market opportunities which do not require high entry costs. The many new combinations that new technologies offer allow firms to enter some new and fast growing markets, like the market for personal computers, which do not require high initial investments. Furthermore, new information technologies can be used to improve productivity and reduce costs in traditional sectors, hence expanding the maturity period. In this way, countries that have achieved a certain stage of development can maintain their competitiveness *vis a vis* less developed countries with lower labour costs but a less developed technological basis. Good examples of this way of benefiting from technology are the shipbuilding industry in South Korea or the automobile industry in Spain.

This last point brings us to the basic alternatives that developing countries have to face in the design of their technology policy. For instance, countries can specialise in new market opportunities created by the latest technologies, but which are not fully exploited by technologically leading countries[14], thereby becoming followers in those markets. Alternatively, countries can use those new technologies to upgrade traditional industries.

But the 'technology choice' *par excellence* has been, and will probably still be in the future, the choice between developing technology domestically or acquiring it from abroad. In the early stages of this research, a simple optimal control model was developed with

---

13 On how to benefit from cooperative R&D see Teece (1986) and on the importance of learning to learn see Stiglitz (1987).

14 This can be due to limits in the investment capacities of those more advanced countries or to the low profitability of those market segments

foreign technology and domestic R&D as the two instrumental variables that increase the control variable, consumption, so as to maximise social welfare. The results of that model were not very surprising: each instrumental variable should be used up to the point at which their marginal contribution to social welfare was the same.

This result provided the basis for one of the main assumptions underlying throughout this research: it is not possible to consider the domestic development of technology and the acquisition of foreign technology as an either/or choice. Both instruments have to be used jointly in the process of technological development. In the early stages, foreign technology is the only real alternative for "taking off". Later on, even if 'indigenous R&D' does not win any patent race, its contribution is essential to facilitate reverse engineering and technology transfer. Even in the later stages, when the country has succeeded in finding a niche of industrial specialisation and is technologically mature, foreign sourcing of technology remains necessary[15]. If we look at the most successful case of technology policy, Japan , we can see how now in the nineties, its firms are still trying to get foreign technology through strategic alliances such as the Toshiba-Motorola and the Hitachi-Intel agreements in the semiconductor field or through international cooperative R&D projects such as the Integrated Manufacturing Systems initiative. Therefore, the choice between "buying technology from abroad" or "developing it domestically" can be justified and maintained for analytical purposes only.

Nowadays, it is not conceivable to think of technological self-sufficiency. What we may find in the real world is a variety of degrees of technological dependence from abroad as expressed by different values of the ratio between the technological balance of payments and the domestic expenditure in R&D. But even this cannot give us a complete picture of the technological situation of a certain economy. Although it is hard to subscribe fully to

---

15 In a recent paper presented at the Technology Economy Programme of the OECD, it was reported that in a survey to USA multinational corporations, the most mentioned cause for opening R&D laboratories abroad was foreign sourcing of technology. For a more analytical approach see Mowery (1989)

the so called 'national systems of innovation' approach proposed by Freeman (1982) and Lundval (1988) as an analytical tool, because it relies almost completely on a totally institutional and descriptive basis, nobody can deny that the national specificities of each case must be born in mind in any normative analysis of technology policy.

In order to provide that minimum framework of reference, it is necessary to present some stylized facts drawn from some real world situation. For that purpose, the Spanish experience, which after all has been the situation driving all this research from the begging, has been chosen. The next few pages give a very summarised panorama of the technological evolution of Spain in the last few decades. Once again, by approaching a certain particular example the analysis may lose some generality. But that is usually the price that has to be paid to gain some realism in our assumptions and relevance for our propositions.

I.2.2. Some basic facts about the technological evolution of Spain in the last decades.

The purpose of this section is to provide a condensed profile of the technological evolution of a prototypical latecomer country: Spain. In 1986, Spain joined the EEC and this event produced an important structural shock for the Spanish economy. It opened a process of adjustment that has produced serious disruptions in many economic indicators. For this reason, we will try to avoid making reference here to the period after 1986.[16]

The Spanish economy experienced a spectacular process of growth between the early sixties and 1975. While in 1963 the Spanish GDP was just 6.5% of the Euro 12 total GDP, that percentage rose to 9.2 in 1975. Over the same period, comparable economies such as Greece, Portugal or Ireland did not experienced any substantial increment in their

---

16 For an analysis of developments in this area after 1986 see Caballero (1991)

share of European GDP. GDP annual rates of growth close to 10%, almost twice as big as the European average and close to "Japanese standards" were not unusual during the sixties. But the Spanish economy suffered more deeply the economic crisis of the seventies and growth fell below the European rate during that period. The process of rapid growth in labour costs initiated in the sixties stopped in the early eighties and the economic boom of the last decade has not produced any substantial increase in labour costs.

During this period, Spanish industry has undergone important structural changes. The UN index of structural change in manufacturing, -a measure of the degree of correlation between the value added shares in 1965 and 1980- shows that only Brazil and Korea suffered comparable transformations in their industrial structures. However, Spanish industry developed patterns of specialisation quite different from those of Far-East Asian NICs or Brazil. If we use the OECD classification of high, medium and low technology products based on the percentage of R&D expenditure over the value of output, we can see that, taking OECD Countries as a reference, Spain has developed a comparative advantage in medium and low intensity products.[17]

The "technology restriction" has been an important constraint on the process of economic growth in Spain. The effects of this constraint have been twofold:

a.- Unlike Korea, the Spanish economy has not been able to develop a comparative advantage in high technology products that are usually "strong demand" products.[18]

b.- On the other hand, Spain relied heavily on foreign sources to obtain new product and process technologies. The domestic generation of technology has been the

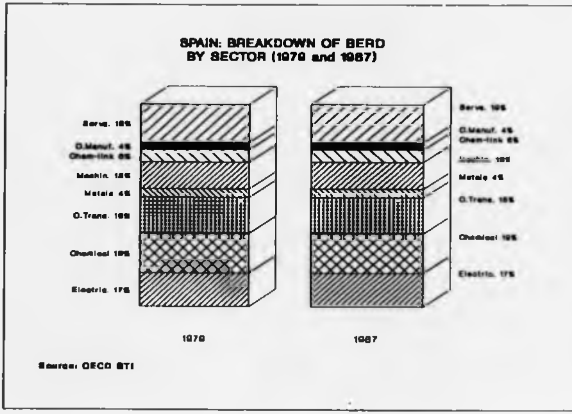
---

17 See OECD STI (1986), R&D, Invention and Competitiveness, Paris, page 71.

18 This has been studied recently in some depth by C. Martin (1990)

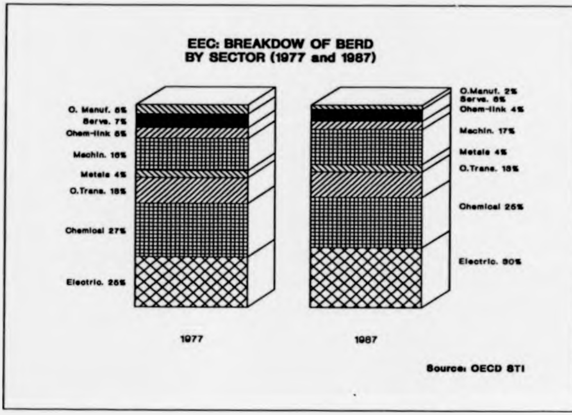
exception and not the rule. In the sixties, this had substantial implications for the balance of payments: any increase in internal or/and foreign demand was followed by an upsurge in the imports of capital goods.

Figure I.1.



More recently, the implications of this technological dependence have adopted the form of slow diffusion of new information technologies and high presence of MNCs. Spanish expenditure on R&D has been traditionally one of the lowest in the OECD area, quite often below that of countries such as Turkey or Ireland. Despite showing two digit growth rates in the eighties, the Spanish gross expenditure on R&D was just 0.72 % of the Spanish GDP in 1989. In industrialised countries like France, Germany, the U.K., Japan and the USA, that percentage has been consistently well above 2%. The number of R&D personnel per thousand labour force in Spain compares to the Portuguese level (2.3 in Portugal and 2.8 in Spain in 1986), and is well below the Irish and Italian levels, 4.8 and 5% respectively. Such a poor record of technological effort as measured in terms of inputs into the R&D process, has its reflection in terms of technological output. During the eighties, domestic patent applications have remained practically unchanged, while the number of patent applications from foreign sources has multiplied by a factor of three.

Figure I.2.



But these differences between the technological patterns of Spain and its two main frameworks of reference, OECD and EEC countries, are not limited to the quantitative measures of technological efforts. Spain shows remarkable differences from those countries in qualitative terms too. The sectoral breakdown of the business enterprise R&D expenditure can give a good insight of the special characteristics of the Spanish R&D effort. Between 1979 and 1987, the sectoral structure of private expenditure in R&D changed considerably. Figure I.1. shows how R&D in services increased remarkably as it also did in the transport and the machinery sectors. The importance of the service sector is linked to the high weight given to the National Telephone Company and the electrical oligopoly which are included in the definition of this sector. These companies increased significantly their R&D expenditure in the eighties. Also included in this sector are engineering services that experienced a high increment in R&D spending towards the end of the period. Particularly remarkable too is the case of transport, which accounted for 28% of total business R&D expenditure in 1985. The "motor vehicles" subgroup, where almost all the firms are MNCs, was responsible for most of that increase. On the other hand, the electrical and chemical related groups lost considerable ground. The increment in the machinery group takes places simultaneously in non-electrical machinery and in office automation and data processing.

Figures I.1. and I.2. compare this sectoral breakdown in Spain with that of the main framework of reference for Spanish industry, the European Community. The differences are quite remarkable. First of all, the panorama for Europe is almost totally stable, with minimal variations over the period considered, while in Spain, R&D expenditure in certain subgroups shows ups and downs. Secondly, the European R&D expenditure is much more concentrated in manufacturing as opposed to services, about 95%, and reaches maximum values in the electrical and chemical subgroups. It is precisely there that the maximum increments take place. Finally, unlike what happens in the Spanish case, in Europe as a whole, the transport sector maintains its relative importance over time.

If we compare the technological intensity[19] of different manufacturing sectors in Spain with the average of the OECD, we can confirm the low-tech profile of the Spanish economy. In the high technology sectors, only in aerospace does Spain show a similar technological intensity to that of its OECD partners. In all the other high-tech sectors, Spain has a much lower technological intensity. We have to go down to some low technology sectors such as ferrous metals and fabricated metals to find similar R&D intensities in Spain and in the OECD. It is worthwhile mentioning that the technological

---

19 Measured as the percentage of BERD over total output in that sector.

intensity of some low technology sectors such as other transport and shipbuilding have higher intensities than medium-tech sectors.

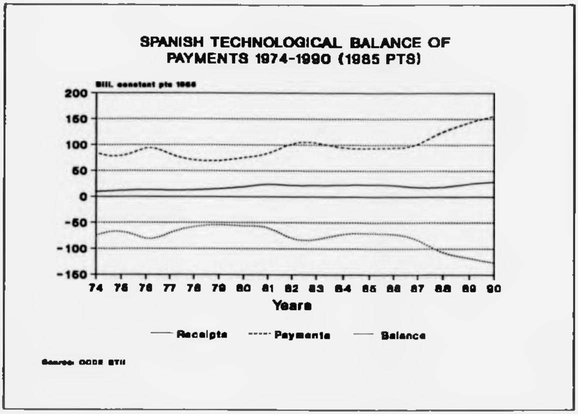
Table I.1.

TECHNOLOGICAL INTENSITY IN HIGH, MEDIUM AND LOW-TECH SECTOR SPAIN AND AVERAGE OECD

	SPAIN 1986					OECD . 11 Members
	BERD (Mill.Pts)	OUTPUT (Bill.Pts)	V.A. (Bill.Pts)	Technol. Intensity	Technol. Effort	Technol. Intensity
HIGH						
Aerospace	10765	41	25	26.3	43.1	22.7
Computers	5696	103	28	5.5	20.3	17.5
Electronics	9296	262	108	3.5	8.6	10.4
Pharmaceuticals	8636	344	142	2.5	6.1	8.7
Instruments	618.1	45	23	1.4	2.7	4.8
Electrical Machinery	6610	611	263	1.1	2.5	4.4
MEDIUM						
Motor vehicles	12884	1674	467	0.8	2.8	2.7
Chemicals	9762	1594	553	0.6	1.8	2.3
Other manufacturing	280.7	128	55	0.2	0.5	1.8
Non-electrical Mach.	5731	837	394	0.7	1.5	1.6
Rubber and plastics	3724	675	264	0.6	1.4	1.2
Non-ferrous metals	418.4	372	100	0.1	0.4	1
LOW						
Other transport	1230	94	40	1.3	3.1	–
Stone, clay & glass	2213	858	413	0.3	0.5	0.9
Food beve.& Tobacco	3828	4223	1171	0.1	0.3	0.8
Shipbuilding	678.2	136	47	0.5	1.4	0.6
Petroleum Refining	1901	1109	396	0.2	0.5	0.6
Ferrous metals	2187	1017	315	0.2	0.7	0.6
Fabricated metals	2867	827	359	0.3	0.8	0.4
Paper, printing	694.6	996	429	0.1	0.2	0.3
Wood & furniture	97.7	568	241	0.0	0.0	0.3
Textiles & footwear	440.7	1488	570	0.0	0.1	0.2
Total Manufacturing	90558	18002	6405	0.5	1.4	

Source: OECD, DTSI and **Industrial Structure Statistics**, Paris 1987.

Figure I.3.



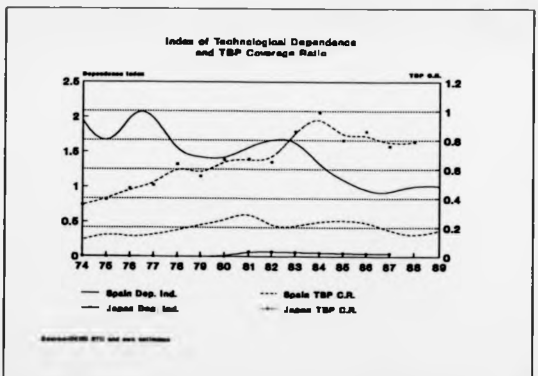
Even in medium-tech sectors, where Spain has a comparative advantage similar to the average of the OECD countries, Spain lags behind in technological effort. This is a first indication that the Spanish comparative advantage in those sectors is based on imported technology. As a matter of fact, this is the most remarkable feature of the Spanish technological profile.

Over time, the Spanish technological balance of payments (TBP) has been deteriorating constantly. The Spanish TBP deficit has been multiplied by a factor of four in the last fifteen years (see figure I.3.). The two main indicators of foreign technological dependence, the ratio of technology payments over national BERD and the TBP coverage ratio are shown in figure I.4.. The technological dependence index shows a declining trend during the period under consideration, and in particular in the last seven years. On the contrary, the TBP coverage ratio remains practically unchanged over the whole period. As technological receipts have not increased significantly in the period considered, this pattern seems to indicate that the increase in BERD has been, to a certain extent, complementary to the importation of foreign technology.

Figure I.4. also shows the same technological dependence indexes for the Japanese case. It is interesting to see how Spain and Japan show very different patterns. The Japanese index of technological dependence has been close to zero in the seventies and it has started to increase only in the eighties but keeping very low values. On the contrary, the Japanese TBP coverage ratio shows a consistent upward trend between 1974 and 1988.

Studies of the Spanish acquisition of foreign technologies have provided some interesting qualitative information. The most interesting observations are the following:

Figure I.4.



a.- USA, Germany and, to a lesser extent France, obtained most the patents granted in Spain to foreign firms. Japan accounted for a minimum in the number of patents granted in Spain to foreign firms.[20]

b.- If we split the technological payments into payments for technological assistance and for licenses, we can see that the former have increased their importance at the expense of the later. In the eighties, technological assistance accounted for approximately 80% of the payments and the other 20% went to patents. In 1974 those percentages were 42% and 58% respectively.[21]

c.- Approximately 60 firms accounted for more than 70% of the technology payments in the early eighties. In 1990, the first 60 firms still accounted for 62,34 % of the total of technology payments.[22]

d.- Technology payments are highly concentrated by sectors. In 1984, 22,4% of the payments corresponded to motor vehicles. That same year, five sectors accumulated more than 55% of the payments.[23]

e.- Most of the contractual agreements of technology transfer include a combination of bundled services such as licensing of patent or trade mark, technical assistance, know-how transfer, etc.[24]

---

20 See Martín C. and Rodríguez L. (1985) page 71

21 See Martín C. and Rodríguez L. (1985) page 86.

22 See Sanchez P. (1984). This percentage has declined consistently in the eighties. See Puech (1991).

23 See Martín C. and Rodríguez L. (1985) page 98

24 Martín C. and Rodríguez L. (1984) page 41.

f.- Licensing contracts include a fixed fee, in many cases complemented by a royalty fee.

g.- Most of the Spanish companies acquiring foreign technology are directly or indirectly linked with the foreign firm supplying the technology.

h.- Almost all the companies acquiring technology from abroad (>91%) carry out complementary R&D activities in Spain.

Although it is not possible to complement this vision of technological dependence with information on other ways of acquiring foreign technology, -i.e. foreign direct investment of MNCs and the import of capital goods with incorporated technological change[25]- this condensed technological profile of the Spanish economy suggests the following stylized facts which will underlie the modeling throughout this thesis:

1.- Latecomer industrialisation requires foreign sourcing of technology, which will need complementary R&D. These are not mutually exclusive activities.

2.- Latecomer industrialisation is based on the exploitation of comparative advantages of the developing country, which usually competes in world markets through price competition on more or less standardised products.

3.- Licensing of foreign technology, imports of capital goods with embodied technological change and diffusion of new technologies are usually parts of the same process.

25 All evidence seems to point out that these activities are often carried out as complements and not as substitutes of contractual forms of technology transfer. Consequently, the total picture should not differ substantially from the partial one presented here.

4.- Licensing of foreign technology very often involves other forms of contractual transfer of technology.

5.- Licensing contracts usually combine different forms of payments, but they almost always involve the payment of a fixed fee.

I.2.3. Plan of the thesis.

The thesis is divided into four distinctive parts. The introductory part, chapters I and II, are dedicated to the presentation of the objectives and motivation for the thesis, the discussion of some methodological issues and to the justification and discussion of the realism of the assumptions that will be maintained throughout most of the following chapters. Some empirical evidence from previous studies on issues such as the international differences in the prices of factors of production and cost structures is also included, thus going beyond the Spanish case that has been at the centre of the discussion in this chapter.

The second part of the thesis is dedicated to the study of two major issues concerning the licensing of innovations in an international context. Chapter III examines the impacts of differences across countries in both production costs and in R&D costs on the possibility of *ex-ante* licensing. In that chapter, some conclusions about the potential consequences of these differences for the rate and direction of technological progress are drawn.

Chapter IV addresses several questions about the social welfare implications of international licensing in an oligopolistic context. It is shown that under certain conditions, the number of licenses sold and the price paid for each one of them will be above their socially desirable levels for those variables.

The third part includes chapters V, VI, VII and VIII and deals with the second major topic of the dissertation: the relative incentives for the introduction of a process innovation in countries with asymmetric cost structures. Chapter V inquires into the problem of the inter-relationships between technological change and market structure. Taking a simplified version of a model developed by Vickers (1986) as a benchmark, we study different alternative set ups to inquire into the possibility of generalising his conclusions. We also analyse what is the influence of the game structure used in these kinds of models on their conclusions.

Chapter VI presents a simple game theoretic structure for studying the relative incentives that firms which face different production costs will have to adopt new process technologies. This analysis is carried out under Bertrand and Cournot-Nash conjectures, which allows us to consider the problem of the influence of oligopolistic conditions in the downstream markets upon the diffusion process. In this chapter two additional extensions are included: the impact of the supplier's behaviour on the pattern of diffusion and the impact of international trade and policy on the incentives to adopt new technology.

In chapter VII a traditional model of international trade is used to prove that, even in that context, the existence of induced effects influencing the direction of technological change can transform free trade into a sub-optimal strategy from the point of view of dynamic efficiency.

As an appendix to the third part of the thesis, chapter VIII considers very briefly the possibility of collusive behaviour between the supplier of a cost-reducing technology and one of the two potential adopters of that technology. We consider how the collusive behaviour of supplier and user of the technology can delay adoption by the second potential adopter (and is the only chapter in the thesis in which 'time' is the strategic variable).

Finally, chapter IX puts together the main conclusions developed in the thesis with some other results already available in the literature tying them up with the policy problems presented in the introductory part of the thesis. Here, particular attention is paid to the differences between social and private incentives to carry out R&D domestically and to license foreign technology. This problem is considered in the context of international oligopolistic competition, which introduces new elements for the design of technology policy that cannot be considered in the analysis of the closed-economy case.

Spain Main R&D indicators from OECD S&TII Data-Base

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1. GERD Pts	48668	61110	67938	89724	100697	118923	148030	189559	221155	265030	320080
2. GERD PPP $	713.6	856.6	930.9	1150.1	1195.5	1318.3	1552.7	1837.4	2083.4	2437.2	2863.8
3. GERD Annual Growth	4.9	10	-0.7	16.1	0.5	6.5	14.7	15.4	10.1	13.4	12.7
4. GERD/GDP	0.37	0.4	0.4	0.46	0.45	0.47	0.53	0.59	0.62	0.67	0.72
5. % GERD Finan.Public	50.1	48.6	52.9	49.5	49.6	47.3	45.2	46	48.5	..	..
6. % GERD Finan.Private	47.5	50	45.9	49.1	49.1	51.9	49.6	51.4	48.8	..	..
7. Total R&D Personnel	30164	30905	31329	30509	30946	34080	34966	40212	42913	..	..
8. R&D Person.Rate Growth	4.7	2.5	1.4	-2.6	1.4	10.1	2.6	15	6.7	..	..
9. R&D Pers./1000 L.F.	2.2	2.3	2.3	2.2	2.2	2.5	2.5	2.8	2.9	..	..
10.Total researchers	13457	13732	14376	13761	14227	15299	16215	19476	20890	..	..
11.Total RSE aver.an.growth	9.6	2	4.7	-4.3	3.4	7.5	6	20.1	7.3	..	..
12.Total RSE as perc. L.F.	1	1	2.3	2.2	2.2	2.5	2.5	2.8	2.9	..	..
13.BERD R&D (mill.nat.curr.)	24307	32129	33121	46862	52143	65411	85795	110338	126707	153880	188660
14.BERD(mill. current PPP $)	356.4	450.4	453.8	600.7	619.1	725.1	899.9	1069.5	1193.7	1415.1	1688
15.BERD(an. grow.fix.prices)	-0.7	15.8	-7.9	24.3	-0.3	13.1	20.8	15.9	8.4	14.9	14.4
16.BERD as % GERD	49.9	52.6	48.75	52.23	51.78	55.00	57.96	58.21	57.29	58.06	58.94
17.BERD as % DPI	..	0.24	0.22	0.27	0.27	0.3	0.35	0.39	0.41	0.45	..
18. % BERD financ. by ind.	94.9	94.8	93.6	93	94	92.1	83.4	86	83.6	..	..
19.Ind-fin.BERD(A.A.G.fixP.)	-0.6	15.7	-9.1	23.5	0.8	10.8	9.4	19.5	5.4	..	..
20.Ind-fin.BERD as %DPI	..	0.23	0.21	0.26	0.25	0.28	0.3	0.34	0.34	..	..
21.% BERD fin.by Govr'nt	2.8	2.9	4.1	4.8	4	6.5	7.7	11	13.8	..	..
22.Total ind.R&D pers.(FTE)	11911	12303	12006	12914	12904	15022	16859	19007	20361	..	..
23.T.Ind. R&D pers.(A.A.G)	-5.6	3.3	-2.4	7.6	-0.1	16.4	12.2	12.7	7.1	..	..
24.Business Enterp. RSE	2950	2994	3226	3409	3526	4019	4853	6160	6835	..	..
25.Business Enterp. RSE(AAG)	-0.6	1.5	7.7	5.7	3.4	14	20.8	26.9	11	..	..
26.Hi-Ed.exp.R&D HERD(nat.cur)	8211	9660	11833	15244	17805	20755	24676	28660	34313	42431	50937
27.HERD (mill.current PPP $)	120.4	135.4	162.1	195.4	211.4	230.1	258.8	277.8	323.3	390.2	455.7
28.HERD (AAG fixed prices)	8.5	3	9.4	13.2	4.6	5.1	9.5	4.7	13	17	12

29.HERD as % of GERD	16.9	15.8	17.42	16.99	17.68	17.45	16.67	15.12	15.52	16.01	15.91	
30.HERD as % of GDP	0.06	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.1	0.11	0.11	
31.Hi-Ed. total R&D pers (FTE)	..	..	..	..	..	..	..	..	..	..	..	
32.Hi-Ed.total R&D pers(FTE)AAG	..	..	..	..	..	..	..	..	..	..	..	
33.Hi-ed. RSE (FTE)	7138	7202	7518	7001	7830	8363	8746	9256	9527	..	..	
34.Hi-ed. RSE AAG	25.6	0.9	4.4	-6.9	11.8	6.8	4.6	5.8	2.9	..	..	
35.Hi-ed. RSE as % of nat.Total	53	52.4	52.3	50.9	55	54.7	53.9	47.5	45.6	..	..	
36.Govr'nt perform.as % of GERD	33.2	31.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
37.Gvr't budg.R&D appr.(n.cur.)	..	..	47816	54773	60040	73624	88827	100313	129864	163206	221154	
38.Gvr't budg.R&D appr.as %GDP	..	..	67938	89724	100697	118923	148030	189559	221155	265030	320080	
39.Defense R&D % G't R&D appr.	..	..	4.9	6.4	6.4	6.6	7.1	5.8	8.9	12.6	19.1	
40.G't budg.civ.R&D appr.as%GDP	..	..	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
41.Nat. Patent Applications	10859	10877	10227	10201	9850	10700	11298	14361	23390	26251	..	..
42.Domestic patent applications	1893	1876	1718	1646	1498	1784	2149	1652	1741	1841	..	..
43.Foreign Patent applications	8966	9001	8509	8555	8352	8916	9149	12709	21649	24410	..	..
44.External patent applications	1746	1599	1848	1477	1540	2056	1785	2135	2263	2722	..	..
45.Tech.Bal.of payts.Recpts Pts	7642	10873	16698	15707	18265	20781	23378	24994	20419	21231	34194	
46.Tech.Bal.of payts.Paynts.Pts	34704	44393	52382	78984	88338	84742	93814	103816	113128	160745	190446	
47.Tech.Bal.of payts.Balnc.Pts	-27062	-33520	-35684	-63277	-70073	-63961	-70436	-78822	-92709	-139514	-156252	
48.Tech.Bal.of payts. Coverage	0.22	0.24	0.32	0.2	0.21	0.25	0.25	0.24	0.18	0.13	0.18	
49.Exp/Imp ratio aircrafts	0.23	0.25	0.22	0.53	0.7	0.8	0.6	0.56	0.7	..	..	
50.Exp/Imp rat.Offic.m.& Compt.	0.27	0.33	0.46	0.42	0.2	0.4	0.47	0.42	0.38	..	..	
51.Exp/Imp rat.Com.Eq.& electr.	0.29	0.28	0.25	0.27	0.24	0.23	0.27	0.21	0.15	..	..	
52.Exp/Imp rat.Elect.Trans.Eq.	0.54	0.47	0.49	0.45	0.47	0.52	0.51	0.43	0.34	..	..	
53.Exp/Imp rat. Scien. Inst.	0.15	0.15	0.17	0.17	0.19	0.2	0.23	0.19	0.17	..	..	
54.Exp/Imp. ratio Drugs	0.6	0.79	0.79	0.68	0.8	0.89	0.99	0.89	0.91	..	..	

Balassa, B. (1977) "A Stages Approach to Comparative Advantage", **World Bank Staff Working Paper,** n.256, Washington D.C., The World Bank.

Caballero F. (1991) "España, Europa y las Nuevas Tecnologías", **Palau 14**, (forthcoming).

Ernst D. and O'Connor D. (1989), **Technology and Global Competition: The Challenge for Newly Industrialising Economies**, OECD, Paris.

Ernst D. and O'Connor D. (1991) **Competing in Advanced Electronics. The Challenge for Newly Industrialising Economies**. OECD Development Centre, Paris.

European Commission, "Economic Convergence in the Community", **European Economy,** no.46, December 1990. pp 139-160.

Fagerberg J. (1988) "International Competitiveness", **Economic Journal,** June.

Freeman C. (1982) **The Economics of Industrial Innovation,** 2nd edition, Frances Pinter, London.

Jorde, T.M. and Teece D.J. "Innovation and Cooperation: Implications for Competition and Antitrust", **Journal of Economic Perspectives**, vol. 4 n.3, Summer, pp. 75-96.

Krugman, P. (1979) "A Model of Innovation, Technology Transfer and the World Distribution of Income", **Journal of Political Economy,** 87, vol. 87, n. 2, April, pp. 253-66.

Lundvall B.A. (1988) "Innovation as an Interactive Process. From User-Producer Interaction to the National System of Innovation" in Dosi et al. (eds), **Technical Change and Economic Theory**, Frances Pinter, London.

Martín González, C. and Rodríguez Romero, L. "**La Transferencia Contractual de Tecnología en la Economía Española**", Programa de Investigaciones Económicas, Fundación Empresa Pública, Documento de Trabajo 8401.

Mowery D.C. (1989) "Collaborative Ventures Between US and Foreign Manufacturing Firms", **Research Policy**, vol. 18, pp. 19-32.

OECD STI (1986), R&D, **Invention and Competitiveness**, Paris.

OECD (1990a) Technology/Economy Programme (TEP) Background Report, Chapter 9, **Technology and the Process of Internationalisation-Globalisation**, first draft.

Puech, R. (1991) "La Balanza de Pagos Tecnológica en 1990", **ICE Boletín Económico**, Mayo 6-12, pp. 1443-52.

Sánchez P. (1984) **La Dependencia Tecnológica Española. Contratos de Transferencia de Tecnología entre España y el Exterior**, Ministerio de Economía y Hacienda, Madrid 1984.

Schott J.J. (1990) **The Global Trade Negotiations: what can be achieved**, Institute for International Economics, September,

Stiglitz J. (1987) "Learning to Learn, Localised Learning and Technological Progress" in Dasgupta P. and Stoneman P. (eds) **Economic Policy and Technological Performance**, Cambridge University Press, Cambridge.

Stoneman, P. (1987) **The Economic Analysis of Technology Policy**, Oxford University Press.

The Economist (1990) "The Point of Patents", September, 15, p. 17.

Teece, D.J. (1986) "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy", **Research Policy**, vol. 15, pp. 285-305.

Vickers J. (1986) "The Evolution of Market Structure when There is a Sequence of Innovations", **Journal of Industrial Economics**, 35, September, pp.1-12.

Chapter II: Assumptions and Methodological Considerations

II.1. Introduction

Throughout this thesis, a series of basic assumptions have been maintained because, in my opinion, they reflect well some fundamental characteristics defining the economic environment surrounding R&D and diffusion phenomena in latecomer industrialisation. In this chapter, the suitability of these assumptions to the kind of situation described in the previous chapter is discussed in some depth. The degree of realism of these assumptions is also assessed. The two major assumptions can be stated as follows:

1.- there are differences in cost conditions across economies, particularly in economies with different degrees of technological development, and

2.- there is a common global market represented by a "world" demand function.

Differences in the abilities of countries to carry out R&D or to adopt new technologies will both be considered as part of the different cost conditions. Although this assumption will not be discussed in depth here, it is based on the personal conviction that production and innovation decisions within the firm can be separated only for analytical purposes. In the real world, the boundaries between both types of activities is becoming increasingly blurred, and the traditional "blueprint shops" of our old textbooks, in which firms look for the best technology available at any point in time, are no longer in business.

But apart from these two main assumptions, many other decisions had to be taken to define the limits and the framework of reference of this thesis. The first one concerned the methodological approach to be taken. Except in one case, all the models included here are a sequence of relatively simple game theoretic situations. The suitability of this approach does not need justification, for it is the predominant approach in the literature on industrial organisation and theoretic models of technological change[26]. The simplicity of the models presented below finds its justification in the fairly complicated situations that are tackled here. The use of linear demand and cost functions is a direct consequence of the assumption of asymmetric cost conditions, which are tractable, without excessive complexities, only in examples like those used in the following chapters.

Games involving technology have not been modelled here as timing games. Timing games are certainly more suitable for patent races than for the type of problems that arise in the context of technology policy in latecomer industrialisation. These problems are of a more structural nature, and variables such as the evolution of market structure, the influence of the trade regime on the speed of diffusion or the number of licensees acquiring a new technology, do not necessarily call for the explicit consideration of time.

Besides these general methodological considerations and a discussion on the main two assumptions of the thesis, the last section of this chapter includes a discussion and a definition of the boundaries of the thesis.

II.1. Assumption 1: Differences in production costs.-

Despite the often alleged disappearance of the "nation state" and its replacement by the "globalisation" of economic activity, there is clear evidence that national borders still matter as determinants of the conditions under which production is carried out. In the

---

26 See for instance Reinganum (1989)

models included in this thesis, it is assumed that 'conditions of production' are the main element differentiating one country from the rest. Even in today's highly internationalized world, production conditions differ widely from one country to another and the present trends seem to indicate that the likelihood of narrowing those gaps is low.

These differences in 'conditions of production' include the following components:

a.- Differences between countries as regards production technologies effectively used by firms located in each one of them. Countries do not have access to the **same technologies** under the **same conditions**. Firstly, countries do not have the same technologies available to them because technological knowledge is not a free good. As a commodity, technological knowledge is expensive to obtain and difficult to trade. Property rights over technological knowledge or simple secrecy limit access to technology. But even if all countries could have free access to technological knowledge, the ability to use it would remain different from country to country. Using new technologies often requires the joint utilization of skills, which are not evenly distributed across countries, because there are substantial differences in the stock of technological knowledge that they have accumulated over time.[27]

b.- Countries also differ in their availability of natural resources and in their endowments of primary factors of production. Factors of production do not have the same degree of mobility and this is reflected in production conditions in each country. The availability of natural resources that can only be exploited on the spot are the most obvious and traditional example of this.

---

27 See Teece (1981) for an excellent explanation of these differences.

c.- Countries also differ in their supply of man-made elements such as transportation infrastructure, communications, public services, human capital, etc. which by their own nature, are country specific. Most of these elements have many of the characteristics of a public good, whose benefits can be enjoyed only in certain places. These elements cannot be traded because they are not mobile at the international level. For this reason, they are crucial as determinants of the economic environment of countries. They may be the result of specific public policy measures, but they can also result from the accumulation over long periods of time of certain patterns of economic activities or behaviour. In a recent study, Aschauer (1989) has measured their impact on country productivity. The results of this study urge higher awareness of the importance of these elements as determinants of the 'competitiveness' of countries.[28]

d.- Public policy interventions in products and factor markets, particularly in the labour markets, introduce all sorts of distortions in prices. These price distortions introduce factor price differentials not just across countries, but also across industries within the same country.[29] Macroeconomic policy measures also modify substantially the economic environment for agents as we will see further below. But industrial regulations and policies also introduce distortions in the local prices of inputs and outputs.

The main consequence that derives from these differences in the economic environment of countries is the existence of substantial cost differences between firms operating in different countries. As it was pointed out above, differences exist even when

---

28 See Aschauer (1989).

29 For an exposition of the traditional literature dealing on this subject see for instance Chacholiades (1978) chapter 20.

countries have similar conditions of access to the same technologies. Different conditions of production imply the following asymmetries across countries:

a.- Producers have to pay **different prices for the factors of production** that they buy in different countries. Be it because it is not possible to find in the real world the conditions that are theoretically required for factor price equalisation, or be it because remaining obstacles to trade and/or factor mobility do not allow it, the truth of the matter is that factor prices differ widely across countries. As we will see below, empirical evidence shows that substantial factor price differentials remain even between industrialized countries with similar technological capabilities.

b.- Given different factor-price vectors, firms make **different choices of production techniques**, even when they face the same production possibility set. As a result, the input mix is expected to differ according to the location of productive facilities. Therefore, we can expect that the cost structure of similar companies producing the same goods will be different across countries. For this reason, the adoption of the same new process technology can be expected to produce:

i) different new costs of production for a given output level, as firms face different input prices.

ii) different cost reductions in relative terms, as the initial and final cost levels are different.

c.- Differences in the 'conditions of production' will also have an impact on the incentives that firms located in **different countries will have to develop new process technologies**, that reduce the utilization of those inputs which are relatively more expensive in their respective countries. Despite having a long history[30] in economic theory, induced innovation seems today relegated to a secondary position in the literature on technological change. The incentives to innovate are proportional to the payoffs that firms can derive from innovation, but the latter are not independent of the **direction of technological change.** This is particularly so when one considers the influence of previous sequences of technological advances on today's decisions: the cumulative effect of a series of innovations can determine what will be the next one.

Although the issue of induced investment is only specifically included in chapter VIII, the question of different countries' preferences over possible alternative R&D projects will be a constant theme throughout this thesis.

d.- Finally, different factor prices also influence the **R&D process.** The generation of new technologies should also be considered as a production process itself, although not independent from other production activities within the firm. As such, all the international differences mentioned in the previous paragraphs also affect the R&D process. This results in different production costs of new technologies for firms located in different countries. The requirement of very specific factors of production for this special production process, makes differences in countries' capabilities to produce new technologies particularly large.

The activities of multinational corporations could be viewed as a way of reducing those differences. However, authors like Freeman or Lundval agree in pointing out that the special inputs needed for the R&D process are country

30 Binswanger and Ruttan (1978) is an excellent milestone in the literature on this subject which has not had many high quality follow ups. It is worthwhile noting here that the famous 1962 NBER 1st conference on technological change was titled "The Rate and Direction of Innovative Activity". Much of the work that followed that conference was centred on the "Rate" of technological change, and very little attention has been paid to its direction. More recently, economic historians such as Paul David and Brian Arthur have stressed this point in their study of the choices between alternative technologies.

specific instead of firm specific. They refer to the existence of 'national systems of innovations' as complex mechanisms involving all sorts of historical, institutional, social and educational variables, which are inherent to nations and are the ultimate determinants of their technological performance. Pavitt and Patel (1990) have recently provided some empirical evidence on this subject.

The discussion of these theoretic questions is beyond the objectives of this chapter. As it is usually done in many other similar models, it will be assumed here that the cost of developing new technologies is different across countries, because both primary inputs as well as specific inputs for the R&D process have different prices and are available in different degrees from one country to another. Nevertheless, I would like to stress here that very little is known about the micro-micro aspects of the R&D process. Important questions such as how do differences in the cost of capital for R&D purposes influence the behaviour of firms or the internal organization of the R&D departments, deserve much more attention in the future. In this regard, our black box is still quite dark. However, as we will see in several chapters below, the configuration of the R&D production process and the strategic behaviour of suppliers of new technology plays a central role, not just in patent races but also in the diffusion and licensing on innovations. For that reason, it is difficult to assess the acceptability of the assumptions that will be made in the following chapters about some supply-side aspects of these processes.

All the elements listed above have been taken into account in the design of the models presented in the thesis. In the early stages of this thesis, they were adopted to a certain extent as axioms which seemed reasonable and acceptable in view of the discussions of these issues existing in the literature reviewed at that time. Fortunately, recent research work has provided some supporting empirical evidence. The degree of realism of the first one of the two basic assumptions, i.e. the existence of differences in factor prices and in cost structures across countries, can therefore be assessed.

II.2.1. Differences in factor prices.

According to traditional trade theory, free trade should guarantee, in the absence of significant transportation costs, factor price equalization among trade partners. However, a quick look at modern trade theories indicates quite clearly that factor price equalization is one of the first "well established results" of traditional trade theory that crumbles when international markets are not perfectly competitive as the Hecksher-Ohlin-Samuelson model predicted.

For instance, when production takes place under increasing returns to scale, preferences are equal, and two countries have the same factor structure, the existence of differences in the size of the country will imply different market shares for producers in each country. In the trading equilibrium, they cannot have the same market shares, for in that case the marginal revenue for producers would be the same due to the existence of the same factor prices in both countries. But if factor prices were the same, they would produce the same quantities of goods in full employment. Therefore, factor price equalisation is not possible in this case.[31]

From a theoretical point of view, there are reasons to believe that, even when spatial costs are not important, factors are mobile and "nationalism has not reared its ugly head" as Samuelson put it, market imperfections and failures will preclude the existence of just "one real wage and one real rent". But let us look at the empirical evidence.

---

31 In their excellent textbook, Dixit and Norman (1979) show the difficulties for factor price equalisation.

In the context of the recent debate about the loss of competitiveness of American industry, the issue of differences in the real cost of capital for the American economy vis-a-vis countries such as Japan or Germany, has been raised as one of the major factors hindering the maintenance of the US industry's hegemonic position. The recent report of the MIT on US Productivity and Competitiveness has highlighted the importance of this burden for the US economy. Also in a world in which maintaining technological leadership is of crucial importance, international differences in the cost of capital for R&D investments are bound to be of upmost importance for global competition.

II.2.1.1.- The cost of capital

Recent empirical work by Ando and Auerbach (1988) and particularly McCauley and Zimmer (1989) at the Federal Reserve Bank of New York, have shown different degrees of divergence in international comparisons of the cost of capital for investment projects. These studies calculate the cost of capital using different methodological approaches. In the case of the very influential study by McCauley and Zimmer (1989), the cost of capital for corporations is defined as the 'minimum before-tax real rate of return that an investment project must generate in order to pay its financing costs after meeting its tax liabilities'. Therefore, these studies take into account not just differences in real interest rates across countries, but also variables such as debt/equity ratios, leverage ratios, tax structures and fiscal incentives and a long list of other institutional and regulatory elements defining the financial environment of firms operating in the countries under consideration. In McCauley and Zimmer (1989)[32], the following variables enter into the definition:

---

32 This particular paper has been criticized by Marsh P. (1990) on the grounds that it measures the cost of equity as the inverse of the price-earnings ratio, hence ignoring the effect of future growth opportunities that seem to have played an important factor in the Japanese case in particular. Measuring this and other components of the cost of use of capital presents many methodological difficulties that have been sorted out in different ways. For an in-depth discussion about these differences in methodology see Poterba (1991). However, we shall retain McCauley and Zimmer's results as Poterba's survey shows these results are not far away from those obtained in

- Nominal interest rates
- Inflation rates,
- Financing ratio: Debt/Equity,
- Investment tax credits,
- Tax reductions on corporate interest payments,

TABLE II.1.

EXAMPLES OF ESTIMATED COST OF CAPITAL FOR VARIOUS PROJECTS

Equipment and machinery with physical life of 20 years

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
USA	11.2	11.7	11.2	11.5	13.5	11.5	10.6	11.3	11.1	9.1	10.2	11.2
Japan	5.9	6.9	7.6	8.8	8.8	8.5	8.8	8.4	8.3	7.8	7	7.2
Germany	7.7	7.3	7.5	8.6	8.8	7.8	7	7.2	7.1	6.9	7	7
UK	8.8	10.8	9.8	12.7	10.3	10.7	10.8	9.3	9.4	7.8	8.2	9.2

Factory with physical life of 40 years

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
USA	10	10.4	8.9	9.3	10.1	12.4	10.8	12.8	12.6	9.3	9	10.2
Japan	2.8	4.2	5.1	6.2	6.8	6.6	7	6.3	6.1	5.8	4.8	5
Germany	5.5	5.5	5.6	7	7.4	6.3	5.4	5.7	5.5	5.2	5.4	5.4
UK	6.7	9.9	7.8	12.2	7.7	8.7	8.8	7.6	8.3	6.1	6.6	7.9

R&D Project with 10 yrs payoff lag

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
USA	12.5	12.9	11.9	12.4	8.3	18.4	15.2	20.3	20.2	14.8	18.2	20.3
Japan	3.9	5.7	6.5	7.3	8	8.3	8.7	7.7	9.2	9.4	8.4	8.7
Germany	13.4	13.8	13.3	15.6	15.7	14.7	13.9	14.6	13.9	14.6	13.9	13.2
UK	18.2	28.4	21.1	33.4	24.2	29.5	29.2	24.4	25.4	18.9	20.6	23.7

Expensed item with physical life of 3 years

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
USA	39.5	40.6	42.4	43.3	38.5	40.5	39.3	39.6	39.1	36.7	39.4	40.4
Japan	35	35.1	35.4	36.4	36.1	36	36	35.7	35.6	35.3	34.8	34.9
Germany	34.7	34.7	34.7	35.4	35.4	35.1	34.7	34.8	34.8	34.6	34.7	34.8
UK	39.4	40.6	41.4	42.5	40.5	40	39.6	38.4	37.7	36.1	37	37.4

Source: McCauley and Zimmer (1989)

---

other studies, and furthermore, this study shows a variety of examples included in table II.1 that is not easy to find in other studies.

- Depreciation allowances,
- Differential growth rates,
- Employee retirement payments, and
- Propensities of firms to hold liquid assets.

The results of this study for several types of projects are presented in table II.1.. In the case of capital goods (machines with 20 years of physical life), the price of capital in the USA was approximately double that in Germany in the period under consideration. Furthermore, the two European countries do not show a common pattern, with the UK approaching the cost in the US, while Japan and Germany have quite similar profiles.

It is interesting to notice how the differences between countries are magnified by the cost structure of the research projects. The low cost of funds gives a greater advantage to Japanese and German firms in long term projects.[33] Therefore, one can expect that investment patterns will be highly sensitive to differences in the cost of capital.

Particularly important for technology policy are the results in McCauley and Zimmer (1989) concerning R&D investment. R&D decisions are essentially investment decisions. This study shows that for a 10 year pay-off lag R&D project, the required rates of return vary widely in the four countries studied. For instance, in 1980 this rate was estimated as 7.3% for Japan and 33.4% in the UK: a difference of over 26 points! Given the strong penalties for long R&D projects in those countries where the cost of funds is high, we can expect that among countries, their preferences for different R&D projects will vary according to the payoff lags of those projects. As for the reasons explaining these important differences in the cost of financing R&D projects, tax credits for R&D activities, that can reach rates as high as 20% of the total investment in Japan, must be added to the general reasons listed below.

---

33 This point was highlighted by the MIT Commission on industrial productivity in their final report

Among the causes pointed out by McCauley and Zimmer that account for these differences in the costs of capital we find the following:

a) Macroeconomic stability, which makes savers in Japan and Germany willing to accept lower returns to their investments due to the lower risk attached to those investments. This allows creditors to rely more heavily on short-term loans that can be renewed regularly, which results in lower costs of capital as compared to the cost resulting from long-term fixed-interest loans.

b) Factors affecting personal savings. Savings ratios are higher in Japan and Germany than in the US and the UK. Furthermore, Japanese and German savers get lower payments on their savings.

c) Relations between corporations banks and governments. This is a less obvious cause, although it might be not less important than any other. This is particularly so in Japan, where credit rationing places a heavy burden on credit to consumers and favours corporations.

d) The corporate and personal income tax structure does not have an important impact upon the final cost of capital. However, tax credits in Japan and Germany for R&D investments reduce significantly the cost of capital for these kinds of purposes.

II.2.1.2.-The cost of labour

Despite its high international mobility, the cost of capital and financial capital in particular, still shows remarkable differences between countries. These differences are, to a large extent, the consequence of domestic micro and macroeconomic policies, whose effects are geographically limited. In the case of a much less internationally mobile factor of production such as labour, one should also expect substantial differences in its price across countries.

As a matter of fact, that is the case. International differences in nominal and real unit labour cost are remarkable, not just when we compare countries with very different economic environments. Even when we look at more or less homogeneous economic areas such as the OECD countries or the European Community, these differences remain important. This is one of the conclusions included in a recent report on the process of economic convergence in the European Community in the last thirty years[34].

TABLE II.2.

REAL UNIT LABOUR COSTS IN NATIONAL CURRENCY (1972 = 100)

	1975	1978	1981	1989
Belgium	107,4	109,6	111,7	97,7
Denmark	106,0	102,1	101,9	95,8
Germany	103,8	100,4	101,4	92,7
Greece	97,6	107,3	113,1	113,4
Spain	102,5	103,4	102,2	87,6
France	107,3	107,0	109,4	98,2
Ireland	108,8	100,1	104,6	88,0
Italy	104,6	100,3	101,3	96,9
Luxbrg.	118,7	117,8	119,5	108,0
Netherlands	105,6	101,7	99,5	88,8
Portugal	129,7	111,8	110,0	89,1
United Kingdom	110,1	99,6	100,7	97,4
EUR12	106,3	102,1	103,1	94,8

Source: Commission of the European Communities.

Table II.2. shows the evolution of real unit labour costs between 1972 and 1989 for the 12 member states of the European Community. Table II.3. shows the convergence of nominal unit labour costs, in terms of their annual percent change between 1961 and 1990.

34 See European Economy, no. 46, December 1990, pp.149 and ss.

Both tables give evidence of the limited impact of the Community policies in achieving a more homogeneous economic environment in Europe, at least as far as the labour market is concerned. After thirty years of policy coordination, the measures of dispersion in the annual percent change of nominal unit labour costs are higher today than in the sixties. It is interesting to note how divergence in the evolution of labour costs peaks in periods of economic crisis (1975 and 1978-81), while convergence is possible in periods of economic bonanza.[35]

TABLE II.3.

CONVERGENCE OF NOMINAL UNIT LABOUR COSTS IN THE EEC
(Annual percent change)

	Weighted Average		Dispersion w.r.t.average		Dispersion w.r.t. lowest	
	Eur 12	Eur 7	Eur 12	Eur 7	Eur 12	Eur 7
1961-69	3,9	4,0	2,4	2,0	5,8	3,6
1970-71	8,7	8,5	2,6	2,3	7,6	4,6
1972	7,1	6,2	1,5	1,4	2,4	2,1
1973	9,3	8,3	2,5	2,2	4,6	4,4
1974	16,3	12,9	4,5	3,8	8,6	5,6
1975	18,9	12,0	6,5	5,3	14,1	9,8
1976-78	10,0	6,2	4,6	2,9	8,8	5,3
1979-80	12,1	7,6	5,3	3,6	8,1	4,6
1981	11,6	7,4	5,5	3,5	9,8	5,4
1982-85	6,6	4,1	5,0	2,4	8,0	4,2
1986	4,3	2,5	2,7	1,1	4,0	1,7
1987	3,9	2,2	3,3	1,7	4,6	2,5
1988	3,3	0,6	3,5	1,2	5,0	2,1
1989	4,3	1,2	4,2	1,3	6,4	2,8

Source: European Commission

This evidence suggests that the evolution of unit labour costs in different countries is also highly sensitive to policy actions affecting those countries. Despite the coordination

35 This study also shows that convergence in the evolution of labour costs is higher for members of the Exchange Rate Mechanism excluding Spain, Italy and the UK (Eur 7).

of policies in this group of countries, tied to each other by strong economic links, the impact of those policies in their respective labour markets produces very different effects in terms of direction and magnitude.

II.2.2. Differences in costs structures.

Given these differences in input prices, standard microeconomic theory would predict significant international differences in cost structures. In a recent study by the Commission of the European Communities, in which data from a data-base of accounting information of companies have been used, Laudy (1990) has provided some interesting evidence about the cost structure of manufacturing in seven European countries[36] and Japan.

TABLE II.4.

COST STRUCTURE OF MANUFACTURING FIRMS IN EUROPE AND JAPAN
(Percentage over total turnover)

	Max		Min		Mean	S.Dev.	Range
Purchases of intermediate inputs	74,5	(Japan)	66,6	(Nether.)	70,8	2,8	7,9
Pay-roll costs	26,6	(FRG)	15,3	(Portugal)	19,8	3,5	11,3
Financial costs	4,8	(Portugal)	1,2	(FRG)	2,8	1,1	3,6
Capital maintenance	6,6	(Portugal)	3,1	(Japan)	5,0	1,1	3,5
Taxes	3,4	(Japan)	1,1	(Portugal)	2,1	0,7	2,3
Results after taxes	6,7	(Nether.)	2,2	(Japan)	3,7	1,5	4,5

Source: Commission of the European Communities

36 Germany, France, Italy, Belgium, Portugal, Netherlands and Spain

Table II.4. shows that intermediate inputs account for the largest share of the turnover of manufacturing companies in all cases, with a mean value of 70.8%. Despite their smaller size, it is the significant volatility in the share of pay-roll costs, financial costs and the cost for maintaining the working capital, that matter here.

The dispersion around the mean value in the percentage of turnover accruing to labour is particularly high. In that case, the standard deviation is largest and the range of values is more than 50% of the mean. Profits after taxes are also very variable, with a range of values around the mean far bigger than the mean. As regards financial costs, the standard deviation is also significantly high (more than one third of the mean). The dispersion in the cost for maintaining capital is also large.

TABLE II.5.

COST STRUCTURE OF CHEMICALS INDUSTRY IN EUROPE AND JAPAN
(Percentage over total turnover)

	Max		Min		Mean	S.Dev.	Range
Purchases of intermediate inputs	80,1	(Portugal)	66,9	(Germany)	71,9	4,1	13,2
Pay-roll costs	25,7	(Germany)	8,5	(Portugal)	16,4	4,9	17,2
Financial costs	6,4	(Portugal)	0,8	(FRG)	2,8	1,6	5,6
Capital maintenance	7,5	(Portugal)	3,8	(Japan)	5,2	1,1	3,8
Taxes	5,2	(Japan)	0,9	(Portugal)	2,9	1,2	4,4
Results after taxes	9,5	(Nether.)	2,7	(Portugal)	5,1	2,4	6,8

Source: Commission of the European Communities

One might argue that these differences could be the consequence of the different industrial structures in those countries: a different sectoral composition of manufacturing industry could explain these differences. However, the same study includes data about one particular case, the chemicals industry, which show that those differences are even larger for this industry, which uses a fairly homogeneous technology in all the countries under consideration. Once again, the data show high volatility in the share of pay-roll costs, financial costs, maintenance costs and profits over turnover.

These results are due to the combined effect of different input prices and the subsequent input mix choices of firms facing different input price vectors. This study also includes some estimates of the relative importance of each one of these effects. The analysis included in the study shows that neither one of these effects can be neglected in explaining the variability in the cost structure shown above, despite some important differences between countries.

II.3. ASSUMPTION 2: WORLD DEMAND FUNCTION.

The second main assumption that will be held throughout the thesis is that of one single international market for all the products that are sold by oligopolistic competitors located in different countries. In the absence of any barriers to trade and when transportation costs are negligible, it will be assumed that any national or domestic market is equally accessible to firms operating at home as to firms operating from abroad.

In the first cases of industrialisation such as Great Britain, the importance of internal demand for the sustainability of the process seems to have been more important than in the XXth century export-led models of development like Spain, Japan or South Korea. But there are some other major reasons for choosing this assumption.

In the recent Technology Economy Programme at the OECD, one of the main conclusions included in its final report is the identification and characterisation of a new phase in the process of internationalisation of economic activities, a concept now often referred to as "globalisation" or "global competition". This term describes a "set of conditions in which an increasing fraction of value and wealth are produced and distributed world-wide within a system of interlinking private networks"[37].

This new stage in the process of internationalisation of economic activity presents some characteristics that differentiate it from previous stages. Among the main new characteristics of this stage are the following:

1.- As a result of several decades of internationalisation of economic activities, this new stage in the process is characterised by the formation of highly concentrated international supply structures. As the OECD TEP background report indicates "the erosion of earlier well entrenched domestic oligopolies has led in some instances to clearly recognisable forms of international or world oligopoly with quasi-cartel features. But in most industries, somewhat more complex supply structures involving quite strong forms of rivalry and competition prevail today."[38]

2.- A second major feature of globalisation is the important role of technology in driving international competition. In world-wide competition, technology plays a central role. The development of new products and processes is a key element to achieve privileged positions in markets throughout the world. But technology also determines, to a large extent, the framework for new forms of competition and organizational structures of economic activities. The high pace of technological change is dramatically shortening the life cycle of new products. Furthermore, the development of these news products requires increasingly higher sunk costs of research and development. Finally, new information technologies allow new forms of internal organisation of the firms and their activities throughout the world.

---

37 OECD (1990a), Chapter 9, p.1.

38 OECD (1990a) chapter 9, page 19.

These are the coordinates of new forms of market structure that, according to some, define the third main element of globalisation.

3.- In the Tokyo and Paris conferences of the TEP, there was an important discussion about the emergence of a new term, techno-globalism. This concept designates a new form of industrial organisation in which an enterprise establishes a full range of operations at a world-wide scale, ranging from R&D to sales, which results in the loss of national identity of corporations.

From my own personal point of view, techno-globalism is as yet only a tendency, and, as it is suggested in the OECD (1990) TEP report, we risk here going faster in the definition of new concepts than the real world is realising them. However, one cannot ignore the emergence of new organisational forms, half way between the traditional hierarchical structure of corporations and the market organisation of economic activities. Particularly interesting is the necessity often expressed by firms of having access to new technologies or larger markets, which is driving them to expand the geographical scope of their activities. Strategic alliances with other companies who have those technological assets or who might be interested in marketing other firms' products offer an excellent opportunity to achieve global scope without having to increase the internal dimensions of firms through internal or external growth. The development of this new form of co-operation between firms will certainly modify competitive conditions in world markets and its economic consequences will have to be carefully analysed. But this is not the place to engage in a debate on the many interesting problems that these new developments pose to competition policy or to public policy toward MNCs.

This new framework for competition certainly does not apply in the same way and with the same intensity to all markets and nations. Not all commodities are internationally traded to the same degree and, not all nations' economies are internationally open to the same extent. However, this global framework is the most relevant for the objectives of this research for two main reasons:

a.- Firstly, globalisation and more generally, the internationalization of economic activities, affects high technology industries most intensively. The table below shows measurements of internationalisation of some high-tech sectors in OECD countries between 1970 and 1985 and the average for manufacturing industry. As we can see, international trade has grown in these high technology sectors above the average growth rate of manufacturing industry.

TABLE II.6.

MEASUREMENTS OF TRADE VOLUME IN OECD COUNTRIES IN SELECTED SECTORS (1970-1985)

		1970		1978		1982		1985	
		1	2	1	2	1	2	1	2
382	Non-electrical machinery	17.4	20.2	22.7	27.2	25.3	28.7	28.5	27.5
383	Electrical Machinery	11.8	12.4	18.7	19.0	20.7	19.6	22.3	19.0
384	Transport Equipment	16.6	18.8	22.8	24.2	27.1	27.9	27.8	25.4
3–	Manufacturing	12.4	12.2	16.5	16.1	17.9	17.3	19.5	17.0

1 = Import penetration ratio
2 = Export Performance

Source: OECD Production and Trade Compatible database.

The importance of high-tech sectors in international trade, runs in parallel with their importance in foreign direct investment. A recent study by the Statistical Office of the European Communities[39] has stressed the importance of industrial

39 See Spanneut (1990).

sectors such as electronics and electrical equipment, alongside services, as a major component of intra-EEC FDI and FDI between Japan, the USA and the EEC.

b.- Latecomer industrialisation is heavily dependent on foreign markets, where competition must be faced from developed and industrialising countries.

In some cases, as in electronics in South Korea, the developing country protects its domestic market from foreign competition in the targeted sector. This might shed some doubt on the realism of the assuming just one single world demand function. However, it is usually the case that, as in the example mentioned above, domestic markets account for a minimum percentage of domestic production[40], and the real battleground for economic success of these kinds of industrial policies are the export markets.

In some other cases, like Spain or Ireland, their economies are integrated in common markets, where despite some regional or national differences, competition is open in an international sense.

II.4.- Boundaries to the study.

As it is often the case, in the course of this research some decisions had to be made to define the limits of its contents. This section spells out those limits and discusses very briefly some of the reasons behind our decisions.

II.4.1.- Process innovation versus product innovation.

All the models included in the thesis are centred on process innovations, i.e. "new or significantly improved production methods involving changes of equipment or

---

40 As late as in 1988, the domestic market for the electronics industry in Korea accounted only for 37% of total production. See Houlder. V. "The Giddy Years have gone for the Electronics Industry", Financial Times, November 16, 1990.

production organisations or both, intended to produce new or improved products which cannot be produced using conventional plants or production methods, or essentially increasing the production efficiency of existing products"[41].

The emphasis is placed here on the possibility offered by technological change to reduce production costs instead of introducing new products. This is so for the following reasons:

a.- It has often been recognised in the literature that process innovation is a more general assumption than product innovation, although some of the characteristics of the latter can sometimes be modelled as process innovations (for instance improvements in the quality of already existing products), even if this is not always the case.

b.- A recent study by Kraft (1987) has provided empirical evidence of how process innovations are linked to product innovations. This research has proved the existence of a recursive model, in which product innovation leads to process innovation. However, the reverse implication cannot be proved. Therefore, this evidence seems to confirms that process innovation is a more general case.

c.- As we noted above, latecomer industrialisation in the case of Spain has relied heavily on the supply of traditional goods and services at lower prices. For this reason we think that, at least for this particular case, this is the most suitable assumption.

41 OECD (1990b) page 25.

II.4.2.- Market relationships: Multinational corporations as vehicles of technological change, joint ventures, international technological cooperation and strategic alliances.

A large percentage of international diffusion of technological change takes place as the result of the activities of MNCs. However, this topic has been kept outside the boundaries of this study. The emphasis has been put here on the influence of market structure and market failures on the process of technological development of countries. The technological activities of MNCs are closely related to issues such as the internal organisation of corporations or their international strategy. Therefore, these technological activities are not directly influenced by market conditions, and hence they fall outside the scope of our analysis. The importance of these activities in the technological development of countries is unquestionable, but their nature is essentially different from that of the phenomena considered in this research.

Furthermore, the nature of the public policy problems that these types of activities pose to policy makers are substantially different from those that arise in a world where there are no problems of 'identity' relative to the nationality of the firm. The high flexibility of operations that multinational corporations have make obsolete many of the traditional policy instruments available to policy makers in the past. For instance, the argument for public intervention to promote R&D spending that is based on the important differences between social and private returns to innovation becomes less consistent from a political point of view, if the beneficiary of public support is a multinational corporation that will spread the social benefits of innovation beyond national borders. The main question that arises in this context is who should be the subject of public policy intervention.[42] But again, these kinds of questions are not of a different nature to those considered here, and for that reason they will remain outside the scope of the thesis.

---

42 See Reich (1990) for an interesting presentation of the questions involved in this issue.

As it was mentioned before, new ways of acquiring foreign technology or developing innovations in a cooperative way, have experienced an important upsurge in the recent past. These have taken different forms, from bilateral strategic alliances between companies to publicly supported R&D programmes like Sematech in the USA or Esprit in Europe. On this subject, it is important to distinguish between:

1.- cooperative efforts that are pushed forward by national public authorities like the Eureka initiative or by international organisations like the ESPRIT programme, and

2.- R&D cooperative efforts that are the result of inter-firm agreements without any institutional framework supporting them.

In the second case, it is obvious that this is a situation similar to that of the technological activities of MNCs. Once again, we find that these activities take place outside the market environment, as they usually respond to the strategic needs of the corporations. Furthermore, the number of companies from technologically less developed countries involved in these kinds of operations is comparatively small.

In the case of international cooperative R&D programmes, the situation is quite different. The Spanish experience in the European R&D programmes has shown how difficult it is to reconcile the interest of the countries entering these agreements as partners, as these countries have very different technological needs and very different technological capabilities. For the time being, these programmes reflect mostly the preferences and technological demands of countries at the technological frontier, which are involved in global competition with rivals of similar characteristics. Up to now, it is possible to claim that these programmes have not evolved to suit the needs of technologically less developed countries. Designing cooperative games involving not just ex-ante but also ex-post cooperation between the parts involved in the programmes is an interesting agenda for research, but these problems are of a different nature to the ones discussed here below.

In the following chapters a sequence of self-contained theoretical models based on the above assumptions is presented, with the objective of sheding some light on some of the questions that have been raised in these two introductory chapters. In order to preserve continuity throughout the thesis, the "down-to-earth" matters that have been discussed in these first two chapters will be left aside. These theoretic models are based on the assumptions discussed in this chapter. The connection between these applied and policy matters and the results obtained from the models that follow will be established in the last chapter. The conclusions included in it should be the basis for the design of technology policy guide-lines.

Ando A. and Auerbach A. J.(1988) "The Cost of Capital in the United States and Japan: A Comparison". **Journal of the Japanese and International Economies**, 2, pp. 134-58.

Aschauer, D.A. (1989) "Is Public Expenditure Productive?", **Journal of Monetary Economics**, 23, pp. 177-200.

Binswanger H.P., Ruttan V.P. et al. (1978) **Induced Innovation: Technology, Institutions and Development**, John Hopkins U.P. Baltimore.

Chacholiades, M. (1978) **International Trade Theory and Policy**, McGraw Hill, New York.

Dertouzos M.L., Lester R.K. and Solow R.M. (1989) **Made in America, Regaining the Productive Edge**, MIT Press, Cambridge Massachusetts.

Ernst D. and O'Connor D. (1989), **Technology and Global Competition: The Challenge for Newly Industrialising Economies**, OECD, Paris.

European Commission (1990) "Economic Convergence in the Community", **European Economy**, no.46, December, pp. 139-160.

Kraft K. (1987) "Are Product- and Process-Innovations Independent of Each other?" **Wissenschaftzentrum Berlin fur Sozialforschung**, W.P. IIM/IP 97/36, November.

Laudy J. (1990) "Cost Structure of Manufacturing Firms in Europe and Japan" DGII-B, European Commission, mimeo.

McCauley R. and Zimmer S.A. (1989) "Explaining International Differences in the Cost of Capital: The US and UK vs Japan and Germany", **Federal Reserve Bank of New York**, W.P. 8913, August.

Marsh P. (1990) **Short-Termism on Trial**, Institutional Fund Managers Association, London.

OECD (1990a) Technology/Economy Programme (TEP) Background Report, Chapter 9, **Technology and the Process of Internationalisation-Globalisation**, first draft.

OECD (1990b) **Project of Innovation Manual**, OECD Paris November.

Pavitt K. and Patel P. (1990) "Large Firms in the Production of World's Technology: an Important Case of 'Non-Globalisation'". **Journal of International Business Studies**, (forthcoming).

Poterba J. M. (1991) "Comparing the Cost of Capital in the United States and Japan: A Survey of Methods", **FRBNY Quarterly Review**, Winter, pp. 20-32.

Reinganum J.F. (1989) "The Timing of Innovation: Research and Development and Diffusion" in Schmalensee R. and Willig R. **Handbook of Industrial Organisation**, North Holland, Amsterdam, vol.1, pp. 849-905.

Samuelson, P.A. (1949) "International Factor-Price Equalization Once Again", **Economic Journal**, June, pp. 181-97.

Spanneut C. (1990) 'Direct Investment of the European Community', **EUROSTAT** provisional report, August.

Reich R. (1990) "Who is Us", **Harvard Business Review**, January-February, pp. 53-64.

Teece D.J. (1981) "The Market for Know-how and the efficient International Transfer of Technology", **Annals of the American Academy of Political and Social Science**, November, pp. 81-96.

Part II Licensing

Chapter III: International Licensing Versus Domestic R&D and the Rate and Direction of Technological Change

III.1. Introduction.

Licensing is one of the most important means of international transmission of new technologies. Mansfield et al. (1979) estimate that the U.S. revenue from R&D would fall by one third if international licensing of technology were not permitted. But beyond its importance, for both the exporter and the importer, licensing is a peculiar way of international diffusion of technology, with very specific characteristics. These peculiarities and characteristics have an impact not only on the rate of international diffusion of technology but also on the incentives to develop new technologies. All these circumstances require a special treatment of this subject in this thesis.

New models of licensing have recently been developed by Katz and Shapiro (1985), Gallini and Winter (1985), Kamien and Tauman (1986). Shapiro (1985) offers a very good survey of these new developments. The results cover the design of optimal licensing contracts and the study of some information problems that arise in this context. Of particular importance for the subject of this thesis are some findings that relate to the frequency of licensing contracts and their effects on licensing incentives, or "ex-ante" effects as they are known in the literature.

Katz and Shapiro (1985) have concluded that if two part tariff licensing contracts (with a fixed fee and a per unit royalty rate) are possible, it will always be in the interest of both parties to reach licensing deals. Even when that is not possible and monitoring problems impede the utilization of per unit royalty fees, licensing agreements will be reached under certain demand elasticity conditions and when the innovations are relatively small.

However, these results are obtained for closed economy frameworks which do not capture the special circumstances that arise in international markets. Nevertheless, they seem to point out to a higher frequency of licensing in the international context than within domestic markets. As a matter of fact, there is empirical evidence supporting that hypothesis.[43] The existence of transport costs and barriers to trade have been traditional arguments used to explain the high frequency of international licensing of technology.[44] One of the aims of this chapter is to try to identify some reasons for licensing of a strategic nature, as those pointed out by Shapiro (1985), but which are specific to the conditions prevailing in the international context.

Gallini (1984) and Gallini and Winter (1985), have stressed the effects of licensing on development incentives. They have suggested that the possibility of licensing can be used by a firm in a patent race to deter a rival's R&D activity. These authors and Katz and Shapiro (1985) also suggest that the prospective benefits that the licensee would obtain from licensing could become a factor discouraging firms from trying to win a patent race.

In the legal literature on the international transfer of technology, some authors have pointed out that patents hinder the international transmission of innovations. On the other hand, some of these new analytical models suggest that the existence of patents (which after all, make licensing possible) is a condition favouring the transmission on new

---

43 See Caves et al. (1983), Taylor and Silberston (1973) and Oppenheim and Scott(1970).

44 See Sahal (1982).

technical advances. This point is confirmed in one of our models below, but the question that arises then does not refer to the rate of transmission of technical knowledge, but to the nature and characteristics of the innovations that are generated and transmitted in that context.

This part of the thesis consists of two basic models which are an attempt to study international licensing from two different perspectives. The first one is based on earlier models by M.T.Flaherty (1980) and Gallini (1984), and stresses the importance of differences in factor prices in the process of generation of new process technologies in countries with asymmetric levels of technological skills. The model in the next chapter is based on Arrow (1962) and Kamien and Tauman (1984).

Both models are expansions of a simple duopoly game in a final good industry, for which a new process innovation is discovered. In both of them, the existence of a previous game in R&D and the possibility of licensing the result of the R&D process introduce certain types of asymmetries in the otherwise symmetric Cournot-Nash game on the final good market.

III.2. A MODEL OF LICENSING VS. DOMESTIC GENERATION OF R&D.

Let us assume two firms located in different countries, each of them producing a homogeneous final good that will be sold in an international market, without any kind of transportation costs. As each firm buys its inputs in a different national market, the input prices that they face will be different. This implies that the average cost of producing one unit of the final good, (which will be assumed to be constant for each firm), may be different from one country to another, even when both firms are using the same technology.

Firms and countries will differ in the relative "level of scientific and technological development" of their research and development laboratories. This difference will be reflected in the different costs of developing the same new process technology in each country. This "level of scientific and technological development" is like a public intermediate good. Whenever a firm in one country undertakes a R&D project, it generates an externality because it will be contributing to increase the "level of technological development " in that country, but the effect of this increment on its own R&D costs for the next periods will be negligible.[45]

The new process technologies will be internally generated by the firms producing the final good, i.e. the sector is vertically integrated in that direction, and there is no possibility of entry in the R&D sector by any third firm. Thus, a firm can acquire new technology either by developing it on its own or by buying a license to use a new technology developed by its competitor.

A new process technology will be characterized by a shift of the isoquants toward the origin. As firms face different factor prices in each country, a certain new technology will not produce the same average cost reduction in both countries. This implies that, if there is no market for the technology, i.e. each firm is going to use a technology developed on its own, the R&D projects undertaken by firms in each country will not necessarily be the same. Each firm will try to reduce its production costs by saving in the utilization of inputs that are relatively more expensive in its own country. Obviously, this effort will be constrained by the physical and technical conditions of production in the R&D sector.

---

45 The difference in the technology level between two countries or "technology gap" as it is usually known, can make reference to two different things or, sometimes to both of them simultaneously. We can say that there is a technology gap between two countries whenever the technology used by the firms in one country is more advanced than the technology used by their competitors abroad, in the sense that the first firm can produce more sophisticated products or a certain product at a lower cost. However, some authors refer to the technology gap between countries whenever the stock of technology available to the firms in each country is not the same. Here, we shall say that the technology gap persists even in those cases where firms in both countries are using the same technology, but their ability to develop new technologies is not the same.

In order to eliminate the influence of this kind of technical conditions, some type of "neutrality" will be introduced in the production of new technologies. We shall assume that for one firm, the cost of producing a new technology resulting in average cost combinations (c_1,c_2) for firms 1 and 2, that keep a constant Euclidian distance from the original average cost combination, (k_1,k_2), will be constant. In other words, if we define as $r_i = r_i(c_1,c_2)$ the total R&D cost function for firm i of producing a new technology that, given the initial average cost combination (k_1,k_2), will result in average costs (c_1,c_2), we shall assume that,

Assumption 1.- For all (c_1,c_2) such that $c_1 \leq k_1$, $c_2 \leq k_2$ and $||(k_1,k_2)-(c_1,c_2)|| = s^0$, then, $r_i(c_1,c_2) = r_i^0$, where s^0 and r_i^0 are constants. Furthermore, we shall assume that $(\delta r_i/\delta c_j) < 0$ and $(\delta^2 r_i/\delta c_j^2) > 0$ for $i,j = 1,2$.

Under assumption 1, the two duopolists will never pursue the same R&D project. Furthermore, patents are useful here as long as they can be sold to trade technological knowledge, i.e. patents are a pre-condition for licensing as they confer a property right to their holder, who can trade it in the market-place. In this model, the ownership of a patent right will not impede the rival firm from reducing its costs of production. As Arthur (1987) has suggested, at any point of time, there are multiple possible paths for research. If a firm obtains a patent for a new process to produce more cheaply a final good under certain conditions (input prices), a rival located in a different country and facing different market conditions, could look for a new process technology in a different direction. In that case, the patent awarded to the first producer would not protect him against a competitor who has reduced his production costs.[46] Only if one firm

---

46 Of course, one could think of one firm undertaking all the possible R&D projects and deterring entry in the R&D sector by patenting all the possible new processes in all the future periods, but it is plausible to assume that, if the range of prospective innovations is large enough, the cost on doing this would be prohibitive.

chooses to reduce its costs by acquiring a license from its rival, will that patent have any utility for the patentee.

We shall also assume that firm 1 has an initial technological lead over firm 2 that is reflected in a cost advantage in production and another cost advantage in the generation of technological knowledge.

Assumption 2.- At the initial stage, firm 1 uses a technology and faces input prices allowing it to have lower initial average costs of production, i.e. $k_1 < k_2$, and,

Assumption 3.- The R&D costs of developing the same technology producing average costs (c_1^0, c_2^0), will be lower for firm 1 than for firm 2; i.e. $r_1(c_1^0, c_2^0) \leq r_2(c_1^0, c_2^0)$.

Assumption 3 is justified on the grounds of the existence of a "technology gap" between the two countries, whose nature was discussed in chapter two. In this chapter, the different initial average costs introduced by assumption 2 could be due to: a) differences in the technology used by the two firms, or b) different input prices faced by the firms when the technology is the same.

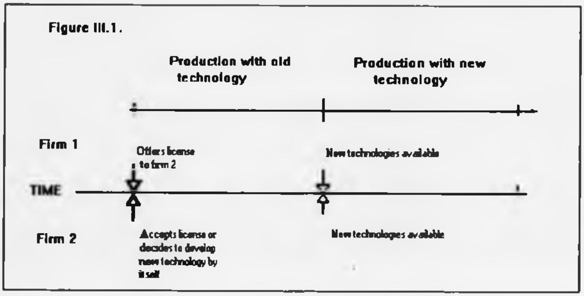
The game will be formulated in the following way. There will be two periods of time only. At the beginning of the first period of time, both firms have to decide how much output they are going to produce during this period and what will be the technology that they will have available to use at the beginning of the second period of time.[47]

The technology game that both firms will play at time zero will be the following. The firm operating in the technologically advanced country -that we will identify as firm 1 operating in country 1- will offer a license of a certain new technology that it will develop

47 In order to avoid discounting, we shall consider that the cost of a new technology will be accounted for in the period in which that technology will be used.

during period 1 to firm 2. This announcement will not entail any kind of pre-commitment by firm 1. Firm 2, can then either to accept the offer or to reject it and develop a different new technology, in which case firm 1 will develop a different R&D project to be used only by itself. Finally, both firms will choose a certain output level to produce and compete in a Cournot-Nash fashion in the final good market. Perfectness of the equilibrium will thus require Nash equilibria of all the sub-games.

FIGURE III.1.



The game in the final good market will be a standard Cournot-Nash duopoly game in which quantities are the strategic variables. Each i^{th}-firm will fix its level of output, x_i, to maximize

(1) $$\pi^i (x_i,x_j^*) = [\, p(x_i,x_j^*) - c_i] \, x_i \qquad \text{for } i=/=j=1,2$$

where $p(x_i,x_j)$ is the inverse demand function, c_i is the constant average cost of producing the final good for firm i, and x_j^* is the output level for firm j that maximizes profits for firm j.

The solution for (1) will be characterized as a function of the average cost parameters, c_1 and c_2, and can be written as follows,

$$(2) \qquad \pi^{1*}(c_1,c_2) = \pi^1[x_1^*(c_1,c_2),x_2^*(c_1,c_2)] = [p(x_1^*,x_2^*) - c_1]\, x_1^*$$

$$(2') \qquad \pi^{2*}(c_1,c_2) = \pi^2[x_1^*(c_1,c_2),x_2^*(c_1,c_2)] = [p(x_1^*,x_2^*) - c_2]\, x_2^*$$

In the R&D game, firms will try to maximize their total profits, net of the results in the research sector. Each firm will have perfect information on the solutions to its rival's optimization problem, so that they will know if it is in their own interest to do R&D or to pay for a license.

In the R&D game, the technologically more advanced firm (firm 1), will offer a license to firm 2 to use a new technology developed by firm 1. This technology would imply constant marginal costs of production of c_1' when used in country 1 and c_2' when used by firm 2 in country 2. Firm 1 will also set a lump sum royalty fee, ϕ, that firm 2 will have to pay for the right to use the patent held by firm 1. Therefore, firm 1 will offer to firm 2 a license contract that will consist of a vector (c_1',c_2',ϕ) which summarizes the conditions of the licensing contract. The optimal contract must maximize profits for firm 1 and hence, the vector (c_1', c_2', ϕ) would be the solution to the following problem,

$$(3) \qquad \max_{c_1,c_2,\phi > 0} \quad V_1' = \pi^1(c_1,c_2) - r_1(c_1,c_2) + \phi$$

$$\text{s.t. } c_1 \leq k_1 \text{ and } c_2 \leq k_2$$

However, this solution must satisfy two additional constraints to solve the two stage game. Firstly, firm 1 will face the following constraint when setting the fee,

(4) $$V_2' - \phi \geq V_2^*$$

or $$\pi^2(c_1',c_2') - \pi^2(c_1^*,c_2^*) + r_2(c_1^*,c_2^*) \geq \phi$$

i. e. the license fee is bounded from above by the difference in profits that firm 2 would make under licensing and under the alternative to accepting the contract. Thus, equation (3) can be simplified as,

(3') $$\max_{c_1', c_2' > 0} V_1' = \pi^1(c_1',c_2') - r_1(c_1',c_2') + \pi^2(c_1,c_2) - \pi_2(c_1^*,c_2^*) + r_2(c_1^*,c_2^*)$$

$$\text{s.t.} \quad c_1 \leq k_1 \text{ and } c_2 \leq k_2$$

If the licensing solution is achieved with average cost combination (c_1',c_2'), firm 2 would be making the following profits,

(4) $$V_2' = \pi^2(c_1',c_2') - \phi.$$

Finally, licensing will occur if and only if it is Pareto superior to the independent development of the innovation by each competitor.

However, if firms find it more profitable to undertake individual R&D projects, the final solution will be the result of the following Cournot-Nash game where the (c_1,c_2) levels resulting from a certain innovation will be the strategies open to the firms,

(5) firm 1 $$\max_{c_1,c_2 > 0} V_1^* = \pi^1(c_1,c_2) - r_1(c_1,c_2)$$

$$\text{s.t. } c_1 \leq k_1 \text{ and } c_2 \leq k_2$$

(6) and firm 2 $$\max_{c_1,c_2 > 0} V_2^* = \pi^2(c_1,c_2) - r_2(c_1,c_2)$$

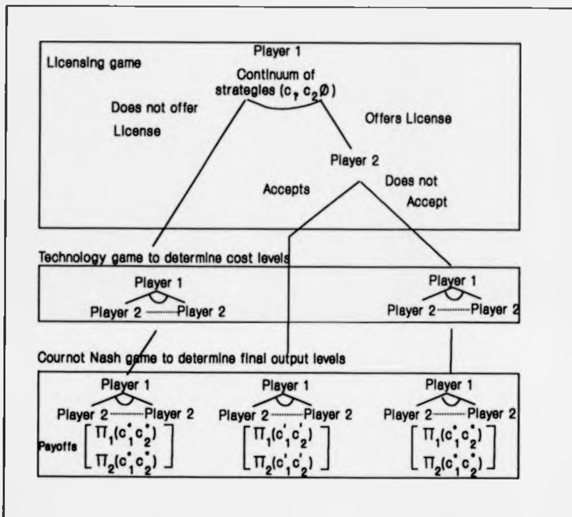
$$\text{s.t. } c_1 \leq k_1 \text{ and } c_2 \leq k_2$$

with the following final solution for the industry

$$(7) \qquad (c_1^*, c_2^*) = [\min\{c_1^{(5)}, c_1^{(6)}\}, \min\{c_2^{(5)}, c_2^{(6)}\}]$$

where $(c_1^{(5)}, c_2^{(5)})$ and $(c_1^{(6)}, c_2^{(6)})$ are the solutions of (5) and (6) above.

Figure III.2



It is important to note that only if $r_i()$ is a separable function, will the solution to these problems imply no cost reduction for the rival firm. Only in this case, can we assure that $c_2^{(5)} = k_2$ and $c_1^{(6)} = k_1$.

Figure III.2. shows the extensive form of the game.

The solution to the previous could imply the choice of certain cost combinations that would make the duopolistic market structure unsustainable. In order to avoid unnecessary complications, we shall assume that the solution to the R&D game will never imply a drastic innovation, in the sense that the duopolistic market structure will persist after this game is played, irrespective of whether licensing happens or not. This will require the introduction of the following assumption,

Assumption 4.- The cost of firm j producing an innovation that results in a cost combination (c^-_1,c^-_2) such that $\pi^i(c^-_1,c^-_2)<0$ or $p(c^-_1,c^-_2)< c^-_i$ is high enough as to imply,

$$V_j' = \pi^j(c_j) - r_j(c_1,c_2) < 0$$

where $\pi^j(c_j)$ are monopoly profits for firm j.

III.2.1.- THE CASE OF "PERFECTLY DIFFERENT" COUNTRIES.-

The existence of differentiated input markets implies that the process innovation will not produce the same cost savings in the two countries. The difference in benefits that a certain innovation will bring to the two firms will depend on the nature of the innovation and on the degree of dissimilarity between the two countries. In principle, a new process technology could imply some positive cost savings in both countries. However, it is possible to conceive of situations in which the existence of innovations does not reduce production costs when applied in one country, while bringing positive cost savings in the other country. This could happen if there are factors of production that are not mobile between countries but specific to each one of them. A new technology that induces the substitution of a more expensive input for a cheaper one which is country-specific, would produce this result. Although this might be an unlikely possibility, it simplifies the analysis considerably. Another possible case that would bring us close to this situation would be an innovation of the third, and often forgotten type, suggested by Schumpeter alongside with process and product innovations: an organizational innovation.

A more realistic approach with a more restricted feasible set will be studied in the next section of this chapter, where the results obtained in this section are generalised.

In order to obtain explicit solutions to the problems formulated in the last section, assumption 1 will be replaced with,

Assumption 1'.- The cost function in the R&D sector will be

(8) $r_1(c_1,c_2) = (m/a^2)\,[(c_1-k_1)^2 + (c_2-k_2)^2]$ for firm 1 and

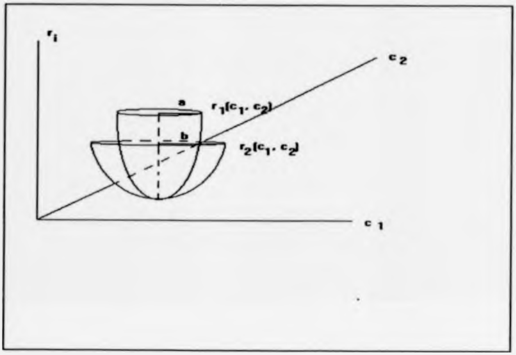
(8') $r_2(c_1,c_2) = (m/b^2)\,[(c_1-k_1)^2 + (c_2-k_2)^2]$ for firm 2

with $c_1 \leq k_1, c_2 \leq k_2$ and $a > b$ where a, b and m are positive constants.

This is just a special case of assumption 1 and already incorporates assumption 3. Thus, the cost function will be a section of an elliptic paraboloid of the kind portrayed in figure III.3. The constant 'm' captures the steepness of increase in the R&D costs as we depart from the original average cost combination, (k_1,k_2). Parameters a and b indicate the speed of increase in the R&D cost as we move away from (k_1,k_2) in any direction in the (c_1,c_2) plane. Hence, assuming that $a > b$ implies that the cost of developing a certain innovation producing a cost combination (c_1,c_2), will be higher in country 2 than in country 1, such as assumption 3 states.

Note that this function is separable in the cost reduction variables. Therefore, if each firm decides to undertake its own R&D project and there is no licensing, each firm will choose an R&D project that would not reduce costs in the other country. Only when licensing occurs, one of the firms may be interested in reducing the production costs of its rival. This is due to the separability of the $r_i()$ functions. Technologies and cost conditions are assumed different in each country to the point that a new technology reducing c_i does not have to imply a lower c_j. The R&D costs of firm i will raise if it spends money in reducing c_j. Only if firm i gets some revenue from the sale of the license to firm j, the optimal R&D project for firm i will reduce firm's j costs.

Figure III.3.



The introduction of assumption 1' transforms (3') into,

$$(3'') \quad \max_{c_1,c_2 > 0} V_1' = \pi_1^*(c_1,c_2) - m \frac{(c_1-k_1)^2 + (c_2-k_2)^2}{a^2} + \phi$$

$$\text{s.t.} \quad c_1 \leq k_1, c_2 \leq k_2 \quad \text{and}$$

$$\pi^2(c_1,c_2) - \pi^2(c_1^*,c_2^*) + r_2(c_1^*,c_2^*) \geq \phi$$

and (5) and (6) into

$$\text{(5')} \quad \max_{c_1,c_2 > 0} V_1^* = \pi^1(c_1,c_2) - m \frac{(c_1-k_1)^2 + (c_2-k_2)^2}{a^2}$$

$$\text{s.t. } c_1 \leq k_1 \text{ and } c_2 \leq k_2$$

$$\text{(6')} \quad \max_{c_1,c_2 > 0} V_2^* = \pi^2(c_1,c_2) - m \frac{(c_1-k_1)^2 + (c_2-k_2)^2}{b^2}$$

$$\text{s.t. } c_1 \leq k_1 \text{ and } c_2 \leq k_2$$

Solving (3") with the second constraint as binding, we get the following first order conditions,

$$\pi_1^1(c_1',c_2') - 2\,(m/a^2)\,(c_1' - k_1) + \pi^2_1(c_1',c_2') = 0$$

$$\pi^1_2(c_1',c_2') - 2\,(m/a^2)\,(c_2' - k_2) + \pi^2_2(c_1',c_2') = 0$$

which can be written as

$$\text{(9)} \quad c_1' = k_1 + \mu_1 [\, \pi^1_1(c_1',c_2') + \pi^2_1(c_1',c_2') \,]$$

$$c_2' = k_2 + \mu_1 [\, \pi^1_2(c_1',c_2') + \pi^2_2(c_1',c_2') \,]$$

with $\mu_1 = a^2 / 2m$ and π^i_j the partial derivative of π^i with respect to c_j.

First order conditions for (5') and (6') will be

$$\pi_1^1 - 2\,(m/a^2)\,(c_1 - k_1) = 0$$

$$- 2\,(m/a^2)\,(c_2 - k_2) = 0$$

$$\pi^2_2 - 2\,(m/b^2)\,(c_2 - k_2) = 0$$

$$- 2\,(m/b^2)\,(c_1 - k_1) = 0$$

giving the following Cournot-Nash equilibrium for the non-licensing case,

(10) $$c_1^* = k_1 + \mu_1 \pi^1{}_1(c_1^*,c_2^*)$$
$$c_2^* = k_2 + \mu_2 \pi^2{}_2(c_1^*,c_2^*)$$

with $\mu_2 = b^2 / 2m$ and μ_1 as defined above.

As expected, when there is no licensing, if the two countries are "perfectly different", neither firm will choose a research project that could reduce the costs of its rival whenever it has access to the new technology. Therefore, we can conclude that the solutions to problems (3") and (5) and (6) will be given by the following proposition,

Proposition 1.- Under assumptions 1' to 4, the solution to the R&D and licensing games defined by (3"), (5) and (6) will be given by,

$$c_1' = k_1 + \mu_1 [\, \pi^1{}_1(c_1',c_2') + \pi^2{}_1(c_1',c_2') \,]$$
$$c_2' = k_2 + \mu_1 [\, \pi^1{}_2(c_1',c_2') + \pi^2{}_2(c_1',c_2') \,]$$

and

$$c_1^* = k_1 + \mu_1 \pi^1{}_1(c_1^*,c_2^*)$$
$$c_2^* = k_2 + \mu_2 \pi^2{}_2(c_1^*,c_2^*)$$

It is interesting to note already the similarity between the solutions to the two problems. For instance it is interesting to notice that, for firm 2, the difference between the licensing solution and the R&D solution will be a function of the difference in R&D costs captured by the terms a and b or μ_i. If the R&D costs in country 2 grow much faster than in country 1 as we depart from (k_1,k_2), the licensing solution will be more biassed in favour of reducing production costs in country 1.

The particular cost structure introduced by assumption 1' allows us to differentiate very clearly between the effects on the solution values of c_i, of differences in initial cost conditions captured by the k's and differences in R&D abilities and costs in the two countries.

III.2.1.1.- Nash equilibria for the entire game: existence, uniqueness and characterization.

From (9) and (10) we can construct functions F_i

(11) $c_i' = F_i(c_1', c_2')$ for i=1,2 and.

$c_i^* = F_i(c_1^*, c_2^*)$ for i=1,2.

(12) $F(c_1', c_2') = (F_1(c_1', c_2'), F_2(c_1', c_2'))$.

$F(c_1^*, c_2^*) = (F_1(c_1^*, c_2^*), F_2(c_1^*, c_2^*))$.

Assumption 4 guarantees the persistence of the duopolistic structure, i.e., it restricts the values of (c_1^*, c_2^*) and (c_1', c_2') within a feasible sets $[c^-_1, k_1] \times [c^-_2, k_2]$ where c^-_i are the critical values of c_i' or c_1^* that make output values in the solution equal to zero, i.e. $xj' = 0$ and $x_j^* = 0$. Hence, functions F_i and F will be continuous under the usual assumptions of continuity and differentiability of the demand function.

The set defining the two feasible sets of our two problems, the Cartesian product $[c^-_1, k_1] x [c^-_2, k_2]$, is a compact convex set by construction. Thus, Brouwer's Fixed Point Theorem guarantees the existence of a solution for (12), and consequently for (9) and (10).

Finally, the solutions to the optimisation problems defined by (3"), (5) and (6) will be global if and only if the objective functions V'_1, V^*_1 and V^*_2 are strictly concave for the relevant values of (c_1, c_2). In that case, we can ensure that the equilibria for both types of solutions will be unique.

III.2.1.2.- Analysis of results: Differences in R&D efforts between the two countries.

A simple look at (10) is not enough to know which firm will make a larger R&D effort when both firms develop their own technologies independently. The difference in R&D effort will be given by,

(13) $(k_2 - c_2) - (k_1 - c_1) = -\mu_2 \pi^2{}_2 + \mu_1 \pi^1{}_1$

The value of this difference will depend on the relative values of $\pi^i{}_j$. These values will turn out to be very important in our subsequent analysis. They indicate the change in the profits made by the firm in the final good market induced by a change in average costs to the firms. From equation (1) and making use of the first order conditions of that problem, we have,

(14) $\pi^i{}_i = [p'((\delta x_1/\delta c_i) + (\delta x_2/\delta c_i)) - 1]\, x_i + (\delta x_i/\delta c_i)\,[p - c_i]$

$= [p'(\delta x_j/\delta c_i) - 1]\, x_i + (\delta x_i/\delta c_i)\,[p + p' x_i - c_i] =$

$= [p'(\delta x_j/\delta c_i) - 1]\, x_i \leq 0$

(15) $\pi^i{}_j = [p'((\delta x_1/\delta c_j) + (\delta x_2/\delta c_j)) - 1]\, x_i + (\delta x_i/\delta c_j)\,[p - c_i]$

$= [p'(\delta x_j/\delta c_j) - 1]\, x_i + (\delta x_i/\delta c_j)\,[p + p x_i - c_i] =$

$= [p'(\delta x_j/\delta c_j) - 1]\, x_i \geq 0 \quad \text{iff } p' \leq \delta c_j/\delta x_j$

Now, assuming that the demand for the final product is linear, we can show that the RHS of equation (13) will usually be negative. In fact, from (14) we have that

$\pi^i{}_i = [p'/3 - 1]\, x_i^*$

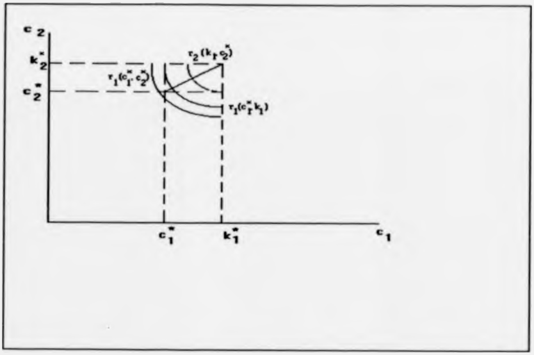
Having a greater effort in country 2 would imply that

$(k_2 - c_2) > (k_1 - c_1) \quad \text{iff} \quad \mu_2 x_2^* > \mu_1 x_1^* \quad \text{or}$

(16) $(\mu_2/\mu_1) > (x_1^*/x_2^*)$

but $\mu_1 > \mu_2$ by assumption, i.e. having a larger R&D effort in country 2 will require a reversal in the order of technological development in both countries, and still this will not be sufficient to ensure (16).

Figure III 4.



A normal solution to (10) is illustrated by figure III.4. Firm 1 produces an innovation that results in average production costs (c_1^*, k_2), with research and development costs of r_1^*, indicated by the isocost curve R_1^*. Meanwhile, firm 2 will produce an innovation resulting in unit costs of production (k_1, c_2^*) of at a cost r_2^* indicated by isocost curve R_2^*. In the final good market, firms will face the average cost vector (c_1^*, c_2^*).

Finally, we should bear in mind that the existence of the restrictions imposed by assumption 4 and the requirement that $c_i \leq k_i$ will imply that under certain values for the parameters of our model, only one solution to the problem (either licensing or domestic development) will prevail. In those cases the next sections would become irrelevant. However, whenever the parameters allow for both types of solutions, we should examine whether one of the strategies will be dominant over the other. This is the purpose of the next section.

III.2.1.3. Analysis of results: Dominance of strategies and sub-game Nash perfect equilibrium.

The question here is to determine whether licensing or developing technologies domestically will always be the solution to the overall game. In other words, we will check if there are any incentives for any player to deviate from one of these possible outcomes.

These two outcomes imply different types of solutions in terms of the role played by each player in the overall game: if licensing dominates, firm 1 will play a leadership role in the overall game while if firms develop their own technologies, both firms enter the R&D game as Nash players. Thus, it is not easy to make a direct comparison of both solutions. However, that comparison can be made in an indirect way.

Following Katz and Shapiro (1985), licensing will be the choice in the R&D game if it produces an outcome that is Pareto superior to the non-licensing choice. In other words, if by licensing the innovation, firm 1 can increase its profits without reducing the profits made by firm 2 in the R&D game, licensing will be the final outcome of the R&D game. Hence, if we can prove that by setting a license fee that is equal to the R&D costs incurred by firm 2 in the non-licensing solution, firm 1 can produce the non-licensing cost combination and still increase its profits without reducing the profits made by firm 2, licensing will be a dominant strategy in the R&D game.

According to the definitions given above, licensing will be a dominant strategy if

(17) $V_1'(c_1^*,c_2^*) + V_2'(c_1^*,c_2^*) > V_1^*(c_1^*,c_2^*) + V_2^*(c_1^*,c_2^*)$ or

(17') $V_1'(c_1^*,c_2^*) > V_1^*(c_1^*,c_2^*)$

because $V_2'(c_1^*,c_2^*) = V_2^*(c_1^*,c_2^*)$.

But (17') is equivalent to

(17'') $r_2(k_1,c_2^*) = r_2(c_1^*,c_2^*) > 0$

Note that if $a \geq b$, i.e. if firm one is at least as technologically developed as firm 2, in the sense that it can produce any new technology at an equal or lower cost than firm 2, firm one will be the technological "leader".

Thus, the average cost vector that maximizes profits in the non-licensing choice, can be produced in a more efficient way by firm 1 with a subsequent license of the patent for the new innovation to firm 2. As total revenue in the final good market will be the same no matter how the cost combination (c_1^*,c_2^*) has been produced, total profits made under licensing will be greater for at least one firm without reducing total profits for the other, if the cost combination (c_1^*,c_2^*) is produced with licensing.

This result is just a consequence of the existence of economies of scope that one firm enjoys in the production of technology, and it is independent of the initial technology gap between the initial average costs of the firms. Therefore, the following proposition will always hold,

Proposition 2.- Under assumptions 1' to 4, licensing by means of a license fee will be a Pareto superior to the independent development of R&D in each country.

This dominance of the licensing outcome will also ensure the existence of sub-game perfect Nash equilibrium, provided that the Cournot games in quantities played downstream have a solution. Given that the entire game has a Nash equilibrium as it was shown above, if we look at figure III.2. we can confirm that every sub-game has a Nash equilibrium and neither player has any incentive to move away from the licensing solution.

Only under very special circumstances that are presented in the annex to this chapter, the players would be indifferent between licensing and the independent development of the innovation. But as it is shown in the annex, that will happen only if both solutions produce the same cost reductions, and under the strong asymmetries introduced in the model, that would be an unlikely outcome.

III.2.1.4.- Analysis of results: the rate and direction of technological progress in the licensing solution.

From a welfare point of view, it is important to know what are the social consequences that licensing imposes on both countries. In that sense, it is also important to know what will be the fee charged on firm 2 for the acquisition of the new technology, and what will be the relative cost reduction that this new technology will bring about.

For that purpose, we will have to compare the equilibrium values of the solutions to (9) and (10), i.e., c_1' against c_1^* and c_2' against c_2^*. This difference will be,

(18) $$k_1 - c_1' - k_1 + c_1^* = c_1^* - c_1' = \mu\,[\pi^1_1(c_1^*,c_2^*) - \pi^1_1(c_1',c_2') - \pi^2_1(c_1',c_2')]$$

and,

(18') $$k_2 - c_2' - k_2 + c_2^* = c_2^* - c_2' = \mu\,[\pi^2_2(c_1^*,c_2^*) - \pi^2_2(c_1',c_2') - \pi^1_2(c_1',c_2')]$$

The sign of the differences between the values of the endogenous variables c_i^* and c_i' will depend on the sign of the terms in brackets above. Using (14) and (15) we can establish that

(19) $$c_1^* - c_1' < 0 \ (>0) \text{ if and only if } \pi^1_1(c_1^*,c_2^*) - \pi^1_1(c_1',c_2') - \pi^2_1(c_1',c_2')] < 0 \ (>0)$$

or

$$[p' \frac{\delta x_2^*}{\delta c_1}(c_1^*,c_2^*) - 1]x_1^* - [p' \frac{\delta x_1'}{\delta c_1}(c_1',c_2') - 1]x_2' -$$

$$- [p' \frac{\delta x_2'}{\delta c_1}(c_1',c_2') - 1]x_1' < 0 \ (>0)$$

$$(20) \qquad c_2^* - c_2' < 0 \ (>0) \text{ if and only if } [\pi^2_2(c_1^*,c_2^*) - \pi^2_2(c_1',c_2') - \pi^1_2(c_1',c_2')] < 0 \ (>0)$$

or

$$[p' \frac{\delta x_1^*}{\delta c_2}(c_1^*,c_2^*) - 1]x_2^* - [p' \frac{\delta x_2'}{\delta c_2}(c_1',c_2') - 1]x_1' -$$

$$- [p' \frac{\delta x_1'}{\delta c_2}(c_1',c_2') - 1]x_2' < 0 \ (>0)$$

In these two expressions, two terms are negative and only one is positive.[48] Little can be said about the their absolute value, and consequently, the sign of these two equations will be uncertain in principle. However, we can prove the following proposition,

Proposition 3.- Under assumptions 1' to 4, and if the objective functions are strictly concave, the licensing game will produce a process innovation that will result in smaller cost reductions in both countries than those that the R&D game would produce, only if the two countries have similar R&D capabilities (i.e. a is close to b). If the two countries are very different as regards their ability to carry out R&D, the licensing strategy will produce higher cost levels for country 1 but lower cost levels for country 2 than the R&D solution.

Proof.-

Substituting the solution to the R&D game, (c_1^*, c_2^*) in the first order conditions of the licensing game as defined in (9) we get

$$(\delta V'_1 / \delta c_1) = \pi^1_1(c_1^*,c_2^*) - 2\,(m/a^2)\,(c_1^* - k_1) + \pi^2_1(c_1^*,c_2^*)$$

$$(\delta V'_1 / \delta c_2) = \pi^1_2(c_1^*,c_2^*) - 2\,(m/a^2)\,(c_2^* - k_2) + \pi_2^2(c_1^*,c_2^*) = 0$$

But from the first order conditions to the R&D game we know that

---

48 The π_i^i terms are considered as negative while the π_i^j terms are considered as positive. These are the normal signs for these terms under 'normal demand conditions'. There are some possible but unlikely circumstances in which these terms are different. See Seade (1980) or Dixit (1984) for a detailed discussion of this.

$$c_1^* = k_1 + \mu_1 \pi^1_1(c_1^*, c_2^*) \qquad \text{and}$$
$$c_2^* = k_2 + \mu_2 \pi^2_2(c_1^*, c_2^*)$$

In the second equation the same would happen if $a = b$. But in the more general case in which $a > b$, if we add and subtract at the same time $(2m / b^2)(c_2^* - k_2)$, we get

$$\pi_2^1(c_1^*, c_2^*) + (c_2^* - k_2)[(2m / b^2) - (2m / a_2)]$$

As $\pi_2^1(c_1^*, c_2^*) > 0$ and $a > b$ by assumption, this expression will be positive if and only if

$$\pi_2^1(c_1^*, c_2^*) > (c_2^* - k_2)[(2m / a_2) - (2m / b_2)]$$

and that will be the case when the difference between a and b is not very large.

Finally, total differentiation of V_1' at the Cournot-Nash solution gives, after substitution of the first order conditions,

$$dV_1' = \pi_2^1(c_1^*, c_2^*)\, dc_2 + [(c_2^* - k_2)[(2m / b^2) - (2m / a_2)] + \pi^2_1(c_1^*, c_2^*)]\, dc_1$$

This expression is positive unless

$$\pi^2_1(c_1^*, c_2^*)\, dc_1 + \pi_2^1(c_1^*, c_2^*)\, dc_2 < [(k_2 - c_2^*)[(2m / b^2) - (2m / a_2)]]\, dc_2$$

Hence as we move away from (c_1^*, c_2^*), the value of the objective function V_1' grows if we increase c_1 and c_2 simultaneously, in case of relatively similar values for the parameters a and b. However, if a and b are very different, V_1' will increase in the neighbourhood of (c_1^*, c_2^*) if we take $dc_1 > 0$ and $dc_2 < 0$.

This result applies to local comparisons of the two solutions. To generalise it to all the possible values of (c_1, c_2), it is sufficient to ensure that the solutions to the two problems defined in (3*), (5) and (6) are unique. But, that will be ensured by the assumption of strict concavity of the objective functions V'_1, V^*_1 and V^*_2. [49]

■

Thus, we can conclude that, whenever both licensing and developing technology domestically are feasible solutions, licensing will be a dominant strategy if both firms have different abilities in the production of technology, but the rate and direction of the technological change produced will be different under licensing than under autonomous development of technology. The sign of this difference will depend on the relative ability of two countries to carry out R&D, i.e. the values of the parameters a and b. If the two countries are more or less equally able to conduct R&D, the possibility of international licensing will slow down the rate of technological development. However, if there is an important difference between a and b and R&D costs are relatively important as compared to production costs, i.e. m is big, the licensing equilibrium would imply a higher production cost in country 1 and a lower production cost in country 2, as compared to the outcome resulting from autonomous R&D in each country.

An economic reading of these results can be obtained from equations (19) and (20). These equations establish that, if there is licensing, the cost reduction in country 1 will be a direct function of the variation in industry profits resulting from it. If there is autonomous R&D, cost reduction in country 1 will be just a direct function of the variation in its own profits resulting from a lower production cost. However, in country 2 there is an additional factor: the difference in countries' ability to carry out R&D counts and we can get a higher cost reduction for country under autonomous R&D than under licensing. This will be the case when the difference between a and b and m are big enough as to compensate to country 1 for the loss in profits resulting from providing a technology to a competitor more advanced than the technology that it could develop on its own. In this

---

49 See Takayama (1985), chapter 1, section C.

case, the income than country 1 gets from carrying out R&D for a competitor compensates country 1 from the losses that it makes from facing a more efficient competitor. To a certain extent, one can say that in this case, the firm in country 1 specializes in doing R&D instead of manufacturing the final good.

These results are related to those obtained by Gallini (1984) and, particularly, Gallini and Winter (1985). This last paper analyzes the implications that the possibility of licensing has on firms incentives to carry out R&D. In a similar duopolistic framework, it is proved that the availability of licensing encourages research when the firms' initial production technologies are close in costs and discourages research when initial costs are asymmetric.

However, in this model, the differences in countries abilities to carry out R&D have been emphasised. We have seen that these differences in scientific and technological development are important to determine the rate and direction of technological change. If they are large and R&D costs are relatively high as compared to production costs, we can find a certain type of specialization in the most advanced country in the production of technology.

III.2.2. GENERALIZATION TO NON-PERFECTLY DIFFERENT COUNTRIES.

The results of the previous section can be expanded to allow for more or less similar countries. We shall maintain the difference in the level of technological development between both countries, but the feasible set of average cost combinations produced by technological change will be restricted. Thus, now we shall assume that, despite the differences in factor prices between countries, any R&D project will result in positive cost savings when applied in each country, although these cost savings will be of different order of magnitude in each country.

For that purpose we shall assume that there exist two frontier lines that represent the limit R&D projects for each firm. These lines will be

(21) $c_2 = k_2 - s_1k_1 + s_1c_1$ and

(22) $c_2 = k_2 - s_2k_1 + s_2c_1$ with $s_1 < s_2$

The interpretation of these lines is as follows. For instance, (21) gives us the limit R&D project for firm 1 in the sense that this is the R&D project producing a maximum cost reduction in country 1 for a given cost reduction in country 2.

The introduction of this new assumption will modify equations (3) to (7) above. The most interesting change will take place in the non-licensing solution. In that case, (5) and (6) will become now,

(5") firm 1 $\max_{c_1,c_2 > 0} V_1^* = \pi^1(c_1,c_2) - (m/a^2)\,[(c_1 - k_1)^2 + (c_2 - k_2)^2]$

s.t. $c_1 \leq k_1$ and $c_2 \leq k_2$

and $c_2 \leq k_2 - s_1k_1 + s_1c_1$

$c_2 \geq k_2 - s_2k_1 + s_2c_1$

and

(6") firm 2 $\max_{c_1,c_2 > 0} V_2^* = \pi^2(c_1,c_2) - (m/b^2)\,[(c_1 - k_1)^2 + (c_2 - k_2)^2]$

s.t. $c_1 \leq k_1$ and $c_2 \leq k_2$

and $c_2 \leq k_2 - s_1k_1 + s_1c_1$

$c_2 \geq k_2 - s_2k_1 + s_2c_1$

It is easy to see from these expressions that proposition 2 about the dominance of the licensing strategy would be maintained, as well as proposition 3 about the rate and direction of technological change. However, the introduction of these new boundary values for the production costs resulting from the innovation may pose difficulties for the existence of a solution to the two problems. As a matter of fact, the c_2 lines defined in (21) and (22) reduce the set of feasible solutions. Therefore, all these results remain intact, subject to the existence of a feasible solution to both problems. However, if one of the constraints defined by (21) and (22) becomes binding, these results might not hold. This possibility will increase as the constraints reduce the size of the feasible set or, in other words, as the two countries become more similar to one another.

III.3. CONCLUSIONS

In this chapter we have seen that, in an international context in which firms and countries differ not only in their initial production costs but also in their respective degree of technological development, the possibility of ex-ante licensing will discourage the less developed country from carrying out domestic R&D. The existence of economies of scope in the production of innovations will make the licensing solution preferable to domestic R&D in both countries, since both countries can benefit from the higher efficiency of country in the production of new technologies.

In comparison with previous results in Gallini (1984) or Katz and Shapiro (1985), the licensing solution will prevail under a broader set of circumstances if the two competitors are located in different countries. This result would be confirmed by the higher frequency of licensing across borders than within local markets.

The strong dominance of the licensing solution and the consequences that this conclusion implies for the direction of technological change, should be taken into consideration in the discussion about the choice of the appropriate technology. Some authors like Francis Stewart (1982) have emphasised this point as an important one for technology policy in less developed countries.

The implications of licensing for the rate and direction of technological change are very important. In this model, we have examined the influence of differences in the degree of technological development between countries on the rate and direction of technological change. Completing the work of Gallini and Winter (1985) commented upon above, we have seen that, in a duopolistic context, licensing will speed up innovation when production costs are similar for the two firms [Gallini and Winter]. But if the two firms have similar cost structures in the production of new innovations, the possibility of licensing will tend to slow down technological change. Only if differences in R&D costs are significant, do we find that the licensing solution will speed up technological change in the less developed country as compared to the rate of innovation resulting from the domestic development of new technology in that country. In that case, one country becomes "specialized" in the production of technology, because the income that it would get from the fixed fee paid by the other country would compensate for the losses that supplying a more advanced technology to a competitor would produce.

In this framework, public policy intervention may be justified because the social and private costs and benefits of producing technological change will not be independent of the way in which that technology has been produced. Profits to the domestic firm in the less developed country will be almost the same with both solutions. However, the social cost of technology will be higher if it is acquired through licensing because all the positive externalities generated by doing domestic R&D will be lost. This will be particularly important in a dynamic context, in which the accumulation of R&D skills over time can reduce the future costs of carrying out R&D autonomously. In the developed country, private profits will be increased with licensing, but social benefits will not be increased by the same amount if licensing reduces the rate of technological change, because less positive externalities will be generated. But the welfare aspects of international licensing will be the central topic of the next chapter.

Proposition 2 is subject to one limitation: it is possible that the dominance of the licensing strategy is just weak under certain circumstances. We have to remember that (c_1',c_2') is the solution to (9) and this implies that,

$$V_1'(c_1',c_2') + V_2'(c_1',c_2') \geq V_1'(c_1^*,c_2^*) + V_2'(c_1^*,c_2^*) >$$
$$> V_1^*(c_1^*,c_2^*) + V_2^*(c_1^*,c_2^*)$$

This inequality will hold as an equality if $c_1' = c_1^*$ and $c_2' = c_2^*$. As we already saw before, if there are no R&D cost differences and a = b, i.e. $\mu_1 = \mu_2 = \mu$, the solutions to (9) and (10) above will be the same

a.) if $\pi^1{}_2 = \pi^2{}_1 = 0$, we will have that $(c_1^*,c_2^*) = (c_1',c_2')$, and the first inequality above will be an equality. Using (15), this would happen in the very special case when,

$$p' \frac{\delta x_2'}{\delta c_2}(c_1',c_2') = p' \frac{\delta x_1'}{\delta c_1}(c_1',c_2') = 1$$

b) if $\pi^1{}_1(c_1',c_2') + \pi^2{}_1(c_1',c_2') = \pi^1{}_1(c_1^*,c_2^*)$ and $\pi^{21}(c_1',c_2') + \pi_2{}^2(c_1',c_2') = \pi_2{}^2(c_1^*,c_2^*)$. In general, we cannot give any precise characterisation of these situations, but in the case of linear demand functions, it is possible to solve the expressions above. Then, those conditions become

$$(6/9)\,[Z - 3c_1^* + 2c_2^*] = (6/9)\,[Z - 3c_1' + 2c_2'] - (4/9)\,[Z - 3c_2' + 2c_1']$$

and

$$(6/9)\,[Z - 3c_2^* + 2c_1^*] = (6/9)\,[Z - 3c_2' + 2c_1'] - (4/9)\,[Z - 3c_1' + 2c_2']$$

where Z is the intersection of the demand function with the Y axis. This can be rewritten as

$$2Z = 9c_1^* - 3c_1' + 2c_2' - 6c_2^* \qquad \text{and}$$

$$2Z = 9c_2^* - 3c_2' + 2c_1' - 6c_1^*$$

As in that case $c_1' = c_1^*$ and $c_2' = c_2^*$, the expressions above can be simplified into

$$2Z = 6c_1 - 4c_2$$

$$2Z = 6c_2 - 4c_1$$

which solves for $c_2 = Z / 5$ and $c_1 = 7Z / 15$.

Looking at expressions (19) and (20) above we can get an economic interpretation of this result. Note that the directions of the inequalities will depend on the variation of industry profits and company profits as costs are reduced. In the simplest case of the two, the cost reduction will be bigger for country one in the licensing equilibrium than in the R&D equilibrium, if lowering firm 1's costs increases the profits of that firm more than the total profits of the industry. The same applies to country 2 if a and b are close enough to each other. However, if country 1 has a relatively high technological level as compared to country 2, a low value for c_2^* can be expected in the R&D equilibrium. In that case, country 1 can increase its profits by selling to country 2 a better technology than it could have developed by itself. This would happen only if that technological difference is big enough as to compensate the effect of $\pi_2^1 > 0$, i.e. the adverse effect on its own profits of reducing its rival's costs.

Therefore, we can conclude that when demand functions are linear, the functions $\pi^i_i(c_1',c_2') + \pi^j_i(c_1',c_2')$ and $\pi^i_i(c_1^*,c_2^*)$ only intercept once over the $[c_1,c_2]$ plane along the straight line defined by the multiples of $c_2 = Z / 5$ and $c_1 = 7Z / 15$. For any value of c_1 and c_2 below that line, the absolute value of $\pi^i_i(c_1^*,c_2^*)$ will be greater that the value of $\pi^i_i(c_1',c_2') + \pi^j_i(c_1',c_2')$.

These two very special cases would not come up as the solution to our problems, as they depend on very special parametric conditions. We would normally expect to observe cases in which $c_1' =/= c_1^*$ and $c_2' =/= c_2^*$. The direction that these inequalities will take under different circumstances is important to know. For instance, if $c_1' > c_1^*$ and $c_2' > c_2^*$, this would imply that licensing will be a 'progressive' alternative, in the sense that the gains obtained from the economies of scope that licensing permits to obtain will be applied to the achievement of further cost reductions. However, if $c_1' < c_1^*$ and $c_2' < c_2^*$, licensing would slow down the rate of cost reduction in both countries.

References: Chapter III

Arthur B. (1987) "Competing Technologies: An Overview", in Dosi G. (Ed) **Technical Change and Economic Theory,** MacMillan, London, 1989.

Contractor F. J. (1981) **International Technology Licensing Compensation Cost and Negotiation**, Lexington , Mass. Lexington Books.

Dixit A. (1984) "Comparative Statics for Oligopoly", **Princeton University**, Discussion Papers in Economics, n. 81.

Flaherty M.T. (1980) "Industry Structure and Cost-Reducing Investment" **Econometrica**, 48, n.5 July, pp.1187-1209.

Gallini N. (1984) "Deterrence by Market Sharing;: A Strategic Incentive for Licensing", **American Economic Review**, December, 74, pp. 931-41.

Gallini N. and Winter R.(1985) "Licensing in the Theory of Innovation", **Rand Journal of Economics**, 16, n. 2, Summer, pp. 237-52.

Katz M. and Shapiro C. (1985) "On the Licensing of Innovations", **Rand Journal of Economics**, Winter, 16, n.4, pp. 504-521.

Mansfield E., Romeo A. and Wagner S. (1979) "Foreign Trade and US Research and Development", **Review of Economic and Statistics**, 61, pp.49-57.

Oppenheim S.C. and Scott J. C. (1970) "Empirical Study of Limitations in Domestic Patent and Know-how Licensing" **IDEA**, vol. 14, n. 2, Summer, pp. 193-211.

Sahal D. (ed)(1982) **The Transfer and Utilization of Technical Knowledge**. Heath & Co. Lexington Books. Lexington Mass.

Seade J. (1985) "Profitable cost Increases and the Shifting of Taxation: Equilibrium Responses of Markets in Oligopoly", **Warwick Economic Research Papers**, n. 260, Coventry.

Shapiro C. (1985) "Patent Licensing and R&D Rivalry", **American Economic Review**, 75, n. 2, pp. 25-30.

Stewart F. (1982) "Industrialization, Technical Change and the International Division of Labour", in G.K. Helleiner (ed) **For Good or Evil: Economic Theory and North South Negotiations,** Croom Helm, London.

Takayama A. (1985) **Mathematical Economics** MacMillan, New York.

Taylor C.T. and Silberston Z.A. (1973) **The Economic Impact of the Patent System: A Study of the British Experience**, University of Cambridge, Department of Applied Economics Monograph n. 23, Cambridge University Press, Cambridge.

Chapter IV: The Impact of the International Licensing of Process Innovations on Domestic Social Welfare.

IV.1. Introduction.

The previous chapter has dealt with several positive issues that arise in the context of international licensing. This chapter considers some welfare implications of international licensing.

In recent years, Gallini and Winter (1985), Katz and Shapiro (1985 and 1986), Kamien and Tauman (1984 and 1986), and Ireland (1988), have tackled some of the interesting problems that arise in this particular form of ex-post and arms-length cooperation between companies. Although Sahal (1982) among others, made important contributions to understand the magnitude, characteristics, varieties and direct economic consequences of this phenomenon, the above mentioned authors were among the first in presenting economic analyses of licensing in strategic environments.

These contributions have modified substantially the economic understanding of licensing that was derived from earlier work in International Economics. In some cases, these contributions have disclosed some interesting forms of strategic behaviour (Gallini and Winter (1985)). In other cases, they have clarified the economic effects of different forms of licensing (Kamien and Tauman (1986) and Ireland (1988)) and other studies have highlighted different aspects of optimal behaviour when there is the possibility of licensing (Katz and Shapiro (1985) and (1986)).

Nevertheless, despite the importance of those findings, little has been done to insert this new approach into the international context. The relatively marginal attention paid to the welfare impact of the licensing of new technologies in this strand of the literature could in part explain this fact. But in international licensing, the existence of transfer payments as fixed fees or royalties to the foreign patent holder must be deducted from social welfare to calculate the welfare impact of the license, and this fact requires specific consideration.

The unquestionable importance of aspects such as those mentioned earlier in international licensing and the quantitative importance of this phenomenon in international economic relations,[50] both call for more research efforts in this direction.

This chapter addresses some basic matters concerning the welfare impact of the international licensing of a new process innovation by a foreign patent holder to a domestic group of oligopolistic producers of a certain final good. Its main objective is the identification of the potential market failures that might appear in such a market structure. This should be the prior step in the definition of any kind of policy recommendation on this matter. It will be shown that, in these kinds of market conditions and if the number of oligopolistic firms is relatively large, the private market equilibrium implies a number of licenses sold and a price paid for each license which is above the socially optimal equilibrium. This result is a consequence of the difference between the public and private incentives to buy licences. It seems to contradict the intuition suggesting that the more licenses that are bought the higher domestic welfare will be, as these will lower the costs of our domestic firms. However, this intuition disregards the fact that the willingness to buy the license depends on the number of firms in the industry. The model presented here suggests that the higher this number is, the higher will be the rivalry between firms to get

---

50 OECD's Science and Technology Indicators Department estimate that 1987, 13 major OECD countries obtained receipts from the sale of technology that amounted 41bn US $.

the license because the opportunity cost of not having the patent increases. Rivalry between oligopolists raises the price of the fixed fee above the socially optimum price.

The model also shows that, according to what has been suggested in the traditional literature on licensing, at least under certain conditions, the net contribution of the license to the social welfare of the country may turn out to be negative.

This work relies direct and substantially on earlier work by Kamien and Tauman (1984a,b and 1986) and Ireland (1988), but also indirectly on some ideas suggested by Quirmbach (1986) and Fudenberg and Tirole (1985). The former two papers focus on the market outcomes of licensing games where a patent holder sells a license either in an open market at a price that is optimal for him or by using an auction mechanism. They both provide clear-cut results in terms of number of licenses sold, prices, revenues for the patent holder, etc. The model presented in this chapter, is based on a model developed by Kamien and Tauman (1984b and 1986). The indirect link existing between our work and Quirmbach (1986) and Fudenberg and Tirole (1985) stems from the nature of the market failure that we identify here, which has some resemblance to the ones presented in those papers, although in their cases, this kind of market failure appears in contexts where there is no licensing.

IV.2. International licensing of a non-drastic innovation by means of a fixed fee only: the non-drastic innovation.

This model is an extension of that of Kamien and Tauman (1984b and 1986). The model features a game in three stages between a foreign patent holder who wants to license a patent for a process innovation and domestic firms operating in an oligopolistic market for a given final good where Cournot conjectures are assumed. In the first stage of the game, the patent holder announces a fixed fee, r, that will be the price that firms will have to pay for the right to use the patent. In the second stage, the oligopolistic competitors react simultaneously and decide whether or not to buy the license. Finally, domestic firms play a Cournot game in the market for the final good and realize their payoffs. In this kind of game, the patent holder enjoys a "leader" position as he can take the reaction functions of the oligopolistic firms as constraints for the profit maximization problem that he faces in chosing his optimal strategy, r. The strategies for the oligopolistic firms are their decisions on acquiring the new technology or not.

In this model it will be assumed that the patent holder does not use his patent to produce the final output and compete with the existing oligopolists in their domestic market as an exporter. This possibility exists and the conditions under which the patent holder would start selling in the domestic market are described in Kamien and Tauman (1986). But introducing it in the model would complicate the calculations without adding significant insights to the kind of effects which are described here. Therefore, this possibility will be ruled out by assuming a prohibitive tariff on the imports of the final good.

As is usual in these models, the need to parameterize results requires the use of a particular example. It will be assumed that all firms have the same cost function prior to the sale of the license. Firms buying the license will have a positive reduction of "ϵ" in their previous constant average costs of production "c". For the time being, we will assume that the innovation is not drastic in Arrow's sense. There are n firms in the industry facing a linear demand function of the form

$p = a - \sum_{i=1}^{n} q_i$, where p is the price for the homogeneous final good, and q_i is the output of the i-th firm.

Each one of the k firms buying the license will make profits equal to

$\pi_i = q_i\,(p - c + \epsilon) - r$ for $i = 1,2,3,\ldots k$ or $i \in S$, where S is the set of firms buying the license. Meanwhile, each firm not buying the patent will make profits given by,

$$\pi_j = q_j (p - c) \qquad \text{for } j = k+1,\ldots n, \text{ or } j \in S^c, \text{ i.e. the complementary set of S.}$$

Total profits to the licensor will be,

$$\pi_{pH} = k\,r$$

IV.2.1. The market outcome.

Kamien and Tauman (1984b) have solved the market outcome for this kind of situation. As one might expect, the final result depends on:

1- the total number of firms in the industry, n, and

2- the final number of licenses sold, k.

Although the number of licenses sold is an endogenous variable, the final market equilibrium also depends on k, because when this number is relatively high, firms not buying the license leave the market for the final good, hence introducing a discontinuity in the payoff functions. In this sense, although the size of ϵ "per se" does not make the innovation "drastic" as defined by Arrow (1962),[51] the number of licenses sold can have that effect on the equilibrium of the industry. Thus, for $k \geq (a-c)/\epsilon$, only firms buying the license will produce a positive output, while for $k \leq (a-c)/\epsilon$, both types of firms produce positive outputs. Therefore, a new discontinuity is introduced in the reaction function faced by the patent holder.[52] For this reason, from now on, the analysis will be carried out for each one of the intervals defined by the $k \gtrless (a-c)/\epsilon$ partition of the non-negative subset of the real line. Henceforth, they will be called cases A and B. In order to

---

51 According to Arrow (1962), an innovation is drastic if it reduces the average cost of production below the market price previous to the introduction of the innovation

52 See Kamien and Tauman (1984a)

distinguish between these cases and Arrow's definition of drastic innovation, the following definition is introduced,

Definition.- An innovation will be drastic in the Kamien-Tauman sense if the number of licenses sold and the absolute reduction in production costs that the innovation produces drive the market price below the average production cost of the firms that did not buy the license.

Case A.

If the number of licenses sold is $k \leq [(a-c)/\epsilon] - 1$,. then a firm will buy the license if the price that it has to pay for it is below or equal to the profits that it will make from acquiring the patent, i.e. firm i will buy iff

(1) $$r \leq \pi_i(k,n) - \pi_j(k-1,n) \quad i \epsilon S, \; j \epsilon S^c$$

where $\pi_i(k,n)$ are Cournot profits that firm i makes when it is one of the k firms buying the license and $\pi_j(k-1,n)$ are profits made by the firm when it does not buy the license and k-1 firms do. For a non-licensee, the situation would be, firm i does not buy the license iff

(2) $$r \geq \pi_i(k+1,n) - \pi_j(k,n) \qquad i \epsilon S, \; j \epsilon S^c$$

With linear demand and cost functions, the general solution for Cournot profits is

$$\pi_i = [a - (n+1)c_i + nc_j]^2 / (n+1)^2$$

and substituting into (1) we get the inverse demand function that the patent holder faces when all firms keep on producing after the licensing process is over:

(3) $$r^p = n\epsilon\,[2(a-c) + (n-2k+2)\epsilon] / (n+1)^2$$

This is the inverse of the private demand function for the license that oligopolists will present in a non-regulated market for the new technology. According to the allocation procedure suggested by Kamien and Tauman and reproduced here, the patent holder will take this as a reaction function and will supply a number of licenses k^p that maximizes his revenues. That number will be given by the tangent line between the patent holder's iso-profit curve and the reaction function in (3). From the definition of the patent holder's profits and (3), it is easy to see that this will happen when,

(4) $$k^p = \frac{(a-c)}{2\epsilon} + \frac{(n+2)}{4}$$

However, this is just the characterization of the internal solution and corner solutions will be important here. First, we have one corner solution when the total number of firms in the industry is smaller than this interior solution, $k^p = n$ [53]. On the other hand, as the value of k is bounded by $(a-c)/\epsilon$, this will be another possible corner solution.

Case B.

If the total number of licenses sold is $k \geq (a-c)/\epsilon$, only firms buying the license make positive profits. Therefore, the decision rule depends on the comparison between the price of the license and the profits made by each one of the firms producing a positive output, because the alternative of not buying the patent implies making zero profits. In other words, a firm will buy the license if and only if

$$r \leq \left(\frac{a - c + \epsilon}{k + 1}\right)^2$$

Notice that this reaction function faced by the patent holder now yields the following payoff function,

$$\pi_{pH} = k\,(a-c+\epsilon)^2 / (k+1)^2$$

---

53 In other words, in this case $(\delta\pi pH/\delta k) > 0$ in the optimum.

which is a decreasing function of k. This can be explained by the fact that the patent holder is now facing an inelastic demand function for his licenses. As $k = (a-c)/\epsilon$ belongs to the feasible set for this maximization problem, (as a matter of fact, it is the lower bound of the feasible set), it will be the solution to our problem. Hence we can conclude that,

Proposition 1 (Kamien and Tauman). The market solution for the licensing game described above will be given by k^P, where

Case A: if $k \leq (a-c)/\epsilon$

$$k^P = \begin{cases} n, & \text{when } n \leq 2\,[[(a-c)/\epsilon] + 1]\,/\,3 \\ \dfrac{(a-c)}{2\epsilon} + \dfrac{(n+2)}{4} & \text{when } 2\,[[(a-c)/\epsilon] + 1]\,/\,3 \leq n \leq 2\,[[(a-c)/\epsilon] - 1] \end{cases}$$

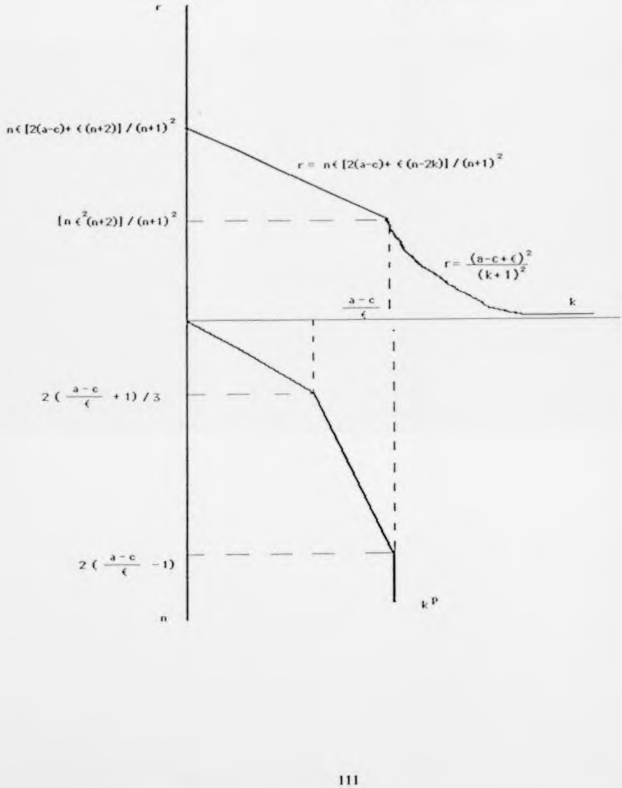
and,

Case B: if $k > (a-c)/\epsilon$ $\quad k^P = (a-c)/\epsilon$.

Proof.- (See Kamien and Tauman (1986) annex).

Figure IV.1. shows the relationship between the total number of firms in the industry, the number of licenses sold and the demand function and equilibria values in the market for licenses.

Figure IV. 1.


r
nϵ [2(a-c)+ ϵ (n+2)] / (n+1)²
r = nϵ [2(a-c)+ ϵ (n-2k)] / (n+1)²
[n ϵ²(n+2)] / (n+1)²
r = (a-c+ϵ)² / (k+1)²
a - c / ϵ
k
2 (a - c / ϵ + 1) / 3
2 (a - c / ϵ - 1)
k^p
n

IV.2.2. The social optimum.

In order to be able to evaluate the performance of this market for the new technology, let us assume now that the foreign patent holder will not be directly facing an oligopolistic industry but instead, a social planner that will buy the licenses from the patent holder and will distribute them later among firms in the oligopolistic user-industry.[54] However, the basic mechanism of license allocation presented in the previous section will be maintained here. We will still assume that the patent holder quotes a profit maximizing fixed fee taking into account the reaction function of the social planner, and given that fee, the latter will then decide the number of licenses to be bought so as to maximize domestic social welfare. The standard measure of social welfare, industry profits plus consumer surplus, will be used.

In this section the social-planner's demand function for patents will be derived first, and then, equilibrium values in the market for the new technology will be found.

IV.2.2.1. The social demand for licenses.

First, let us start by defining the domestic social welfare functions gross of the cost of licenses for the case in which the innovation is drastic in the Kamien-Tauman sense and then for the case in which it is not,

Lemma 1.

In a market with n firms, where k firms produce at constant unit costs (c-ε) and (n-k) firms produce each with an average production cost c, social welfare, W, before subtracting the cost of the licenses, is equal to

---

54 The way these licenses are distributed later is not important here. We can assume that they are freely available to firms in the industry and the purchase is financed through an income tax

Case A:

$$(5) \quad W = \frac{n(a-c)^2(n+2)+2(a-c)k\epsilon-k^2\epsilon^2}{2(n+1)^2} + \frac{[(a-c)+(n-k+1)\epsilon]\epsilon k}{n+1}$$

if $q_l > 0$ and $q_s > 0$, and

Case B:

if $q_l > 0$ and $q_s = 0$

$$(5') \qquad W = \frac{k(k+2)(a-c+\epsilon)^2}{2(k+1)^2}$$

where q_s is the output of each one of the n-k firms and q_l is the output of each one of the k firms using the new technology.

Proof.

Case A.- If $q_s>0$,

$$W = (1/2)(a-p)[kp_l+(n-k)q_s] + (p-c)(n-k)q_s + (p-c+\epsilon)kq_l - kr =$$

$$= (1/2)[(a+p-2c)(n-k)q_s + (a+p-2c+2\epsilon)kq_l] - kr =$$

$$= (1/2)(a+p-2c)[(q_l-q_s)k + n\,q_s] + \epsilon\,k\,q_l - kr \;;$$

substituting the general Cournot solutions for q_s, q_l and p,

$$q_l = (a-c+[n-k+1]\epsilon)/(n+1) \quad ; \quad q_s = (a-c-k\epsilon)/(n+1) \; ; \quad p = (a-k\epsilon+nc)/(n+1)$$

we get the result above.

<u>Case B.-</u> If $q_u = 0$,

$$W = ([a-c]/2)\, k\, q_l + (p-c+\epsilon)\, kq_l - k\, r = \frac{a + p - 2c + 2\epsilon}{2}\, k\, q_l$$

and given that $q_l = (a-c+\epsilon)/(k+1)$ and $p = a - kq_l$, the result above can be obtained by simple substitution.

∎

Note that the welfare function defined by (5) is increasing and concave in k for any $k \leq (a-c)/\epsilon$. Indeed,

$$\frac{dW(k)}{dk} = \frac{1}{2(n+1)}\, [2(a-c)\epsilon - 2k\epsilon^2] + \frac{1}{n+1}\, [(a-c)\epsilon + (n-2k+1)\epsilon^2]$$

which is positive under this condition, i.e. if the innovation is not drastic in the Kamien-Tauman sense, and

$$\frac{d^2W}{dk^2} = \frac{-2\epsilon^2}{2(n+1)^2} + \frac{-2\epsilon^2}{n+1} < 0$$

If the number of licenses sold is such that only those with a license remain operative, i.e. if the innovation is drastic in the Kamien-Tauman sense, the social welfare function depends just on k, the number of operating licensees .

Now we can calculate the socially optimal number of licenses that the planner would be willing to buy for each fee fixed by the patent holder. This will give us the inverse demand function faced by the patent holder as the reaction function that he will have to use as a constraint in his profit maximization problem. This inverse social demand for licenses will be given by the maximum willingness to pay for each license bought by the social planner, as measured by the difference in social welfare which will be obtained when a different number of licenses is sold.

Given the fixed fee, the social planner will demand a number of licenses that maximizes the social welfare functions defined above. In other words, the social planner will buy licenses as long as $k \leq (a-c)/\epsilon$ and $W(k) - W(k-1) \leq r$, and will not buy a number of licenses for which $W(k) - W(k-1) > r$. Hence, for a given r, the socially-optimal number of licenses will be k^s, such that $W(k^s) - W(k^s-1) = r$ if $k^s \leq (a-c)/\epsilon$. However, for any number of firms above the number of firms that makes $k=(a-c)/\epsilon$, no more than $k = (a-c)/\epsilon$ licenses will be demanded as there is only room for that number of firms in the market and any additional licenses bought would be useless. Hence one can expect that the social demand for licenses will become inelastic at that point.

The general expression for the socially optimal demand for licenses, both for the case in which $k \leq (a-c)/\epsilon$ and when $k > (a-c)/\epsilon$, is given by lemma 2,

Lemma 2.-

The socially optimal number of licenses that a central planner will buy for a any fixed fee, r, will be given by,

Case A.

If the innovation is not drastic in the Kamien-Tauman sense,

(6) $$r^s_A = \frac{[2(a-c)(n+2)+\epsilon\{2n(n+3)-2k(2n+3)+5\}]\,\epsilon}{2(n+1)^2}$$ or

Case B.

if the innovation is drastic in the Kamien-Tauman sense, i.e. $k > (a-c)/\epsilon$, then

(6') $$r^s_B = \frac{(2k+1)}{2(k+1)^2k^2}\,(a-c+\epsilon)^2$$

Proof.- (See annex)

It is important to note that in case B, the patent holder faces an inelastic demand function similar to what happened in the private market equilibrium.

IV.2.2.2 Social-welfare properties of the private demand for licenses

The inverse demand functions obtained in the previous section indicate the maximum amount of money that the social planner would be willing to pay for a certain number of licenses. Now, the socially-optimal demand functions can be compared with the demand function for licenses resulting from the individual actions of the oligopolistic industry that was calculated in section 2.1. First, we can get the following result ,

Proposition 2.- If the foreign patent holder sells to the oligopolistic industry a number of patents k such that $3 < k$ with $k \leq [(a-c) / \epsilon]$, we can say that,

a) for the same number of licenses, each oligopolist will be willing to pay for each license a price above the maximum price that the social planner would be willing to pay for each one of those k patents, or

b) for any given positive price for which those demand functions are defined, the number of licenses that the oligopolistic industry would buy is bigger than the number of licenses that the social planner would buy at that price.

Proof.-

If $k < [(a-c) / \epsilon]$, the relevant socially-optimal demand function for licenses is defined by (6). Subtracting (3) from (6) we get

(7) $r^s - r^m = \epsilon\,[2(a-c)(2-n) + \epsilon\,(2n-6k+5)] / 2\,(n+1)^2$

which is negative for $n > 3$.

∎

It is quite obvious from (3) and (6) that both demand functions are linear and the absolute value of the market demand function is bigger than that of the socially-optimal demand function for licenses. If they ever intersect it is for low values of k and n. Hence, we can get the following corollary,

Corollary.- Under the conditions of proposition 2, the difference between the private and social reservation price for a given number of licenses grows with the number of licenses sold.

Proof.-

From (3) and (6) it is simple to check that

$$\frac{dr^m}{dk} - \frac{dr^s}{dk} = \frac{3}{2(n+1)^2} > 0$$

∎

These results state that when the patent holder sells a number of licenses that is below the number of firms in the industry, the private demand for licenses is above the social demand. Consequently, if the patent holder faces an oligopolistic industry buying his licenses, a market failure may result in too many licenses demanded at a price that is too high from a social point of view.

The explanation for this market failure has to be found in the different value given to the license by the social planner and by each oligopolist. For the social planner, a new license sold increases social welfare because average costs in the industry are reduced, total output expands and price falls which results in an increase in consumer surplus. However, for each new licensee that buys the license there is a double source of benefits from buying the license:

a) first, he gets a direct benefit from reducing his marginal cost, that is offset to a certain extent by the resulting reduction in the price of the final good that he sells,

b) but secondly, there is an indirect gain arising from the increase of his market share at the expense of his licensed and non-licensed competitors. This gain is larger the larger the number of already existing licensees is, and this explains our corollary.

This second source of profits is very important for our result because it is not present in the benefits from the innovation that the social planner computes being just a transfer of profits across firms.[55]

The source of this market failure can also be described as deriving from the fact that if the number of licenses sold is less than the number of firms in the industry, there is a socially optimal number of licenses, but while the social planner is indifferent about the identity of those firms, each oligopolist strives to avoid being one of the non-licensees. The cost of this struggle to avoid the disadvantage of having high marginal costs is lower for each oligopolistic competitor than for the whole society, and as a result, it is possible that too many licenses are sold at a too high price.

Before concluding this section, it is important to notice that proposition 2 also applies in the case $k > [a-c]/\epsilon$, because for those values of k

(8) $$r^{s} - r^{p} = \frac{-2k^2 + 2k + 1}{2k^2 (k+1)^2} < 0$$

55 Similar kinds of effects have been obtained before in different contexts by Fudenberg and Tirole (1985) and Quirmbach (1986) The later proves that a joint venture will adopt a new process technology more slowly than a non-cooperative group of firms, as the former will take into account the negative effects of the adoption on the profits of the other members of the joint venture, while the non-cooperative firm will not take those effects into account. The introduction of the paper by Fudenberg and Tirole deals on the difference between the two benefits that accrue to the innovator in a model concerning timing of adoption, but the social welfare consequences of that difference are not explored.

But we must remember that in this case, $k = [a-c]/\epsilon$, because both, social and private demand functions become inelastic. Therefore, just part a in proposition 2 could apply here.

IV.2.2.3. The socially optimal equilibrium in the market for licenses.

The results of the previous section provide information about the reaction functions that the patent holder has to face when he has to deal with different types of buyers of the patent. It suggests that the social planner will tend to buy less licenses and to pay a lower price for them than the oligopolistic industry. However, nothing has been said about the actual market equilibrium that would be reached in each case. In principle, for instance, one could think of a situation in which the social planner pays a lower price for the licenses, but buys more licenses than the oligopolistic industry. But to explore this possibility it is necessary to characterize the equilibrium in the market for licenses when the patent holder faces a social planner. The following proposition describes that market equilibrium.

Proposition 3.- If the patent holder faces the reaction function of a social planner buying licenses such as defined in lemma 2, the market outcome, k^s, will be given by

$$(9) \quad k^s = \begin{cases} n & \text{for all } n \leq n_1 \\ \dfrac{2(a-c)(n+2) + \epsilon[2n(n+3)+5]}{4(2n+3)\epsilon} & \text{for } n_1 < n < n_2 \\ \dfrac{(a-c)}{\epsilon} & \text{for } n \geq n_2 \end{cases}$$

where n_1 and n_2 are the values of n that solve respectively,

$$6n_1^2\epsilon + 2[3\epsilon-(a-c)]\, n_1 - 5\epsilon - 4(a-c) = 0$$

and $$2n_2^2\, \epsilon + 6[\epsilon - (a-c)]\, n_2 + 5\epsilon - 8(a-c) = 0$$

Therefore, for values of the parameter $n \leq n_1$, all the existing firms in the industry will become licensees, but for values of n higher than n_2, the patent holder will maximize profits selling a number of licenses less than the number of firms in the market. However, for $n>n_2$, the innovation becomes drastic in the Kamien-Tauman sense, because just the licensees, $(a-c)/\epsilon$ firms, can remain operational in the market, and consequently, the social planner would not want to buy more than that number of licenses. Hence, although for different reasons depending on whether $n \gtrless n_2$ only if $n < n_1$ there will be complete diffusion of the new technology among the previously existing firms.

Now a comparison can be established between the two kinds of market equilibria described in propositions 1 and 3.

<u>Proposition 4.-</u> If we define k^p as the number of licenses sold to the oligopolistic industry, for given values of ϵ, a and c we will have that,

i) if the number of firms in the market $n \leq n_1$, there will be complete diffusion of the licensed technology among the existing firms, irrespective of whether the patent holder is selling them to an oligopolistic industry or to a social planner.

ii) if the number of firms in the industry is such that $n_1 < n \leq 2\,[[(a-c)/\epsilon] + 1]/3$, n licenses will be sold to the oligopolistic industry and $k^s < n$ to the social planner.

iii) if the number of firms in the industry is $2[[(a-c)/\epsilon] + 1]/3 < n \leq 2\,[[(a-c)/\epsilon] - 1]$, the interior solutions are such that $k^p > k^s$.

iv) if the number of firms n is such that $2\,[[(a-c)/\epsilon]-1] < n < n_2$, then $k^p = ([a-c]/\epsilon) > k^s$ and finally

v) for $n > n_2$, $k^s = k^p = ([a-c]/\epsilon)$.

Proof.- (See annex)

This proposition proves that the market failure commented upon before usually results in fact, in an excessive number of licenses being sold in the market place from the social point of view. In those other cases in which we have a corner solution for both demand curves, the number of licenses sold is the same. However, in those cases, the oligopolists acting individually will pay a license fee that will be higher than the fee that the social planner would be willing to pay for the same number of licenses.

Proposition 5.- If $n > 1$, and $k^s = k^p = n$ or $k^s = k^p = (a-c)/\epsilon$, the market equilibrium fee paid in the private market for licenses will be higher than the fee paid if the same number of licenses is sold to a social planner.

Proof.

The proposition follows immediately from expression (7) after substituting the value of k for n and $(a-c)/\epsilon$.

∎

Drawing conclusions about the market equilibrium values of the license fees for the other cases is not simple. However, we can prove the following result,

Lemma 3.- For those values of $n > 3$ such that both k^s and k^p reach interior solutions, the market-equilibrium fixed fee paid by the firms will be smaller than the fee paid by the social planner.

Proof.- (See annex)

IV.3. MARKET VALUE AND SOCIAL VALUE OF THE PATENT.

In the former section it has been established that the private market value of the license for the new technology differs from the social valuation that a central planner would give to the license. But the latter value is a first-best from the social point of view. It gives the best responses from the social point of view that correspond to a given combination of cost reduction and fixed fee per license established by the patent holder.

However, one can still question what is the difference between the private-market cost of the license - as given by the price actually paid by the oligopolist industry for that license -, and the social value of the patent as measured by the increase in social welfare (consumer surplus and profits) that it produces. This question is particularly important in open economies where there is a transfer payment to foreign nationals of the fees collected from the sale of the license. In this case, the contribution of the license to social welfare must be net of those transfers made to the foreign sector.

The social value of the license will be the result of subtracting total social welfare net of the cost of the licenses, when n or k firms have a license allowing them to produce at $[c-\epsilon]$ average costs and total social welfare before the license is introduced, i.e. when n firms produce at constant average costs equal to c.

Instead of analyzing the three possible outcomes corresponding to the cases in which $k=[(a-c)/\epsilon]$, $k=[(a-c)/\epsilon]+[(n+2)/4]$ and $k=n$, we shall concentrate on the last and most interesting one. When $n=k$, the social value of the license will be given by the difference between total welfare when n firms are operating with average costs $[c-\epsilon]$ and c, which given the value of W(n) given above, it will be defined as

$$(10)\quad W(n;c-\epsilon)-W(n;c) = \frac{n(n+2)[a-c+\epsilon]^2}{2(n+2)^2} - \frac{n(n+2)[a-c]^2}{2(n+1)^2} =$$

$$\frac{n(n+2)[2(a-c)\epsilon+\epsilon^2]}{2\,(n+1)^2} = \frac{4n^2\epsilon\,(a-c) + 2n^2\epsilon^2\,(2-n)}{2\,(n+1)^2};$$

Meanwhile, according to Kamien and Tauman (1986, page 476), when k=n the patent holder will receive from the oligopolistic market a total revenue equal to,

$$(11)\quad \pi_{PH} = \frac{4n^2\epsilon^2\,[(a-c)/\epsilon + 1 - n/2]}{2\,(n+1)^2}$$

Therefore, we can conclude that

Proposition 6.- For k=n, the social value of the license net of its cost will be,

$$(12)\qquad W(n;c-\epsilon) - W(n;c) - \pi_{PH} = = \frac{2\,(a-c)\epsilon\,[2n-5n^2] + \epsilon^2\,[4n^3-7n^2+2n]}{2\,(n+1)^2}$$

and consequently,

$$W(n;c-\epsilon) - W(n;c) - \pi_{PH} > 0 \quad \text{iff} \quad 2\,[(a-c)\,/\,\epsilon] > [(4n^2-7n+2)\,/\,(5n-2)]$$

and

$$W(n;c-\epsilon) - W(n;c) - \pi_{PH} < 0 \quad \text{iff} \quad 2[(a-c)/\epsilon] < [(4n^2-7n+2)\,/\,(5n-2)]$$

Note that for relatively small values of n and ϵ as compared to the value of (a-c), which is precisely for the kind of values for which n=k, the numerator in (12) will be negative. Therefore, for those values of our parameters n, ϵ and (a-c), the net effect on welfare of the introduction of the license in the oligopolistic markets may be negative.

This conclusion would not have important implications for closed economies, where the patent holder is just receiving an internal transfer of income from the oligopolists. However, it has important implications in an open context, because it implies that the oligopolistic firms will pay to the foreign patent holder a total revenue, which is above the total welfare increase that the new technology will bring about into the domestic market.

Proposition (6) provides a formal proof to this possible outcome in international licensing, that has often been suggested in the traditional literature on licensing, but which has seldom been presented formally in a strategic context.

IV.4. Licensing of an innovation by means of a fixed fee only: the case of drastic innovations in Arrow's sense.

Kamien and Tauman have shown that in case of a drastic innovation in Arrow's sense, the sub-game perfect equilibrium of the licensing game that has been used above implies just one producer in the market using the new technology in monopolistic conditions.

However, the patent holder in this case does not appropriate fully the monopolist profits of the producer as the latter can always refuse to buy the license and obtain the profits of an oligopolist with n-1 competitors using the old technology. Therefore, the maximum price, r^p, that the patent holder could expect to make for the only license that he will be selling in this case will be the difference between the monopoly profits with costs of $c-\epsilon$, $\pi^m(c-\epsilon)$, and the oligopolist profits with costs c and n competitors, $\pi_i(n;c)$.

From the social point of view, the maximum amount of money that a social planner would be willing to pay for just one license of the drastic innovation will be the following

$$r^s = \pi^m + \delta CS - n\,\pi_i$$

where δCS is the increase in social welfare resulting from the output expansion and the impact of a new monopoly price below the previous marginal cost.

In this case, it is easy to see that the difference between r^p and r^s has an ambiguous sign. This difference is equal to

$$r^s - r^p = \delta CS - (n-1)\, \pi_i(n;c)$$

This difference is an increasing function of

i) n as $\pi_i(n;c) = (a-c)^2/(n+1)^2$

ii) the difference between the old cost and the new monopoly price.

Therefore, for a drastic innovation of a given size, one can expect to find a market failure similar to that commented upon in the previous section. There, the oligopolistic industry was very competitive, but the private market equilibrium produced a price below the socially optimal one if there were just a few competitors in the oligopolistic market.

It is interesting to note here that this result is consistent with another result obtained by Kamien and Tauman (1986), who point out that the patent holder will make more profits from the license as the oligopolistic market approaches perfect competition, $n \to \infty$, because in that case the opportunity cost of not buying the license increases as $\pi_i \to 0$.

IV.5. Caveats and conclusions.

Technology has become a major factor of production in modern industrialized economies. Only those firms and countries having access to up-to-date technology can have access to the economic quasi-rents that are usually the result of imperfect competition in that kind of market. The need to acquire that technology as soon as possible before those quasi-rents are diluted by the effect of competition or by the appearance of new generations of innovations, may distract governments' attention from the price that is being pay for that technology. In many instances, public policy is oriented towards the provision of economic incentives to increase the propensity of domestic firms to buy foreign technology. Sometimes, this policy can take the form of the distribution of information about the characteristics of new technologies, and in other cases, it is implemented by the removal of all the possible obstacles that may hamper the licensing process, or even by direct subsidies for the acquisition of foreign patents.

It has been shown in this chapter that there are reasons to believe that the market allocation of resources to purchase foreign licenses can be in many cases above the social optimum. Competition in oligopolistic markets can lead firms in those markets to bid a price for the license which is above the social optimum. But it also can result in too many licenses sold from a social point of view. Consequently, these results suggest that public policy should pay attention to the amount of domestic resources devoted to licenses, and it should also tend to induce a reduction in the number of licenses bought by the domestic firms.

However, the identification of these market failures should not lead us directly to propose policy actions aimed at reducing the number of licenses bought by the domestic industry. In first place, the limitations in terms of generality of the model presented above are many. Secondly, these conclusions are drawn in the context of a static model of partial equilibrium. This implies that any potential externalities that the new technology could have upon other sectors have not been accounted for. Furthermore, the process of technological change requires very often the accumulation of technological knowledge in the form of know-how that could be derived from having access to different generations of technologies. Therefore, there could be some potentially beneficial effects derived from the license that could "spill over" in time, which are not accounted for in the model.

Finally, the implementation of those policies via taxes or bureaucratic supervision of the process may result in further misallocations of resources, whose magnitude is difficult to compare with the one that has been detected here.

But I think that there are some more interesting lessons that can be learned from this simple exercise.

A) First, it has shown that competitors in oligopolistic markets have strong incentives to get licenses for new technologies, even in the context of Cournot competition, where rivalry is not very strong. As one may expect and the empirical evidence shows, the incentives to licence in this international context are higher than those detected by Katz and Shapiro (1985) for firms operating in the same market. What is not so trivial is that those incentives seem to increase with the number of competitors in the market.

B) The traditional literature on licensing has stressed the importance of ancillary restrains restraints and excessively high prices demanded by the licensor as the main source of concern from a social welfare point of view. Although ancillary restraints require more careful attention, the approach for considering the social desirability of the market equilibrium that has been taken here is totally different to the traditional ones: even in the present context where the patent holder has a "leader" position, it is the competition among oligopolists that results in an excessive allocation of resources to the purchase of licenses. This suggests new possibilities to tackle an old problem with new weapons. For instance, forming a coalition among the buyers of licenses could be an alternative to consider.

C) When countries have to choose between engaging in R&D efforts or adopting a passive attitude and acquire foreign technology, the costs of the latter alternative are often not as clear as those of the first one. Another potential source of social costs that may arise from licensing which is not present in the current literature has been pointed out here. It suggests that the market structure of the group of producers using the license has to be considered in order to assess the effects on social welfare of the transfer of technology through licensing.

Proof of lemma 2.-

Case A.

As it was pointed out above, for $k \leq (a\text{-}c) / \epsilon$, the welfare function defined at (5) is increasing and concave in k. Therefore we can ensure that in the domain $[0,(a\text{-}c)/\epsilon]$ there is a k that maximizes (5) as defined in lemma 1. After subtracting the cost of licenses, domestic social welfare is equal to,

$$W(k) = \frac{n(a-c)^2(n+2)+2(a-c)k\epsilon-k^2\epsilon^2}{2(n+1)^2} + \frac{[(a-c)+n-k+1)\epsilon]\epsilon k}{n+1} - kr^d$$

As k is an integer, the socially optimal k will the be the minimum k that makes $W(k) - W(k\text{-}1) = r^d$. The value of function W() for k-1 is easy to get from the expression above. Subtracting both we get,

$$W(k)-W(k-1) = \frac{n(a-c)^2(n+2) + 2(a-c)k\epsilon - k^2\epsilon^2}{2(n+1)^2} +$$

$$- \frac{n(a-c)^2(n+2)+2(a-c)\epsilon(k-1)-(k-1)^2\epsilon^2}{2\,(n+1)^2} - r^d +$$

$$+ \frac{[(a-c)+(n-k+1)\epsilon]\epsilon k - [(a-c)+(n-k+2)\epsilon]\epsilon(k-1)}{n+1}$$

$$= \frac{2\epsilon(a-c) - \epsilon^2[2k-1]}{2(n+1)^2} +$$

$$+ \frac{\epsilon k[(n-k+1)\epsilon-(n-k+2)\epsilon] + \epsilon[(a-c)+(n-k+2)\epsilon]}{n+1} - r^d$$

$$= \frac{2\epsilon(a-c) - \epsilon^2(2k-1)}{2(n+1)^2} + \frac{-\epsilon^2 k + \epsilon[(a-c)+(n-k+2)\epsilon]}{n+1} - r^s$$

$$= \frac{2\epsilon(a-c) - \epsilon^2(2k-1)}{2(n+1)^2} + \frac{2(n+1)[(a-c)\epsilon + n\epsilon^2 - 2k\epsilon^2 + 2\epsilon}{2(n+1)^2} - r^s$$

$$= \frac{2(a-c)\epsilon(n+2) + \epsilon^2[2n^2+6n-4kn-6k+5]}{2(n+1)^2} - r^s$$

$$= \frac{\{2(a-c)(n+2) + \epsilon[2n(n+3)-2k(2n+3)+5]\}\epsilon}{2(n+1)^2} - r^s$$

The social planner will buy licenses until the point in which the last license sold will make $W(k)-W(k-1)=0$, i.e.

$$r^s = \frac{\{2(a-c)(n+2) + \epsilon[2n(n+3)-2k(2n+3)+5]\}\epsilon}{2(n+1)^2}$$

<u>Case B.</u>

For case B, we depart from (5') and subtract its value at k-1 from W(k) getting,

$$W(k) - W(k-1) = \frac{k^3(k+2) - (k-1)(k+1)^3}{2\,(k+1)^2\,k^2}\;[a-c+\epsilon]^2 =$$

$$r^s = \frac{2k+1}{2(k+1)^2k^2}\;[a-c+\epsilon]^2$$

∎

Proof of Proposition 3.-

The profits for the patent holder will be given by

$\pi_{PH} = k^S r^S =$

$$= \frac{[2(a-c)(n+2)+\epsilon\{2n(n+3)-2k(2n+3)+5\}]\epsilon}{2(n+1)^2}\;k$$

Maximizing with respect to k we get the following first order condition[56]

$$\frac{d\pi^{PH}}{dk} = \frac{[2(a-c)(n+2)+\epsilon\{2n(n+3)-4k(2n+3)+5\}]\epsilon}{2(n+1)^2} \geq 0$$

and solving for k we get the following interior solution,

$$k^* = \frac{2(a-c)(n+2) + \epsilon[2n(n+3)+5]}{4\epsilon\,(2n+3)} =$$

The corner solution $n = k^*$ will take place for values of $n \leq k^*$ for k^* given by (7) above, i. e. when

$$6n^2\epsilon + [3\epsilon-(a-c)]\,n - 5\epsilon - [2(a-c)/\epsilon + 5/2] = 0$$

which defines n_1.

As one could have expected, the socially-optimal demand function for licenses for case B shows for any value of k a negative marginal revenue equal to

$$\frac{d\,\pi_{pH}}{d\,k} = [a-c+\epsilon]^2\left[\frac{-8k^3 - 14k^2 - 8k - 2}{4\,(k+1)^4\,k^4}\right] < 0$$

Therefore, the patent holder will maximize profits for $k^* = (a-c)/\epsilon$, that is the upper bound of the interior solution described above. This corner solution will occur for values of n bigger or equal to n_2 which is the value of n that makes,

$$\frac{2(a-c)(n_2+2) + \epsilon[2n_2(n_2+3) + 5]}{4\,(2n_2+3)\quad\epsilon} = \frac{a-c}{\epsilon}$$

that can also be expressed as,

$$2n_2^2 + 2[3\epsilon - 7(a-c)]\,n_2 - 5\epsilon + 20(a-c) = 0$$

---

56 It is easy to see that second order conditions for a maximum are fulfilled as the inverse demand function for licenses is concave in k.

This completes the proof.

■

Proof of Proposition 4.-

We shall start by proving part (iii) of the proposition. The interior solution of k^s can be written as

$$k^s = \frac{(a-c)(n+2)}{2\epsilon\,(2n+3)} + \frac{2n(n+3)+5}{4\,(2n+3)}$$

while

$$k^p = \frac{(a-c)}{2\,\epsilon} + \frac{n+2}{4}$$

Note that the first two parts of the RHSs of these expressions are related as follows,

$$\frac{(a-c)(n+2)}{2\epsilon(2n+3)} > \frac{a-c}{2\,\epsilon} \quad \text{for all } n \geq -1 \text{ because} \quad \frac{(n+2)}{(2n+3)} < 1$$

for those values of n. Furthermore, the second parts of the RHSs those expressions are

$$\frac{2n(n+3)+5}{4(2n+3)} > \frac{n+2}{4} \qquad \text{for any } n > 0$$

because $2n^2+6n+5 < 2n^2+7n+6$. Therefore, we can conclude that for a given value of $2[[(a-c)/\epsilon]+1]/3 < n \leq 2[[(a-c)/\epsilon]-1]$, $k^s < k^p$.

(i) and (ii) follow directly from propositions 1 and 3 once we have proven that $n_1 \leq 2[[(a-c)/\epsilon]+1]\,/\,3$. But given that

$$k^p = \frac{(a-c)}{2\epsilon} + \frac{(n+2)}{4} \qquad \text{and}$$

$$k^s = \frac{(a-c)(n+2)}{2\epsilon\,(2n+3)} + \frac{2n(n+3)+5}{4\,(2n+3)}$$

are both increasing and continuous in n, $k^p(n) > k^s(n)$ for all positive values of n implies that $k^p(n)$ intersects $k = n$ for a higher value of n than $k^s(n)$ does.

To prove (iv) and (v), we can see that as $k^p(n) > k^s(n)$ for all positive values of n, $k^p(n)$ intersects the horizontal line $k=[a-c]/\epsilon$ for a smaller value of n. Therefore, $2[[(a-c)/\epsilon]-1] > n_2$ and this completes the proof.

∎

Proof of Lemma 3.-

From section IV.2. we know that the profits of the patent holder are equal to

$$\pi_{pH} = k\, r(k)$$

Optimisation with respect to k requires that

$$r(k^*) = -r'(k^*)\, k^*$$

where k^* is the optimal number of licenses sold at prices $r(k^*)$. In the case of the interior solution of the private market equilibrium,

$r(k^p) = 2n\, k^p$ while in the case of the social planner,

$r(k^s) = (2n + 3)\, k^s$

Therefore, $r(k^p) > r(k^s)$ if and only if

$$k^p/k^s > (2n+3) / 2n$$

Substituting the values of k^p and k^s given by (3) and (6), we can confirm that the previous inequality is equivalent to

$$[a-c] / \epsilon > [4n^2 + 16n + 15] / [4n^2 - 2n - 12]$$

but given that we are in an interior solution to the private market problem, $n \leq 2\,[[(a-c)/\epsilon]-1]$ as shown in proposition 1. This constraint can also be expressed as $([3n/2] - 1) \leq [(a-c)/\epsilon]$. A sufficient condition for

$$[a-c] / \epsilon \geq ([3n/2] - 1) > [4n^2 + 16n + 15] / [4n^2 - 2n - 12]$$

is that $n > 4$.

Arrow K. (1962) "Economic Welfare and the Allocation of Resources for Invention", in **The Rate and Direction of Inventive Activity**, R.R. Nelson ed. Princeton N. Jersey, Princeton University Press.

Fudenberg D. and Tirole J. (1982) "Pre-emption and Rent Equalization in the Adoption of New Technology". **Review of Economic Studies**, vol. LII, pp. 383-401.

Gallini N.T. and Winter R.A.(1985). "Licensing in the Theory of Innovation". **Rand Journal of Economics**, vol. 16, No. 2, Summer, pp. 237-252.

Kamien M.I. and Tauman Y. (1984a). "The Private Value of a Patent: A Game Theoretic Analysis". **Zeitschchrft fur Nationalokonomie**. Supp. 4. pp. 93-118.

-- and -- (1984b) "Fees Versus Royalties and the Private value of a Patent". Discussion Paper No. 583, Centre for Mathematical Studies in Economics and Management Science, Northwestern University.

-- and -- (1986) "Fees Versus Royalties and the Private Value of a Patent". **Quarterly Journal of Economics**, vol. CI, pp. 471-491.

Ireland N.J. (1988) "On Licensing of Innovations and the Maintenance of Competition". Mimeo, Dept. of economics, University of Warwick, January.

Katz M.L. and Shapiro C. (1985) "On the Licensing of Innovations", **Rand Journal of Economics**, vol. 16, pp. 504-520.

-- and -- (1986). "How to Licence Intangible Property". **Quarterly Journal of Economics**, vol CI, pp. 567-589.

Quirmback H.C. (1986) "The Diffusion of New Technology and the Market for Innovation". **The Rand Journal of Economics**, vol.17, No.1, Spring, pp. 33-47.

Sahal D. (ed) (1982) **The Transfer and Utilization of Technical Knowledge**. Heath & Co. Lexington Books. Lexington Mass.

Shapiro C. (1985) "Patent Licensing and R&D Rivalry", **American Economic Review**, vol. 75, pp. 23-30.

Part III Adoption and Diffusion

Chapter V: Sequential Models of Innovation and Market Evolution in Asymmetric Economies

V.1.- Introduction.

Since the early work of Schumpeter, the economic consideration of technological change has been related to the problem of market-structure dynamics. However, when this problem has been reconsidered in a formal way between 1962 and the early 80's, economists have concentrated their studies on the influence of market structure on the rate of technological change, and little attention has been paid to a central issue in Schumpeter's work: the impact of technological change on the evolution of market structure.

Gilbert and Newberry (1982), Kamien and Schwartz (1982) and Reinganum (1983) were the first to question the relative advantages and disadvantages of incumbent firms or new entrants in game-theoretic models of patent races. But in these models only games with just one innovation were considered and they did not explore the impact of a sequence of innovations on the initial market structure.

In Reinganum (1985)[57], this problem was addressed for the first time, but the structure of the model is extremely simplified. Reinganum considers only drastic innovations that preserve the initial monopolistic structure.

---

57 The excellent paper by M.T. Flaherty (1980) which presents a very different approach to that in the papers discussed here, merits special mention.

The class of models that seems to have established itself as "the" appropriate way of approaching and tackling this problem has its roots in Vickers (1986). In this paper, Vickers studies conditions for the persistence of technological leadership by a firm (what he calls "increasing dominance") and for variations in the identity of the firm with lowest marginal costs ("action-reaction" in Vickers terms). Beath et al. (1987) adapt Vickers' model of process innovations to a setting with product differentiation and new product innovations, and Delbono (1988) uses a similar structure to incorporate in the model gradual approximations in the technological level of both firms, although he incorporates important differences in the auctioning process.[58]

In this "family" of models, a sequence of new technologies is produced, and two duopolists that compete in a final-product market bid in an auction for the exclusive right to use a patent. In this auction, there is no strategic conduct whatsoever on the side of the two duopolists, and both players have perfect information, not only about the characteristics of the new technology, but also about their rival. Furthermore, there is no uncertainty about getting the patent and if a firm outbids its rival in the auction, it will win the patent with certainty. In this sense, the game is deterministic, as Delbono admits, and given the parametric data of the game (market conditions and initial cost structure) the final equilibrium is known by each player before the game starts.

In spite of this lack of strategic behaviour in the technology game, these authors establish some links between the type of duopolistic competition in the final-product market and the evolution of the market structure. Leaving aside some qualifications made by Beath et al.,[59] all these authors point out that low (high) levels of competition in the

58 Harris and Vickers (1987) provides a completely different approach to study the influence of technological change on market structure, but, to our knowledge, this line of research has not been developed any further.

59 Beath et al. (1987) have shown that the nature of that relationship depends on the existence of price or product competition in the market for the final good. In a model with product innovation in which different 'generations' of the same product can be sold, they reach conclusions that are the opposite of those obtained by Vikers.

final-product market imply leap-frogging (increasing dominance) in the technological leadership of the market.

All the models of sequential innovation, including Reinganum's, concur in predicting quite simple (sufficient) conditions for the occurrence of permutations in technological leadership. In the real world, we find lots of cases of technological asymmetry between firms competing in national or international markets that are perpetuated over time. Changes in technological leadership are the exception and not the rule. However, it seems hazardous to impute this generality to the existence of high levels of rivalry in the final-product markets. This discrepancy between the predictions provided by economic theory and reality, is a sufficient motivation to examine closely the structure of this family of models, because this could help us to learn to what extent these predictions are induced by the particular way in which the models have been set up.

This is the main concern of this chapter. The predictions of this family of models seem to be highly dependent on the structure of the game, which has many possible equilibria besides increasing dominance and action reaction in technological leadership. The analysis will be carried out in two stages. Firstly, the characteristics of different equilibria in this family of models will be studied using a simplified version of the model proposed by Vickers. In a second stage, the structure of the game will be altered in order to study how these modifications alter the results.

One important feature of these models is that they relate the outcome of the technology game to the market conditions prevailing in the final-good market. Identifying the nature of those relationships will be the purpose of section V.5.. In it, Vickers' results are examined from a comparative-statics point of view. In this way, one can get a better idea about the generality of his results.

In sections, V.2. to V.4., a simplified version of Vickers' model with only two innovations is introduced. Despite its simplicity, this model captures all the features of the models used by Vickers and Beath et al. But this simplification allows to identify the direct benefits that stem from winning the patent, and those derived from the strategic advantage in future auctions that winning today implies. Furthermore, with this simple game structure, we can find necessary and sufficient conditions for four different types of equilibria which are combinations of the two simple types of equilibria studied by other authors.

The last sections of the chapter present several modified versions of the basic model. As the results of these models depend heavily on the structure of the game, it seems that, only by adapting the model to particular cases, can we draw conclusions which are applicable to those cases.

V.2. The Model and Preliminary Results.

The model consists of two different but related games. First, let us assume that two firms producing a perfect substitute compete as duopolists in the market for the final good. On the other hand, a technology game is played by these two firms. Both firms are competitors to gain cost-reducing patents to produce the final good.[60]

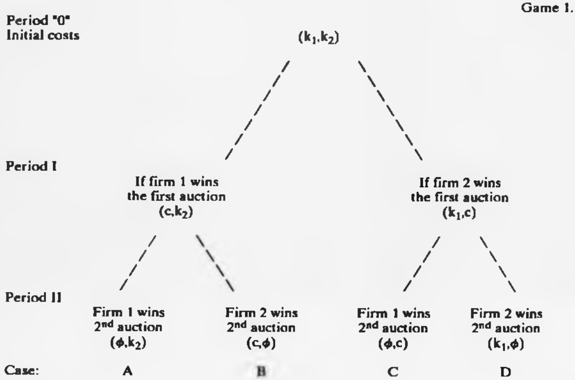
Initially, at time zero, firm 1 has lower constant average costs than firm 2, i.e. $k_1 < k_2$. At the end of this period, two new process innovations are announced and both firms bid for the new patents. The winner of the first patent will be able to produce the final good with average costs "c" during time period I. The winner of the second patent will enjoy average costs $\phi < c < k_1 < k_2$ during period II. The firm with the highest reservation price for each patent will be the winner of the auction. However the winner

60 As Delbono points out, this kind of games are quite general as they can be adapted to study product innovations.

will not have to pay his reservation price to get the patent but just a small amount above the bid made by his rival, i.e. his rival's reservation price. Finally, it will be assumed that the cost reductions brought about by the innovations will not be drastic enough to eliminate the duopolistic market structure.

The nature of the game and the resulting cost structure in each period are shown in game 1.

Game 1.



Note that this collection of cases includes the two cases studied by Vickers: "A" would coincide with what he calls "increasing dominance" and "C" is a three period example of "action-reaction".[61] However, this model includes two extra possibilities which are but

---

61 According to Vickers, there will be "increasing dominance" when the firm that enjoys an initial cost advantage maintains and increases that advantage by winning all the subsequent new patents, while its rival keeps its initial cost level all along the duration of the game. On the contrary, the term "action-reaction" denotes a kind of equilibrium in which the identity of the low-cost firm alternates from one period to the next one. As a certain strand of the literature has kept this nomenclature (see Beath et al. (1987) and Delbono (1988)), we shall adopt it here too.

combinations of the other two. Thus, it is possible that one firm "overtakes" the other but in two periods instead of only one. It is also possible to have one firm passing its rival and building an increasing dominance afterwards.

Nevertheless, Vickers' "non-historical" approach is maintained here, in the sense that one firm can bid for a patent under the same conditions than his rival can, irrespective of the difference in their initial cost levels.

Sub-game perfect equilibrium will be used here as we will require time consistency in the behaviour of the players. The two innovations will be announced at the end of period "0". Both firms will make their calculations about their own and their rival's reservation prices and each one of them will know who will win each patent. Hence, reservation prices for each patent will reflect not only present conditions, i.e. current costs for each firm, but also:

- the "past", because current costs will depend on who won the last patent, and

- the "future", because the identity of the winner of today's auction will have an impact on the future auction. This impact will be twofold. First, whoever wins the second patent will have to face a competitor with a given cost level, and that level will be determined by the outcome of the previous auction. Secondly, the cost levels with which firms face the second auction will have an influence on their respective chances of winning the second auction, but those initial cost levels will be the result of the first auction.[62]

---

62 Alternatively, one could think of a "closed-loop" perfect equilibrium, that would be time consistent forwards too. I have worked out this model, which is not exactly the same, but the main conclusions are basically the same. However, this departure from Vickers' original model has the advantage of allowing to compute the absolute and relative impact of the existence of a second patent race on the firm's reservation prices for the first innovation. In that case, the existence of a second patent raises the reservation price for the first patent in both firms, but this increment is relatively bigger in the initially high cost firm. This asymmetry of the model will be commented later.

In the rest of this section, necessary and sufficient conditions for each type of equilibrium are derived. As it is usual in this kind of model, we shall proceed backwards. For simplicity the effect of discounting will not be taken into consideration.

a. Period II.

As this is the final period, the value of the patent for any firm will be just the difference in current profits for that firm in the only two possible outcomes: when it wins the second patent and when it loses the auction. Each firm will have two different reservation prices depending on who won the first auction.

In cases A and B, i.e. when firm 1, the initially low cost firm wins the first patent, the reservation prices for the second patent for firms 1 and 2 will be,

(1) $P^1_{II} = \pi^1_{II}(\phi,k_2) - \pi^1_{II}(c,\phi)$ and

(2) $P^2_{II} = \pi^2_{II}(c,\phi) - \pi^2_{II}(\phi,k_2)$,

where P_{it} and π_{it} denotes reservation prices and profits for firm i=1,2 in period t=I,II. The first (second) argument in the profit function indicates the cost level for firm 1 (2).

In cases C and D, i.e. when firm 2, the high cost firm at the beginning of the game, wins the first patent, reservation prices will be,

(1') $P^1_{II} = \pi^1_{II}(\phi,c) - \pi^1_{II}(k_1,\phi)$ and

(2') $P^2_{II} = \pi^2_{II}(k_1,\phi) - \pi^2_{II}(\phi,c)$.

Comparing two by two these equations we can know which firm wins the second patent. However, to compute the net payoffs for each firm, we will have to subtract the price of the patent from the profits that it will make in the second period. This will give us the following payoffs, V, for each firm in each case,

Case A:

firm 1: $V^1_{II} = \pi^1_{II}(\phi,k_2) - \pi^2_{II}(c,\phi) + \pi^2_{II}(\phi,k_2) = \sigma_{II}(\phi,k_2) - \pi^2_{II}(c,\phi)$

firm 2: $V^2_{II} = \pi^2_{II}(\phi,k_2)$

Case B:

firm 1: $V^1_{II} = \pi^1_{II}(c,\phi)$

firm 2: $V^2_{II} = \pi^2_{II}(c,\phi) - \pi^1_{II}(\phi,k_2) + \pi^1_{II}(c,\phi) = \sigma_{II}(c,\phi) - \pi^1_{II}(\phi,k_2)$

Case C:

firm 1: $\pi^1_{II} = \pi^1_{II}(\phi,c) - \pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,c) = \sigma_{II}(\phi,c) - \pi^2_{II}(k_1,\phi)$

firm 2: $V^2_{II} = \pi^2_{II}(\phi,c)$

Case D:

firm 1: $V^1_{II} = \pi^1_{II}(k_1,\phi)$

firm 2: $V^2_{II} = \pi^2_{II}(k_1,\phi) - \pi^1_{II}(\phi,c) + \pi^1_{II}(k_1,\phi) = \sigma_{II}(k_1,\phi) - \pi^1_{II}(\phi,c)$

where σ_{II} are the industry joint profits in period two.

b. Period I.

Reservation prices for the first patent will capture the influence of the result of the first auction on the second one. For that purpose, it is necessary to define the value functions, for each firm, of winning and losing the first auction.

Let $\mu_i(r,s)$ be the present value of all present and future net auction bids for firm $i = 1,2$, when firm 1 has costs r and firm 2 has costs s. Hence, if firm 1 wins the bid for the first patent, its value function will be,

$$\mu_1(c,k_2) = \pi^1{}_I(c,k_2) + \max\{\pi^1{}_{II}(\phi,k_2) + \pi^2{}_{II}(\phi,k_2) - \pi^2{}_{II}(c,\phi),\ \pi^1{}_{II}(c,\phi)\} \quad \text{or,}$$

(3) $$\mu_1(c,k_2) = \pi^1{}_I(c,k_2) + \max\{\sigma_{II}(\phi,k_2) - \pi^2{}_{II}(c,\phi),\ \pi^1{}_{II}(c,\phi)\}$$

while, if firm 1 loses the bid for the first auction, we will have,

$$\mu_1(k_1,c) = \pi^1{}_I(k_1,c) + \max\{\pi^1{}_{II}(\phi,c) + \pi^2{}_{II}(\phi,c) - \pi^2{}_{II}(k_1,\phi),\ \pi^1{}_{II}(k_1,\phi)\} \quad \text{or,}$$

(4) $$\mu_1(k_1,c) = \pi^1{}_I(k_1,c) + \max\{\sigma_{II}(\phi,c) - \pi^2{}_{II}(k_1,\phi),\ \pi^1{}_{II}(k_1,\phi)\}$$

As firm's 1 reservation price for the first patent is just the difference between the maximum profits that this firm will make if it wins the auction and the profits resulting from losing the auction, this price, $P^1{}_I$ will be

(5) $$P^1{}_I = \mu_1(c,k_2) - \mu_1(k_1,c)$$

Similarly, this reservation price for firm 2 could be defined as,

(6) $$P^2{}_I = \mu_2(k_1,c) - \mu_2(c,k_2) \qquad \text{where}$$

(7) $$\mu_2(k_1,c) = \pi^2{}_I(k_1,c) + \max\{\sigma_{II}(k_1,\phi) - \pi^1{}_{II}(\phi,c), \pi^2{}_{II}(\phi,c)\} \qquad \text{and}$$

(8) $$\mu_2(c,k_2) = \pi^2{}_I(c,k_2) + \max\{\sigma_{II}(c,\phi) - \pi^1{}_{II}(\phi,k_2), \pi^2{}_{II}(\phi,k_2)\}$$

c. *Definition of equilibria*

From the definitions above, one can conclude that the necessary and sufficient conditions to have "increasing dominance" (case A), as the equilibrium in our game, will be those that enable us to have at the same time

$P^1_I > P^2_I$ and $P^1_{II} > P^2_{II}$

and the equilibrium will bring "action-reaction" (case C) if and only if

$P^1_I < P^2_I$ and $P^1_{II} > P^2_{II}$

Finally, for the other two equilibria we have,

$P^1_I > P^2_I$ and $P^1_{II} < P^2_{II}$ in case B and

$P^1_I < P^2_I$ and $P^1_{II} < P^2_{II}$ in case D.

Before establishing the equilibrium conditions of the game, it may be interesting to specify some of its characteristics. The main ones are the following:

1.- The game is finite, and the cost structure after the last auction will have an impact on the last period current profits only. If we assume that both firms keep on competing in the product market after the technology game has finished, the reservation price for the last patent will be higher for both firms, and this will have induced effects on the other previous auctions.

2. As patents are allocated in auctions, only the winner has to incur in costs in the patent race. In this way, we lose one of the most important features of R&D races. As Dasgupta (1988) and others have pointed out, in patent races, losers do not get any return to their efforts and winners get all the rewards. Here, there is no cost derived from losing an auction other than operating with higher costs in the product market. Hence, an important incentive to win the patent is not being taken into account here. A priori, there is no reason to believe that this incentive will be different for each firm, (unless some kind of asymmetry in the R&D costs, which each firm has to incur in order to achieve the same innovation, is added to the initial cost asymmetry between firms).

3.- The auctioning process has some peculiarities that do have a strong influence on the outcome of the game, as will be shown in the next section. Who wins the patent is determined by the difference in reservation prices, but the cost of the patent is equal to the bid made by the firm that loses the auction. This implies that winning today's auction has an impact on future auctions. This influence is twofold: first, it determines who will be the low cost firm in the next auction, and second, it has an indirect effect on the reservation prices for the next patent, and hence, on the possibilities of winning that next patent and on the payoffs derived from doing so.

With these considerations in mind, let us proceed with the characterization of each kind of equilibrium.

V.3. Necessary and Sufficient Conditions for Each Kind of Equilibrium.

In the game described in the former section, the identity of the winner of the second auction will depend just on the sign of the following two expressions,

(9) $\sigma_{1I}(\phi,k_2) - \sigma_{1I}(c,\phi)$ and

(9') $\sigma_{1I}(k_1,\phi) - \sigma_{1I}(\phi,c)$

If firm 1 is the low-cost firm and (9) is positive (negative), firm 1 (2) will win the second and final patent. But if firm 2 is the low cost firm and (9') is positive (negative) firm 2 (1) will be the winner of the second patent.

The identity of the winner of the first auction depends on the sign of $(P^1{}_1 - P^2{}_1)$. But note that the "max" expressions in (3), (4), (7) and (8) will depend precisely on the sign of (9) and (9'). This relationship reduces the possible specifications of differences between $P^1{}_1$ and $P^2{}_1$ as defined in (5) and (6) to only four possible cases. These are expressed by equations (10)-(13) that summarise the values of the differences in reservation prices for first patent that the two companies will have depending on the outcome of the second auction :

$$(10)\quad P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(\phi,k_2) - \sigma_{II}(\phi,c) + \pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) - \sigma_{II}(\phi,c)$$

$$(11)\quad P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(\phi,k_2) - \sigma_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) - \pi^1_{II}(k_1,c)$$

$$(12)\quad P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + \pi^2_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2)$$

$$(13)\quad P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + 2\sigma_{II}(c,\phi) - \pi^1_{II}(k_1,\phi) - \sigma_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2)$$

Following the process of elimination that can be found in the appendix, (9) and (9') together with (10)-(13), these necessary and sufficient conditions for each type of equilibrium can be obtained,

Case "A" will occur if and only if:

A1.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) > 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) > 0$ and

$\sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(\phi,k_2) - 2\sigma_{II}(c,\phi) + \pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) > 0$

or if

A2.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) > 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) < 0$ and

$\sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(k_2,\phi) - \sigma_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) - \pi^1_{II}(k_1,\phi) > 0$

Case "B" will occur if and only if:

B1.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) < 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) < 0$ and

$\sigma_I(c,k_2) - \sigma_I(k_1,c) + 2\sigma_{II}(\phi,c) - \sigma_{II}(\phi,k_1) - \pi^1_{II}(k_1,\phi) - \pi^2_{II}(\phi,k_2) > 0$

or,

B2.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) < 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) > 0$ and

$$\sigma_I(c,k_2) - \sigma_I(k_1,c) + \pi^2_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2) > 0$$

Case "C" will occur if and only if:

C1.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) < 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) > 0$ and

$$\sigma_{II}(\phi,k_2) - \sigma_{II}(\phi,k_1) + \pi^2_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2) < 0$$

or,

C2.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) > 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) > 0$ and

$$\sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(\phi,k_2) - 2\sigma_{II}(c,\phi) + \pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) < 0$$

Case "D" will occur if and only if:

D1.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) > 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) < 0$ and

$$\sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(k_2,\phi) - \sigma_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) - \pi^1_{II}(k_1,\phi) < 0$$

or,

D2.- $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) < 0$; $\sigma_{II}(c,\phi) - \sigma_{II}(\phi,k_1) < 0$ and

$$\sigma_I(c,k_2) - \sigma_I(k_1,c) + 2\sigma_{II}(\phi,c) - \sigma_{II}(\phi,k_1) - \pi^1_{II}(k_1,\phi) - \pi^2_{II}(\phi,k_2) < 0$$

V.4. Direct and Induced Effects and the Vickers Assumption.

The necessary and sufficient conditions presented above are a generalization of the results in Vickers (1986). In his paper, Vickers concludes that the following assumption is sufficient to have action-reaction in an n-period model:

<u>Assumption 1</u> (Vickers).- For any period t and cost levels $k>0$, $c>0$ such that $k>c$,

$$\sigma_t(c,k+\epsilon) < \sigma_t(c,k)$$

i.e. industry joint profits will be higher the lower the cost level of the high-cost firm is.

However, the inverse of assumption 1, (i.e., that joint profits are increasing with respect to the cost of the high-cost firm), is not sufficient to ensure increasing dominance. For this later case, Vickers only provides a necessary condition, namely, that the high cost firm is making zero profits.

As assumption 1 is fulfilled in the Cournot-Nash case with linear demand function, Vickers goes on to identify action-reaction in the technology game with low levels of rivalry in the market for the final good that both firms produce. On the contrary, in his second proposition, Vickers finds that zero profits in the high cost firm is a necessary condition for increasing dominance.[63] From there, Vickers concludes that a high level of rivalry in the output market is a necessary condition for a stable condition of increasing dominance in the technology game.

Before considering those conclusions, let us see what is the economic interpretation to these results. In a recent paper, Beath et al. (1989) point out the two kinds of incentives that oligopolistic firms with different costs have in patent races. First, there is the incentive provided by the cost reduction that the patent will produce. If two firms have different average production costs, they will have different incentives to engage in a cost reducing investment. This incentive is independent from the fact that firms are competing in a patent race, and it can be computed as the difference in profits made by the firm with and without the patent. But on the other hand, oligopolistic firms will also compete for a patent because there is a competitive threat in patent races: losing a patent race implies that a rival has won it, and hence, you will face a stronger competition in the product market, in other words, there are benefits derived from being the first to innovate. The magnitude of this incentive can be known only in an indirect way.

---

63 This is consistent with our sufficient conditions A1 and A2.

In any case, in the race for just one patent, without any further future innovations (as it happens with the second patent in our model), the sum of these two effects for each firm is reflected by reservation prices such as those given in (1) and (2), and it will be called direct effect. Which firm will have the highest total incentive or reservation price will depend on the sign of expressions (9) or (9'). This is clear because the profit incentive can be measured as,

$$\Omega^1 = \pi^1(\phi,k_2) - \pi^1(c,k_2) \quad \text{and} \quad \Omega^2 = \pi^2(c,\phi) - \pi^2(c,k_2)$$

and the total effect is given by (1) and (2). The incentive derived from the competitive threat will be the difference between,

$$P^1 - \Omega^1 = \Phi^1 = \pi^1(c,k_2) - \pi^1(c,\phi)$$

$$P^2 - \Omega^2 = \Phi^2 = \pi^2(c,k_2) - \pi^2(\phi,k_2)$$

Consequently, the differences in profit incentives and incentives due to the competitive threat can be defined as:

(14) $\Omega^1 - \Omega^2 = [\pi^1(\phi,k_2) - \pi^1(\phi,c)] + [\pi^1(k_2,c) - \pi^2(k_2,c)]$

(14') $\Phi^1 - \Phi^2 = [\pi^1(k_2,\phi) - \pi^1(c,\phi)] + [\pi^2(k_2,c) - \pi^1(k_2,c)]$

Note that the last two terms in brackets in (14) and (14') have the same absolute value but different sign, and therefore, they cancel out and the combined effect of the profit incentive and the competitive threat is just the result of the addition of the first two terms. Furthermore, notice that this combined effect is equal to (9) and consequently, its sign will be the same as that of (9). However, which incentive will be greater in absolute value for each firm depends not just on the sign of (9) but also on the relative difference in profits between the two firms prior to the auction, i.e. the second term in brackets.

As a matter of fact, the combined direct effect can be positive or negative, irrespective of the sign of (14) and (14'). However, which firm will have a higher incentive to get the patent coming from the profit incentive or from the competitive threat will depend on the initial cost difference between k_2 and c. Actually, for a given value of the terms in (9), if the initial cost difference is relatively small, the profit incentive will be greater for the low cost firm, and the competitive threat will be greater for the high cost firm, but which one will be dominant will depend just on the sign of (9). This is so because the first term in brackets in (14) will always be positive and the first term in brackets in (14') will always be negative, but (14) will turn negative only if the cost asymmetry between c and k_2 is big enough to make $[\pi^1(k_2\text{-}c) - \pi^2(k_2\text{-}c)]$ negative and big enough, and (14') will turn positive only if $[\pi^2(k_2\text{-}c) - \pi^1(k_2\text{-}c)]$ is positive and big enough. On the other hand, if the initial cost difference is relatively large, the profit incentive will be greater for the high cost firm, and the incentive derived from the competitive threat will be greater for the low cost firm, but again, the net effect will be given by the sign of (9).

In a model with a sequence of innovations and patent races, the combination of these two effects still remains and can be found in the terms $\sigma(c,k_2) - \sigma(c,k_1)$ in (10)-(13). However, when a sequence of innovations is considered, the former two incentives are not the only ones. In the particular auctioning system considered here (as well as in Vickers (1986) and others), the following effects, that will be called induced effect, are introduced in the n-1 first auctions:

1- If a given firm wins today's auction, that firm will become the low cost firm in the next period, and consequently, that firm will have lower or higher incentives to win the next auction, depending on the sign of (9) and (9'). That will have a negative or positive influence of the willingness to pay for the patent currently being auctioned. Hence, the direct effect that arises from the profit incentive and from the competitive threat can be reinforced or offset by the existence of future auctions.

2- If a given firm wins today's auction and (9) and (9') are negative, his competitor will have a higher direct net incentive to win tomorrow's race. Consequently, to win tomorrow's patent, our firm will have to pay a higher price for it, as his rival's reservation price will be higher. Again, this effect will encourage or discourage firms to win today's patent depending on the sign of (9).

V.5. Discussion of Equilibria.

The necessary and sufficient conditions in A1, A2, B1, B2, C1, C2, D1 and D2, capture the influence of the direct and induced effects for the two auctions. They are obtained from all the possible combinations of expressions (9), (9') and (10) to (13).

It is interesting to notice that, for instance, the cases of increasing dominance in A1 and action-reaction in C2 have in common some necessary conditions. Namely both require that

(9) $\sigma_{11}(\phi,k_2) - \sigma_{11}(c,\phi) > 0$ and

(9') $\sigma_{11}(k_1,\phi) - \sigma_{11}(\phi,c) < 0$

These conditions imply that the low cost firm at the time when the second auction takes place will win that auction too, only if that firm is the firm with low costs at the beginning of the game. But if firm 2 is the low cost firm at the time of the second auction, then it will lose that auction. Hence, no matter what happens in the first auction, firm 1 will win the second one.

However, in both cases there is a third condition which is determinant to have either action-reaction or increasing dominance, because this condition gives us the winner of the first auction i.e.

$$\sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(\phi,k_2) - 2\sigma_{II}(c,\phi) + \pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) \gtrless 0$$

Leaving aside the direct effect of the first auction, the effect induced by the existence of a second auction is:

$$\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) + \pi^1_{II}(\phi,k_1) + \pi^2_{II}(\phi,k_2) - \sigma_{II}(c,\phi) =$$
$$= \sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) + \sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) + \pi^1_{II}(\phi,k_1) - \pi^1_{II}(\phi,k_2)$$

This effect will be either negative or positive but with a small absolute value. Hence, only if the direct effect of the first auction is negative, i.e.. favourable to firm 2, and relatively large in absolute value, we can expect action-reaction. Otherwise, increasing dominance will normally result when (9)>0 and (9')<0.

Cases C1 and B2 require (9)<0 and (9')<0. If these conditions are met, action-reaction occurs but not necessarily in the first auction. Note that in this case, the signs of (9) and (9') fulfil assumption 1 and if this assumption remains valid for the direct effect in the first auction, action-reaction is the only possible outcome. In fact, the induced effect here is ,

$$\pi^2_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2) < 0$$

and hence, it is always favourable to firm 2, i.e. the initially high cost firm. If the direct effect in the first auction is favourable to the initially low cost firm and it offsets the induced effect, action-reaction will occur but only after one period of increasing dominance. Obviously, assumption 1 ensures that the high cost firm will win the second auction.

The inverse to assumption 1 arises when both (9)>0 and (9')>0. Then we can have increasing dominance, A2 or increasing dominance for firm 2 after action-reaction in the first period, D2. As Vickers points out, contrary to what might be expected, this is not a sufficient condition to have increasing dominance. Here, the direct effect in the second auction is always favourable to the firm that won the first one, and hence, it is just the opposite to what happens when (9) and (9') are both negative. However, the induced effect does not always reinforce the direct effect now. It is equal to:

$$[\sigma_{II}(\phi,k_2) - \sigma_{II}(k_1,\phi)] + [\pi^2_{II}(\phi,k_2) - \pi^1_{II}(k_1,\phi)]$$

which has no definite sign. Notice that the second term in brackets is always negative and this will counteract the positive direct effect. Ultimately, the sign of the induced effect will depend on the relative values of $\sigma_{II}(\phi,k_2)$ and $\sigma_{II}(k_1,\phi)$. If $\sigma_{II}(\phi,k_2)<\sigma_{II}(k_1,\phi)$, the induced effect will be negative and favourable to the second firm. Consequently, one can conclude that although the reverse to assumption 1 plays has a contrary influence over the direct effect than assumption 1, it is the induced effect what does not provide sufficiency to ensure increasing dominance.[64]

Finally, if (9)<0 and (9')>0, cases B1 and D2 can arise. Here, the direct effect in the second auction is always favourable to firm 2, the initially high cost firm. The induced effect in the first auction is,

$$2\sigma_{II}(\phi,c) - \sigma_{II}(k_1,\phi) - \pi^1_{II}(k_1,\phi) - \pi^2_{II}(k_2,\phi) < 2\sigma_{II}(\phi,c) - \sigma_{II}(k_2,\phi) - \sigma_{II}(k_1,\phi)$$

that can be positive or negative depending on the absolute value of the differences in (9) and (9').

From the discussion above some conclusions can be drawn already about the structure of this kind of model:

64 As we will see in the second part of the chapter, the way the induced acts on present auctions depends on the way the game is designed, and the reverse of assumption 1 can be a sufficient condition to guarantee increasing dominance in a modified game

1. firstly, assumption 1 (i.e. if industry joint profits are higher the lower the cost level of the high-cost firm are), and its reverse are central to determine the sign of the direct effect, but,

2. the complete evolution of market structure is complemented by the induced effect, and the influence of this effect depends on the way the game has been modelled.

In the next section, the implications of assumption 1 are examined. The rest of the chapter consists of several alternative versions of the basic game, which show how the influence of the induced effect varies as new assumptions are introduced in the game.

V.6. JOINT PROFITS AND FIRMS' COSTS.

The direct effect plays a crucial role in determining the outcome of the technology game. This direct effect depends on how joint industry profits change when firm costs change. Under Cournot assumptions, and for a linear demand function, joint industry profits are an inverse function of the cost level of the high cost firm. Furthermore, zero profits in the high cost firm is a necessary condition for increasing dominance. Based on these two results, Vickers (1986) identifies a certain relationship between rivalry in the product market and rivalry in the technology game. A particular version of assumption 1 will help us to explore the generality of Vickers' results using comparative statics.

From Dixit (1984) one can conclude that in any duopolistic structure with constant marginal costs $c_1 > c_2$ and product homogeneity, when the high cost firm changes its cost levels, assumption 1 can be expressed as

(15) $(d\sigma/dc_1) = (d\pi_1/dc_1) + (d\pi_2/dc_1) < 0$ with

(15a) $(d\pi_1/dc_1) = -\Gamma^{-1}[p_2 x_1 a_1 (v_1 - r_2)] - x_1$ and

(15b) $(d\pi_2/dc_1) = \Gamma^{-1}[x_2 p_1 a_2 (1 - r_2 v_2)]$

where

$$\Gamma = \begin{vmatrix} \delta^2\pi_1 / \delta x_1^2 & \delta^2\pi_1 / \delta x_2^2 \\ \delta^2\pi_2 / \delta x_1^2 & \delta^2\pi_2 / \delta x_2^2 \end{vmatrix} > 0$$

$a_1 = \delta^2\pi_1/\delta x_1^2 < 0$; $a_2 = \delta^2\pi_2/\delta x_2^2 < 0$; [65]

v_i = conjectural variation for the i^{th} firm,

x_i = output of the i^{th} firm,

$p_i = (\delta p(x_1,x_2)/\delta x_i)$

and r_i = is the slope of firm i's reaction function.

The cross effect ($d\pi_2/dc_1$) is always non-negative, but the effect of a change in the costs of the high cost firm on its own profits can go either way. There is a negative direct effect represented by $-x_1$, but there is an indirect effect acting via quantities that can reinforce or offset this direct effect.

It is easy to check that for a general Cournot-Nash equilibrium with constant marginal costs, $v_i=0$ and

(16) $d\sigma/dc_1 < 0$ if and only if $-p_2x_1a_1r_2+x_2p_1a_2 < x_1\Gamma$ or

$d\sigma/dc_1 > 0$ if and only if $-p_2x_1a_1r_2+x_2p_1a_2 > x_1\Gamma$

With a linear demand function, the expressions above can be reduced to:

$d\sigma/dc_1 \gtrless 0$ iff $2(p_1)^2[x_1-x_2] \gtrless x_1\Gamma$

but the left hand side of this expression is always negative because $x_1 < x_2$ and consequently, $d\sigma/dc_1$ is always negative as Vickers finds out. However, it is not possible to generalize this result from (16) above to any kind of demand function without further

65 These sign conditions are required by stability assumptions (see Dixit (1984)).

elaboration. Note that in the left hand side of (16), the first term is negative while the second is positive while the right hand side of (16) is also positive.

As regards to the inverse of assumption 1, (15) suggests that it will usually arise in cases of intense competition between the two firms in the product market. But this result is also subject to some qualifications. When there is competition in that market, the conjectural variations will approach one as the product becomes perfectly homogeneous and then, $[v_1 - r_2]$ will be negative as Dixit proves for the normal case when $r_2 < 0$. As a result, (15a) will have a positive component and a negative one. (15b) will not have any influence here as it will be equal to zero.

The former discussion points out that there is some kind of link between market structure and the sign of the direct effect in the technology game. However, this link cannot be generalized in the sense that Vickers does when he establishes that

> "(the conjectural variation) is regarded by some people as an index of 'competitiveness' since collusion is approached as the conjectural variation approaches 1 and Bertrand behaviour is approached as the conjectural variation approaches -1. In this language, it can be stated that in a single patent race, the incentive of the high cost firm minus the incentive of the low cost firm increases as behaviour in the product market becomes less competitive and more cooperative" (...) "...assumption 1 is likelier to hold as behaviour in the product market is less competitive". [Vickers (1986) p.11].

Demand conditions seem to play an important role in the sign of the direct effect as can be seen from expression (15), although the conjectural variations also have an important influence. However, simulations with a linear demand function $p=100-x_1-x_2$, $c=20$ and $v_1=v_2=0{,}5$ show that joint industry profits fall when the costs of the high cost firm fall from 39 to 37 but increase if they fall from 23 to 21 for instance.

This kind of result, besides product differentiation,[66] could help to explain the different results obtained by Vickers and Beath et al.. But in sequential models of innovation, the induced effect plays a crucial role in the outcome of the technology game. In the next sections, a series of variations to the basic model proposed by Vickers are presented in order to study how his conclusions are modified as the structure of the game varies.

V.7. Sequential Innovations With Free Diffusion.

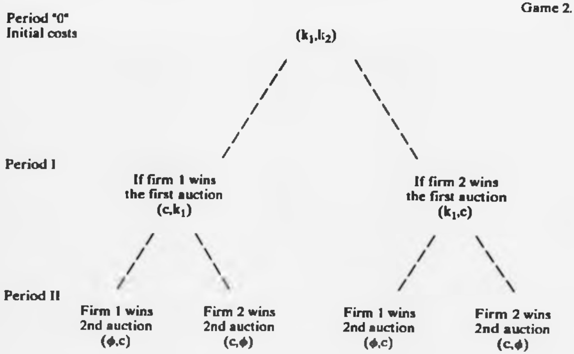
It has been argued often that one of the market imperfections associated with the technology markets is due to the low cost of transmission of the information, which facilitates almost free diffusion of some technologies. This has been considered as factor playing in favour of the high cost firms and countries. However, in case of "free diffusion" in game 1 - i.e. if at the beginning of each period the high cost firm can use the technology abandoned as obsolete by its rival at zero cost- the structure of the game is simplified and the influence of future innovations is lost. In other words, with free diffusion there is no difference between a game with a sequence of innovations and a sequence of games with only one innovation each. Nevertheless, this model is also valid for any number of time periods, as long as the patents give an exclusive access to the new technology but just for one period of time.

In this setting, the action-reaction equilibrium is as likely as any other and it does not depend on the assumption 1.

66 Note that under product differentiation, conjectural variations are not symmetric in the competitive case as they will be $v_i = -(p^1{}_i/p^1{}_j)$.

Let us assume the same game structure as in game 1. However, it will be assumed that at the beginning of each period, the high cost firm can use for free the technology abandoned as obsolete by its rival. This gives the following game 2.

Game 2.



Note that now, only two final price structures remain but the number of possible equilibria is still four. If the final price structure is (ϕ,c) the payoffs of the second period to firm 1 are,

$$\mu_1 = \sigma(\phi,c) - \pi^2{}_{II}(c,\phi)$$

and to firm 2 are,

$$\mu_2 = \pi^2{}_{II}(\phi,c)$$

but if the final price structure is (c,ϕ),

$$\mu_1 = \pi^1{}_{II}(c,\phi) \quad \text{and} \quad \mu_2 = \sigma(c,\phi) - \pi^1{}_{II}(\phi,c)$$

From here, it is easy to define the reservation prices for the first innovation as,

$$P^1_I = \pi^1_I(c,k_1) + \max[\sigma(\phi,c) - \pi^2_{II}(c,\phi), \pi^1_{II}(c,\phi)] -$$
$$- \pi^1_I(k_1,c) - \max[\sigma(\phi,c) - \pi^2_{II}(c,\phi), \pi^1_{II}(c,\phi)]$$

$$P^2_I = \pi^2_I(k_1,c) + \max[\sigma(\phi,c) - \pi^1_{II}(\phi,c), \pi^1_{II}(\phi,c)] -$$
$$- \pi^2_I(c,k_1) - \max[\sigma(\phi,c) - \pi^1_{II}(\phi,c), \pi^2_{II}(\phi,c)]$$

Conditions to know which firm will win the first innovation are derived from the difference between P^1_I and P^2_I, but

$$P^1_I - P^2_I = \sigma(c,k_1) - \sigma(k_1,c) = 0$$

Thus, no firm shows a reservation price different from its rival's in any auction and who will win is not known. Note that the initial asymmetry between firms is lost after one period and has no influence on the outcome of the game.

In terms of our discussion in section V.4., what free diffusion introduces is a substantial difference in the technology game. First, the induced effect is the same for both firms. But second, this is due to the fact that, with free diffusion the technology game is no longer a patent race: the firm losing one auction can still improve its technology, not as much as the winner, but it will have lower production at no cost at all. Using a terminology introduced by Dasgupta, firms are indifferent between fighting for the patent in the auction and waiting.

Finally, note that action-reaction still remains as a possible equilibrium, but assumption 1 has no influence on its appearance. However, free diffusion ensures that increasing dominance will exist only if $k_2 - k_1 < c - k_1 < \phi - c$.

V.8. Sequential Innovation With No-Reversible R&D costs.

As we pointed out before, in the models by Vickers and Beath et al. R&D costs are reversible as the firm not winning the patent does not incur into any R&D cost. This is not the case in real life as any firm competing for an innovation has to incur into positive R&D costs while only the winner will obtain some reward for these expenses. Furthermore, in the models mentioned above, firms always enter the patent race. This is logical when this is free, but if there is some non-reversible cost in joining the patent race, firms will have to decide first whether to enter the patent race or not.

```
                         Firm 1
                     /           \
                    /             \
                   /               \
                  /                 \
                 /                   \
             Enter                Do not enter
              /                          \
          Firm 1                        Firm 2
         /      \                      /      \
     Enter    Do not enter          Enter    Do not enter
       /            \                 /            \
      /              \               /              \
```

Payoffs:

If $\sigma(\phi,k) > \sigma(c,\phi)$
$V^1 = \pi^1(\phi,k) - \pi^2(c,\phi) + \pi^2(\phi,k)$
$V^2 = \pi^2(\phi,k) - z$

If $\sigma(\phi,k) < \sigma(c,\phi)$
$V^1 = \pi^1(c,\phi) - z$
$V^2 = \pi^2(c,\phi) - \pi^1(\phi,k) + \pi^1(c,\phi)$

$V^1 = \pi^1(\phi,k) - z$
$V^2 = \pi^2(\phi,k)$

$V^1 = \pi^1(c,\phi)$
$V^2 = \pi^2(c,\phi) - z$

$V^1 = \pi^1(c,k)$
$V^2 = \pi^2(c,k)$

with $\phi < c < k$

The structure of the game is very simple. Each firm has to pay a fixed amount z to enter the patent race. If both firms joint the race, the firm with the highest reservation price wins it, and that will depend on $\sigma(\phi,k) \gtrless \sigma(c,\phi)$. But in that case, the firm losing the race has to pay the R&D cost z. If one firm joins the race and the other does not, then the first one will win it at a cost equal to z, but the other firm would save that amount. If neither of the two firms enter the race, the innovation is not adopted. It is easy to see that a solution with both firms entering the patent race is not a Nash equilibrium because whatever is the sign of $\sigma(\phi,k)-\sigma(c,\phi)$, the firm losing the auction would win z by not joining the race. The only possible Nash equilibria are:

- firm 1 enters and 2 doesn't if $\sigma(\phi,k)>\sigma(c,\phi)$ and if $\pi^1(\phi,k)-z>\pi^1(c,k)$
- firm 2 enters and firm 2 does not if $\sigma(\phi,k)<\sigma(c,\phi)$ and if $\pi^2(c,\phi)-z>\pi^2(c,k)$

The second condition above is important to avoid no firm joining the race. If the single period game above is expanded to the general game 1 with three periods, we get the following reservation prices for the two firms in period 1:

$$P^1{}_I = \pi^1{}_I(c,k_2) + \max[\pi^1{}_{II}(\phi,k_2) - z\,,\ \pi^1{}_{II}(c,\phi)] - \pi^1{}_I(k_1,c) - \max[\pi^1{}_{II}(\phi,c) - z\,,\ \pi^1{}_{II}(k_1,\phi)]$$

$$P^2{}_I = \pi^2{}_I(k_1,c) + \max[\pi^2{}_{II}(k_1,\phi) - z\,,\ \pi^2{}_{II}(\phi,c)] - \pi^2{}_I(c,k_2) - \max[\pi^1{}_{II}(c,\phi)-z, \pi^1{}_{II}(\phi,k_2)].$$

Note that the second condition implies that the first terms in the brackets are maxima because if we require that $\pi^1(\phi,k)-z>\pi^1(c,k)$ and $\pi^2(c,\phi)-z>\pi^2(c,k)$ the former implies that,

$$\pi^1{}_{II}(\phi,k_2) - z > \pi^1{}_{II}(c,\phi) \text{ because } \pi^1{}_{II}(c,k) > \pi^1{}_{II}(c,\phi) \quad \text{and}$$

$$\pi^2{}_{II}(k_1,\phi) - z = \pi^1{}_{II}(\phi,k_1) - z > \pi^2{}_{II}(\phi,c) = \pi^1{}_{II}(c,\phi)$$

and $\pi^1{}_{II}(c,k) > \pi^1{}_{II}(c,\phi)$ for any $k<c$.[67]

Subtracting $P^2{}_I$ from $P^1{}_I$ we get,

$$P^1{}_I - P^2{}_I = \sigma(c,k_2) - \sigma(c,k_1) + [\pi^1{}_{II}(\phi,k_2) - \pi^1{}_{II}(\phi,k_1)]$$

---

67 Similarly, $\pi^2(c,\phi)-z > \pi^2(c,k)$ implies that $\pi^1{}_{II}(\phi,c)-z > \pi^1{}_{II}(k_1,\phi)$ and $\pi^1{}_{II}(c,\phi)-z > \pi^1{}_{II}(\phi,k_2)$ $\pi^2(c,k) > \pi^2(\phi,k_1) > \pi^2(\phi,k_2)$ for any k.

where the term in brackets at the right hand side is always positive. Therefore, it is possible to conclude that the reverse to assumption 1. i.e. $\sigma_t(c,k+\epsilon) > \sigma_t(c,k)$ is a sufficient condition for increasing dominance.

This result, contrary to Vickers' conclusions, is due to the new structure of the game. Notice that while the induced effect was acting in favour of the second firm in Vickers' model, here, it is always favourable to firm 1. As a result, action-reaction is possible if and only if the direct effect act in the opposite direction and is big enough to compensate the induced effect.

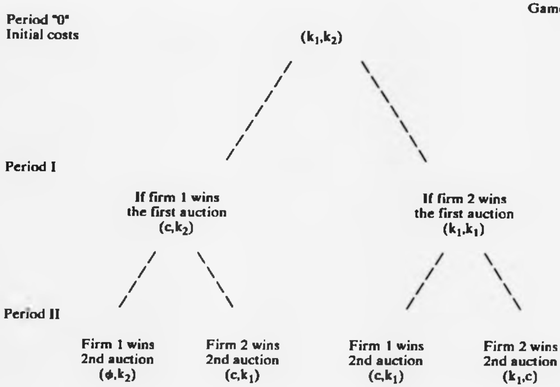
V.9. Differences in the Ability to Adopt New Technologies. ("History Matters").

In game 1 described in section V.2, both firms have the same opportunities to have access to any innovation that is auctioned at the beginning of each period. This is one of the most striking characteristics of Vickers' model. In a model with n+1 periods and n innovations, it is hard to envision that a firm that has lost n-1 auctions and is technologically far behind its rival, can win the last auction and become the low cost firm overnight.

In game 3 below, a factor reflecting the influence of the relative backwardness of a firm has been incorporated to the game. This can be done in several ways. One can think of some extra costs that the high cost firm has to pay for the patent but which the low cost firm does not have to incur. Alternatively, it is possible to imagine a situation in which the high cost firm cannot have access to the "latest" technology at the beginning of each period, but to the immediately more advanced technology to the one it is using. Note that now, if firm 2 wins the first auction, symmetry is restored and firms have the same incentive to win the second patent.

A particular case of this game is the case in which the innovation reduces costs in each firm by a certain fixed amount that is subtracted from its past constant marginal costs, i.e. $k_2 - k_1 = k_1 - c = c - \phi$.

Game 3.



Following the usual procedure, the difference in reservation prices in the first period will be

$$P^1_I - P^2_I = \sigma(c,k_2) + \max[\sigma(\phi,k_2)-\pi^2_{II}(c,k_1), \pi^1_{II}(c,k_1)] - \sigma(k_1,k_1) - \max[\sigma(c,k_1)-\pi^2_{II}(k_1,c), \pi^1_{II}(k_1,c)] - \max[\sigma(k_1,c)-\pi^1_{II}(c,k_1), \pi^2_{II}(c,k_1)] + \max[\sigma(c,k_1)-\pi^1_{II}(\phi,k_2), \pi^2_{II}(\phi,k_2)]$$

The first interesting result that arises here is that assumption 1 and its reverse have no influence on the direct effect while asymmetry is preserved. Note that the direct effect in the first period depends on the sign of $\sigma(c,k_2) - \sigma(k_1,k_1)$, i.e. how joint industry profits vary when the cost levels of each firm start to diverge from a certain common level. It can be proved that both under Cournot and under Bertrand conjectures and with a linear demand function, this difference is positive if $(k_1 - c) = (k_2 - k_1)$. However, this is not necessarily true when $(k_1 - c) =/= (k_2 - k_1)$. Hence, Cournot behaviour in the product market plays in favour of the first firm in the first auction, not necessarily leading to action-reaction.

The induced effect has no definite sign. If $\sigma(\phi,k_2)-\sigma(c,k_1) > 0$, it is just

$$\pi^1(\phi,k_2) - \pi^2(k_1,c) + 2\pi^2(\phi,k_2) - 2\pi^2(c,k_1)$$

However, if $k_2-k_1 = k_1-c = c-\phi$ it will usually be positive under Cournot behaviour producing increasing dominance as a result.

V.10. Conclusion.

This chapter has analysed the structure and limitations of a series of models of sequential innovation that try to explain market evolution. For that purpose, a very simplified version of the model developed in Vickers (1986) has been presented.

Two kinds of incentives to win each auction are distinguished: the direct effect, which exists in any single period game and the induced effect, which is due to the influence of the sequence of innovations and auctions. In the original model used by Vickers and others, the first one depends on how joint industry profits vary when the costs of the high-cost firm change. However, this is not true when "history matters". Then, the direct effect depends on how industry profits vary when costs diverge.

The induced effect captures the influence of future auctions on the willingness to pay for the patent currently being auctioned. This effect depends heavily on the structure of the game, particularly whether or not there is free diffusion and when R&D costs are reversible.

In spite of being highly dependent on the structure and the assumptions of the game, these models can shed some light into the forces affecting adoption and diffusion of new technologies. Furthermore, the differences in the results obtained when the assumptions are altered as it is done in Beath et al. (1987) and here, can help us to isolate and identify the impact of those assumptions.

When there is free diffusion and firms can obtain without any charge the technology auctioned in the previous period, the induced incentive is the same for both the high and the low cost firm. The only incentive to win the current patent is the "profit incentive" identified by Beath et al. (1989) which can be derived of having lower production costs in the next period. In this case, both firms have a strong incentive to wait for free diffusion instead of bidding for the new technology.

If the situation takes the form of a patent race and R&D costs are sunk costs, i.e. if the firms have to pay a fixed amount to participate in the auction, it is possible to find a sufficient condition for increasing dominance. That sufficient condition is exactly the reserve to the Vickers assumption. If joint industry profits are higher when the costs of the high cost firm are higher, i.e. $\sigma(c,k+\epsilon) > \sigma(c,k)$, there will be increasing dominance. Furthermore, while in Vickers' model the induced effect was always acting in favour of the high cost firm, here it always favours the low cost firm.

Finally, we should be aware of the reservations concerning the optimality of this kind of auctioning mechanisms. For a detailed discussion on this topic see Vickery (1961) and Myerson (1981).

In the next chapter, the problems of the evolution of market structure will not be considered. The emphasis will be put on the problem of the relative incentives that firms have to adopt new technologies in an asymmetric context where the direction of technological change matters.

We can assume either:

i) $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) > 0$ and $\sigma_{II}(k_1,\phi) - \sigma_{II}(\phi,c) < 0$, then

(10) $P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + \sigma_{II}(\phi,k_2) - 2\sigma_{II}(\phi,c) + \pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2)$

Under assumption (i), firm 1 will always win the second auction and depending on the sign of (10) we could have type A or type C equilibria. Both are possible because (i) implies,

$$\sigma_I(c,k_2) - \sigma_I(k_1,c) > 0$$
$$\sigma_{II}(\phi,k_2) - \sigma_{II}(\phi,c) > 0$$

but $\pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) - \sigma_{II}(\phi,c) < 0$ because,

$$\pi^2_{II}(k_1,\phi) + \pi^2_{II}(\phi,k_2) < \pi^1_{II}(\phi,k_1) + \pi^2_{II}(\phi,k_1) = \sigma_{II}(\phi,k_1) < \sigma_{II}(\phi,c)$$

and the sign of (10) could go either way.

ii) $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) > 0$ and $\sigma_{II}(k_1,\phi) - \sigma_{II}(\phi,c) > 0$, then

(11) $P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + \pi^2_{II}(\phi,k_2) - \pi^1_{II}(k_1,\phi) - \sigma_{II}(\phi,k_2) - \sigma_{II}(k_1,\phi)$

Here, (ii) implies that the firm that won the first auction will win the second one too. Hence, cases A and D are the only two possible outcomes depending on the sign of

(11), which is uncertain because although $[\pi^2_{II}(\phi,k_2)-\pi^1_{II}(k_1,\phi)]$ is always positive, (ii) does not imply any sign on $\sigma_{II}(\phi,k_2) - \sigma_{II}(k_1,\phi)$.

iii) $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) < 0$ and $\sigma_{II}(k_1,\phi) - \sigma_{II}(\phi,c) < 0$, then

(12) $P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + \pi^2_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2)$

Here, (iii) implies that the firm that lost the first patent will always wins the second auction. Consequently, only cases B and C are possible. Furthermore,

$$\pi^2_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2) = \pi^1_{II}(\phi,k_1) - \pi^1_{II}(\phi,k_2) < 0.$$

As a result, if assumption 1 holds for any period, only case C can occur. But if the reverse of assumption 1 holds for the first auction, case B may appear.

iv) $\sigma_{II}(\phi,k_2) - \sigma_{II}(c,\phi) < 0$ and $\sigma_{II}(k_1,\phi) - \sigma_{II}(\phi,c) > 0$, then,

(13) $P^1_I - P^2_I = \sigma_I(c,k_2) - \sigma_I(k_1,c) + 2\sigma_{II}(\phi,c) - \sigma_{II}(k_1,\phi) - \pi^1_{II}(k_1,\phi) - \pi^1_{II}(\phi,k_2)$.

In this case, firm 2 always wins the second auction. However, nothing can be said with certainty about the sign of (13).

Beath, J. Katsoulacos, Y. and Ulph, D. (1987) "Sequential Product Innovation and Industry Evolution", **The Economic Journal**, 97, Conference Papers, pp. 32-43.

——, (1989) "Strategic R&D Policy" **The Economic Journal**, 99, Conference Papers, pp. 74-83.

Dasgupta P. (1988) "Patents, Priority and Imitation or the Economics of Races and Waiting Games", **The Economic Journal,** 98, March, pp. 66-80.

Delbono, F.(1987) "Market Leadership with a Sequence of History Dependent Patent Races", mimeo Linacre College, Oxford.

Dixit A. (1984) "Comparative Statics for Oligopoly", W. Wilson School, Princeton University, Discussion Paper, n. 81.

Flaherty, M. (1980) "Industry Structure and Cost-Reducing Investment" **Econometrica**, 48, pp. 1187-1209.

Gilbert R. and Newberry, D. (1982) "Pre-emptive Patenting and the Persistence of Monopoly", **American Economic Review**, 74, pp. 514-26.

Harris, C. and Vickers J. (1987) "Racing with Uncertainty", **Review of Economic Studies**, LIV, pp. 1-21.

Kamien M.I and Schwartz N. (1982) **Market Structure and Innovation**, Cambridge University Press, Cambridge.

Myerson R.B. (1981) "Optimal Auction Design", **Mathematics of Operations Research**, vol. 6 N. 1, February, pp. 58-73.

Reinganum, J.F. (1983) "Uncertain Innovation and the Persistence of Monopoly", **American Economic Review**, 73, pp. 741-48.

----- (1985) "Innovation and Industry Evolution", **Quarterly Journal of Economics**, 99, pp. 81-99.

Vickers J. (1986) "The Evolution of Market Structure when There is a Sequence of Innovation", **Journal of Industrial Economics**, 35, September, pp. 1-12.

Vickrey R. (1961) "Counter-speculation, Auctions and Competitive Sealed Tenders", **Journal of Finance**, March, pp. 8-37.

Chapter VI: International Diffusion of New Process Technologies with Asymmetric Duopolists

VI.1. Introduction.

The theoretical study of the diffusion of new technologies has benefited from important contributions in the last two decades. However, little attention has been paid to the specific implications and circumstances that accrue when diffusion processes take place across national borders. Different strands of the literature on technological change and international trade as diverse as Teece (1977), Gomulka (1971) or Jensen and Thursby (1987)[68] take the existence of diffusion as a phenomenon playing a role in their arguments. However, the explanation of diffusion is not the central object of their works.

Another strand of the literature starting with Posner (1961), Vernon (1966), Hufbauer (1966) and more recently continued by Krugman (1979), Cheng (1984), Dollar (1986) and Jensen and Thursby (1987), stresses the importance of different levels of technological development among countries, or "technological gap",[69] to explain changes in

68 Lee (1984 a and b) and Cimoli et al. (1986) approach the issue of international diffusion in a more direct way. But Cimoli's work considers it in a very general framework that includes aspects such as structural and institutional differences among countries and Lee's work is more a model of technological transfer. Neither of these models considers the timing of the adoption of the innovation across countries in a explicit way.

69 The difference in the technology level between two countries or "technology gap" as it is usually known, can make reference to two different things or, sometimes to both of them simultaneously. We can say that there is a technology gap between two countries whenever the technology used by the firms in one country is more advanced than the technology used by their competitors abroad, in the sense that the first firm can produce more sophisticated products or a certain product at a lower cost. However, some authors refer to the technology gap between countries whenever the stock of technology available to the firms in each country is not the same. Here, we will say that the technology gap persists even in those cases where firms in both countries are using the same technology, but their ability to develop new technologies is not the same.

the patterns of trade between countries over time. Undoubtedly, the so called "technology gap" has an important influence on the timing of adoption of new technologies by different countries. However, little is known about international diffusion when countries have similar levels of technological development. In any case, one could question whether this "technological gap" is the one and only determinant of international diffusion.

The objective of this chapter is to explore the impact of different types of asymmetries between firms and countries on the international diffusion of a new process innovation, leaving the effects of the "technology gap" on a secondary plane. This is not done because the "technology gap" is not considered as an important factor to explain diffusion. On the contrary, I consider it as a relevant factor. But here, the emphasis is put on finding some other less obvious factors of a strategic nature, which also have an impact on international diffusion of new technologies.

The following sections deal with the relative incentives to adopt an innovation in the presence of initial cost asymmetries and strategic interactions between the firms. The influence of the technological gap is reduced to the initial differences in average costs of production in two countries. The strategic interactions are of a very simple kind, but they include different forms of oligopolistic behaviour by the innovating firms (Cournot-Nash and Bertrand conjectures) and the supply-side behaviour of a monopolist selling the innovation to the two duopolists.

The influence of cost asymmetries was first emphasized in the diffusion literature by P. David (1985). The importance for diffusion of strategic interaction between the potential adopters was firstly mentioned in Reinganum (1981). Later, Stoneman and Ireland (1984) pointed out to the influence on the pattern of diffusion of strategic behaviour by the supplier of the new technology. However, the kinds of strategic interactions that will be used here are closer to those developed in Vickers (1986) and Beath et al. (1987).

In this chapter, mutual cost asymmetries and strategic interaction are brought together to study the relative incentives to adopt different types of innovations, that would produce different cost reductions in the two different countries which we will be considered. For this purpose, a very simplified setting will be assumed with two firms, each one operating from a different country and competing in an international market. In this sense, this model resembles Reinganum's 1981 model. Reinganum proved that in a perfectly symmetric duopoly, both firms would not adopt a cost reducing innovation simultaneously. In that situation, one firm will adopt the new technology later and will obtain lower profits than the first adopter. But there are two Nash equilibria and it is not possible to tell which firm will lead in the process of adoption. "*Ceteris paribus*", both firms have the same probability of being the first adopter.[70]

In the same paper, Reinganum reports on results obtained by M.T. Flaherty (1980) and herself (1980) for the asymmetric case, in two unpublished papers. In this case, firms do not adopt simultaneously either, but the identity of the leader in the process of adoption will depend here on its "comparative advantage in implementing the new technology".[71] This type of analysis is closer to the type of situation studied in this chapter. However, the model presented here differs from those in Reinganum (1981) and Fudenberg and Tirole (1985) in the sense that those models focus on the precise timing of diffusion as a sequence of calendar dates, rather than on the order of adoption as it is done here.

The results obtained in this chapter are similar to those reported by Reinganum but the analytical framework is considerably simpler here. Furthermore, this chapter includes some possible expansions of particular relevance to the international diffusion of

70 This paper has been criticized on different grounds by Fudenberg and Tirole (1985), Quirmbach (1986) and Grindley (1986). For our purposes here, the contribution made by Fudenberg and Tirole has particular importance. They show that under certain conditions, the diffusion solution provided by Reinganum does not hold and there are equilibria for which late simultaneous adoption results.

71 Reinganum (1981) page 404.

technology, such as supply-side considerations. Section VI.2 sets up a simple model with only one "world demand" function and presents some results on the influence of different production costs across countries. Section VI.3 compares the incentives to adopt different new technologies under Cournot-Nash and Bertrand conjectures in the market for the final product. That section reconsiders some of the questions that were addressed in the previous chapter. It examines the impact of the different cost reductions that a new process technology can bring about, when it is introduced in different countries. Section VI.4 develops the simple model incorporating some structure concerning the conditions of supply of the innovation, and section VI.5 introduces demand asymmetries between countries.

VI.2. THE "WORLD-MARKET MODEL" WITH COURNOT-NASH CONJECTURES.

Assume that two different firms, 1 and 2, each one of them operating in a different country, (1 and 2), and producing a homogeneous good. Their output is sold in a "world market" at the same price and there are no transportation costs. The "world" demand function is linear and output units, x_i, are chosen so that it can be written in the following the form,

$$p = A - x_1 - x_2$$

Firms buy their inputs in their own domestic markets, and consequently, they face different factor prices. There could also exist initial differences in the technology used by each firm. Constant average costs of production are a function of the input prices paid by the firm and the technology used. Firm 2 is assumed to have lower average costs of production, k_2, than firm 1, k_1, prior to the innovation.[72] This difference can be due to: a)

---

72 These average costs will be the unit costs at which firms 2 and 1 will be operating during the first period, unless they introduce the innovation. Note that there is a change in the ordering of the initial costs of firms 1 and 2 with respect to previous chapters.

lower factor prices in country 2 when both firms have the same technology, b) better technology in country 2, with equal prices, or c) some combination of a and b.

There are only two periods of time and at the beginning of the first one, a new cost-reducing technology is available in the market. The price of the technology declines over time and the first adopter will be the firm with a higher reservation price for being the first user. This does not indicate precisely at what point of calendar time each firm will adopt the new technology. In this discrete time setting, only the order in which adoption takes place is relevant. Thus, these periods of time will be defined in such a way that in period one, only the first adopter uses the innovation, while in the second period, both firms are using the new technology.

The cost structure of the firms in the first period will depend on which one adopts first. When firm 1 is using the new technology, it has average costs c_1; when firm 1 is using the old technology, its average costs are k_1 Similarly, prior to the adoption of the new technology, firm 2 has average costs k_2, and after adoption these costs drop to c_2. One can think of each pair of average costs for both firms as corresponding to a different type of technological progress or innovation. As a result of technological change, the firms' isoquants will shift towards the origin. But the different input prices faced by firms operating in distinctive countries will not result in the same average costs for each firm. Thus, the type of the innovation will determine the shift of the isoquants, and this will result in many different possible combinations of average costs for both firms. Table VI.1 summarises the possible cost combinations for the two firms,

By assumption, $k_1 > k_2$, but little can be said a priori about the relative position of c_1 and c_2. In principle, one should think that the case in which $c_1 \geq c_2$ will be the most interesting one. If $c_1 < c_2$, one should expect that firm 1 will be the first adopter, because the change in profits for firm 1 will always be greater than for firm 2, for any initial value of

k_1 and k_2. However, nothing excludes, a priori, the possibility that, even in that case, the low cost firm might adopt first. Therefore, both possibilities remain open.[73]

Table VI.1.

Average costs when:	user of the new technology	non-user of the new technology
firm 1 is	c_1	k_1
firm 2 is	c_2	k_2

c_1 may differ from c_2 due to differences in input prices between both countries. As it has been repeatedly assumed in previous chapters, differences in production costs are not necessarily the result the of differences in technology. If just one factor (say, labour) has a different price, country 2 will be the country paying a lower price for that input. But if one input is cheaper in one country and a second one is more expensive in that country, the identity of countries 1 and 2 will depend on the initial technology. Thus, if $c_1 > c_2$, one will say that the new technology does not change the prevailing "comparative advantage" as measured by the ratio of unit production costs in the two countries.

It is assumed that there is no difference in the adoption costs of firms in each country, and thus, the following adoption rules can establish [74]

- firm 1 will adopt first if and only if

(1) $$F = 9[\pi^{c}_1 - \pi^{k}_1 - \pi^{c}_2 + \pi^{k}_2] > 0$$

- and firm 2 will adopt first if and only if

---

73 c_1 can be greater or smaller than k_2.

74 For simplicity, drastic innovations that eliminate the duopolistic structure are not considered.

(2) $$F = 9[\pi^c{}_1 - \pi^k{}_1 - \pi^c{}_2 + \pi^k{}_2] < 0$$

where for $i = 1,2$,

$\pi^c{}_i$ = profits made by firm i when it is a user of the new technology and its rival is not.

$\pi^k{}_i$ = profits made by firm i when it is not a user of the new technology and its rival is.

If the i^{th} firm ($i = 1,2$) is not using the new technology in a certain period of time and its rival j ($j = 1,2$) is already using it, the problem for firm i will be to find x_i to

$$\max \ \pi^k{}_i = (A - x_i - x_j - k_i)\, x_i$$

and for the j^{th} firm, the problem would be to find x_j as to

$$\max \ \pi^c{}_j = (A - x_i - x_j - c_j)\, x_j$$

Assuming Cournot-Nash conjectures, the simultaneous solution of the two former problems could be written as,

(3) $$\pi^k{}_i = (A + c_j - 2k_i)^2 / 9$$
$$\pi^c{}_i = (A + k_j - 2ck_j)^2 / 9 \qquad i = / = j = 1,2.$$

A function $F(c_1, c_2 \,;\, k_1, k_2)$ is defined as the difference in reservation prices between firms 1 and 2, for a certain technology producing costs (c_1,c_2). The sign of F will not be the same for every pair (c_1,c_2). The low cost firm, 2, will benefit more from being the first user than the high cost firm 1, because it already has a larger market share. However, firm 1 will have lower profits than firm 2 when it doesn't have the new technology and its rival has it, and in a sense, one could say that firm 1 loses more than firm 2 if it is not the first adopter. Thus, who will benefit more from being the first adopter, and consequently who will be willing to pay more to be the first innovator, is not a trivial question.

F can be considered as a function of c_1 and c_2 taking k_2 and k_1 as parameters initially fixed . Its sign depends on the values of c_1 and c_2, i.e. on the nature of the innovation. F is continuous in c_1 and c_2. The level curve of function F() for values of the variables (c_1,c_2) and parameters (k_1,k_2) such that $F(c_1,c_2 ; k_1,k_2) = 0$, will divide the set defined by $[0,k_2] \times [0,k_1]$ into two subsets F and F^c. In F, expression (1) above holds and so does (2) in F^c. That is,

$$F = \{ (c_1,c_2) \mid F(c_1,c_2) > 0 \} \qquad \text{and}$$
$$F^c = \{ (c_1,c_2) \mid F(c_1,c_2) < 0 \}$$

These two sets are illustrated in figure VI.1. But before exploring their implications it is necessary to study the frontier between both sets. Given (3), F = 0 will be

(4) $$F = 2A(k_1 + c_2 - c_1 - k_2) + 8\,(k_1c_2 - c_1k_2) + 5(c_1^2 + k_2^2 - k_1^2 - c_2^2) = 0$$

Notice that $F(c_1,c_2;k_1,k_2) = 0$ goes through the point $k_1 = c_1$ and $k_2 = c_2$, because if there is no innovation both firms would be willing to pay nothing for it.

Applying the implicit function theorem to (4) we get the following lemma,

Lemma.- For $F(c_1,c_2;k_1,k_2) = 0$ and values of $k_1 >= c_1$ and $k_2 \geq c_2$ that preserve the duopoly structure,

(5) $$dc_1/dc_2 = (A + 4k_1 - 5c_2) \,/\, (A - 5c_1 + 4k_2)$$

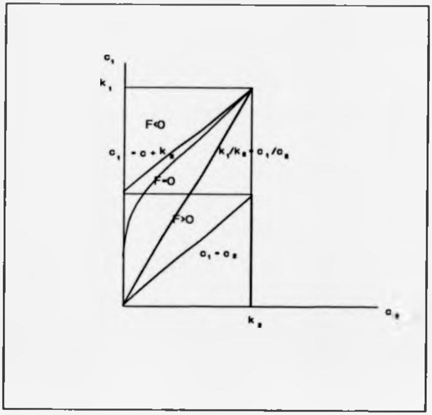
and

$$d^2c_1/dc_2^2 = [-5 \,/\, (A + 4c_1 - 5k_2) < 0 \quad .$$

Proof.- (See appendix)

Differentiating F with respect to c_1 and c_2 we can see that points above and to the left of $F=0$ imply $F<0$ and under and to the right of $F=0$ imply $F>0$. Figure VI.1. describes function F() in the c_1, c_2 space.

FIGURE VI.1.



If α is defined as the initial cost disadvantage for firm 1, i.e. $\alpha = k_1 - k_2$ and β is the cost differential between firms after the innovation, i.e. $\beta = c_1 - c_2$, (4) can be written as

$$(4') \quad F = 2A(\alpha - \beta) + 8(\alpha\beta + \alpha c_2 - \beta k_1) + 5[\beta(\beta + 2c_2) + \alpha(\alpha - 2k_1)] = 0$$

Expression (4') enables the study the pattern of adoption of some particular types of innovations. For instance, all the innovations maintaining the cost differential (in absolute value) between the two firms will be characterized by $\alpha = \beta$ or $[k_1 - c_1] = [k_2 - c_2]$

In that case, function $F(c_1,c_2)$, whose sign indicates which firm will adopt earlier, collapses into,

$$8\alpha(\alpha + c_2 - k_1) + 10\alpha(\alpha + c_2 - k_1) = 18(c_2 - k_1 + \alpha) = 18(c_2 - k_2) \leq 0$$

which implies that $F \leq 0$, and consequently, this type of innovations will always be adopted earlier by the firm in the low cost country, 2.

Innovations which eliminate the cost differential between firms and countries are characterized by $\beta = 0$. In that case, which is the only case considered by Vickers (1986), we know that under Cournot conjectures, the high cost firm will always adopt first (as can be easily seen from expressions (1) and (2) above, because in the Cournot case, we know that[75] $\pi^c_1 + \pi^k_2 > \pi^k_1 + \pi^c_2$). Therefore, for any innovation for which $\alpha = \beta$, the low cost firm will be the first one to adopt it.

This result also applies to those innovations that maintain the relative cost differential between both firms, i.e. those innovations that make $[k_1/k_2] = [c_1/c_2]$. That straight line goes through (k_1, k_2) and $c_1 = c_2 = 0$. It was shown in lemma 1 that $c_1 = f(c_2 ; F(c_1,c_2 ; k_1,k_2) = 0)$ is a concave function that also goes through (k_1,k_2), and $F(0,0 ; k_1,k_2) > 0$. Therefore, all the points in the $[c_1 , c_2]$ space for which $[k_1/k_2] = [c_1/c_2]$ and $k_1 > c_1$ and $k_2 > c_2$ must be beneath those that make $F(c_1,c_2 ; k_1,k_2) = 0$.

<u>Proposition 1.-</u> Under Cournot-Nash conjectures, the relative incentives to adopt a new innovation producing average production costs in each country (c_1,c_2) are such that

a) any innovation producing the same average cost levels in both countries, $c_1 = c_2$, will always be adopted firstly by the high cost country,

---

75 See Vickers (1986) pages 10 and 11.

b) any innovation maintaining the absolute cost differential between the two countries, $[k_1 - c_1] = [k_2 - c_2]$, will always be adopted earlier by the low cost country,

c) any innovation maintaining the relative cost differential between the two countries, $[k_1/k_2] = [c_1/c_2]$, will always be adopted earlier by the high cost country.

Finally, it is necessary to remember that there can be differences in the costs of adoption between the two firms and these will also have an impact on the pattern of adoption. These costs include any other costs necessary to operate with the new technology that are not included in its price. They can be due to differences in the level of technological development in their respective countries. It is easy to see that, any difference in adoption costs between both firms, will shift the function $F(c_1,c_2) = 0$ upwards or downwards, depending on the identity of the firm enjoying this favourable advantage. As a result, the measure of sets F and F^c will change accordingly.

VI.3. The "World Demand Function" with Bertrand Conjectures.

The purpose of this section is to compare the relative incentives that the two firms located in the two countries have if they act as Bertrand duopolists. For this particular case, product differentiation is introduced. It is assumed that the final products produced by the two firms are not perfect substitutes. This product differentiation is reflected in the following demand functions,

$x_1 = M - zp_1 + p_2$ and

$x_1 = M + p_1 - zp_2$

The z term indicates the degree of substitutability between the two goods. Stability conditions require that $z > 1/2$. Furthermore, it is also assumed that substitutability is such that the effect of a variation in the price of one good on the quantity demanded of that good is greater than the crossed effect on the quantity of the other good, i.e. $z > 1$.[76]

In this case, the maximum value of the profit function for the i-th firm if j has innovated and it has not is given by ,

$$\pi^k_i(B) = [z/(4z^2 - 1)]\,[M(2z + 1) + sc_j + k_i\,(1 - 2z^2)]^2$$

and correspondingly,

$$\pi^c_i(B) = [z/(4z^2 - 1)]\,[M(2z + 1) + sk_j + c_i\,(1 - 2z^2)]^2$$

Following the adoption rules defined in (1) and (2) above, the same procedure used in the previous section can be applied here to define the loci of new technologies defined by the unit production costs (c_1,c_2), such that given the initial values of M, z, k_1, and k_2 ,

(6) $$B(c_1, c_2; k_1,k_2) = [z/(4z^2 - 1)]\,[\pi^c_1(B) - \pi^k_1(B) - \pi^c_2(B) + \pi^k_2(B)] = 0$$

This expression has the same meaning as expression (4) above for the Cournot-Nash case. Substituting the values of the maxima of the profit functions we get the expression of a conic section similar to the one obtained in (4). The parametric form of (6) is

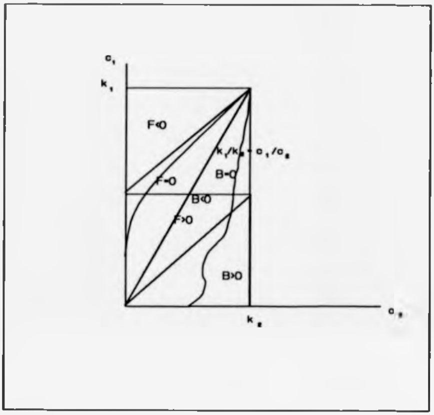
(6') $$B = [k_2^2 + c_1^2 - k_1^2 - c_2^2]\,[z^2 + (1 - 2z^2)^2] + 4z\,(1 - 2z^2)\,(c_1k_2 - c_2k_1) + 2\,M(2z + 1)\,(z - 1)\,(c_1 + k_2 - k_1 - c_2)$$

---

76 Although it will not be necessary to compare these demand functions with the homogeneous product demand function used in the previous section, the relationships between both, the implications of our assumptions and the resulting equilibria have been studied in Singh and Vives (1984) and Okuguchi (1987).

Unfortunately, the partial derivatives of B with respect to c_1 and c_2 have an ambiguous sign which depends on the relative magnitudes of the coefficients in expression (6'). Therefore, B() cannot described in the same way as it was done with F() in the previous section. However, simple inspection suffices to get some information about the location of the (c_1,c_2) points that make $B \gtreqless 0$.

FIGURE VI.2.



The partition of the set $[c_1,0] \times [0,c_2]$ defined by the level set B = 0 will be as shown in figure VI.2. (See a description of this figure in the appendix).

Comparing figures 1 and 2 one can see that there is a set of potential cost pairs (c_1,c_2) representing new technologies for which $F(c_1,c_2) > 0$ and $B(c_1,c_2) < 0$. In other words, some technologies that would be adopted first by the low cost firm under Cournot conjectures will be adopted first by the high cost firm under Bertrand competition and product differentiation. Note that this possibility exists both for cost combinations that alter and others that maintain the 'comparative advantage' of the two firms.

However, the contrary does not happen. There is no innovation that being adopted first by the high cost firm under Cournot conjectures is adopted first by the low cost firm under Cournot conjectures. Moreover, there are some technologies that will be always adopted first by a certain type of firm, regardless of the oligopolistic behaviour of the two firms.

This conclusion is an important nuance to the results pointed out in Vickers (1986). It was shown in the previous chapter that demand conditions are crucial to link market evolution and rivalry in the final-product market. But we have just seen that the key factors determining the evolution of market structure, i.e. the adoption rules in (1) and (2) above, are also affected by rivalry in the product market and the direction of technological change.

For certain types of technological change, i.e. those above $F = 0$ and below $B = 0$, rivalry in the product market does not have any influence whatsoever, as they are always adopted first by the same firm. However, for values of (c_1,c_2) within the boundaries defined by $B = 0$ and $F = 0$, rivalry in the product market does matter. The direction of this influence is always the same one: Bertrand competition and product differentiation delay early adoption by the high cost country for those innovations.

VI.4. Some Supply-side Considerations.

From now on, the Cournot-Nash case will be taken as the benchmark. The two previous sections, it has been shown that in the asymmetric case, the nature of the innovation available for adoption, i.e. the associated (c_1,c_2), is one of the determinants of who will adopts the innovation in the first place. It is reasonable to argue that the (c_1,c_2) combination will be the result of decisions made in the R&D sector. Questions such as who determines which R&D project to pursue and the cost of alternative R&D projects will determine which innovation will be produced in the future.

The demand side conditions of the process of adoption have been studied above, but it is necessary to define some supply structure in the production of R&D to complete the picture of the process of creation and adoption of technological changes. In this way, it is possible to have an integrated view of the sector. Nevertheless, there are some simple supply structures that can give some interesting results.

VI.4.1. Independent R&D producer with sequential innovations.

The set F^c defined in the second section as the new cost combinations that would be adopted earlier by the firm in the low cost country, i.e. firm 2, can be partitioned into F^c_1 and F^c_2, depending on whether the new technology reduces or increases firm 2's initial cost advantage. Assume that a sequence of innovations are introduced in a continuum of time by an independent profit-maximizing R&D laboratory. This continuum of time is divided into many time intervals $\tau=1,2,3,...,T$, each one of them containing two discrete time periods as has been assumed until now. Each new innovation is available for adoption at the beginning of each time interval and by the end of this interval, complete diffusion of that technology has taken place in both countries.

$c_i(\tau)$ and $k_i(\tau)$ will designate cost conditions in two time intervals considered, and these will define the corresponding sets $F(\tau)$ and $F^c(\tau)$.

First of all, note that if a certain innovation producing average costs (c_1,c_2) is introduced at time $\tau=1$, this pair becomes the initial (k_1,k_2) at $\tau=2$. If all the innovations in the sequence give $(c_1(\tau),c_2(\tau))$ pairs that belong to the corresponding $F(\tau)$ sets, then, at time T+1, cost symmetry is restored and any firm can be the first adopter[77]. In other words, assuming that technology in the R&D sector is such that it is always optimal for the R&D producer to produce innovations which are going to be adopted first by the initial high cost firm 1, then there is a certain point of time when initial average costs are the same for both firms. After that date, the results in Reinganum (1981) and Fudenberg and Tirole (1985) apply.

The explanation of this result is simple. Any innovation in F reduces the cost differential between firms. But each $F(\tau)$ set is bounded by $c_1 = c_2$ and $c_1+\alpha=c_2$. As α is reduced when τ increases, there will be a T large enough for which both upper and lower bounds coincide in $c_1 = c_2$.

The same type of result can be produced if all the profit maximizing choices $(c_1(\tau),c_2(\tau))$ for the R&D producer belong to $F^c{}_1(\tau)$, where the low cost firm adopts first but its cost advantage is continuously eroded. However, this will not be the case if the $(c_1(\tau),c_2(\tau))$ combinations always belong to $F^c{}_2(\tau)$. These cost combinations increase the cost differential between both firms, and in the limit, the duopoly structure collapses and the firm in the high cost country disappears.

VI.4.2. Independent R&D producer and small innovations.

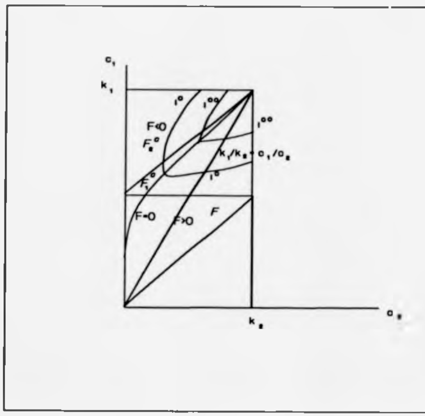
The former results are based on the strong assumption that the cost combinations that maximize profits for the R&D firm always belong to the same set. However, under much weaker assumptions one can prove that an independent R&D monopolist will always

---

77 But if the particular conditions described by Fudenberg and Tirole (1985) apply, late simultaneous adoption will take place.

produce innovations that belong to F_j, and consequently, will always be adopted earlier by the low cost firm, firm 2.

FIGURE VI.3.



To carry out this exercise, it is desirable to eliminate any bias in the cost of producing a certain innovation in favour of any one of the two potential adopters. This requires a certain kind of "neutral" cost structure for the R&D sector. For this reason, it will be assumed that those innovations for which there is the same relative incentive in both countries to adopt them first are relatively cheaper to produce. In other words, cost combinations along the curve $F(c_1,c_2) = 0$ will be relatively cheaper to produce in the sense that any other cost combination near the $F = 0$ loci, producing the same cost reduction in country i but reducing costs a little bit less in country j will be more expensive to produce. (See Figure VI.3.)

$R(c_1,c_2)$ is defined as the R&D cost of producing a certain cost combination (c_1,c_2). This cost function defines a collection of convex and continuous level sets in the (c_1,c_2)-space that imply the same R&D cost for the monopolist. Assume that for a given cost combination (c_1^o,c_2^o) such that $F(c_1^o,c_2^o)=0$,

- any other combination (c_1,c_2^o) such that $c_1>c_1^o$ and $F(c_1,c_2^o)<0$ will be more expensive to produce, and

- any other combination (c_1^o,c_2) such that $c_2>c_2^o$ and $F(c_1^o,c_2)>0$ will be more expensive to produce.

More precisely, the following assumption is introduced,

<u>Assumption.-</u> For each and every point (c_1^o,c_2^o) such that $F(c_1^o,c_2^o)=0$, there will be a continuous R&D-isocost curve I^o, such that

a. $dc_1/dc_2 > 0$ along I^o and

b. if $(c_1^o,c_2^o) \in I^o$ and $(c_1^{oo},c_2^{oo}) \in I^{oo}$, $I^o > I^{oo}$ if and only if $(c_1^o,c_2^o) >> (c_1^{oo},c_2^{oo})$.

Total revenue to the R&D monopolist will be defined as follows. In the first period, it will sell the new technology to one firm (1 or 2 according to their reservation prices for that technology), and this firm will pay the maximum price that its rival will be willing to pay for that particular technology. This assumption was used in the previous chapter and has also been used in Vickers (1986) and Beath et al. (1987) among others.

In the second period, the late adopter pays for the technology a certain percentage, $\sigma \in]0,1]$, of the maximum benefits that it will obtain from adoption, when its rival is already using the innovation.' This percentage will not vary with the identity of the late adopter. The problem for the monopolist is

$$\max V = \begin{cases} q_1 - R(c_1,c_2) & \text{if 1 adopts first} \\ q_2 - R(c_1,c_2) & \text{if 2 adopts first} \end{cases}$$

$(c_1,c_2) \in F,\ (c_1',c_2') \in F^c$ where,

$$q_1 = \pi_2(k_1,c_2) - \pi_2(c_1,k_2) + \delta\sigma\,[\pi_2(c_1,c_2)-\pi_2(c_1,k_2)]$$
$$q_2 = \pi_1(c_1',k_2) - \pi_1(k_1,c_2') + \delta\sigma\,[\pi_1(c_1',c_2')-\pi_1(k_1,c_2')]$$

and δ is a discount factor. Note that the first two terms in the RHS of both equations are always greater than the corresponding term in brackets. This is consistent with the declining price of the new technology and inter-temporal price discrimination on the monopolist's side.

This problem doesn't have a straight forward solution and it is difficult to solve explicitly. However, it is possible to get some qualitative information about its solution. If one can prove that for <u>any cost level</u> given by a R&D-isocost curve, the (c_1,c_2) combination that maximizes the monopolist's profits always belongs to F or F^c, it will not be necessary to determine in an explicit way the absolute level of R&D spending.

In fact, this is the case when the monopolist maximizes profits producing "small" innovations.

<u>Definition.</u>- An innovation is 'small' if, given k_1 and k_2, (c_1,c_2) is such that

$2\delta\sigma\,(k_2-c_2) < A+c_1-2k_2$ and

$2\delta\sigma\,(k_1-c_1) < A+c_2-2k_1$.

Now we can prove that,

Proposition 2.- If the R&D monopolist will maximize profits by producing "small" innovations, the monopolist will always produce innovations that will be adopted first by the low cost firm, 2.

Proof.-

Take a certain R&D-isocost curve I^o, which implies R&D costs for the monopolist equal to R^o, and call

$$(c_1,c_2) = \arg\max V^1 = q^1 - R^o$$

and

$$(c_1',c_2') = \arg\max V^2 = q^2 - R^o$$

Note that for small innovations, q^1 and q^2 are both decreasing functions of (c_1,c_2) and (c_1',c_2'), respectively. This implies that, given the assumed shape of I^o, the monopolist's profits will increase as we move down along the two branches of the R&D isocost curve above and below $F = 0$.

However, the monopolist's profits are not continuous at the point $(c_1,c_2)=(c_1',c_2') \epsilon F(c_1,c_2) = 0$. At that point, both firms will be willing to pay the same price for the technology in the first period, i.e.

$$\pi^2(k_1,c_2) - \pi^2(c_1,k_2) = \pi^1(c_1',k_2) - \pi^1(k_1,c_2')$$

and consequently, either of them can be the first adopter. But if firm 1 adopts first and 2 follows, the monopolist obtains lower profits in the second period than if firm 2 adopts first and 1 follows. (See proof in appendix).[78]

Consequently, the monopolist will maximize profits by producing a cost combination in I^o close to the point $(c_1,c_2) = (c_1',c_2') \epsilon I^o$ to ensure that firm 2 will always

---

78 Alternatively, if Fudenberg's and Tirole's conditions apply, it is obvious that late simultaneous adoption will not be a profit-maximizing solution for the monopolist.

be the first adopter. The existence of such a combination is guarantied by the continuity of the isocost curve.

■

Although this result has been obtained assuming a very particular cost structure in the R&D sector, it can help to advance some conclusions about the relationships between the direction of technological change, and the incentives to develop and to adopt an innovation.

It has been shown that even if the cost structure in the R&D sector is neutral in terms of which firm will be the first innovator, an independent monopolist will tend to produce innovations that will be adopted earlier by the initial low cost firm. From the point of view of the country where the high cost firm is located, there is little incentive to develop that particular technology, because the final cost combination prevailing when total diffusion has taken place, is not particularly disadvantageous for its local firm, i.e. firm 1. The low cost country 2 will always be interested in fostering the innovation that maximises the profits of the monopolistic R&D laboratory, because, even if it does not get the benefits from the R&D producer, it will benefit from the extra profits that early adoption will give to its local firm. Therefore, even when there is no cost advantage in favour of innovations that would be adopted earlier in either country, the low cost country will have higher incentives to foster R&D. Only a cost advantage in favour of those technologies that would be adapted earlier by the high cost firm could induce an independent monopolist to develop an innovation that would be adopted earlier by the high cost firm.

Therefore, one can conclude that, under our assumptions of neutrality and market structure in the R&D sector, market forces will tend to perpetuate the identity of the high and low cost firms in the market of the final product. However, under these conditions, public policy intervention in the high cost country to promote the development of innovations that would be adopted earlier by the domestic firm would be costly in terms of welfare. In addition, as the incentives in the low cost country are greater, retaliation by the low cost country would make public policy intervention by the high cost country ineffective.

VI.5. The two-market model.

VI.5.1. Demand asymmetries.

Until this point, the model included one common "world demand" function, and no transportation costs and consequently, the differences between firms were due only to differences in production costs. In order to introduce the analysis of the impact of trade variables such as trade policy or different market prices in the two countries, separated markets for the final homogeneous good will be assumed, with different market sizes and transportation costs in each country, and possibly, different prices for the final good in each national market.

This section examines the implications for diffusion of asymmetry on the demand side for two monopolists that operate in two different national markets.

For simplicity linear national demand functions will be assumed in each market, with the form

$$y_1 + x_2 = s_1 (D - p_1) \quad \text{for country 1}$$

and

$$y_2 + x_1 = s_2 (D - p_2) \quad \text{for country 2,}$$

where for $i = 1,2$, y_i is the production of the i^{th} firm for its domestic market, x_i is exports of the i^{th} firm to its foreign market, p_i is the price of the final good in country i, and s_i (>0) is a factor reflecting market size in country i. Note that units of output are normalized in a different way than in former sections.

The model also allows for the possibility of different transportation costs from one country to another. Constant unit transportation costs of t_i (i = 1,2) are assumed for firm i selling in a foreign market. By transportation costs consist of any non-production cost added to the domestic cost of the final product, when it is sold in a foreign market. Thus, transportation costs will include not only extra sales and marketing costs incurred by the firm because it is selling in a different market, but also tariffs, foreign taxes and domestic subsidies.[79]

In this setting, firm 1 will choose y_1 and x_1 to maximize

$$\pi_1 = (p_1 - c_1)y_1 + (p_2 - c_1 - t_1)\, x_1$$

and firm 2 will choose y_2 and x_2 in order to maximize

$$\pi_2 = (p_2 - k_2)\, y_2 + (p_1 - k_2 - t_2)\, x_2$$

Under Cournot conjectures, the maximized values of each firm's profits as a function of constant average costs (c_1 k_2) are

$$\pi_1 = s_1(D + k_2 + t_2 - 2c_1/3)^2 + s_2(D + k_2 - 2c_1 - 2t_1/3)^2$$

and

$$\pi_2 = s_2(D + c_1 + t_1 - 2k_2/3)^2 + s_1(D + c_1 - 2k_2 - 2t_2/3)^2$$

Following the definitions of reservation prices for being the first adopter used in section 2, we can define the difference in reservation prices between firm 1 and firm 2, G, as

$$G = 9[\pi_1(c_1\, k_2) - \pi_1(k_1, c_2) - \pi_2(k_1, c_2) + \pi_2(c_1, k_2)]$$

---

79 Our model is similar to Venables' (1985).

Firm 1 will be the first adopter if and only if $G>0$ and firm 2 will be the first adopter if and only if $G<0$.

Assuming total asymmetry between both firms, function G will be equal to

$$(7) \qquad G = (s_1 + s_2)\,[2D(k_1 + c_2 - c_1 - k_2) + 8(k_1c_2 - c_1k_2) + 5(k_2^2 + c_1^2 - k_1^2 - c_2^2]$$
$$+ 2[(k_2-c_2)(5s_1t_2-4s_2t_1) + (k_1-c_1)(4s_1t_2-5s_2t_1)]$$

This expression is very similar to (4) and allows one to differentiate between the incentives of being the first adopter due to cost asymmetry from those due to demand or market asymmetry. The first term in the summation of the RHS of (6) is the equivalent to F in (4) and we will call it F^* which simplifies (6) to,

$$G = F^* + 2[(k_2 - c_2)\,(5s_1t_2 - 4s_2t_1) + (k_1 - c_1)\,(4s_1t_2 - 5s_2t_1)]$$

In order to simplify the interpretation of (6), let us start by assuming that there is cost symmetry between firms 1 and 2, i.e.,$k_1 = k_2$, $c_1 = c_2$ and $k_2-c_2 = k_1-c_1$. In this case, F^* collapses zero and

$$G = 18\,(k_2-c_2)\,(s_1t_2-s_2t_1)$$

Once more, this expression will not always be positive or negative for any value of the parameters, k_1, k_2, s_1, s_2, t_1 and t_2. However, as could have been expected, for any size of the innovation and for any possible difference in market size between both countries (s_1 and s_2), demand asymmetry in the reservation prices for being first between the two firms vanishes when $t_1 = t_2 = 0$. In other words, it is the existence of positive transportation costs between the two countries that produces differences in the reservation prices to be the first adopter.

Of course, if transportation costs are positive, there is a transportation cost combination (t_1,t_2) for each market size pair (s_1,s_2) that eliminates that difference in reservation prices. If $s_1t_2 =/= s_2t_1$, the high cost firm will always adopt any innovation earlier if $s_1t_2 > s_2t_1$ and vice versa.

As the shape and situation of $F^*=0$ is already known from the study of the cost asymmetry case in section VI.2, we can proceed by examining the effect of different demand asymmetries on the relative position of $F^*=0$, given k_1 and k_2. In that sense, if a demand asymmetry implies that $G=0$ is below $F^*=0$ for any cost combination (c_1,c_2), we can say that in the presence of this demand asymmetry, some innovations that would otherwise be adopter earlier by firm 1, will now be adopted earlier by the low cost firm 2, and viceversa.

To study the general case, notice first that along $F^*=0$, (k_1-c_1) will always be greater than (k_2-c_2). Thus, as long as $s = (s_1t_2/s_2t_1) > 4/5$, $F^*=0$ will be below $G=0$ if and only if,

$$\frac{5s_1t_2 - 4s_2t_1}{5s_2t_1 - 4s_1t_2} > \frac{5s - 4}{5 - 4s} > \frac{k_1 - c_1}{k_2 - c_2} > 1$$

From this expression one can conclude that $s > 1$, is a necessary but non-sufficient condition to increase the measure of the set of innovations that are adopted first by the high cost firm. This means that if the combined effect of transportation costs and country size work in favour of the low cost country 2, the high cost country can use trade policy to make its local firm the first adopter of the innovation.

VI.5.2. Comparative statics.

The comparative statics of this version of the model are quite simple. Differentiating function G with respect to T_1 and t_2 we get,

$$dG/dt_1 = s_2\,[10(c_1 - k_1) + 8(c_2 - k_2)] < 0$$

$$dG/dt_2 = s_1\,[10(k_2 - c_2) + 8(k_1 - c_1)] > 0 \text{ for all } (c_1,c_2).$$

If the transportation costs faced by firm 1 are increased (or a tariff is levied on its exports), the number of possible innovations that would be introduced earlier by firm 1 will be reduced. The opposite effect will result from an increase in t_2.

However, the effect of market size is not so clear. Consider,

$$\delta G/\delta s_1 = \delta F^*(c_1,c_2)/\delta s_1 + t_2\,[10(k_2 - c_2) + 8(k_1 - c_1)]$$

and $\delta G/\delta s_2 = \delta F^*(c_1,c_2)/\delta s_2 + t_1\,[10(c_1 - k_1) + 8(c_2 - k_2)$.

The sign of the two former equations is not unambiguous because, (for $i = 1,2$)

$$(\delta F^*/\delta s_i) = 2D(k_1 + c_2 - c_1 - k_2) + 8(k_1c_2 - c_1k_2) + 5(c_1^2 + k_2^2 - k_1^2 - c_2^2)$$

will be positive or negative depending on the values of the new cost combination. Thus, for those cost combinations (c_1,c_2) such that

a.- $G \geq \delta F^*/\delta s_1 > 0$, then $(\delta G/\delta s_1)>0$ but the sign of $\delta G/\delta s_2$ will be uncertain, and if

b.- $G \leq \delta F^*/\delta s_1 < 0$, then $(\delta G/\delta s_2) < 0$, but $\delta G/\delta s_1$ can have either sign.

Cases a or b will appear depending on the relative values of (s_1,s_2) and (t_1,t_2). If the demand asymmetry acts in favour of country 1, any increase in market size for country 1 will increase the number of innovations that the firm in this country will adopt first. But if the export market grows, the effect on diffusion in country 1 can be positive or negative. We can only be sure that this effect will be negative if the market asymmetry works against firm 1, but if this is the case, we can not be sure that an increase in its own market size will have a positive impact on G.

VI.5.3. The impact of trade policies on adoption.

As it has been shown above, zero transportation costs implied demand asymmetry between the two firms and, consequently, in this case $F^* = G = 0$ for any cost combination produced by the innovation. However, if $s_1 = s_2$ and thus $s = 1$, and $t_1 = t_2 > 0$, $G = 0$ is below $F^* = 0$ for all (c_1, c_2) because

$$G = F^* + 2\, s_1 t_2 \,[k_2 - c_2 + k_1 - c_1] > F^*$$

This implies that, even when there is symmetric demand conditions in the two markets and equal but positive transportation costs, the inefficiencies due to the existence of these transportation costs imply that some innovations that otherwise would be introduced earlier by firm 2, will now be adopted earlier by firm 1. This result is important if we recall that transportation costs included policy variables such as tariffs, taxes and subsidies.

It indicates that if country 1 attempts to increase its probabilities of being the first adopter of a new technology, by raising tariffs and this is counteracted by country 2 by an equal but opposite extent, then the final outcome is an upward shift in the boundary line $G = 0$. Consequently, the number of innovations that would be adopted earlier by the high cost firm (country), 1, will increase.

VI.5.4. Diffusion and trade flows.

This model gives some indication of the impact of international diffusion on trade flows. The balance of trade in this sector between both countries will be given by the net exports $x_1 - x_2$ If costs are (c_1, k_2),

$$x_1 = s_2(D + k_2 - 2k_1 - 2t_1 / 3)$$

$$x_2 = s_1(D + c_1 - 2k_2 - 2t_2 / 3)$$

Obviously, the balance will depend on market size and transportation costs as well as on production costs. Nevertheless, if $s_1 = s_2$ and $t_1 = t_2$, the low cost country 2, will be a net exporter of the final good to country 1:

a) before the innovation was introduced in any country,

b) when both firms are using the innovation, and

c) when the low cost firm, 2, is the first adopter of the new technology.

However, if the high cost country 1 is the first adopter, it can temporarily become a net exporter of the final good, but only if the innovation reduces its marginal costs below the marginal costs of its competitor when the latter has not yet introduced the innovation .

VI.5.5. The impact of market size on diffusion.

Differences in market sizes do not seem to have an important impact. From the expressions above it is easy to see that if we subtract F^* from G when $k_2 - c_2 = k_1 - c_1$, we get,

$$G - F^* = 18 (k_2 - c_2) [(s_1/s_2) - (t_1/t_2)] s_2 t_2$$

This expression shows clearly how the transportation or trade policy variables t and the market size have an impact similar in magnitude but of different direction upon the adoption decision of the firms. Thus, if for instance, firm 1 has a relative transportation cost disadvantage but it has a market size advantage that offsets that disadvantage, it will increase its chances of being the first one to innovate.

VI.6. CONCLUSIONS.-

This chapter is an attempt to study the mechanism of diffusion of new technologies across countries facing different types of asymmetries, but excluding the influence of the "technology gap" between the two countries. In a very simple model with only two firms, one in each country, competing in the international market for a final good as Cournot duopolists, it has been shown that the nature of the new technology available for adoption will be the crucial factor determining which firm will adopt the innovation earlier. Consequently, the conditions of supply of new technologies in the R&D sector will have an important influence on the subsequent process of diffusion of new technology. All this suggests the necessity of approaching the study of technological change from an integrated point of view.[80]

Under particular supply conditions in the R&D sector, some specific results can be obtained. For instance, under the cost conditions described in section VI.4.2. an independent R&D laboratory will produce innovations that will always be adopted earlier by the low cost duopolist. Section VI.4.1. shows that if a series of innovations of this kind happen over time, the high cost firm will eventually disappear.

The relative incentives that the two firms have to adopt the innovation earlier under two simple types of duopolistic conjectures have also been compared. For some new technologies, the type of duopolistic behaviour downstream does not have any impact on the pattern of adoption. However, for some types of technologies, Bertrand conjectures increase the relative incentives of the low cost firm more than those of the high cost firm and the diffusion pattern is changed. This may happen both for technologies that maintain and change the initial comparative advantage.

---

80 See for instance Stoneman and Ireland (1984).

Finally, the model has been expanded by differentiating the markets for the final product in each country to examine the influence of demand asymmetries. In this case, transportation costs and any other non-production costs borne by exported output, will have an important influence on diffusion. Any trade policy measure devised by the high cost country to improve its probability of being the first adopter (e.g. an increase in tariffs), when offset by a similar policy of the same intensity by the low cost country, will have a net positive effect in favour of the high cost country, i.e. the original ratio of average production costs.

All these results are obtained at the cost of a low level of generality (linear demand curve and constant average costs), in the context of an example, and therefore, one must be conscious of their limitations. But in many cases, and to the best of my knowledge, this is the first time in which some of these questions are addressed in the literature on diffusion. The main aim of this chapter has been trying to identify the direction of some effects in a context, that despite its relative simplicity presents sufficient complexities and intractabilities.

New insights into the mechanism of international diffusion of technology could arise under more general assumptions. Alternatively, the consideration of new conditions of supply in the R&D sector could produce new solutions. These are only two lines of possible future research in a field demanding much more attention that it has received until now.

Proof of lemma 1.-

This expression is positive unless either of the following happens:

a) $A + 4k_1 > 5c_2$ when $A + 4k_2 < 5c_1$ or

b) $A + 4k_1 < 5c_2$ when $A + 4k_2 > 5c_1$

However, this possibility can be ruled out if we restrict our attention to the economically significant values of (c_1,c_2) and (k_1,k_2). As we have assumed that the duopolistic structure will be maintained regardless who adopts first, the economically meaningful values of (c_1,c_2) and (k_1,k_2) are only those that ensure positive outputs for both firms after diffusion is complete. The winning firms will have the following output levels,

$$x_1 = [(A + k_2 - 2c_1) / 3] > 0 \quad \text{and} \quad x_2 = [(A + k_1 - 2c_2) / 3] > 0$$

As k_1 is always bigger or equal than c_2 , $3(k_1 - c_2) \geq 0$. But from the restriction on x_2 above, $(A + k_1 - c_2) > c_2$, therefore the sum of the two RHS of these inequalities can never be negative. Hence, the b possibility above has to be eliminated for economically relevant values of (c_1,c_2) and (k_1,k_2).

The other possibility requires $A + 4k_2 > 5c_1$. By the restriction on x_1 above we know that $A + k_2 - c_1 > c_1$. This possibility may still occur but only if and only if $3(c_1 - k_2) > A - k_2 - 2c_1$.

However, this possibility can be ruled out. Notice that $[dc_1/dc_2] = 0$ for $c_2 - [(A + 4k_1) / 5] > k_2$ because $A > k_2$ and $k_1 > k_2$. Furthermore, for $c_1 = 0$

$$dc_1/dc_2 = (A + 4k_1 - 5c_2) / (A + 4k_2) > 0$$

as we have seen that the numerator cannot be negative. AS we are considering values of $c_2 \leq k_2$ only, i.e. point to the left of $c_2 = [(A + 4k_1) / 5]$, the slope of the function $c_1 = f(c_2 ; F = 0)$ between that critical point and $c_2 = k_2$ will always be positive.

Description of the loci B = 0 in figure VI.2.

Firstly, note that for the values of (c_1,c_2) and (k_1,k_2) such that $[k_1/k_2] = [c_1/c_2]$, i.e. for cost reductions that maintaining the relative cost differential between both firms, B() as expressed in (6') is equal to

$$[k_2^2 + c_1^2 - k_1^2 - c_2^2] [z^2 + (1 - 2z^2)^2] + 2 M(z - 1) (c_1 + k_2 - k_1 - c_2) =$$

$$= 2M (2z + 1) (z - 1) (c_1 - k_1 + k_2 - c_2) + \tag{6''}$$

$$+ [(c_1 - k_1) (c_1 + k_1) + (k_2 - c_2) (k_2 + c_2)] [z^2 + (1 - 2z^2)^2]$$

In (6"), the second term

$$[(c_1 - k_1) (c_1 + k_1) + (k_2 - c_2) (k_2 + c_2)] [z^2 + (1 - 2z^2)^2] \leq 0$$

because along the straight line defined by $[k_1/k_2] = [c_1/c_2]$, the $(k_1 - c_1)$ difference is bigger than the $(k_2 - c_2)$ difference.

For the same reason, and given that $(c_1 + k_1) > (c_2 + k_2)$ along the same line, the first term $\{ 2M (2z + 1) (z - 1) (c_1 - k_1 + k_2 - c_2) \}$ is also non-positive. Therefore, the total sum in (6") will be negative when $[k_1/k_2] = [c_1/c_2]$ and equal to zero in the point $(c_1,c_2) = (k_1,k_2)$, where there is no cost reduction.

In other words, the level set defined by B() = 0 does not cross the line defined by $[k_1/k_2] = [c_1/c_2]$ for positive values of the cost reduction. Therefore, we can see the first important difference to the Cournot-Nash case: all those innovations which maintain the proportional cost differential between both firms, will be adopted earlier by the low cost firm.

Given that B = 0 does not cross the line defined by $[k_1/k_2] = [c_1/c_2]$ for $c_1 < k_1$ and $c_2 < k_2$, the level curve B = 0 must be below or above that straight line.

Firstly, a sufficient condition for B > 0 can be provided. Note that if $c_1^2 - c_2^2 > k_1^2 - k_2^2$, B() is always positive. This condition will be met by points down and to the right of the rectangle. Therefore, for those points, B > 0, as it happened in the Cournot-Nash case.

Secondly, note that for $k_1 - c_1 = k_2 - c_2$, (6') becomes

$$B = [(c_1 - k_1)(c_1 + k_1) + (k_2 - c_2)(k_2 + c_2)]\ [z^2 + (1 - 2z^2)^2] + 4z\,(1 - 2z^2)\,(c_1k_2 - c_2k_1) < 0$$

For the particular case in which $c_2 = 0$, this expression is always negative. Thus, we can conclude that for points above and to the left of the rectangle B() will always be negative. B = 0 will thus be located underneath $[k_1/k_2] = [c_1/c_2]$ as shown in figure VI.2.

Proof of proposition 2.- (Completion)

At $(c_1,c_2) = (c_1',c_2') \in F(c_1,c_2) = 0$ we know that

$$F = 2A(k_1 + c_2 - c_1 - k_2) + 8(k_1c_2 - c_1k_2) + 5(c_1^2 + k_2^2 - k_1^2 - c_2^2) = 0$$

Furthermore, if $c_1 = c_1'$ and $c_2 = c_2'$, the difference in revenues to the monopolist in the second period depending on who adopted in the first will have the same sign that

$$Q = 9[\pi^2(c_1,c_2) - \pi^2(c_1,k_2) - \pi^1(c_1',c_2') + \pi^1(k_1,c_2')] =$$
$$= 4[(c_2^2 + k_1^2 - c_1^2 - k_2^2) + A(k_2 + c_1 - k_1 - c_2) - (c_2k_1 - c_1k_2)]$$

If we substitute in this equation the value of $A(k_2+c_1-k_1-c_2)$ from its value in (4), the sign of M is the same as the sign of

$$2(k_1c_2 - c_1k_2) + c_1^2 + k_2^2 - k_1^2 - c_2^2 = 2\alpha(c_2 - k_2) + 2\beta(c_2 - k_2) + \beta^2 - \alpha^2 < 0$$

because $c_2 \leq k_2$ and for any point that satisfies (4), $\alpha > \beta$.

Beath J., Katsoulacos Y. and Ulph D. (1987), "Sequential Product Innovation and Industry Evolution", **Economic Journal**, AUTE Conference Papers, vol. 97, pp.32-43.

Cimoli M., Dosi G. and Soete L. (1986), "Innovation Diffusion: Institutional Differences and Patterns of Trade: A North-South Model", SPRU, University of Sussex, DRC Disc. paper n. 36.

Cheng L.(1984), "International Competition in R&D and Technological Leadership: An Examination of the Posner-Hufbauer Hypothesis", **Journal of International Economics**, vol. 17, March, pp. 15-40.

David P. (1969) "New Technology Diffusion, Public Policy and Industrial Competitiveness", **Symposium on Economics and Technology**, Stanford University, March 17-19.

Dollar D. (1986), "Technological Innovation, Capital Mobility and the Product Cycle in North-South Trade", **American Economic Review**, vol.76, n. 1, March, pp. 177-190.

Flaherty M.T., (1980), "Timing Patterns of New Technology Adoption in Duopolistic Industries", Unpublished Manuscript.

Fudenberg D. and Tirole J. (1985), Pre-emption and Rent Equalization in the Adoption of New Technology", **Review of Economic Studies,** vol. 52, June, pp. 383-401.

Gomulka S.(1971) **Inventive Activity, Diffusion and the Stages of Economic Growth,** Institute of Economics. Aarhus.

Grindley P. (1986), **A Strategic Analysis of the Diffusion of Innovations: Theory and Evidence**, Unpublished Doctoral Dissertation, London School of Economics.

Hufbauer G.C. (1966), **Synthetic Materials and the Theory of International Trade,** Harvard University Press, Cambridge, MA.

Jensen R, and Thursby M. (1987), "A Decision Theoretic Model of Innovation, Technology Transfer and Trade", Research Seminar in International Economics, University of Michigan, Disc. Paper n 199.

Krugman P. (1979), "A Model of Innovation, Technology Transfer and the World Distribution of Income", **Journal of Political Economy**, vol. 87, n. 2, April, pp. 253-66.

Lee K. (1984 a), "International Technology Transfer and Technology Diffusion Effects", Northwestern University, Disc. Paper n. 621.

— (1984 b), "Market Structure and International Technology Transfer", Northwestern University, Disc. Paper n. 622.

Okuguchi K. (1987) "Equilibrium Prices in the Bertrand and Cournot Oligopolies", **Journal of Economic Theory**, vol. 42 pp. 128-139.

Posner M.V. (1961), "International Trade and Technical Change", **Oxford Economic Papers**, vol. 31, pp. 323-41.

Quirmbach H.C. (1986), "The Diffusion of a New Technology and the Market for an Innovation", **Rand Journal of Economics**, vol. 17, n. 1, Spring, pp. 33-47.

Reinganum J.F. (1980), "On the Diffusion of New Technology: A Game Theoretic Approach", Social Science Working Paper n. 312, Pasadena, California Institute of Technology.

---- (1981), "On the Diffusion of a New Technology: A Game Theoretic Approach", **Review of Economic Studies**, vol. 48, June, pp. 395-405.

— (1983), "Market Structure and the Diffusion of a New Technology", **Bell Journal of Economics**, vol. 12, December, pp. 618-24.

— (1984), "Practical Implications of Game Theoretical Models of R&D", **American Economic Review**, Papers and Proceedings, vol. 74, May, pp. 61-66.

Singh N. and Vives X. (1984) "Price and Quantity Competition in a Differentiated Duopoly", **Rand Journal of Economics**, vol. 15, pp. 546-554.

Stoneman P. and Ireland N.J. (1984), "Innovation and Diffusion: the Implications of an Integrated Approach", Summer Workshop on Technological Change, Warwick University.

Teece D.J. (1977), "Technology Transfer by Multinational Firms: the Resource Cost of Transferring Technological Know-How", **Economic Journal**, vol. 87, June, pp. 242-61.

Vernon R. (1966), "International Investment and International Trade in the Product Cycle", **Quarterly Journal of Economics**, vol. 53, May, pp. 190-207.

Vickers J. (1986) "The Evolution of Market Structure when There is a Sequence of Innovation", **Journal of Industrial Economics**, vol. 35, September, pp. 1-12.

CHAPTER VII: INTERNATIONAL TRADE, ENDOGENOUS INNOVATION AND DYNAMIC EFFICIENCY

VII.1. INTRODUCTION.

In the last fifteen years, there has been an important surge of interest in incorporating technology related issues into international trade models. As technology is an essentially dynamic variable, the new trade models developed to include technology issues have in many cases had to take time into account. The simultaneous consideration of time and technology has produced new results that contradict the standard conclusions from the conventional theories of trade. Good and recent surveys of these new developments can be found in Cheng (1984), Soete (1985) and Lyons (1987).

It is difficult to consider trade and technological change in a simultaneous and comprehensive way. Economists have had to choose among the many facets that these two problems present. In some cases, they have concentrated their attention on studying the effect of new products and processes on the patterns and composition of trade and, ultimately on welfare. In those cases where technology has been considered endogenously, economists have studied how trade policies can affect the rate and direction of R&D or the pattern of diffusion of a new technology. Finally, technology has sometimes been considered either as a tradable commodity or as a factor of production which can be highly mobile across borders.

Within the first line of inquiry, the most remarkable result is the so called *immiserizing technological progress*. According to this result, an increase in the productivity of factors intensively used in one country's export industry will have an adverse effect on the terms of trade of that country. If the country's demand for its export good is relatively insignificant and the international demand for that good is inelastic, technological change would have an adverse effect on the country's welfare.

Stoneman (1987) has suggested another kind of adverse effect that may arise from the combination of trade and technological change. This argument considers the implications of trade policies in terms of dynamic efficiency when there is learning by doing. Although free trade can be efficient from a static point of view, when there is induced technological change, one country's future possibilities of production can be influenced by the characteristics of the new technology, and these can be influenced by the present trade regime. Thus, a trade off between static and dynamic efficiency appears, as it usually happens when technological change is considered.

The purpose of this chapter is to show in a formal way how this trade off can arise even when there is not any learning by doing. In the context of a conventional model of international trade, it is shown that trade policies can introduce biases that affect the rate of factor augmentation. As a result of this, under certain technological conditions, having free trade when the innovation is produced can have an adverse effect on the country's future welfare.

VII.2. THE MODEL.

Assume two different countries, home and rest of the world, that produce two different final goods, y_1 and y_2, under constant returns to scale. To produce these goods, two basic inputs are used. The domestic country has an initial endowment X^i of each factor of production i = 1,2 . In the foreign country, these initial endowments will be given by X^{i*}. The linearly homogeneous production functions in each sector are the same in both countries and can be written as:

(1) $$y^1 = f^1(Q_{11}, Q_{12})$$

(2) $y^2 = f^2(Q_{21}, Q_{22})$

where Q_{ji} is the total amount of factor of production X^i used in the production of final good j, with $i = 1,2$ and $j = 1,2$.

Constant returns to scale allow us to write $Q_{ji} = y_j q_{ji}$, where q_{ji} is just the amount of factor of production X^i used in the production of only one unit of final good j.

In equilibrium, perfect competition ensures that:

(3) $p_1 = w_1 q_{11} + w_2 q_{12}$

(3') $1 = w_1 q_{21} + w_2 q_{22}$

where p_1 is the relative price of good 1 in terms of good 2, whose price is assumed to be the same in both countries for simplicity, and w_i is the price of input $i = 1,2$.

Full employment of both inputs requires that:

(4) $X^1 = Q_{11} + Q_{21}$

(4') $X^2 = Q_{12} + Q_{22}$

In order to complete the description of the static equilibrium of each economy at any point in time, some assumption about the regime of trade between the two economies is needed.[81] But let us turn to the technology side of the model.

It will be assumed that there is some kind of technological asymmetry between the two countries. This asymmetry is introduced in the model by assuming that industries in

---

81 This static model can be generalized and incorporated into a dynamic one by assuming that each static equilibrium corresponds to a certain point in a continuum of time. For that purpose, it can be assumed that there are stable steady-state paths of growth for the two economies, both under free trade and autarky. An innovation introduced at a specific point in time would shift the economy from one steady state to a new one. However, as this generalization would not alter the results, the static approach will be maintained.

the domestic country will be the first to introduce a certain process innovation, developed at home or abroad. The innovation is ordered at a certain moment $t=0$. The innovation is adopted later by the foreign country and there is a final moment, T, when diffusion is complete and all the firms in both countries are using the same technology.[82]

Technological leadership in the domestic country has implications for the direction of technological change. The characteristics of the new process technology are going to be determined or induced by production conditions in the home country. In order to reduce costs, the current distribution of income between factors of production is taken into account and the new technology will tend to save the relatively better paid input. The production conditions that will have an impact on the direction of technological change will be those prevailing in the relevant domestic industry at time $t=0$.

This assumption is clearly plausible if the new technology is developed or ordered from an external R&D laboratory by the domestic industry. It can also be justified on the grounds of some priority in adoption times: when deciding the rate and direction of technological change, only the "taste" of the first customer matters.

In any case, income flows generated by the trading of technology will not be taken into account here. When the new technology is developed at home, it will be assumed that it is produced using one factor of production only (that can be called "scientists") which is used at full capacity. In order to be able to exclude the influence of this sector in the national income accounting, it will be assumed that the total return to scientists will be a fixed amount and that "scientists" have a zero marginal product when used in the production of final goods.

---

82 As it will be seen later, this innovation will not normally be neutral in any sense and consequently, in a dynamic context, each economy will be in different steady states at $t=0$ and at $t=T$. As the emphasis is put here on the potential dynamic inefficiencies that trade regimes can generate, only the different final equilibria that can be achieved at time $t=T$, depending on the trade regime prevailing at time $t=0$ will be relevant here.

This idea was suggested by Hicks (1932) and later developed by Kennedy (1964), von Weisacker (1966), Drandakis and Phelps (1966) and Binswanger (1974), who assumed that the direction of technological change is actually influenced by the relative distribution of income between the factors of production. According to these authors,[83] if the production function of good y_j can be written as

$$(5) \qquad y_j = f^j\{A(t)Q_{j1}, B(t)Q_{j2}\}$$

where A(t) and B(t) are two factor augmenting coefficients, we can define a certain "Invention Possibility Frontier"[84] as the geometric locus of points giving the different maximum proportional increments a(t) and b(t), of the factor augmenting coefficients, i.e. different rates of factor augmentation, for a fixed R&D budget. Hence, we can define,

$$(6) \qquad b(t) = \Phi[a(t)]$$

where $a(t) = [(dA(t))/dt) / A(t)]$ and $b(t) = [(dB(t)/dt) / B(t)]$. Function Φ is assumed to be decreasing and concave towards the origin reflecting the fact that there is a trade off between the rates of factor augmentation. In other words, increasing rates of factor augmentation in factor 1 can be attained only at the expense of lower rates of augmentation in factor 2, and this will take place at an increasing rate.

If we define the rate of unit cost reduction at any moment t as:

$$(7) \qquad c(t) = \left[\frac{dC(t)}{dt}\right]/C(t) = a(t)\Theta + (1-\Theta)\,b(t)$$

where Θ and $(1-\Theta)$ are the relative shares of inputs 1 and 2 in the total cost of output. The domestic industry will choose the direction of technological change, i.e. it will choose the

83 More precisely, the version adopted here is the one proposed by Drandakis and Phelps (1966).

84 There has been a certain disagreement on whether to call this curve the Invention Possibility Frontier or the Invention Possibility Frontier, and some comments on this can be found in Binswanger (1974) and Stoneman (1983). Here, the first option will be taken.

a(t) and b(t) so as to minimize expression (7) above, subject to the technical constraint expressed by (6). That is, the domestic industry will "order" a new technology such that,

$$\max_{a(t),\, b(t) > 0} c(t) = a(t)\,\Theta + (1-\Theta)\,b(t) \quad (8)$$

$$\text{subject to } b(t) = \Phi\,[a(t)]$$

An interior solution to this problem will require a tangency between the isocost-reduction lines defined by (7) and the Invention Possibility Frontier. Consequently, in an interior optimum, the following condition must be fulfilled:

$$\Phi'[a(t)] = \frac{-\Theta}{1-\Theta} \quad (9)$$

Under different trade regimes, the relative shares of the two factors of production will vary, both in the whole domestic economy and within each industry. As a result, it is reasonable to assume that this will have an impact on the direction of technological change and consequently, different biasses will be induced on technological change under free trade and under autarky. In turn, this will imply a different shift outwards in the Production Possibility Frontier at time t=T, depending on the trade regime prevailing at time t=0. The next section studies the impact of opening to trade on the relative shares of the two factors of production, within the two domestic industries.

VII.3. THE IMPACT OF OPENING TO TRADE ON FACTOR SHARES WITHIN EACH INDUSTRY.

Assume that at time t=0, there is a prohibitive tariff at home so that no trade takes place between the two countries. The introduction of a demand side in the two-sector general equilibrium model described by (3), (3'), (4) and (4') above, will yield the well established standard autarky equilibrium, as described in any traditional text on International Trade.[85]

This equilibrium defines a certain distribution of income in the domestic economy as a whole and within each industry in particular. As a result of these factor shares, the direction of the technological change taking place in either industry after time $t=T$, will be endogenously determined by equation (9). Let us call Θ^* the factor share of input 1 in industry 1 under autarky. For a given Θ^*, the optimum rate of factor augmentation under autarky that can be defined as $a^*(t)$ and $b^*(t)$.

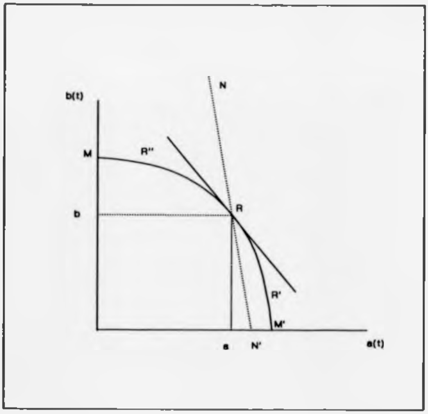
One such case is shown in figure VII.1, where MM' is the Invention Possibility Frontier and the optimum rates of factor augmentation under autarky are given by point R, as a result of factor shares in industry 1, Θ^* and $(1-\Theta^*)$ defined by the autarkic equilibrium.

Given the direction of technological change, when the innovation has been fully adopted and is being used by all the firms at time $t=T$, the production possibility frontier between goods y_1 and y_2 at T, associated to the trade regime at time $t=0$ is determined by the rates of factor augmentation $a^*(t)$ and $b^*(t)$. However, it is important to note that the different $[a(t),b(t)]$ combinations along the Invention Possibility Frontier existing at $t=0$ will usually yield different production possibility frontiers at time $t=T$.

Assume that at time $t=0$, the prohibitive tariff is partially or completely removed so that we move towards a free-trade regime. Assume that the international price of good y_1 is higher than its domestic price under autarky, and that the home country has a comparative advantage in the production of good 1, i.e. the home country will tend to export good y_1 and import good y_2.

---

85 See Dixit and Norman (1980) for instance.



Furthermore, assume that factor 1 is intensively used in the production of good y_1 and factor 2 is intensively used in the production of good y_2. Finally, any possibility of factor intensity reversals for any level of output, relative input price ratios and both, prior and after the introduction of the new technology is ruled out by assumption. In other words,

$$(q_{11}/q_{12}) > (q_{21}/q_{22}) \text{ for all } y_1,y_2 > 0;\ w_1/w_2 > 0\ , \text{ for any } t \text{ in } [0,t]$$

Under these assumptions, the Stolper-Samuelson (1941) theorem assures that removing the prohibitive tariff on imports will raise the real wage and the share in international income of factor 1, while reducing the same variables for factor two, i.e.,

(10)

$$\frac{d\,w_1}{d\,p_1} > 0 \qquad \frac{d}{d\,p_1}[w_1X^1/(p_1y_1+y_2)] > 0$$

$$\frac{d\,w_2}{d\,p_1} < 0 \qquad \frac{d}{d\,p_2}[w_2X^2/(p_1y_1+_2)] > 0$$

However, to know how opening to trade influences the direction of technological change, we need to know first its impact on the rates of factor share augmentation [a(t),b(t)]. This depends on how opening to trade affects the relative factor shares in the industry "ordering" the innovation at time t=0. The following lemma establishes this relationship between the direction of technological change and the rates of factor share augmentation, which depends on the elasticity of factor substitution.

Lemma 1.- The removal of a prohibitive tariff by the domestic country will increase (reduce) the factor share of the input intensively used in the domestic export industry, if and only if the elasticity of substitution as defined by

$$\sigma = \frac{d(q_{12}/q_{11})}{d(w_2/w_1)} \frac{w_1/w_2}{q_{12}/q_{11}} \quad (15)$$

is bigger (smaller) than -1.

This is not a surprising result. As the tariff is removed, if the home country has a comparative advantage in the production of good 1, the relative price of that good will tend to increase and more resources will be allocated into that sector. Relative prices will also change as predicted by the Stolper-Samuelson theorem. As good 1 is intensive in factor 1, the price of factor 1 will increase. This will induce a mechanism of substitution of inputs that will tend to offset the rise in the relative weight of factor 1 in the total costs of sector 1. The capacity to compensate for using more of the relatively more expensive input will depend on technical conditions, i.e. having an elasticity of substitution more or less than 1 in absolute terms.

VII.4. The induced effect of trade policies on the direction of technical change and on domestic welfare: the small country case.

The purpose of this section is to draw some welfare implications about the dynamic consequences of having autarky or free trade at a certain point in time when technological change is taking place. If we assume that the home country is small and takes international prices as fixed, the study of the consequences on welfare of opening to free trade can be reduced to studying its impact on the production of good y_1, for each output level of good y_2. In other words, it will be sufficient to compare the production possibility frontier resulting from autarky and the production possibility frontier resulting from free trade, both at $t=0$.

As it was shown in the last section, opening to trade has an impact on the factor shares within each industry. Therefore, lemma 1 can be applied to learn about this indirect impact of trade policies on the direction of technological change.

In figure VII.1, we can identify the initial autarky equilibrium at point R. This equilibrium implies that technological change will augment factor 1 (factor 2) at a rate equal to a^o (b^o). The removal of the prohibitive tariff will lead either to a position such as R' if the elasticity of substitution is bigger than -1, or to R" if the elasticity of substitution is less than -1.

If technological change was originated at time $t=0$, initial biasses on technological change such as those indicated by points R, R' or R" in figure VII.1 will produce different production possibility frontiers at time T. In fact, if the production function is Cobb-Douglas, the rate of growth in the production of y_1 will be given by,

$$r = \frac{y_1}{y_1} = \alpha \frac{Q_1}{Q_1} + (1-\alpha) \frac{Q_2}{Q_2} + \alpha\, a(t) + (1-\alpha)\, b(t)$$

If there is no growth in the availability of the two factors of production between $t=0$ and $t=T$, r is determined only by

$$r = \alpha\, a(t) + (1-\alpha)\, b(t)$$

which is a negatively sloped straight line in the a(t),b(t) space. This line is denoted by NN' in figure VII.1 for the autarky case. Any point above and to the right of this line will imply higher levels of output at time T than those implied by the rate of growth r^A achieved when there was autarky at $t=0$. Note that depending on the technology in the R&D sector, NN' and the Invention Possibility Frontier can have one or more intersections.

Also depending on the relative position of R, R' and R'' and the slopes of NN' and MM', we may have that, for a given combination of both inputs used in the production of y_1, opening to trade could increase or decrease the total production of that final good. If the country is small, to study the relationship between trade regimes, the distribution of income between inputs at $t=0$ and the production possibilty frontier resulting from induced technological change, all what is necessary is to study how different points on the Innovation Possibility frontier relate to the future production possibilty frontier.[86]

Movements along the Invention Possibility Frontier can be decomposed as the sum of two different effects: a positive output augmenting effect that goes from R to H in figure VII.2 and a negative factor augmenting effect that goes from H to R'.

To study these changes, equation (5) can be rewritten as,

(5') $\quad y_1(t) = A(t)\, f^1\, [Q_{11}, (B(t)/A(t))Q_{12}]$

making use of its linear homogeneity condition.

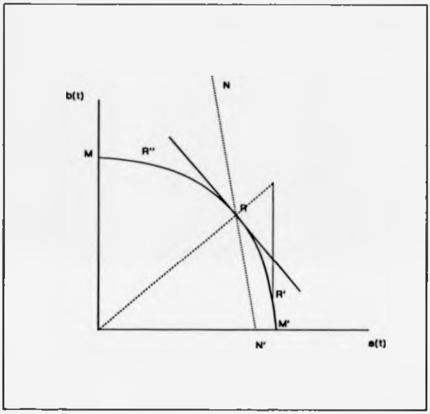
---

86 For this comparison, we will assume that there is free trade at time $t=T$.

Let us define a new variable ϕ [87], such that when we move along the Invention Possibility Frontier, ϕ changes and consequently, A(t) and B(t) also change but in the following way:[88]

$$\text{(11)}\quad \begin{array}{lll} \text{a.- if } \phi = \phi^o & [dA/d\phi] = 0 \text{ and } [dB/d\phi] = 0 \\ \text{b.- if } \phi < \phi^o & [dA/d\phi] < 0 \text{ and } [dB/d\phi] > 0 \\ \text{c.- if } \phi > \phi^o & [dA/d\phi] > 0 \text{ and } [dB/d\phi] < 0 \end{array}$$

FIGURE VII.2.



---

87 We can think of ϕ as the absolute value of the slope along MM'.

88 In terms of this new variable, the exercise that we are developing in this section is just mapping each point in the Invention Possibility Frontier into different production possibility frontiers in the $[y_1,y_2]$ space and comparing them taking the one resulting from $\phi = \phi^0$ as a reference.

Thus, in case a we remain on point R, case b indicates a movement towards R" whereas in case c we approach R'.

It is important to note that the relative magnitude of a change in A and B due to a certain change in ϕ, i.e. $[(dA/d\phi)/(dB/d\phi)]$ is related to the curvature of the Invention Possibility Frontier. The more concave the Invention Possibility Frontier is, the smaller $[(dA/d\phi)/(dB/d\phi)]$ will be in absolute value.

Now, ϕ will enter equation (5') as a parameter, so that it can be rewritten as,

(5") $$y_1(t;\phi) = A(t;\phi)\, f^1(Q_{11}, (B(t;\phi)/A(t;\phi))\, Q_{12})$$

Using the envelop theorem at point t=T, we get that, for a given combination of both inputs (Q_{11},Q_{12}), the maximum output y_1 that can be obtained will vary with ϕ according to the following expression,

(12) $$\frac{dy_1}{d\phi} = \frac{dA}{d\phi} f^1(Q_{11}, \frac{B(t;\phi)}{A(t;\phi)} Q_{12}) + f^1{}_2 Q_{12} \left[\frac{dB}{d\phi} - \frac{B\, dA}{A\, d\phi}\right] =$$

$$= \frac{dA}{d\phi}\left[\frac{y_1}{A} - \frac{B}{A} f^1{}_2 Q_{12}\right] + \frac{dB}{d\phi} f^1{}_2 Q_{12}$$

From the expression above, it is not possible to know directly how the y_1 output at time T will change in response to a movement away from autarky at time t=0, for all the possible fixed values of y_2. However, something can be said about $[dy_1/d\phi]$ as y_1 approaches 0. The limit of (12) as y_1 tends to cero,

(13) $$\lim_{y1 \to 0} \frac{dy_1}{d\phi} = -\frac{dA}{d\phi}\frac{B}{A} f^1{}_2 Q_{12} + \frac{dB}{d\phi} f^1{}_2 Q_{12}$$

is negative (positive) in case of a movement downwards (upwards) along the Invention Possibility Frontier. Hence, for very low levels of output of the final good y_1, the production possibility frontier at time T will be flatter if at time $t=0$ there was autarky (free trade) and the elasticity of substitution was smaller (bigger) than -1. Consequently, the following proposition can be made:

Proposition 1.- If opening to trade at time $t=0$ increases (decreases) the factor share of an input intensively used in the industry where an innovation takes place at that time, then, for a given level of output y_2 close to the maximum attainable at time T, the maximum attainable level of y_1 will be lower (higher) if there was free trade in $t=0$ instead of autarky.

For higher levels of output y_1, the relative position of the production possibility frontier at time T for a given value of y_2, will depend on parametric conditions of the Invention Possibility Frontier and the production function. By Euler's theorem we know that:

$$\frac{y_1}{A(T)} = Q_{11}f^1_1 + Q_{12}f^1_2 \frac{B}{A} \quad \text{or} \quad \frac{y_1}{A(T)} - \frac{B}{A} = Q_{11}f^1_1$$

and substituting in (12) we get that,

$$\text{(14)} \qquad \frac{dy_1}{d\phi} = \frac{dA}{d\phi} Q_{11}f^1_1 + \frac{dB}{d\phi} Q_{12}f^1_2$$

which can be negative or positive depending on the magnitude of the two terms at the RHS of (14), because, by the definition of ϕ in (11), A(t) and B(t) change in opposite directions when ϕ deviates from ϕ^o. Thus, the following proposition can be made,

Proposition 2.- At time T, total output in the y_1 industry can be larger if at time $t=0$ there was a prohibitive tariff instead of free trade if and only if:

$$\sigma > -1 \quad \text{and} \quad \left| \frac{dA}{d\phi} Q_{11}f^1_1 \right| < \left| \frac{dB}{d\phi} Q_{12}f^1_2 \right|$$

It is important to note that these are necessary and sufficient conditions. Their economic intuition is more obvious is we express this proposition as,

$$(15) \quad \frac{dy_1}{d\phi} \gtrless 0 \text{ iff } -\frac{dA/d\phi}{dB/d\phi} \gtrless \frac{Q_{12}f^1_2}{Q_{11}f^1_1} = \frac{Q_{12}w_2}{Q_{11}w_1}$$

Hence, we can say that for a given y_2, with $\sigma > -1$, opening to trade will lead to a production possibility frontier inside the one corresponding to autarky, if:

1. For a given factor share, the Invention Possibility Frontier is strongly concave, or if,

2. For a given curvature of the Invention Possibility Frontier, the returns to input 2 are relatively large in comparison to the returns to the input intensively used in the industry where the innovation takes place, i.e. factor 1.

If $\sigma > -1$, as we move away from autarky, the more concave the Invention Possibility Frontier is, the faster the rate of reduction in B for a given increase in A grows. Thus, if the Invention Possibility Frontier is very concave, it is possible that for any y_2, the maximum y_1 resulting from having autarky at $t = 0$ is bigger that the maximum y_1 that would result from free trade.

However, the last proposition depends on some technical conditions in the production of the innovation. But a stronger result than proposition 2 can be obtained, in which those technical conditions do not matter,

<u>Proposition 3.-</u> $\sigma > -1$ is a sufficient condition to have $[dy_1/d\phi] < 0$ when we depart from autarky at time $t = 0$

The proof of this result is quite simple. As (13) indicates, when $\sigma > -1$, opening to trade will lead to a production possibility frontier corresponding to free trade inside the production possibility frontier that we get at time T if we had autarky at $t=0$. Hence, when $\sigma > -1$, this result holds for some small values of y_1. But according to proposition 2, for the other values of y_1, an additional condition is necessary, namely,

$$-\frac{dA/d\phi}{dB/d\phi} < \frac{Q_{12}f^1{}_2}{Q_{11}f^1{}_1}$$

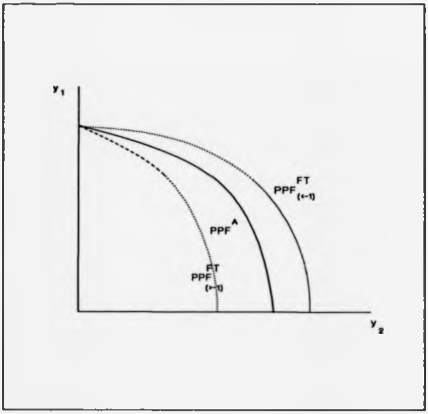
According to (13), this condition is fulfilled for some values of y_1. But the production function $y_1 = f^1\ (AQ_{11,}BQ_{12})$ is homogeneous of degree one and, given the international terms of trade, the input price ratio will be constant in the home country for any (y_1,y_2) combination, and consequently, the ratio

$$\frac{Q_{12}f^1{}_2}{Q_{11}f^1{}_1}$$

will be constant for any output level of y_1.

In other words, if the sign of (15) is always the same for any value of (y_1,y_2). As a result of this, the different production possibility frontiers that can be obtained from the mapping from the Invention Possibility Frontier onto the (y_1,y_2) space will never intercept each other. Thus, the map of production possibility frontiers corresponding to different values of ϕ along the Invention Possibility Frontier will look like figure VII.3.

Some welfare conclusions can be obtained at this point. If there is free trade at time T, the welfare effects of having free trade or autarky at $t=0$ will depend on international prices. But the sign of the welfare change will depend on the elasticity of substitution between inputs in the industry producing y_1 at the time when the innovation was ordered. Consequently, the following result can be obtained,



Corollary.- For a small economy, having free trade at time $t=0$ will have an adverse effect on welfare at time T, if an innovation to be used by its export industry is ordered at $t=0$ and used at $t=T$ and the elasticity of substitution in that industry is bigger than -1.

The economic interpretation of this result could be the following. The theory proposed by Kennedy and von Weisacker suggests that, when ordering a process innovation, firms will try to save more on that factor of production which has highest share of costs in that industry. Opening to trade involves changes in the relative prices of both outputs and inputs. When the elasticity of substitution is bigger than -1, the factor intensively used in the export industry will earn higher returns in proportion to the industry costs.

In terms of the Kennedy-von Weisacker theory, if $\sigma > -1$, opening to trade will have the result of introducing a stronger bias against that factor when the process innovation is ordered. As a result of this, at time T, as input units are transferred from the y_2 sector to produce y_1, the maximum output levels of y_1 that can be produced are lower if the innovation was ordered having free trade instead of autarky at $t=0$.

VII.5. Some final comments.

The previous section has shown that introducing free trade at a certain point in time, can produce some dynamic inefficiencies due to the induced effects produced by factor shares on the rates of factor augmentation that characterize a new process innovation in the domestic export industry. As has been discussed in the introduction, market imperfections such as economies of scale and externalities have been put forward to warn about the potential negative effects of free trade in a dynamic context.

To prove that such dynamic inefficiencies can also arise in a perfectly competitive context, particularly when the production of technology is considered, has been the aim of this chapter. Nevertheless, this chapter has identified the direction of some economic effects, whose occurrence has to be considered just as a theoretical possibility. In this section includes some considerations that could help in the process of approaching the real world from our abstract assumptions.

First of all, the Invention Possibility Frontier is an analytical tool that has been the subject of much criticism. Very little is known about the production conditions prevailing in the R&D sector. However, the most simple idea supporting the Kennedy-von Weisacker model, i.e. the existence of a trade off between choosing R&D projects that augment different factors of production at different rates, seems to be plausible enough.

In our opinion, assuming that the choice of R&D projects is carried out according to the optimization problem expressed by (8) and nothing else, is much more questionable. In doing so, we are assuming that in some sense, firms in the domestic export industry have some kind of myopic behaviour.

Furthermore, the Invention Possibility Frontier makes endogenous the direction but not the rate of technical change. The rate of production of R&D is undetermined in the Kennedy-Drandakis-Phelps model.[89] In fact, production and trade in technology have been assumed out from our model in order to isolate the effects that we were searching for in a simplified model.

But the production of R&D absorbs resources from the rest of the economy, and furthermore, technology can be an internationally traded commodity itself. We can incorporate these two considerations in a simple model to show how free trade in the presence of R&D can then have an unequivocally positive effect on welfare.

Let us consider a situation in which only two goods can be produced in two technologically asymmetric economies: "food" and "blueprints". By technological asymmetry we mean that:

1. Given a certain endowment of resources in each country, average productivity in the food sector is higher in country 1, and, if all resources are devoted to the production of food, maximum quantities f_1 and f_2 can be obtained.

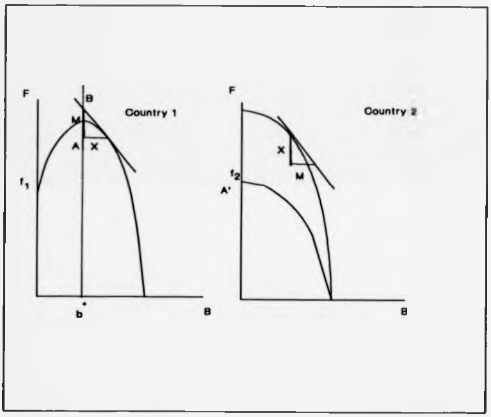
---

89 However, Binswanger (1974) takes account of this problem.

2. If some resources are withdrawn from the food sector and used by the R&D sector, the maximum amount of food produced in country 1 can be increased up to a certain point b^*, and will decrease for higher levels of R&D. To make things simple, let us assume that any amount of resources withdrawn from the R&D sector in country 2 reduces the production of food in that country. The resulting production possibility curves are illustrated in figure VII.4.

Finally we will assume that only food enters the social utility function in both countries.

FIGURE VII.4.



If there is no possibility of trade between the two countries, maximum welfare in each country is achieved in points A and A'. This is due to the fact that country 1 faces a negative opportunity cost in using some resources in the R&D sector for blueprint production below b^*. However, after point A, that opportunity cost becomes positive and the price for blueprints is zero. For country 2, it is clear that A' is a corner social optimum.

In the case that technology and food can be traded, and if using country's 1 blueprints can increase food production in country 2, a Pareto superior solution like the one described by B and B' can be reached. In this case, free trade makes the price of blue prints positive, and that makes the world's rate of technical change larger under free trade than under autarky.[90]

Finally, although having free trade can have negative consequences on welfare at time T, we cannot forget that still, it is superior to autarky at $t=0$. Here we have that one trade regime is efficient from a static point of view but inefficient in dynamic terms. In such a situation, to know the final net effect on welfare we require an intertemporal social utility function where an intertemporal social rate of discount of preferences between the two dates is specified.

One main conclusion can be drawn from the propositions in this chapter. Even when we consider the small country case and welfare comparisons can be simplified by taking international prices as given, the introduction of dynamics and process innovations in a model of international trade of the Hecksher-Ohlin class, facilitates the realization of results that are opposite to the traditional main results of that class of models. Very specific models like the one presented here can help to identify new effects that where not included in traditional models of trade. However, most of these new results are just economic effects acting in different directions and, like Lyons says, "we are still a long way

---

90 Note that if there is free diffusion of technology, we would approach the autarky equilibrium in the limit. This kind of effect has been recently pointed out in a game theoretic model by Jensen and Thursby (1987).

from a comprehensive understanding but at least the bounds of our ignorance have been reduced".[91]

91 Lyons (1987) page 170.

Proof of lemma 1.

If the innovation is taking place in the sector in which our domestic country has a comparative advantage, i.e. industry 1, we need to check the signs of:

$$(16) \qquad \frac{d}{dp_1}[\, w_1q_{11}/(w_1q_{11}+w_2q_{12})]$$

$$(17) \qquad \frac{d}{dp_1}[\, w_2q_{12}/(w_1q_{11}+w_2q_{12})]$$

taking into account the information provided by (10). The first one of these can be written as:

$$\frac{d}{d\,p_1}[1/(1+Z)] = \frac{-\,Z'}{(1+Z^2)}$$

where

$$Z = \frac{w_2\,q_{12}}{w_1\,q_{11}}$$

Hence, the sign of (16) will be the opposite to the sign of Z'. The latter will be given by,

$$(18) \qquad Z' = \frac{d[\frac{w_2}{w_1}\ \frac{q_{12}}{q_{11}}]}{d\,P_1} = \frac{q_{12}}{q_{11}}\ \frac{d(w_2/w_1)}{dP_1} + \frac{w_2}{w_1}\ \frac{d(q_{12}/q_{11})}{d(w_2/w_1)}\ \frac{d(w_2/w_1)}{dP_1} =$$

$$= [\frac{q_{12}}{q_{11}} + \frac{w_2}{w_1}\ \frac{d(q_{12}/q_{11})}{d(w_2/w_1)}]\ \frac{d(w_2/w_1)}{dP_1} \gtrless 0$$

By the Stolper-Samuelson theorem we know that w_2 and w_1 will move in opposite directions when the price of good 1 changes, i.e. $[d(w_2/dw_1)/dp_1]<0$. Hence, the sign of (18) above will be the inverse of the sign of (19) below,

$$\frac{q_{12}}{q_{11}} + \frac{w_2}{w_1}\frac{d(q_{12}/q_{11})}{d(w_2/w_1)} \lessgtr 0 \qquad (19)$$

The elasticity of substitution between inputs 1 and 2 in the production of final good 1, is usually defined as,

$$\sigma = \frac{d(q_{12}/q_{11})}{d(w_2/w_1)}\;\frac{w_1/w_2}{q_{12}/q_{11}}$$

and substituting this definition in (14) above, (14) becomes

$$(19') \qquad \frac{q_{12}}{q_{11}} + \sigma\,[q_{12}/q_{11}] = [1+\sigma]\;[q_{12}/q_{11}]$$

because,

$$\frac{d(q_{12}/q_{11})}{d(w_2/w_1)} = \sigma\,\frac{q_{12}/\,q_{11}}{w_2\,/\,w_1}$$

From (19') we can conclude that,

$$\text{sign}\,\{\frac{d}{dp_1}[1/(1+Z)]\} = -[\text{sign } Z'] = \text{sign}\,[1+\sigma]\,[q_{12}/q_{11}]$$

and,

$$\frac{d}{dp_1}[\,w_1q_{11}/(w_1q_{11}+w_2q_{12})]\;\begin{cases} >0 & \text{if and only if } \sigma < -1 \\ <0 & \text{if and only if } \sigma > -1\end{cases}$$

As (16) and (17) will have opposite signs, the following necessary and sufficient conditions completes the proof of lemma 1,

$$\frac{d}{dp_1}\left[w_2q_{12}/(w_1q_{11}+w_2q_{12})\right] \begin{cases} < 0 & \text{if and only if } \sigma < -1 \\ > 0 & \text{if and only if } \sigma > -1 \end{cases}$$

Ahmad S. (1966) "On the Theory of Induced Innovation", **Economic Journal**, vol 76, n.309, pp. 344-57.

Binswanger H.P. (1974) "A Microeconomic Approach to Induced Innovation", **Economic Journal**, vol. 84, December, pp. 940-958.

Cheng L. (1984) "International Trade and Technology: A Brief Survey of the Recent Literature", **Weltwirtshaftliches Archiv**, 120, pp. 165-89.

Dixit A. and Norman V. (1980) **Theory of International Trade**, Cambridge University Press/Nisbet, Welwyn Garden City.

Drandakis E.M. and Phelps E.S. (1966) A Model of Induced Invention, Growth and Distribution", **Economic Journal**, vol 76, pp. 823-40.

Hicks J. (1932) **The Theory of Wages**, 2nd ed. MacMillan, London.

Jensen R. and Thursby M. (1987) "A Decision Theoretic Model of Innovation and Technolofgy Transfer and Trade", Seminar Discussion Paper, University of Michigan, April.

Kennedy C. (1964) "Induced Bias in Innovation and the Theory of Distribution", **Economic Journal**, vol. 74, pp. 541-7.

Lyons B. (1987) "International Trade and Technology Policy" in P. Dasgupta and P. Stoneman (eds) **Economic Policy and Technological Performance**, Cambridge University Press, Cambridge.

Soete L. G. (1985) "Innnovation and International Trade" in B.R. Williams and J.A. Bryan-Brown (eds) **Knowns and Unknowns in Technical Change**, Technical Change Centre, London.

Stolper W. and Samuelson P.A. (1941) "Protection and Real Wages", **Review of Economic Studies**, vol. 9, pp.58-73.

Stoneman P. (1983) **The Economic Analysis of Technological Change**, Oxford University Press, Oxford.

Stoneman P. (1987) **The Economic Analysis of Technology Policy**, **Clarendon Press**, Oxford.

von Weisäcker C.C. (1966) "Tentative Notes on a Two sector Model with Induced Technical Progress", **Review of Economic Studies**, pp. 245-51

Appendix to part III

Chapter VIII : A Note on the Adoption of New Technologies under Collusive Behaviour: A Case of Supply-side Induced Diffusion.

VIII.1. Introduction.

In spite of the criticisms, the work of J. Reinganum (1981a), (1981b) and (1989) has opened an interesting field of research in the economic theory of diffusion. According to Quirmbach (1986) when he says that Reinganum's results are due to the declining time profile of the prices of the new technologies and not to strategic interaction of the players, but one must also admit that her work has provided us with new insights into the forces at work in the diffusion of new technologies. In fact, the work of Quirmbach (1986) adopts Reinganum's methodology to re-interpret some of her results and to obtain new ones.

One of the main contributions in Quirmbach (1986) is the consideration of the strategic role played by the supplier of the new technology. Although the role of supply factors in diffusion processes had been previously considered in Stoneman and Ireland (1982), Quirmbach is the first to study supply factors in a game-theoretic analysis of diffusion.

However, Quirmbach (1986) left unresolved the problem of diffusion of a new technology from a monopolist who sells the process innovation to a group of competing rivals. The diffusion patterns in this situation are complicated due to the so called "durable good problem" studied by Coase (1972), Bulow (1982), Stokey (1979 and 1982) and Gul and Sonnenschein (1986). Recently, Grindley has shown that the strategic behaviour of the supplier of an innovation can induce firms to adopt an innovation at different points in time. This is possible because the innovator can exploit the rivalry between the firms in the downstream market and price discriminate over time.

In Grindley's model there is just one innovation that can be adopted by two Cournot duopolists at two points in time, T_1 and T_2. Time is a discrete variable and this assumption has very important effects on the answers that he gets from the model. His set up is convenient to show the possible existence of diffusion processes derived from rivalry between two potential adopters of the innovation in an integrated context, but many of the rich features of the "durable good problem" are lost on the way.

This chapter is an attempt to explore the existence of alternative equilibria of this type. The approach taken here is similar to that of Stokey (1979) and to Ireland and Stoneman (1985). The former emphasizes the importance of the "absolute" time at which innovation occurs. The later stresses the importance of order effects. However, emphasis is placed here on the importance of the time gap between the points of time at which firms adopt.

To a certain extent, this chapter constitutes a digression from the main lines of the thesis. However, this digression is worth while for two reasons. Firstly, this model emphasises the importance of supply factors in the process of diffusion. This is an important aspect of the whole process of technological change and for this reason, it is a central theme throughout the thesis. Secondly, the possibility of more or less tacit collusion between suppliers and adopters of new technologies has been neglected in the past. However, there has always been a great political concern about the strategic use of technologies by countries or interests groupings in certain countries. The recent debate about technological dependence in Europe and the USA[92] has raised this problem once and again. But this political concern has not been supported by any formal economic

92 See for instance Dertouzos M.L., Lester R.K. and Solow R.M. (1989).

analysis. Supporters of "technological independence" have claimed that if technological progress in a certain industry in concentrated in one country or is under the control of a limited group of firms, they may restrict the supply of new technologies to competitors. This may be particularly important when these innovations are incorporated in key intermediate inputs used by many other industries as is the case of semiconductors.[93] On the other hand, defenders of free-market policies maintain that productive efficiency should be the only determinant of 'who produces what'. Competition policy will suffice to avoid unfair or practices restricting competition, as there is no reason to believe that technological winners would distort the market mechanism.

With all the necessary caveats that should accompany the formulation of propositions based on simple models like the one presented here, this chapter has the aim of raising some question marks by proving the possible existence of a certain type of stable collusive equilibria in the diffusion process that could distort the 'free-market mechanism' of diffusion.

VIII.2. THE ORIGINAL FORMULATION OF THE PROBLEM.

Consider the following situation proposed by Quirmbach. Assume that a firm, F, produces a new technology that could be useful for two firms (1 and 2) in the production of some final good. These two firms are Cournot duopolists in the market for the final good. The effect of innovation on those two firms is the reduction of their constant unit costs of production. So far, no specific assumptions are made about the relative level of these unit costs in the two firms before the innovation is adopted.

---

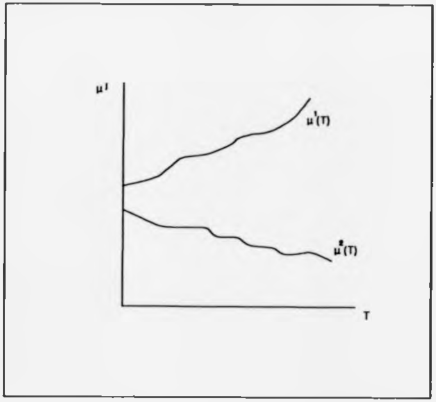
93 Very recently, Spencer and Jones (1991) have studied the possibility of vertical foreclosure in the international trade of a key intermediate product when there are differences in the cost of production. The the best of my knowledge, this is the only case in which the problem of 'dependence', although not technological dependence, has been formally analysed.

Both firms will benefit from the adoption of the new process technology because their unit costs will be reduced. When they adopt the innovation, both firms have a new technology that improves their relative position against "nature", but the relative situation in their market is unaltered by the introduction of the new equipment. However, technological change can also have an impact on that market structure if adoption is not simultaneous in time for the two firms. The first adopter will have a cost advantage relative to his starting position and his profits will be higher as long as the other firm does not adopt and restore initial relative positions.

Thus, the profits that one firm will make depend on its decision whether to adopt or not and on whether its rival has already adopted or not. But it is also true that the reservation price of the innovation that the first firm adopting the innovation will have, will be an increasing function of the time gap, τ, during which, it is the only firm using the new technology. On the other hand, the later adopter will have a reservation price that is a decreasing function of this time gap. At this stage, the questions about why and which firm should adopt earlier are not raised here. For the time being , it will be assumed that one firm will adopt first and a Nash equilibrium for this case will be identified.

It is obvious that the supplier of the innovation would be interested in obtaining some profits from the rivalry between the two competitors in this game, to add to those that he will get if both firms adopt at the same time. Intertemporal price discrimination would help to achieve that purpose and this is the main idea put forward by Grindley. However, this point has not been fully exploited in the existing literature. First, it is often assumed that the supplier of the innovation announces different prices at certain points in time and then, firms take their adoption decisions. The problem with this set up is the following: if agents are rational and time consistent in their adoption decisions, will it be profitable for the monopolist to supply the same good at different prices both firms at different points in time? In other words, will the optimal τ^* for the innovator be a finite number different from zero?.

Figure VIII.1.



The second objection stems from the "durable good problem" which can introduce time inconsistency. The problem is graphically illustrated by the example in figure VIII.1. Let's assume that the monopolist offers the good at times T_1 and $T_2 = \tau_1$. But, if firm 1 adopts at time 1 and pays a reservation price just below $\mu^1(\tau_1)$, the innovator could then maximize profits by selling the new technology to firm 2 at time $T_1+\epsilon$, for a small value of ϵ. Thus, firm 1 would not be time consistent when paying any $\mu^1(\tau) =/= \mu^1(0)$. The only Nash equilibrium in this case would imply both firms adopting almost at the same time.

VIII.3. A FRAMEWORK FOR SUPPLY-SIDE INDUCED DIFFUSION.

The question now is: in what type of situations could we find that the optimal τ for the innovator is significantly different from zero, preserving time consistency. The following paragraphs describe a situation in which such a case exists and explore its equilibrium conditions. This framework is also helpful to address some other related questions where "history matters".

Assume that the average cost of producing the innovation decreases with time. Then, a time-consistent equilibria where the optimum τ is different from zero can be found. This assumption differs slightly from the traditional "learning by doing". Here, it is assumed that the average cost of producing a second unit of the good will decrease the further away the date of the second sale is from the first one.

The only theoretical objection that this assumption could arise in this context could come from the difficulty in distinguishing the causes that produce the results presented below. They are no longer due to simple temporal price discrimination because "learning by doing" will be a necessary condition for their existence. But as Stokey (1979) points out, this type of problems is common in some other cases in which there exists price discrimination over time.

Agents have perfect information as regards to the cost conditions of all the firms involved in the case. The basic structure of the case is similar to the one defined in the previous section.

Firms operate with a finite time horizon T. The innovating monopolist offers to one firm - the leader- a new process technology at time zero. Each firm will adopt the new technology whenever it is offered at a price that is such that adoption is profitable, but firms will try to maximize profits and their adoption decisions will be dictated by this rule of behaviour. This maximization condition will be reflected by a reservation price for the innovation. The final price obtained by the monopolist will not necessarily be the exact reservation price for a given τ. However, there is no "a priori" reason to believe that the deviation of this perceived price (probably, the result of a bargaining process) from the reservation price should be a function of τ. Thus we can consider that the relevant demands for the monopolist are just a linear transformation of the reservation price. For the sake of simplicity, it will be assumed that both coincide.

Each duopolist buys just one unit of the new process technology. The cost conditions under which each unit of the innovative good is produced by the monopolist is given by,

$$(1) \qquad TC = \begin{cases} k_0 , & \text{if } \tau = 0 \\ k(\tau), & \text{if } \tau > 0, \text{ with } k' < 0. \end{cases}$$

Finally, let us define, that, per unit of time,

$a^j(\tau) =$ total profits to firm j when both firms have the innovation, j = 1,2.

$b^1 =$ total profits to the first adopter when he is the only one who has the innovation.

$b^2 =$ total profits to the late adopter when the leader has the new technology while the follower doesn't have it yet.

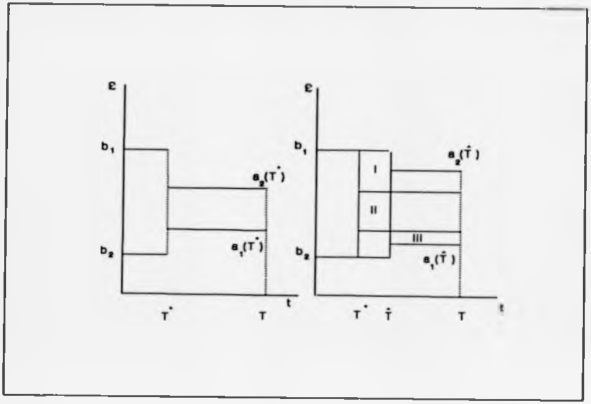
Note that total profits after adoption by the two firms depends on the time gap, τ. As the price of the new technology varies with τ, so will the average cost of production of the firms. The leader will have higher unit costs than the follower because he bought a more expensive machine than his rival. Thus, it will be assumed that $da^1(\tau)/d\tau < 0$ and $da^2(\tau)/d\tau > 0$. Probably, both effects tend to offset each other, the difference being just of second order, but for the time being this possibility will be ignored.

Assume that both firms are equal at time $t = 0$. At that point, the supplier approaches one firm offering the new technology at a price slightly below the maximum price at which this firm is indifferent between becoming the leader or the follower. The offer will be conditioned by the date when the second machine will be delivered to the rival.

The first firm will buy the new technology at $t=0$ if and only if the benefits of being the leader are larger than the benefits of delaying the purchase, i.e.,

$$(2)\quad \tau b^1 + (T-\tau)\, a^1(\tau) - \mu^1(\tau) \geq \tau b^2 + (T-t)\; a^2(\tau) - \mu^2(\tau)$$

Figure VIII.2.



where

$$(3)\quad \mu^2(\tau) = (T-\tau)\,[a^2(\tau)-b^2]$$

and

$$(4)\quad a^1 \leq a^2 \quad ; \quad b^1 \geq b^2$$. (See fig. VIII.2).

Solving for μ^1, we get the maximum possible revenue for the monopolist from selling the new technology to the first adopter,

$$(5)\quad \mu^1(\tau) = \tau\,(b^1-b^2) + (T-\tau)\,[a^1(\tau)-b^2]$$

Hence, the maximum profits for the supplier will be,

(6) $\pi(\tau) = \tau(b^1-b^2) + (T-\tau)[a^1(\tau)+a^2(\tau)-2b^2] - k_o - k(\tau)$

Maximizing (6) with respect to τ subject to $\tau>0$, will give us the necessary and sufficient conditions for the existence of a $\tau^* \neq 0$.

The first order condition requires that

(7) $(b^1-a^1) - (a^2-b^2) + (T-\tau)[a^{1\prime}+a^{2\prime}] = k'(\tau)$

and sufficiency requires

(8) $(T-\tau)[a^{1\prime\prime}(\tau)+a^{2\prime\prime}(\tau)] - 2[a^{1\prime}(\tau)+a^{2\prime\prime}(\tau)] - k''(\tau) < 0$

Proposition 1.- If (7) and (8) hold, there is an optimum and finite τ, τ^*, for the monopolist different from zero.

Let us see what is behind the former two conditions. If we set aside the second order effect, (7) says that the existence of τ^* requires that the industry profits per unit of time must be larger when there is just one firm using the innovation, because the RHS, k', is negative. The intuition for this result is very obvious: to have price discrimination in time, it has to be profitable. Note that this very obvious condition, not examined in Grindley (1987), already imposes some constraints on the relative values of the (b^i-a^i) terms.

The second order effect signifies the existence of an indirect effect on the monopolist's "marginal revenue" (defined with respect to τ), due to the changing cost conditions for the firms in the final good industry as τ varies. The final sign of this effect is not known, but its magnitude will probably-be small.

As regards to the second order condition, note that if we neglect the second order condition, (1) is enough to guarantee sufficiency. For convenience, this second order effect will be ignored.

Up to this point, necessary and sufficient conditions for the existence of an optimum τ for the monopolist different from zero have been considered. But, will this τ^* be a τ of time consistent equilibrium ? That is necessary to have Nash equilibrium.

<u>Proposition 2.-</u> Given proposition (1), for each τ^*, there is a corresponding maximum value of $[b^1-a^1(\tau^*)]$, below which τ^* will not produce a time consistent equilibrium.

<u>Proof.-</u>

Time consistency requires that it is not profitable for the monopolist to sell the second unit at any time before the τ^*, given that the first has been sold out at time zero. The maximum profits that he could make in that way, would be achieved by making the first buyer to pay $\mu^1(\tau^*)$ while selling to the second buyer at $0+\epsilon \approx 0$. In this way he would make

(9) $\pi(0) = \tau^*(b^1 - b^2) + (T - \tau)(a^1 - b^2) - 2\,k_o + T\,(a^2 - b^2)$

Time consistency requires that

(10) $\pi(\tau^*) \geq \pi(0)$

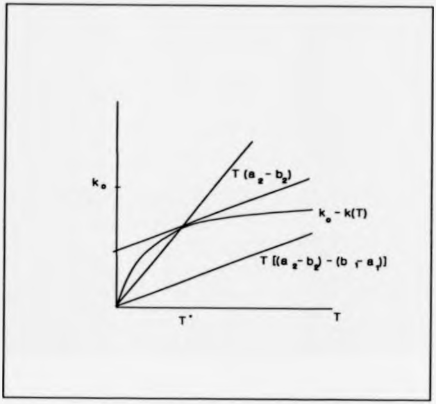
Using (6) at τ^* and (9), (10) becomes,

(11) $k_o - k(\tau^*) \geq \tau^*\,(a^2-b^2)$

Given (1), the maximum τ^* which satisfies (11) does it when it is an equality. Substituting the value of (a^2-b^2) obtained from (11) into (6) at τ^*, we get,

(12) $$\tau^* = \frac{k_o - k(\tau)}{(b^1 - a^1) - k'(\tau^*)}$$ (See fig. VIII.3)

FIGURE VIII.3.



Note that existence depends on parameters of both firms but time consistency depends only on cost conditions and the parameters relative to one firm.

Condition (11) simply states that the benefits to the supplier of postponing the delivery of the second unit due to cost reductions have to be greater that the profits lost by the late adopter while he has to wait for the innovation.

VIII.4. CONCLUSION.

This chapter has considered a situation in which a patent holder sells a new process technology to a duopolistic market using that technology. In contrast with similar models, the possibility of a collusive agreement between one of the duopolists and the patent holder is examined. The durable goods problem makes that coalition unstable, but the declining cost of the new technology enables us to find an equilibrium that supports the coalition. As a result of this collusive behaviour, the two duopolists adopt the new technology at different points in time, and hence, we find a pattern of diffusion. A natural extension of this simple model would be the consideration of a series of innovations introduced at different points in time.

Chapter VIII : References.

Bulow, J.(1982), "Durable-goods Monopolists", **Journal of Political Economy**, pp. 314-332.

Coase, R.H.(1972), "Durability and Monopoly", **Journal of Law and Economics**, vol. 15, April, pp. 143-149.

Dertouzos M.L., Lester R.K. and Solow R.M. (1989) **Made in America, Regaining the Productive Edge**, MIT Press, Cambridge Mass.

Grindley, P. (1987), **A Strategic Analysis of the Diffusion of Innovations: Theory and Evidence**, Unpublished Doctoral Dissertation, London School of Economics, University of London.

Gul, F., Sonnenschein, H. and Wilson, R. (1985) "Foundation of Dynamic Monopoly and the Coase Conjecture", **Institute for Mathematical Studies in the Social Sciences, Stanford University**, Technical Report no. 468.

Ireland, N.J. and Stoneman, P.L. (1985), "Order Effects, Perfect Foresight and International Price Discrimination", **Recherches Economiques de Louvain**, vol. 51, No. 1, March, pp.7-20.

Quirmbach H.C. (1986), "The Diffusion of New Technology and the Market for an Innovation", **Rand Journal of Economics**, vol. 17, No. 1, Spring, pp. 33-47.

Reinganum J.F. (1981a), "On the Diffusion of New Technology: A Game Theoretic Approach", **Review of Economic Studies**, vol.48, pp. 395-405.

Reinganum J.F. (1981b), "Market Structure and the Diffusion of New Technology", **Bell Journal**, vol. 12, pp. 618-88.

Reinganum J.F. (1989) "The Timing of Innovation: Research and Development and Diffusion" in Schmalensee R. and Willig R. (eds.) **Handbook of Industrial Organisation**, North Holland, Amsterdam, vol. 1, pp. 849-905.

Spencer B.J. and Jones R.W. "Vertical Foreclosure and International Trade Policy", **Review of Economic Studies**, vol. 58, pp. 153-170.

Stokey N.L. (1979), "Intertemporal Price Discrimination", **Quarterly Journal of Economics**, vol. 93, pp. 355-371.

Stokey N.L. (1982), "Rational Expectations and Durable Goods Pricing", **Bell Journal of Economics**, vol. 12, Spring, pp. 112-128.

Stoneman P. and Ireland,N.J.(1982) "The Role of Supply Factors in the Diffusion of New Process Technology", **Economic Journal**, AUTE Conference, pp. 66-78.

PART IV CONCLUSIONS

Chapter IX: Conclusions

IX.1. Introduction

The purpose of this chapter is to give an economic interpretation of the propositions and other results obtained in the previous analytical chapters. Given the theoretical nature of the models presented in those chapters, this interpretation cannot have the high of detailed used in the preliminary chapters. In the first two chapters, that level of detail was necessary to identify the main technological characteristics of latecomer countries and to justify the assumptions used in the models. Nevertheless, particular emphasis is put in this chapter on those conclusions which can be relevant for the design of a technology policy suitable for a "latecomer" country. But filling the gap that goes from these conclusions to the detailed design of a technology policy for latecomer countries would be the subject of another thesis.

Throughout this chapter, it will be necessary to bear in mind that the results obtained in the previous chapters have been derived in the framework of simplified examples. The objective of those models has been to identify the existence, direction and possible magnitude of some economic effects which may arise in the context of the situations described in each particular case. Therefore, the propositions developed there must be considered as theoretical possibilities, whose occurrence in the real world is always subordinated to the validity of the assumptions upon which the models have been built.

Having said this, it is my contention that, despite their limitations, these results can be useful to the technology-policy maker. Propositions such as those produced here provide some fundamental elements of economic rationality, which might be used as guidelines in the design of technology policies.

This chapter will reproduce the basic structure of the thesis and it consists of two main parts. The first one deals with the results concerning licensing obtained in chapters III and IV. The second one is based on chapters V to VIII. Trade related issues will also be included in this second part of the chapter.

IX.2. LICENSING OF FOREIGN TECHNOLOGY AS A MEANS TO ACQUIRE TECHNOLOGY

In the technology transfer literature, licensing has always been considered as an expensive means of acquiring technology. In the early seventies, development theorists emphasized the inadequacy of technologies coming from developed countries to suit the technological demands of less developed countries.[94] A second important issue also stressed in that literature is its the concern about the excessive prices charged on technology exports by developed countries.[95]

More recently, the emphasis has been put on the market failures and imperfections that appear in the markets for technology. Authors such as Teece (1981) or Caves et al. (1983) have pointed out these types of deficiencies because:

> *"both the source and the recipient countries lose if technology transfers are diverted toward arm's-length license agreements, that would otherwise have occurred through some joint-ownership channel".*[96]

These losses of social welfare have their origin in the impossibility for the licensor to fully extract all the monopolistic rents generated by the new technology. This is due to the presence of market imperfections arising from the following:

94 See for instance Merhav M. (1969) and Robinson (1979).

95 See Rafii (1984) for a recent empirical study of these issues.

96 Caves et al. (1983) page 265.

a.- Licensing agreements usually involve "small number" bargaining conditions between the parties concerned;

b.- Moral hazard and opportunism problems, which are usually found in these types of environments where there are important information asymmetries;

c.- Uncertainty, because the performance of the new technology in a new economic and technical environment can not be known with certainty;

d.- Risk aversion, particularly for the licensor who risks to lose proprietary control over his invention;[97]

e.- Important transaction, search and adoption costs, which have been calculated at between 2 and 59 per cent of the total cost of the transaction.[98]

These losses usually take the form of high resource costs, particularly for the licensee, who has to bear most of the transaction and adoption costs mentioned above. However, they can also appear in more elaborated forms. Licensing contracts are often subject to many different forms of ancillary restraints which are nothing but contractual clauses to avoid the effects of those market imperfections.[99] However, practices such as geographic restrictions to use the license or minimum price floors, have important effects

---

97 As Horstmann and Markusen (1986) have pointed out, the loss of proprietary control over the innovation can imply particularly high risks if its market value depends on brand reputation or on any other factor that can be damaged by the behaviour of the licensee. In those cases, risk aversion can forestall the licensing agreement, which may be substituted by direct investment or export.

98 See Teece (1981).

99 See OECD (1989) for a detailed account of the different types of ancillary clauses to licensing contracts, there application in OECD countries and their effects on competition.

100 These results are remarkably similar to those obtained by Cheng (1984) in a dynamic control model of technological change.

on the economic performance of the economies of the licensees, as they can distort competition substantially.

This enumeration of the shortcomings that appear in contractual forms of international technology transfer, has to be qualified by their positive effects. The most evident of these advantages is to secure the acquisition of technological knowledge at a lower cost and in a shorter term than by developing the technology afresh. These advantages have been stressed by Krugman (1979) and Jensen and Thursby (1987). In these models of international transfer of technology, the emphasis is put on the welfare consequences for the technologically advanced country, of the diffusion of new technologies in less developed, low labour-cost countries. But the apparently optimistic implications for the less developed countries that are derived from this group of models have to be qualified too, because they usually underestimate the costs for the technologically less developed country of this form of technology sourcing.

In chapters III and IV, a quite different approach to those just mentioned has been taken to study some aspects of licensing. The results obtained in those chapters are based on game theoretic situations. These simple game structures try to emphasise the strategic interactions arising in an international context of technology transfer involving countries at different stages of technological development and with different input prices. In these game theoretic situations, the players interact not just in games for the development of new technologies, but also in normal market games played in an international trade environment and influenced by technological conditions. This combined setting permits the consideration of induced effects that come forth between the technology and market stages of the game.

This approach has been adopted here in an international trade context to tackle the following three main questions:

1. What are the private incentives that firms have to develop new process technologies domestically or to acquire them through licensing from a technologically more developed foreign firm ?

2.- What are the implications for the rate and direction of technological change of the international transfer of technology through licensing ?

3. What are the social welfare costs for a technologically less developed economy of acquiring technology through licensing, and what are the differences between the private and public incentives to access technology by that means ?

IX.2.1. R&D vs. licensing: private incentives.

The first one of these questions has been answered in chapter III in a simplified context. The model presented in that chapter does not take into account the incentives to carry out R&D that appear in patent races. The quasi-rents that firms participating in patent races can obtain from being the first one in developing the innovation are not the main incentive driving the game. The game presented in chapter III stresses the effects of structural asymmetries between firms and countries, paying less attention to short-term effects. On the other hand, it incorporates one characteristic which is seldom present in models of patent races, but which is incorporated in the model presented there. This is that both firms get positive returns from the development of the new technology, irrespective of whether both firms carry out R&D or there is licensing by the innovator.

Proposition 2 in chapter III establishes that, when there is asymmetry in the technological abilities of the two firms, both have strong incentives to reach a licensing agreement instead of carrying out R&D independently. The existence of economies of scope in the production of the new process technology has a strong negative impact on the incentives to carry out independent R&D.

Obviously, if the short-term incentives that arise in patent races are taken into account, this dominance of the licensing strategy might be questioned. However, previous work by Fudenberg et al. (1983) suggests that the participation of a firm with a technological lead in a patent race may pre-empt the technologically less developed firms to enter the race. In a model in which the technological capabilities of firms depend on their accumulated experience, any lead of one competitor precludes the entry of another firm in the patent race. This result is obtained in an environment in which R&D success is stochastic. Only if the patent race has several stages or there is the possibility of altering the accumulation of experience, 'leap-frogging' or changes in technological leadership are possible.[100]

Although these results have been obtained in different settings and from very different assumptions, both seem to indicate that technologically retarded firms have strong incentives to not enter patent races and to obtain technology by other means. The possibility of ex-ante licensing seems to be enough to stop firms in technologically less developed countries carrying out R&D in an independent way. This result leads into the discussion of the other two major questions addressed in chapters III and IV. Let us examine question number 3 firstly, i.e. are there differences between the private and the public incentives to do R&D rather than licence?

IX.2.2. R&D vs licensing: differences between private and social incentives

From the outset, one of the recurrent topics in the literature on licensing has been the appropriateness of the prices paid for foreign technology by firms in less developed countries. The main problem with this question has always been the difficulty of measuring the value of the technology effectively transferred. As Reddy and Zhao (1990) have

100 These results are remarkably similar to those obtained by Cheng (1984) in a dynamic control model of technological change.

recently stated, "like other markets for intangible assets, the imperfection of the technology market makes its transfer price indeterminate".[101] But solving this problem requires the definition of a social value for the license in the first place. This allows comparisons to be drawn between the private and social value of the patent, and indirectly, the examination of differences between private and public incentives to carry out R&D or to license instead.

In chapter IV, a model has been presented in an attempt to answer these questions for the case of process innovations. The market value of the new technology for each firm using it downstream for the production of a final good and the impact of the new technology on social welfare are the two yardsticks applied for the private and public measurement of the value of the technology.

In a context of oligopolistic competition in which a profit maximising external laboratory determines the number of licenses sold and the fees paid for them, demand functions for the licenses are derived for the private oligopolistic sector and for a welfare maximising social planner. It has been proved that when the number of firms is greater than three, the reservation price of the social planner for any number of licenses will always be lower than the reservation price resulting from the oligopolistic private sector. It has also been proved that the market solution implies total payments for the new technology to the foreign sector exceeding the social optimum.

This result is a consequence of the difference between the private and social incentives to acquire the license. From the social point of view, for each fixed fee quoted by the patent holder, there is an optimal number of licenses to be bought. But firms acquiring the license will be better off than those firms who do not get a license. This circumstance opens a competition between the oligopolistic firms striving to get a license, from which the patent holder can benefit. Thus, there is a sort of "common pool" effect in

---

101 See Reddy and Zhao (1990), page 299.

the race for the license. As a result of this effect, part of the gains in social welfare brought about by the new technology are transferred abroad by the oligopolistic firms and a social planner centralising the purchase of the license would avoid this effect.

These results suggest that one should expect to find too much licensing in private markets from the social welfare point of view. According to the model in chapter IV, that will occur more frequently and with more quantitative importance as the number of oligopolistic firms increases.

This brings us to the consideration of the induced effects over the social and of private incentives to carry out R&D that could result from the propositions derived in chapter IV. It is widely established that the existence of externalities in the R&D process impede firms investing in R&D to appropriate fully the returns from their investments. This is the origin of a market failure resulting in under-investment in R&D from the social point of view, by each and everyone of the firms in the industry.[102]

In principle, these results seem to suggest that the possibility of ex-ante licensing reduces even more the private incentives to carry out R&D. Therefore, the ratio between R&D spending and licensing resulting from the free functioning of market forces would be too low from a social point of view. As the private incentives to carry out R&D seem to be positively correlated to the degree of market concentration according to Dasgupta and Stiglitz (1980a), the magnitude of the under-investment in R&D and over-investment in the purchase of licenses would be greater in less concentrated markets.[103]

---

102 See Kamien and Schwartz (1982), Loury (1979) or Lee and Wilde (1980) which are probably the most classic pieces of the literature on this topic.

103 In this sense, any move to eliminate impediments to licensing such as the Spanish example discussed in the first chapter would be damaging to social welfare.

However, this conclusion has to be qualified. The result suggesting excessive licensing from the social viewpoint presented in chapter IV, was the consequence of a "collective" market failure due to a "common-pool" effect arising in the competition among oligopolists to obtain the license. But as Dasgupta and Stiglitz (1980a and 1980b) have suggested, there are also sources of "collective" market failures in R&D competition. In the first one of these papers, the ex-ante rivalry among oligopolists striving to benefit from the monopoly rents accruing to the winner of the R&D race produces duplication of efforts and social squandering of resources. But R&D competition can also produce "collective" market failures originated in "common pool" effects.[104] Under certain conditions determining the shape and slope of the reaction functions of the R&D game, an increase in the R&D investment of each firm[105] may result in the other competitors raising their own individual investment.[106] Collectively, this results in over-investment in R&D, i.e. in the production of the innovation at an earlier date than socially desirable.

According to these results, it seems that there is a justification for public policy intervention modifying the R&D/licensing ratio resulting from the mechanism of market forces. In those cases in which concentration is not high and "collective" market failures resulting in an over-investment in R&D are unlikely, one should expect that the market will produce a R&D/licensing ratio smaller than socially desirable.

Investigating the optimal form of public policy intervention falls outside the scope of this thesis. However, the framework of the analysis carried out here suggests that this

---

104 See Dasgupta and Stiglitz (1980b) and Dixit (1986).

105 In the terminology of those models, this is equivalent to an increase in the conditioned probability of each firm of succeeding in the R&D game in the next infinitesimal time interval, given that no other firm has succeeded by then, or individual hazard rate of each firm.

106 According to Beath et al. (1989), this will happen in those cases in which the incentive to carry out R&D resulting from the "competitive threat" as defined in chapter V, will dominate the profit incentive to carry out R&D.

can be done not just directly via subsidies, but also indirectly by means of restricting or controlling alternative forms of access to foreign technology.[107]

Nevertheless, this conclusion does not take into consideration three very important elements suggesting the need for more direct or indirect support to R&D:

1.- Firstly, as it was mentioned above, the accumulation of experience and technological capabilities plays a fundamental role in the process of technological change. Although the concept "technological capabilities" includes a broad range of elements[108] intervening in the process of innovation, which are difficult to measure, there are grounds to believe that indigenous R&D can contribute more to the creation of technological capabilities than licensing. In the particular case of Spain, Molero (1983) has analysed the difficulties which Spanish firms have experienced in some cases to accumulate technological capabilities from the import of foreign technologies.

   As these types of externalities are hardly internalised by individual firms, it is plausible to assume that public policy should act to re-establish the adequate balance between R&D and licensing and thus correct this market failure.

2.- The socially desirable levels of R&D and spending in licenses mentioned above have not taken into account the possibility of strategic behaviour by foreign governments supporting their own firms in international patent races. In the presence of that kind of strategic public policy, Dixit (1986) and Beath et al. (1989) have suggested that the best domestic response

107 The Indian case is the traditional example of this indirect form of R&D strategy. See Lall (1985).

108 See Desai (1984) for a typology of them.

depends once again on the slope of the firms' reaction function in the R&D game.

3.- The models developed in this thesis are not "timing models" in the sense that the dates of introduction of new technologies either via licensing or independent R&D are not explicitly taken into account. An additional advantage in favour of R&D as compared to licensing, could arise due to the fact that the winner of a patent race will enjoy earlier and for a longer period of time, the benefits derived from the innovation.

Finally, despite the very generic nature of these conclusions for public policy guidance, I think that they have the interest of bringing new and different kinds of issues into the traditional determinants of regulatory policies for international technology transfer. Furthermore, they are based on models similar to those used for the analysis of R&D. In this way, a link is established between licensing and R&D as sources of technology for a less developed country, which should be studied in a more integrated form in the future. A very simple example of this joint consideration of R&D and licensing as alternative instruments for technology acquisition is presented in the annex to this chapter.

IX.2.3. The impact of ex-ante licensing on the rate and direction of technological change.

One of the main results in chapter III was related to the impact on the rate and direction of technological change derived from the possibility of ex-ante licensing. In was shown there that if there are significant differences in the technological capabilities of firms operating from different countries, the possibility of ex-ante licensing would have a double impact:

a.- Firstly, it would bring the direction of R&D in the most developed country closer to those technologies which the 'low-tech' firm would have chosen if licensing were not possible and firms were forced to carry out R&D independently.

b.- The possibility of ex-ante licensing may also curb the global rate of technological progress in the economy considered as a whole. This is the result of eliminating a technologically less advanced competitor in the R&D game.

If there is just one firm doing R&D and having full control of the rate and direction of technological progress: the more advanced firm has less incentives to carry out R&D; and the licensing mechanism induces it to produce technologies which are closer to the needs of its competitor. On one hand, one could talk about a certain kind of "specialisation"[109] in the production of technology in the technologically more developed country. However, the elimination of competition in R&D, even if it is technologically inferior, places the licensor in a situation of "virtual monopoly" in the production and sale of the new technology. This result has interesting implications for both types of countries.

IX.2.3.1. Implications for the technologically less developed country: the appropriateness of the technology transferred

After producing a substantial amount of literature, the debate on the suitability of the technology transferred to the less developed countries is still open.[110] One of the main difficulties in this debate has been the definition of what is meant by "appropriate

---

109 An extreme case of this was published in the press after these conclusions had been written. Rodime Plc., the Fife based company who was the pioneer of the 3.5 inch hard disc drives, announced late in September that is was ceasing operations in its plants in Scotland and Singapore. The company will continue existing as an intellectual property company after reaching licensing agreements with Matsushita Electric Industrial and Hitachi. The company reached that decision after an out of court settlement with IBM in which it was paid US$ 13 mill. The company also has licensing agreements with companies such as Fujitsu, Conner Peripherals and Alps Electric.

110 See Robinson A. (1979)

technology". In chapter III, "appropriateness" for a certain firm or country[111] of a new process technology is identified with the cost reduction that this new technology will produced when applied by that firm or in that given country.

From this perspective, the results in chapter III seem to minimize the importance of the appropriateness of the technology transferred internationally, in particular for countries with more similar cost conditions. When there is licensing, the firm undertaking R&D obtains returns from the cost reduction derived from the application of new technology for the production of a final good downstream, but also from selling the new technology to the less developed firm.

This introduces a certain trade off for the more developed firm concerning the direction of technological change: the closer the new technology is to the one which the low-tech firm would have chosen if there was no possibility of licensing, the lower will be the returns obtained from the exploitation of the new technology through production downstream; but if the technology developed for licensing does not reduce costs in the low-tech country, the firm in the latter country will not be willing to buy the license. Therefore, the firm developing technology for licensing will always modify its choice of R&D projects to meet the needs of the licensee, at least to a certain extent, even if that reduces its returns from the market downstream.

Therefore, for public policy purposes, the problem of the appropriateness of the technology transferred will be less relevant when the cost conditions that firms face in their respective countries are similar. In this sense, economic processes such as European market integration could have an indirect but positive effect upon the direction of technological progress in Europe from the point of view of net importers of technology as Spain or Ireland. Higher integration of financial markets and labour mobility could

111 This identification of technological suitability can be maintained if we admit the existence of a certain kind of direct relationship between country and firm competitiveness.

approximate cost conditions throughout Europe, thus making technologies developed in the more developed economies such as Germany more "appropriate" for technologically less developed countries.

For Third World Countries the situation is very different. We must remember that, according to OECD estimates, 75 per cent of the world licensing takes place among the most developed countries,[112] which are presumably those with more similar cost conditions. This implies that the relatively low weight of Third World Countries as demanders of new process technologies does not contribute much to address the direction of technological change in favour of these countries. Therefore, the problem of the appropriateness of the technology transferred remains an important one for them.

IX.2.3.2 Implications for technologically more developed countries.

One of the most interesting results of the technology transfer literature in the last decades is originated in Krugman (1979), which deals with the effects of technology transfer upon the international distribution of income. According to this strand of the literature, international technology transfer has a negative impact on the relative income levels of the country where the new technologies are produced. As international diffusion of those technologies takes place towards lower cost regions, the comparative advantage of the "innovating" country is eroded.

The political implications of this type of argument have been very important. In the Uruguay Round of the GATT, technologically more developed countries and the USA in particular, have stressed the importance of protecting intellectual property rights, which in fact would introduce restrictions to the technology transfer to the South.

112 See Vickery (1986).

The results obtained in chapter III concerning the impact of licensing on the global rate of technological change have some implications for this issue. The main policy reading that derives from Krugman is that the North can maintain its share in the world's distribution of income only if the rate of technological change is enough to offset the adverse effects derived from the international diffusion of technology. But proposition 3 in chapter III shows licensing of technologies to technologically less developed countries would reduce the global rate of technological change.

If there is just one world producer of R&D who licenses innovations to other firms in foreign countries, the world "output" of technology is substantially reduced. But diffusion still takes place thus deteriorating income levels at home. This suggests that only if licensing allows full extraction of rents derived from the initial relative innovation can income levels of the North can be maintained. Given the difficulties in fully extracting the rents derived from an innovation through licensing, which were mentioned at the beginning of this chapter, this is unlikely to occur. Therefore, a situation of "world technological monopoly" seems to be intrinsically unstable.

IX.3. THE INTERNATIONAL DIFFUSION OF NEW PROCESS TECHNOLOGIES.

From a structural and long-term perspectives, it is commonly agreed that the major benefits that technological change produces in the economy come from the diffusion of innovations across industries over time. The benefits that can be obtained in the short run from being the first innovator are probably the major factor driving innovation. From a social point of view, and in particular in the case of process innovations, the most important benefits derive from the adoption by many producers of the new technology which will allow cost reductions and improvements in productivity and international competitiveness. Consequently, technology policy makers in technologically less developed countries should pay attention to the international patterns of adoption and diffusion of new process technologies.

The second group of models presented in this thesis have the objective of studying the relative incentives to adopt a new process innovation in countries facing asymmetric cost conditions. Those models are not based on "technology-gap"-types of arguments, but on the strategic behaviour that international competitors with different cost conditions will have with respect to the adoption of a cost reducing process innovation.

There is an underlying question which is common to all these models: will market forces generate sufficient private incentives to alter the pattern of adoption of new process technologies ?

It is necessary repeat here once more that cost asymmetries like those introduced in chapters V and VI do not keep any fixed correspondence with the degree of technological development of countries. In principle, a technologically more advanced country could have lower or higher average costs of production than a less advanced one. It would all depend on the technology and the relative cost of factors of production. In this sense, the results obtained in those chapters are independent of the "technology-gap" between the two countries.

In principle, models similar to those presented in chapters V and VI could also be used to study the relative incentives to do R&D in countries with different cost conditions. This would be perfectly possible if we assume that technologies are developed by a third country selling R&D projects to the best bidder. However, I think that these types of models are best suited for the study of relative incentives to adopt new technologies rather than to consider R&D. The study of incentives to carry out R&D under different cost conditions cannot be independent of the technological capabilities to do R&D in both countries. Countries also differ in their abilities to adopt innovations. Transaction or adaptation costs can be quite different in countries with different degrees of technological development. However, these differences are likely to have a lesser impact on their incentives to adopt than on their incentives to do R&D.

A proper study of diffusion would require working with market structures more complex than the duopolies used in the thesis. But this would imply working at the same time with four different groups of firms: those which have adopted the innovation and those which have not adopted it at a certain point in time, in at least two different countries. This difficulty complicates the analysis considerably. For this reason, the models in chapters V and VI are basically models of adoption, because they do not tell much about the pattern of diffusion of the innovation throughout the industry in both countries.

Nevertheless, they still provide some information about diffusion. At any given point in time in the process of diffusion, there will always be one marginal firm in each country which could be the immediate next adopter of the innovation. Although the complete pattern of diffusion will depend on factors such as the existing number of firms in the industry in each country, the models of adoption presented here tell us something about the piecemeal sequence of diffusion.

This part of the thesis includes four different types of results:

1.- First, and most important, it studies the relative incentives that firms facing different cost conditions have to adopt new technologies depending on the type of market competition and on the nature of the innovation (i.e. the direction of technological change and the different cost reductions brought about by the innovation);

2.- The influence on those incentives of the existence of a sequence of innovations;

3.- The impact on the patterns of adoption/diffusion of the existence of a supplier of the innovation, who could have a strategic behaviour;

4.- The consideration of demand asymmetries and restrictions to international trade.

IX.3.1. Incentives to adopt, market competition and the direction of technological change.

The simple model presented in chapter VI has highlighted the importance of the direction of technological change, for the pattern of adoption of process innovations by firms operating from domestic markets, with different cost conditions. For instance, it has been proved that if the innovation maintains the absolute cost differential between both firms it will always be adopted earlier by the firm in the low cost country; but, if the innovation maintains the relative cost differential between the two firms, it will be adopted first by the high cost firm.[113]

This result suggests that the production of innovations and their diffusion are not independent phenomena. The pattern of adoption will depend on the nature of the new technology and, to the extent to which the selection of R&D projects is influenced by local conditions, early adoption can be influenced by the location of R&D production. In any case, having control over the direction of technological change is crucial for influencing the international pattern of adoption.

All these conclusions call for a higher degree of integration in the study of the conditions of the supply of innovations and the analysis of processes of international diffusion of new technologies. But for those purposes, a better understanding of the conditions of production of technological knowledge is required.

---

113 See proposition I in chapter VI

Another important factor determining which firm will have more incentives to adopt a new process technology earlier is the type of competition prevailing in the market for the final product. When product differentiation and Bertrand conjectures are introduced in the model, the set of innovations that would be adopted earlier by the initially high cost firm is reduced substantially. Although there are some types of innovations which are always adopted earlier by that high cost firm, more intense rivalry (Bertrand conjectures) seems to delay adoption by the high cost firm.

As it was shown in chapter V, the relationship between adoption and market competition is not a simple one. Demand conditions and conjectural variations can shift the direction of the effects of different forms of market competition upon the pattern of adoption. However, that relationship certainly exists and this fact calls for increased coordination between technology and competition policies.

IX.3.2. Technological leadership and sequences of innovations.

As it was mentioned in the first part of this chapter, Fudenberg et al.(1983) have indicated that, in the context of patent races, the existence of different stages in the R&D process makes possible "leap-frogging" or alterations in technological leadership.

In the context of diffusion models with a sequence of innovations, Vickers (1986) has suggested that under Cournot conjectures, it is rather likely to observe changes in the firm obtaining the new technology earlier and, consequently, to have changes in technological leadership. This proposition, which does not seem to fit well with observable reality has been scrutinised in chapter V.

The results obtained in that chapter seem to suggest that this rather optimistic expectation about the market-force induced permutations in technological superiority collapse when the basic model is modified. Indeed, when elements such as free diffusion, irreversible R&D costs or the influence of past events are included in the model, the possibility of changes on technological leadership, in terms of which firm has the lowest production costs, becomes more remote.

Nevertheless, these types of models can help us to learn more about the processes of diffusion. By modifying the assumptions of the basic model, it is possible to learn how alternative assumptions influence the different types of incentives firms have to adopt the innovation. This is possible to the isolation of what was called direct and induced effects in that chapter.

The study of the impact of isolated factors entering the sequence of innovations could be useful for technology policy making. For instance, if diffusion is facilitated by some means after the first adoption, the influence of the existence of a sequence of innovation tends to disappear. This is important because ceteris paribus, the existence of a sequence of innovations increases the incentives that the high cost firm has to acquire the next new technology in the sequence.

IX.3.3. The influence of supply side considerations.

Chapter VI and chapter VIII include some consideration of the influence that the supplier of the technology can have on the pattern of diffusion of the innovation in the industry downstream.

In chapter VI, an independent profit maximising R&D laboratory is introduced, but leaving aside any kind of strategic behaviour. At was mentioned above, the introduction of supply-side considerations always requires some assumption about the cost of producing different alternative new technologies. In order to eliminate any bias due to cost advantages in favour of certain technologies which would be adopted earlier by one firm, a "neutral" cost structure is assumed. The purpose of this exercise is to study if, even when it is cheaper to produce those innovations that could be adopted earlier by either firm, the supplier would choose to produce technologies which are adopted earlier by one firm.

Proposition 2 in chapter VI shows that, under those circumstances, an independent monopolist will tend to produce innovations that would be adopted earlier by the low cost firm. This is due to the possibility of extracting more rents from that firm than from the high cost firm in the sale of the innovation.

This result has implications for public policy. If a public authority wants to promote the domestic development of an innovation, it should pay attention to where this innovation will be adopted earlier. The domestic social benefits from R&D will be maximised if the home economy gets not just the rents derived from selling the innovation but if the first adopter of the innovation is a domestic firm. In a situation like the one described in section VI.4., the government of the high cost country has less incentives to foster the development of an innovation by a local independent R&D producer than the government of the low cost country.

Obviously, the government in the high cost country would have more interest in having a different type of innovation developed, i.e. one that would be adopted earlier by its local firm. However, given the "neutral" cost structure, the public authorities would need to induce the R&D producer to deviate from its profit maximising choice of R&D project, and this will have some domestic social costs.

The situation in the last chapter is quite different. There, a strategic interaction between one potential adopter of the innovation and its producer is considered. The objective there is to study the existence of a stable coalition between the first adopter and the monopolist supplying the technology in order to delay adoption by the second adopter. Proposition 2 in chapter VIII shows that the declining cost of producing the technology can eliminate the instability introduced by the "durable goods" problem.

Given that both potential adopters could reach this collusive agreement with the supplier of the innovation, the importance of any non-market link, perhaps politically induced, could have a great importance in the distribution of the benefits of this solution among the players involved.

IX.3.4. Some trade considerations.

To complete the study of relative incentives that firms with different cost conditions have to adopt an innovation earlier, chapter VI introduces demand asymmetries and trade policy considerations. It shows how differences in the domestic market size, but particularly transportation costs and tariffs, modify firms' incentives to adopt.

This suggests that trade policy can be an important tool for diffusion policy. The importance of this type of instrument seems particularly relevant for the high cost country. Indeed, even if the low cost country raises tariffs equal to those set by the high cost country to become the first adopter, diffusion conditions can improve in the high cost country. Some innovations that would be adopted earlier by the low cost firm when there are no tariffs would be adopted earlier by the high cost firm if there is a positive and equal tariff rate in both countries.

But the influence of trade policy on technology is not limited to the diffusion stage. Chapter VII shows how different trade regimes can have induced effects on the direction of technological change. The traditional dilemma between static and dynamic efficiency is presented in that chapter in the following context: which is the optimal trade regime from the point of view of the dynamic evolution of the production possibility frontier ?

When there is learning-by-doing, the future possibilities of production in one country will be conditioned by the nature of technological change. But the direction of technological change depends on the relative returns to the factors of production and these will depend on the existing trade regime. If we accept that the direction of technological change will be influence by the current distribution of income between factors of production, the trade regime will indirectly affect the direction of technological change. R&D will tend to minimise the use of those factors of production receiving higher proportions of national income. When the economy goes from autarky to free trade, the factor share of the input intensively used in the domestic export industry increases, under certain conditions of elasticity of factor substitution. Therefore, under free trade, R&D selection will discriminate against projects using the factor of production intensively used in the export industry. As a result, the new production possibility frontier under free trade might not include production possibilities that could have been attainable if the selection of R&D projects is made under autarky conditions.

All these results indicate that the introduction of technology and dynamic considerations challenge conventional recommendations of international trade theory. Under some conditions, technology policy objectives could make advisable the introduction of restrictions or controls over free trade. However, this could only be done after assessing the costs of that policy measure in the short run in terms of static efficiency.

The main conclusion which can be drawn from these observations is that economic policy makers should consider trade, technology and competition policies as related instruments for industrial policy. A public policy towards business considering all these policies as independent, with different and perhaps conflicting objectives, is bound to be of very limited efficiency.

In section IX.2.2. above, we discussed in rather general terms the possible existence of market failures in the different ways of acquiring new technologies. More specific results can be derived if we integrate the analysis of licensing and R&D in the same analytical framework.

For instance, in the discussion on this issues included in this chapter, the relative incentives for the firms or the social planner have been compared. However, we could inquire about the likelihood of the existence of cases in which the private sector chose to do R&D to develop a given technology, while from a social point of view, it would have been optimal to acquire that technology through licensing. In other words, is it possible to find the private sector carrying out R&D, under circumstances in which a social planner would have rather preferred to license an existing technology from abroad? (Or vice-versa).

Let us see this problem in a very simple model. Let us assume that the market determines the investment in R&D carried out by each firm, d, or the fee paid for the foreign technology, r, as it was done in chapter IV. Let call,

$S^{R\&D}$ = consumer surplus if there is R&D,

S^{lic} = consumer surplus if there is licensing,

G = revenues to the winner of the patent race,

L = revenues to each loser of the patent race,

π^* = revenues to a firm operating with a license,

π = revenues to a firm operating without a license,

All these magnitudes are discounted values.

If there is licensing, k licenses will be sold. In that case, the probability of each one of the n existing firms of getting a license will be (k/n). If there is a patent race, each firm will have a probability of wining it equal to $(1/n)$.

From a private enterprise point of view, the net profits of doing R&D would be,

(1) $[1/n]\, G + [(n-1)/n]\, L - d$

The expected profits when there is licensing are

(2) $\pi^* - r = \pi = [k/n]\,(\pi^*-r) + [(n-k)/n]\,\pi$

Therefore, the private sector will prefer to do R&D if and only if

(3) $[1/n]\, G + [(n-1)/n]\, L - d > \pi^* - r = \pi = [k/n]\,(\pi^*-r) + [(n-k)/n]\,\pi$

From a social point of view, it will be optimal to have the technology developed through R&D if and only if the total social welfare derived from carrying out R&D is greater than the total social welfare of obtaining the same technology buying a license from abroad, in both cases after deducting the costs of obtaining the technology. That is, if and only if,

(4) $S_{R\&D} - S_{LIC} + G + (n-1)\, L - k(\pi^*-r) - (n-k)\pi + rk - nd > 0$

A market economy would be acquiring a new technology in a way which is not the optimal one from the social point of view either if

(5) $S_{R\&D} - S_{LIC} + G + (n-1)\, L - k(\pi^*-r) - (n-k)\pi + rk - nd > 0$ and

(6) $[1/n]\, G + [(n-1)/n]\, L - d < \pi^* - r$

or

(7) $S_{R\&D} - S_{LIC} + G + (n-1)\, L - k(\pi^*-r) - (n-k)\pi + rk - nd < 0$ and

(8) $[1/n]\, G + [(n-1)/n]\, L - d > \pi^* - r$

In the first case, (5) and (6), we have a situation in which the market decides to license a technology that, from a social point of view, should be developed with domestic R&D. In the other case, (7) and (8), the private incentives lead the firms to do R&D, but a social planner would have chosen to buy a license from abroad.

Sufficient conditions for these two types of results are the following,

(9) $rk > nd > S_{lic} - S_{R\&D}$ and

(10) $S_{lic} - S_{R\&D} > nd > rk$ respectively.

These sufficient conditions allow us obtain some results without taking into account explicitly the value of d. Assuming that the innovation reducing production costs in ϵ is not drastic in Arrow's sense, it can be shown that the value of the difference between the two consumer surpluses is

(11) $\epsilon (k-1) [2(a-c) + (n-2k+2)\epsilon] / 2(n+1)2$

where a is the intercept of a linear demand function with the Y-axis as in the preceding chapters.

Using the values of r and k calculated by Kamien and Tauman (1986), for relatively large values of n,[114] the rk product is equal to,

(12) $n\epsilon (n+2) (a-c) / (n+1)2$

Substituting (11) and (12) in the sufficient conditions (5) to (8) above it is evident that, for large values of n, we will never have that

$S_{lic} - S_{R\&D} > nd > rk$

is never possible.

---

114 For $n \geq 2|a-c|/|\epsilon-1]$

In other words, if n is large enough, we will never find the market doing R&D to produce a technology which, from a social point of view, is optimally acquired via licensing. However, the contrary may occur and the private sector will be using licensing while it is optimal to do domestic R&D. This is not always necessarily the case because under some circumstances it is possible that $rk > nd$.

For smaller values of n, parametric conditions determine the direction of the result, but there is no certainty about the impossibility pointed out above.

Beath et al. (1989) "Strategic R&D Policy", **Economic Journal**, 97, Conference Papers, pp. 32-43.

Caves R.E., Crookell H. and Killing J.P. (1983) "The Imperfect Market for Technology Licenses", **Oxford Bulletin of Economics and Statistics**, August, 45, pp. 249-67.

Cheng L. (1984) "International Competition in R&D and Technological Leadership: An Examination of the Posner-Huffbauer Hypothesis", **Journal of International Economics**, 17, pp. 15-40.

Dasgupta P. and Stiglitz J. (1980a) "Industrial Structure and the Nature of Innovative Activity", **Economic Journal**, 90, pp. 266-93.

—— (1980b) "Uncertainty, Industrial Structure and the Speed of R&D", **Bell Journal of Economics**, 11, pp. 1-28.

Desai A.V. (1984) "India's Technological Capability: An Analysis of its Achievements and Limits", **Research Policy**, 13, pp. 303-310.

Dixit A. (1986) "International R&D Competition and Policy", mimeo, Princeton University, December.

Fudenberg D., Gilbert R., Stiglitz and Tirole J. (1983) "Pre-emption, Leap-frogging and Competition in Patent Races", **European Economic Review**, 22, pp. 3-31.

Horstmann I. and Markusen J.R. (1986) "Licensing versus Direct Investment: A Model of Internationalisation by the Multinational Enterprise", Centre for the Study of International Economic Relations, Working Paper n. 8611C, University of Western Ontario, March.

Jensen R. and Thursby M. (1987) "A Decision Theoretic Model of Innovation, Technology Transfer and Trade", Research Seminar in International Economics, Seminar Discussion Paper n.199, University of Michigan, April.

Kamien M. and Schwartz N.L. (1982) **Market Structure and Innovation**, Cambridge University Press, Cambridge.

Kamien M.I. and Tauman Y. (1986) "Fees versus Royalties and the Private value of a Patent", **Quarterly Journal of Economics**, vol. CI, pp. 471-491.

Krugman P. (1979) "A Model of Innovation, Technology Transfer and the World Distribution of Income", **Journal of Political Economy**, 87, pp. 253-266.

Lall S. (1985) "Trade in Technology by a Slowly Industrialising Country: India" in Rosenberg and Frischtak (eds.) **International Technology Transfer: Concepts, Measures and Comparisons**, Preager, New York.

Lee T.K. and Wilde L.L. (1980) "Market Structure and Innovation and Innovation: A Reformulation", **Quarterly Journal of Economics**, 94, pp. 429-436.

Loury G. (1979) "Market Structure and Innovation", **Quarterly Journal of Economics**, 93, pp. 395-410.

Merhav M. (1969) **Technological Dependence, Monopoly and Growth**, Pergamon Press, London.

Molero J. (1983) Foreign Technology in the Spanish Economy: An Analysis of the Recent Evolution, **Research Policy**, 12, pp. 263-286.

Rafii F. "Joint Ventures and Transfer of Technology: The Case of Iran, in Stobaugh and Wells (eds.) **Technology Crossing Borders**, Harvard Business School Press, pp. 203-243.

Reddy N.M. and Zhao L. (1990) "International Technology Transfer: A survey", **Research Policy** 19, pp. 285-307.

Robinson A. (1979) **Appropriate Technologies for Third World Development**, St. Martin's Press. New York.

Teece D. (1981) "The Market for Know-how and the Efficient Transfer of Technology", **Annals of the American Academy of Political and Social Science**, 458, pp. 81-96.

Vickers J. (1986) "The Evolution of Market Structure when there is a Sequence of Innovations", **Journal of Industrial Economics**, 35, pp. 1-12.

Vickery G. (1986) "International Flows of Technology - Recent Trends and Developments", **STI Review**, 1, pp. 47-83.

TITLE ... LICENSING AND DIFFUSION IN OPEN ASYMMETRIC ECONOMIES

AUTHOR ... FRANCISCO CABALLERO SANZ

DEGREE ...

AWARDING BODY UNIVERSITY OF WARWICK
DATE ... 1991

THESIS
NUMBER ...