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ABSTRACT

INNOVPROD was a research network across 11 institutions in Europe between 1996-99. Researchers focused on the links between R&D, innovation and productivity. The approach was mainly empirical and micro-economic. Large databases of comparable cross country information on innovation were a key resource developed and analysed by the Network. There were 14 workshops and conferences over the time period. details of these and associated papers can be found on our Website at www.ifs.org.uk under "research interests".

The key findings (and policy implications are) are:

1 New technologies have significantly increased the demand for skills. Failure of the supply side to keep up has led to inequality of job opportunities and wages. A policy of increasing education and training will reduce inequality and stimulate innovation. Nevertheless, the bulk of the increase in European unemployment is probably not due to mismatch of skills.
2 Using new technologies does not cause workers to have higher wages. There is a correlation between earnings and computer use, but it is because better workers are given better quality technologies.
3 There is no clear correlation between new technologies and job creation at the firm level. Even if there was, this does not justify policies to deal with unemployment by stimulating innovation.
4 Direct government subsidies to private sector R&D are undesirable - they do little to raise measured productivity
5 R&D tax credits stimulate more R&D, but a lot is through relocation of R&D labs from different countries
6 Product market competition stimulates faster innovation. Tough competition policies and removal of regulatory constraints is one of best ways of encouraging innovation
7 Research Joint Ventures are generally desirable but policies should encourage full information sharing.

CHAPTER I

EXECUTIVE SUMMARY

Introduction

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The aims of the Network Innovation, R&D and Productivity were:

1. To investigate the micro-economic roots of the macro-economic problems of growth, unemployment and inequality. Emphasis is placed on the quantitative analysis of innovation data amongst companies, establishments and workers.

2. To document the routes by which technical change impacts upon economic outcomes and how this varies between and within European countries. In particular the group will look at the effects of product, labour and financial markets on the incentives and abilities of organisations to advance technologically.

3. To facilitate the sharing of new results, methods and between European researchers in the economics of innovation.

4. To improve collaborative research between European researchers, especially in the areas of comparative quantitative analysis and links between theory and empirical work

5. The Network plans one large conference per year and three smaller workshops. These are the platforms through which many of the objectives will be achieved and a range of papers have been presented.

6. From time to time the network produces a report of its activities. There have been regular 6 monthly reports and a major 18 months report.

The main output of a thematic network is to engender joint research and a large number of projects and papers have begun (and completed) which would not have otherwise occurred. This are listed in the Annex to the report. We focus here on research findings and policy implications.

1. Research Findings

1.1 Labour Markets

Inequality of employment and wage opportunities is the major problem facing Europe at this time and much research has been devoted to the effects of innovation (especially regarding computers) on the labour market. The main findings are

Technical change increases the demand for skills.

This finding emerges from almost every study and is extremely robust to different measures of skills (education, occupation, cognitive), technology (computers, R&D, patents) and dataset. There is no support for the de-skilling hypothesis.

Technical change appears to be associated with higher wages at the micro level, even when controlling for other factors (e.g. education). But the relationship is spurious - giving someone better technology does not increase earnings directly.

This finding emerges when one tries to control carefully for the fact that the best workers and establishments will tend to also use the best technology. Dealing with this econometric problem in many different ways all seem to destroy the simple correlation stressed by US researchers like Krueger (1994)

Innovative enterprises are, on average, no more likely to shed jobs than create jobs. There is a tendency for product innovations to create more jobs than process innovations.

There is often a positive raw correlation between employment growth and innovation, but this weakens when other variables (age, size, etc) are included.

1.2 Technology Policies

R&D tax credits increase R&D significantly (a 10% tax induced fall in the cost raises R&D by about 10% in the longer run). A lot of this is through multi-nationals relocating their R&D labs in response to a more generous fiscal environment

This emerges from examining `policy experiments' of changing the fiscal incentives for R&D, general corporate tax rates and other tax breaks. It emerges from looking across countries and within the firms of particular countries.

Direct government subsidies to R&D tend to have little effect on R&D or firm performance. They are less desirable in practice than tax credits

Research Joint Ventures are an efficient way of dealing with many market failures. Their anti-competitive features are when they refuse to fully share information.

1.3 Innovation and Market environment

Monopolistic markets produce less innovation than competitive markets. Despite this, high market share firms will often pre-emptively innovate to keep out new entrants.

Anglo-Saxon financial systems force firms to rely more on their internal cash flows. Thus they have lower investment and R&D. Their active take-over markets, however, mean that they use their (fewer) assets more efficiently

Computers do raise productivity. But firms need to introduce many other organisational changes alongside them to make best use of them.

2 Policy Implications

2.1 Labour Markets

Ongoing technical change has placed a demand on the economy to produce more skilled workers. Part of increased inequality and unemployment is due to the failure of the supply side to keep up with demand. This can only be addressed by improving access to education and training, not just for the young but for adults who need to retrain. The quality of education needs to be improved in many countries (especially the UK) for those who are less able and from poorer families.

Having said this, the increase is European unemployment is not mainly due to increased mismatch between the supply and demand for skills. It is likely to be more closely linked with inflexible wage bargaining, high taxes, generous benefits and (to a lesser extent) feeble demand.

It is sometimes said that because innovative firms have higher employment growth, technology policy to improve innovation could reduce unemployment. This is completely wrong!

First, there is no strong evidence that innovative firms have faster employment growth - it depends on the type of innovation and other factors. Secondly, even if there was a strong positive relationship then this does not prove the case as there are general equilibrium effects. For example, the firm may increase marker share at the expense of other firms leaving the total number of jobs unchanged. Thirdly, the fact that technical change has been going on for centuries but structural unemployment is a feature of particular periods (such as the current one) should make one suspicious of the argument that technology is responsible for unemployment. Finally, if technology policy is successful in stimulating innovation then this will increase the demand for skills. This will create more inequality and/or unemployment of less skilled workers unless the supply of human capital can expand.

This is not to say that faster technical progress is not desirable. It is. But innovation is desirable because it increases productivity which leads to lower prices, higher quality and higher real earnings for everyone, not simply those who happen to be in firms using new technologies in production.

2.2 Technology Policy

The inefficacy of direct government subsidies to R&D is disappointing because, in principle, the state should be better at identifying R&D projects with high social value. R&D tax credits will allow the private sector to choose any project so they will focus on those that have the highest private - not social - rate of return. The main problem, however, is to do with information and incentives. The private sector has a much better idea of what projects are likely to be successful than the government. Government bureaucrats also have little incentive to effectively monitor R&D projects compared to their private sector counterparts.

R&D tax credits carry their own problems. There may be re-labeling of expenditures as R&D which are not. There are a large number of design problems. Nevertheless, they do seem more effective. A deeper problem lies with tax competition. To the extent that R&D labs are more footloose than other investments, European governments could be competing against each other for an essentially fixed pool of multi-national R&D. Since R&D tax subsidies are exempt from EU competition rules then there is a danger of an inefficient subsidy race within Europe. *This gives a stronger reason for tax co-ordination across Europe in the R&D field than in other areas.*

2.3 Innovation and Market environment

Weak competition in product markets has been found time and time again to stifle innovation. This may be especially true of managerial innovations (e.g. decentralisation of authority to teams) which appear to be complementary to new technologies.

Weak competition can arise from the practices of dominant firms to restrict entry, but often comes from excessive government regulation which discourages entry and protects incumbents.

Tough competition policy coupled with an overhaul of the EU regulatory burdens on business is the best way to create an environment to foster innovation. This is likely to be a far better proposition than direct policy intervention. Competition authorities should place more weight on the anti-innovation aspects of market power when they consider the effects of firm and government activity.

On finance there are clearly costs associated with the current move to a more `Anglo-Saxon' system which stresses shareholder value. There will probably be costs in the form of lower R&D and innovation (although some may say that these are `too high' in many industries). The benefits of an active take-over market will be greater managerial effort and higher productivity.

The best response is not to stop the trend, but try to improve the costs of the system. Many of the problems seem to occur when firms want to start-up R&D labs and this suggests more efforts to improve the venture capital market, EASDAQ or easier NASDEQ listings.

Conclusions

The Network was a thematic one, but many important policy conclusions have been addressed. This has only been possible by adopting and developing state of the art econometric techniques and datasets.

One surprise was that the evaluations which the EU commissions internally for projects are not easily available to outside researchers. To foster greater institutional learning it would seem imperative to set up, ideally on the Web, a system for accessing the key findings of previous evaluations of EU policies.

Overall, the key recommendation is that policies which change the environment facing firms are more desirable than direct technology policies. *Strengthening the supply of skills in labour markets and the degree of competition in product markets is the best policy to enhance innovation. In terms of traditional technology policies, it is better for governments to move away from direct subsidies of R&D and towards support of more market based mechanisms such as RJVs and tax incentives.*

CHAPTER II

BACKGROUND AND OBJECTIVES OF THE PROJECT

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5. The Network plans one large conference per year and three smaller workshops. These are the platforms through which many of the objectives will be achieved and a range of papers have been presented.

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The Network basically kept to its during the 3 years. One main re-orientation was the plan to have a workshop meeting in each of the 11 partners' locations. It proved to be impossible to organise a workshop in the University of Macedonian. This is primarily because of the illness of the husband of the leader of the Macedonian group.

CHAPTER III

SCIENTIFIC DESCRIPTION

Introduction

The Network produced a large body of scientific work in the economics of innovation. We focus on this chapter in the research findings. There were four main themes in the Network with a project manager leading each theme. These were: technology policy (Laisney), competition (Ulph), finance (Klette), jobs (Van Reenen), wages (Harhoff) and productivity (Gambardella). Each manager reported on their theme and I have synthesised the research reports.

For the sake of clarity I have divided the exposition into *causes* of innovation (direct and indirect policies) and *consequences* of innovation (on firm performance and the labour market). To keep the policy focus at the forefront I first discuss direct policies (public financed R&D, tax credits, Research Joint Ventures - henceforth, RJVs - and other technology policies). Indirect policies include financial markets and product market competition policies. The next part looks at the impacts of technology on firm performance (productivity, stock market value) and the labour market (skills, wages and jobs).

There are a wide variety of approaches, but in general most researchers have taken an micro-econometric approach looking empirically at the associations of technology and other variables amongst firms. Important methodological advances have been made (e.g. econometrics of longitudinal data and count data). There are also substantial contributions on the theoretical front (e.g. RJVs) and a smattering of case studies.

The structure of this chapter is as follows. Section 1 examines direct policies towards innovation (publically financed R&D, fiscal incentives and RJVS). Section 2 looks at work on indirect influences on innovation through the structure of the product market and financial systems. Section 3 examines the impact of innovation on firm performance. Finally section 4 examines the impact of technological change on the labour market - skills, jobs and wages.

1. Direct policies toward innovation: Technology Policies

I will draw upon three surveys produced in the TSER Network (Klette et al., 1998, and David and Hall, 1999, and Encaoua et al., 1998), to organize the presentation of the other studies. We have done extensive work investigating the role of technology policies in stimulating the quantity and quality of innovation. We focus on three major types in the sub-sections below - direct grants/subsidies, tax policies and RJVs.

1.1 Publicly financed R&D

Klette et al. (1998) state that efforts to evaluate quantitatively the economic benefits and costs of R&D subsidies have been rather modest, and that most of the available evaluation studies are based on case studies and interviews. Concentrating on microeconometric studies evaluating the impact of government support for private R&D, they stress the fact that a complete cost benefit analysis would involve estimating (i) direct effects on the profits of supported firms, (ii) indirect effects for those firms, due to the government support of other firms, (iii) effects on the profits of non-supported firms in the same industry as the supported firms, (iv) effects on the rest of the producing sector, (v) the consumer surplus and (vi) the deadweight loss associated with the funding of the program. The authors discuss the methodological and substantial questions posed by this endeavor.

In particular, a precise evaluation of spillovers appears of primary importance, as spillovers are one of the main justifications for government support of innovative activities. Yet there are clearly formidable difficulties in evaluating the items (i)-(v) and the authors note that in the case of spillovers, considering the difficulties in measurement and in dynamic specification it is remarkable that almost all studies trying to estimate something as intangible as knowledge spillovers do report significant results. Methodological problems complicate the situation further. Evaluating the impact of government support on the profits of the supported firms requires reference to the counterfactual outcome in the absence of that support: in the presence of spillovers created by the program it becomes difficult to find similar non-supported firms that can identify the counterfactual outcome.

Klette et al. also echo the skepticism of Klette and Møen (1998), one of the studies they survey. After a detailed evaluation of a series of government programs implemented in Norway throughout the 80s and the 90s in support of information technology, Klette and Møen confirm the negative results of former and less formal analyses. They question the capability of the bureaucracy to gather and process the information necessary to intervene successfully in the improvement of coordination of complementary innovative activities across independent firms, and conclude that these coordination problems often seem to be resolved by private institutions such as industry associations, privately funded research joint ventures and other cooperative research agreements. In future research it could be interesting to examine more directly the role of such cooperative activities.

The focus of David and Hall (1999) is related but different, and concerns the interactions between public and private R&D expenditures, and their joint effects on the economy. Surveying econometric studies in this area they find contradictory estimates of the response of company financed R&D to changes in this category of public expenditures. Using a stylized structural model, they identify the main channels of impact of public R&D, and shed light on recent cross-section and panel data findings at different aggregation levels.

It is important to know to what extent public and private R&D expenditures are substitutes or complements, as private R&D might be crowded out, at the expense of the taxpayer. The contradictory findings in the literature result partly from differences in the level of aggregation, but more importantly from the different channels of influence involved. The literature on the role of government R&D funding has mainly examined how it affects private R&D investment, but influences that run in the other direction also deserve attention.

David and Hall distinguish three taxonomic dimensions. The first opposes direct effects upon the demand and supply of tangible resource inputs and indirect effects which can be described as knowledge spillovers, the latter also having a non-negligible impact on the determination of prices in the research-input markets. The second distinction opposes applied (or contract) R&D to basic (or grant) R&D, and relates to the institutional setting and contractual arrangements that impinge differentially upon the scope for knowledge spillovers, and the nature of the research inputs. The third distinguishes between short-term and long-term, or dynamic effects. This allows for the possibility that the immediate impacts of increased public sector R&D might be to ”crowd out” private R&D, but that they turn out to be complements in the longer run.

The first-order static effect is the impact on prices of research inputs; second-order static effects include the expected effects upon private sector rates of return, and these present both potentialities for crowding out and for complementarities, the latter mainly through the channel of anticipations. Dynamic effects differ in nature from the static effects of anticipations but the econometric identification of the underlying structure requires the existence of shocks in the form of policy changes. There may also be long run crowding out effects: the current mix of public and private funding can shape the structure of the future research system, the appropriate model being putty-clay.

David and Hall focus in their stylized models on two policy instruments at the disposal of the government. The first is the overall level of government R&D expenditure, the second the fraction of funding devoted to basic research. In the short run the level of government R&D expenditure on employment in private R&D is negative, but the share of basic R&D has a positive effect on that variable. Both instruments have a positive effect the wages of researchers. Finally, the share of basic R&D has a positive effect on private R&D expenditure, while the impact of total public R&D expenditure can go both ways. In the longer run the sign of the impact of public R&D expenditure on private R&D employment depends on a variety of elasticities and on the size of the government sector, while the other conclusions remain qualitatively similar.

The authors conclude with a policy after-thought, asking whether crowding out is necessarily bad, and first wonder why this obvious question has not been asked in the economics literature so far. They attribute this to the traditional presumption that the level of private investment is too small, and that hence any further displacement of private R&D by public research programs must be bad. Yet several theoretical models give rise to the possibility that the private marginal rate of return exceeds the social rate. An example may be the drug sector, where private companies complain about universities doing too much research that is close to the market. Their worry is that when university researchers get involved, the rents on what they find will be dissipated by imperfect management of information -- inadequate secrecy during the research process; by constraints that prevent the universities from setting exclusive licensing terms that maximize the licensees revenues.

Policy prescriptions are made difficult by the widely different situations across research areas: direct targeting of research aimed at crowding out some private R&D expenditures and not others would again presuppose a level of information that government agencies are unlikely ever to possess, and David and Hall suggest that altering the way tax credits are paid might be a more promising line of action.

Beise and Stahl (1998) provide a descriptive analysis of the impact of public research on private R&D acivity in Germany, and thus provide an illustration for the preoccupations of David and Hall. The precise question they ask is „Are innovating companies able to identify the contribution of public research to industrial innovations and trace the source of these innovations?“ In a postal questionnaire, 2,300 companies were asked whether they had introduced innovations Bette 1993 and 1995 that would not have been developed without public research. Less than 10% of innovating firms mentioned such an occurrence. Public research based new products represent about 5% of the sales of all new products.

The effectiveness of the technology transfer differs across types of public research institutions: universities are quoted as the most important source while big science laboratories are almost invisible. Beise and Stahl interpret this difference as follows: the main channel for the technology transfer is through academic scientists in firms´ R&D labs using the knowledge they received at public institutions. Big science laboratories and other non academic public research fail on this account because they do not spin off much human capital, as the long term research they engage in requires low staff turnover.

On the side of firms, German firms with R&D activities are more likely to profit from public research, suggesting a complementarity between public and private research. The thesis that geographical proximity is important for high-tech or R&D intensive industries is clearly rejected in the case of Germany: such firms cite remote public research institutes more frequently than less R&D intensive firms.

Polytechnics and Fraunhofer institutes tend to support small companies within their region, while universities and other research labs transfer knowledge more effectively to larger companies, with no regional priority.

The paper by Arora, David and Gambardella (1998) also relates to the preoccupations of David and Hall, as it focuses on the distribution of public funding for research among research teams according to reputation and competence, and on the productivity of these teams according to the allocation of funds they obtain. This is one of the first empirical contributions to the new "economics of science". The authors emphasize that this topic of study is in its infancy and needs to be developed further.

The study is based on an original database which they constructed from the archives of the Italian National Research Center´s five-year program (1989-1993) in the fields of molecular biology, genetic engineering and bio-instrumentation. They obtained a sample of almost 800 research teams proposing research projects, some 350 of which were selected and received, for five years, annual research budgets of varying amounts (and in varying proportions to the sums requested). For these teams, they compiled their budgets, their publications (numbers and journals) produced during and as a result of their research programs, and publications by the team leaders, taking into account work published in the field concerned over the five years preceding the funding request.

To analyze their data, Arora, David and Gambardella propose a model closely matched to their particular problem, though also applicable on a more general level. They find that research returns (measured by research budget) in terms of articles (weighted according to the international reputation of the journals in which they are published) estimated at the individual team level are decreasing (0.6 on average). However, they demonstrate that returns in relation to past performance are of the same order, via the indirect effect of past performance on the probability of future funding. Most of this effect is due to the fact that the probability of a team having its project selected is higher if past performance is good, and the remainder is due to the fact that once chosen, the amount of funding allocated is correspondingly higher.

Bach et al. (1995) provide an example of the case studies mentioned by Klette et al. (1998). They deal with an evaluation of the economic effects of European R&D subsidy programs (BRITE-EURAM) on the basis of direct interviews of 176 partners involved in 50 projects.

They consider as direct effects those effects in accordance with the stated objectives of the research projects, and as indirect effects those that go beyond those objectives, breaking these down into technological, commercial, organ-izational effects and effects on the human capital of participants. Their results show that factors that prove beneficial in the generation of significant effects are (i) the participation in the project of a partner involved in fundamental research (e.g. a university), (ii) the diversity research tasks.

König and Licht (1997) address the determinants of participation in technology policy programs in Germany. They recall that the EC White Paper (1994) and Green Book (1995) expressed the opinion that Europe´s research and industrial base suffers from a shortage in R&D investment compared to competitors, from insufficient coordination of development activities and from a comparatively limited capacity to transform technological achievements into commercial successes, concluding that the authorities should promote the development of future-oriented markets and strive to anticipate changes rather than simply react to them. The German government has broadly adopted these views and goals, further giving a high priority to the support of innovative activities in SMEs.

After discussing economic arguments for R&D support by the government, and mentioning in particular the market failure connected to the presence of risk and uncertainty, they describe the German system of R&D support programs, mainly directed towards high-tech sectors, where spillovers are comparatively large.

In an empirical study based on wave 3 of the Mannheim Innovation Panel (1995), which contains information on participation in government R&D promotion programs, they do confirm that technology policy programs in Germany are concentrated on high- and medium-tech industries. Although the participation probability strongly increases with firm size, innovative SMEs receive substantial amounts of government support. The distribution of participants across industries shows similar patterns for EC and federal programs, but the pattern is different for programs at the level of the Lands.

In order to help assess the impact of government support to R&D on innovation activities, König and Licht analyze the productivity effects of R&D and the relation of R&D to product innovation. They find no evidence that the R&D in supported firms is less efficient than in non-supported firms, but given the static nature of their model, this conclusion must rather be seen as a working hypothesis for future research. Another topic for future research is degree of additionality of public R&D funding. Finally, only week evidence was found that picking the winners might be a strategy behind government support to R&D: supported firms exhibit no better economic performance than non supported firms.

1.2 R&D Tax Credits and other fiscal incentives for innovation

The papers by Bloom, Chennells, Griffith and Van Reenen (1998), and Bloom, Griffith and Van Reenen (1998) examine the impact of fiscal incentives on the level of R&D investment at the aggregate level of the economy, using panel of countries for the years 1979-1994, including Australia , Canada, France, Germany, Italy, Japan, the UK and the US. They thus cover in part items (i)-(iv) of the list given by Klette et al., in part because of the aggregation level and because they only report effects on R&D investment and not the resulting effects on profits.

Economists have traditionally been skeptical of the efficacy of tax incentives, but changes in the fiscal treatment of R&D in the US have provided a „natural experiment“ which improved the identifiability of the price responsiveness of R&D. However, a time series concerning only one country is clearly not ideal, as it is difficult to separate the effects of the tax credit from other contemporaneous macroeconomic events.

Instead the authors resort to a panel of countries that have introduced similar changes in the fiscal treatment of R&D. The first paper describes the different R&D tax incentives and their evolution over time. Its main findings are that there is substantial variation in the cost of R&D between countries and that this variation increased over the period studied, although there was a general downward trend. Differences in the design and implementation of R&D tax credits means that there is also a large within-country variation in their impact over time. The authors conclude that policy-makers differ in their opinions on the role of the state in encouraging R&D, and this is reflected in different tax policies both within and between countries.

Using a simple autoregressive model of R&D investment the second paper finds that R&D is indeed responsive to changes in its user cost, even controlling for demand, country fixed effects, and world macro shocks. The authors consider various extensions of the basic model, and in particular they find evidence of tax competition: changes in the user cost of R&D across countries has an impact on where firms locate R&D.

Having met the objection that tax credits might be ineffective, Bloom et al. Ask in their conclusion whether they should be considered desirable, and cast this question within the more general cost-benefit analysis framework described by Klette et al.: monitoring costs should be included, perverse incentives created by the design of the different tax credits could cause severe distortions, and in a world of international spillovers a country might be better off free-riding than attempting to subsidize innovation itself. The existence of R&D tax rivalry implies that governments may be strategically choosing their R&D policies, and the authors conclude that further research should explicitly model government policy and endogenize the design of R&D tax credits.

The question of the effectiveness of R&D tax incentives also motivates the papers by Dagenais et al. (1996) and Mohnen et al. (1997). Both papers report empirical results for Canada, the first using an unbalanced panel of 434 individual firms from Standard and Poor´s Compustat database over the period 1975-1992, the second published data from Statistics Canada on 26 industries for the period 1963-1992.

The first paper contains a very detailed description of the Canadian system of fiscal R&D incentives and of the construction of a firm-specific synthetic index of R&D tax incentives. On the basis of a generalized tobit model it concludes that, per dollar of R&D tax revenue foregone, the firms in the sample increased their R&D expenditures by $0.98, and that 80% of the associated R&D cost to the government was a transfer payment in support of R&D which firms would have done anyway.

Among the limitations of their study, the authors mention that they could not estimate the extent to which the generous tax treatment of R&D in Canada attracts firms that would otherwise have located their R&D elsewhere, and that their data has the drawback that both small and medium size firms and the biggest R&D spenders in Canada are underrepresented.

In their conclusion they stress the advantage of fiscal incentives over targeted support: the former leave the decision to the individual firm and do not require for the policymaker the massive information necessitated by precise targeting. Moreover the moral hazard connected with collusion between the policy makers and the supported firms is smaller with fiscal incentives.

Given the data limitations mentioned above, the stated goal of the second paper is to reexamine the issue using the whole universe of R&D performed in Canada. The authors combine the R&D data of Statistics Canada with the input-output data and the data on Labour and capital used to compute Canada´s multifactor productivity figures and estimate a dynamic system of factor demand equations with adjustment costs and rational expectations, allowing for complementarity or substitutability between R&D and the other factors of production. They are thus in a position to investigate the effectiveness of promoting R&D through physical capital tax incentives. Intersectoral R&D spillovers measure technical change and are considered as exogenous.

To evaluate the effectiveness of R&D tax incentives, they compare the present value of additional R&D following a tax change to the present value of the costs borne by the government. Their finding is now a $1.2 increase in R&D expenditures to each dollar government cost, a higher figure than in the previous study, possibly explained by the inclusion of the indirect effects of tax incentives via the interrelationships with physical capital investments and R&D spillovers. The transfer part related to this tax policy is still substantial, and again, this study does not investigate whether the generous Canadian tax incentives attract new R&D performers nor whether the additional R&D generated earns high returns.

1.3 Research Joint Ventures

There are a number of inter-related issues lying behind the work done in this area.

The first is the link between innovation and competition, or between market structure and the outcome of R&D competition. This is a long-standing concern, with much discussion of the nature and direction of the connection between the two. Theoretical developments over the last ten to fifteen years have clarified the connections and given us a framework for thinking in which market structure and the nature of R&D competition are simultaneously and endogenously determined[1]. Given the complex theoretical links, a careful microeconometric investigation of the link between market structure and R&D competition raises many difficulties. Work undertaken in this TSER project has made important developments in this direction, which I will survey later on.

There is an obvious link between innovation and research joint ventures (RJVs) in that RJVs are often seen as a way of overcoming some of the market failures in the innovation process. However since RJVs are collaborative agreements they would normally be outlawed under competition policy. A major policy of the EU has been the promotion of RJVs both through block exemptions to competition policy, and by R&D subsidies through various framework programmes. The presumption is that while RJVs collaborate

[1] See for example Beath Katsoulacos and Ulph (1995) for a survey.

on R&D they compete in the product market, and this is how they have typically been modelled in much of the theoretical literature.

1. However the earlier theoretical framework for thinking about RJVs has recently been challenged as not being fully adequate for understanding the link between RJVs, competition and innovation. Work undertaken in this TSER project has gone a long way towards providing a richer framework for evaluation.

2. In this paper I have tried to develop a framework which tries to draw together many of the ideas in the literature on RJVs. I hope this framework might enable us to

(i) better understand the work undertaken in this TSER project and its connection to other literature;
(ii) identify the directions for further research;
(iii) reflect on what conclusions might emerge for policy makers.

The plan of this subsection paper is as follows. In section 1.3.1 I will set out a general overview of the market failure issues which RJVs might be thought to address, and the way they might do this. Annex A.3.2 develops a more formal model to capture these ideas. Section 1.3.2 then reviews the literature and the contribution of the work undertaken in this TSER project to that literature. Section 1.3.3 indicates directions for further research which emerge from this study, while Section 1.3.4 offers some conclusions.

1.3.1 An Overview of Market Failures in Innovation and the Role of RJVs

It is well known there are significant potential market failures in the innovation process. These stem fundamentally from the appropriability problems that arise from the public good nature of knowledge. In the absence of any form of policy intervention these problems imply that the private rate of return to R&D would be extremely low, and consequently there would be considerable under-investment in R&D. To address these problems most governments operate a system of protection of intellectual property rights (IPRs) – the central component of which is patent protection. However, while policy intervention in the form of a patent system provides some correction of the basic market failures, it generates its own distortions, essentially because patents reward firms for discovering information but not for sharing it.

To understand this point consider first a policy system in which
(i) there are no mechanisms for (voluntary) information sharing or research co-ordination among firms;
(ii) patents are completely effective and can prevent all involuntary information leakages or spillovers;

For the moment, suppose also that:

(iii) firms are producing substitute products – an assumption made in much of the literature on innovation, spillovers and RJVs;

(iv) the research paths which firms are pursuing are what Katsoulacos and Ulph (1998) call perfect substitutes. That is the research that all firms are doing effectively leads to the same discovery. This assumption too is widely made in the literature on innovation.

In the discussion that follows, and throughout the paper, I will focus on the case where firms are involved in process innovation. Then, as is well known from the Industrial Organisation literature[2] there will be a number of distortions in the R&D market.

(a) Firms will not usually be able to appropriate the extra consumers' surplus from their innovations. By not taking into account consumers` surplus in their objective firms tend to under-value the returns to R&D, and so will under-invest in R&D. We refer to this as the under-valuation effect.

(b) If, as in the non-tournament [3]model of Dasgupta and Stiglitz (1980), firms make their R&D decisions non-strategically[4], then each firm will have an additional reason for under-investing in R&D. For they take account of the benefit of the R&D to themselves, and so, given the substitute nature of the research, they ignore the potential benefit that the outcome of their R&D could bring to others - if the results of their R&D were shared. Call this the non-strategic under-investment effect.

(c) However, if firms choose R&D strategically then there is a factor leading each firm to over-invest in R&D - since each firm tries to gain at their rival's expense. This over-investment is most dramatic in the case of tournament (race) models, but also arises in non-tournament models where firms choose R&D prior to the output stage of the game. Call this the strategic over-investment effect.

(d) Finally there will be excessive duplication of R&D effort. If information were fully shared then fewer firms need undertake the R&D.

If we drop assumption (iv) and assume instead that firms pursue what Katsoulacos and Ulph (1998) refer to as complementary research paths, then there is no longer a concern under (d) about duplication of effort. Instead the concerns are as follows.

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[2] See the collection of articles in the "Handbook of the Economics of Innovation and Technological Change" (1995).

[3] For a discussion of the distinction between tournament and non-tournament models of R&D competition, see, for example, Beath, Katsoulacos & Ulph (1995).

[4] That is firms choose output and R&D simultaneously rather than sequentially.

(e) Firm's inability to co-ordinate their research will lead to the under-exploitation of the complementarities between their research. Notice that this co-ordination of research will typically require the exchange of information prior to undertaking R&D, so that firms can co-ordinate the direction of their research. Of course, a full exploitation will also require the exchange of information about research outcomes. This is in contrast to the concerns in (b) above which relate entirely to the exchange of information about the outcomes of R&D discoveries. Call this the under-exploited complementarities effect.

(f) Precisely because these complementarities are not fully exploited, firms will under-invest in R&D. Call this the under-exploited complementarities under-investment effect.

If we drop assumption (iii) and assume that firms are producing complementary products, then the above discussion gets modified in two ways. First it is much less likely that firms will be pursuing perfect substitute research paths – though this possibility is still allowed for in what follows. Second, since each firm now gains rather than loses when the costs of other firms are lowered, the magnitude of some of the above effects will be altered. For example, ceteris paribus, the strategic over-investment effect could be much smaller (and possibly even negative).

Consider now the implications of dropping assumption (ii) and allowing for the possibility of spillovers – defined as involuntary, unpaid leakage's of information. In the case where firms produce substitute products and invest strategically in R&D, we have another consideration.

(g) When firms are producing substitute products, then the larger the spillover, the smaller will be the amount of R&D undertaken by each firm. There are two reasons for this. If a firm succeeds in innovating when its competitors do not then it will have less to gain from its discovery since some of the information will leak out to others. However if a firm fails to innovate, while some of its rivals succeed, then it will gain from their discoveries, and so has less to lose from a failure to innovate. Both of these effects will imply that the larger the spillover the smaller the amount of R&D. Call this the spillover under-investment effect. Once again the discussion is somewhat modified when firms are producing complementary products, for now the first of the above effects is positive, since a firm gains from any progress made by the other firms.

So, in the absence of any mechanisms or policies for promoting information-sharing and/or R&D, we can see that patents – and IPR systems more generally – by no means resolve all the market failures associated with R&D. This is true even if the patent system works perfectly.

Three other conclusions emerge from the above discussion.

(I) Many of the failures arise because, under a patent system, firms are rewarded for creating information, but not necessarily for sharing it. Under our assumptions so far, whatever information passes from one firm to another does so involuntarily, and is unrewarded.

(II) There are two types of information that may need to be shared by firms. There is research design information that may need to be shared before any R&D is undertaken. This is necessary for firms to be able to co-ordinate research and exploit complementarities. It may also be necessary to avoid duplication of research effort. There is research outcome information that is shared after firms have made discoveries[5].

(III) The failures are quite complex – some point to under-investment, and some to over-investment.

Before turning to possible policies, let us consider a number of ways in which firms might voluntarily share information.

Firms would presumably be interested in voluntarily exchanging research design information and in co-ordinating research. However, such information is unlikely to be codified and so any exchange will have to take place through meetings etc. Clearly any research co-ordination will also required detailed meetings and planning. I take it that all of this is ruled out by competition policy. This does not mean that in the absence of explicit co-ordination there will be no compatibility of research design and so no possibilities of exploiting complementarities through information-sharing, but rather that such compatibility will be the haphazard outcome of independently taken decisions.

To the extent that it is codified, firms may still be able to exchange research output information. At the very least they could simply give this information away free of charge, and, as Katsoulacos and Ulph point out, would have incentives to do so if firms were producing complementary products.

However another way of sharing research output information is through licensing. The important point about licensing is that it now gives firms a direct financial reward for sharing information. This will raise the rate of return to R&D. However there a number of points make about licensing.

First , licensing would seem to work well when one firm has made a discovery of some new product/technology that is easily described, while another firm has not. It would seem less appropriate when two firms have both discovered and are trying to exploit complementarities through the mutual exchange of information about their discoveries

[5] Recent empirical work by Cassiman and Veuglers (1998) points up the difference between research output spillovers and research input spillovers.

Second, licensing is problematic when there are more than two firms, since the price any one firm is willing to pay to acquire a license will depend on how many other licenses are sold.

Third, even when there are only two firms involved, licensing will only take place when the maximum amount the buyer is willing to pay exceeds the minimum price the seller is willing to accept – and, as is well known, this condition will not always be satisfied. In particular, licensing may not occur when firms produce substitute products and the innovation is sufficiently large.

Finally, in the case where firms produce complementary products, and so would have been willing to give away their discovery free of charge, licensing may introduce a strategic incentive to invest that will lead firms to over-invest in R&D.

Against this background let us consider now the possible role for RJVs. First let me say what I mean by a research joint venture. A research joint venture (RJV) is a mechanism whereby firms are able to take decisions about all aspects of R&D in a collaborative/co-operative fashion.

In particular an RJV can act cooperatively on the following three sequences of decisions.

(I) Research Design and Co-ordination

This embraces two different decisions.

I.1 <u>The number of laboratories to operate.</u>

Here I assume that there are just two options. The RJV can either operate two independent laboratories – essentially one in each firm – or else it can operate a single laboratory staffed by scientists from each firm[6]. I take that this means that all information about research discoveries will be fully shared by the two firms.

I.2 <u>Research Design Co-ordination</u>

In the case where the RJV operates two laboratories, and where there is some potential complementarity between the research paths that each laboratory can pursue, the RJV designs the research strategies to be pursued by each laboratory in such a way as to maximise the potential complementarities.

(II) R&D Co-ordination

Here the RJV chooses the amount of R&D to do in each laboratory so as to maximise expected joint profits. That is R&D is chosen in a cooperative rather than a non-

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[6] Martin (1998) and Vonortas (1994) use the terms *operating entity joint venture* and *secretariat joint venture* to refer respectively to the cases where firms operate 1 or 2 labs.

cooperative fashion. This decision is made taking account of the research decision decisions taken at the previous stage, and anticipating the research output information-sharing decisions to be taken at the subsequent stage.

This aspect of RJV decision-making is self-explanatory, and has been the focus of virtually all the analysis of RJVs to date.

(III) Research Output Information Sharing

The RJV has to decide how much information will be shared depending on what discoveries are made by each of the firms in the RJV.

Intuitively, by operating in this way the RJV can potentially address most of the market failures referred to above.

(b) Through II and III it can reduce non-strategic under-investment since the firms in the RJV will base decisions on the amount of R&D on the benefit to the group rather than to the individual firm.

(c) Also through II and III it can reduce the strategic over-investment, since firms will no longer be trying to innovate ahead of their rivals.

(d) Through I.1 it may be able to avoid duplication by undertaking all R&D in a single lab. Even if the RJV decides to operate two independent labs, the reduction in strategic over-investment will ameliorate the needless duplication.

(e) Through I.2 and III it can increase the extent to which complementarities are exploited.

(f) While through II and can also increase R&D spending to better realise these complementarities.

(g) Finally through II and III, not only is the RJV likely to increase the amount of research output information that is shared, but this sharing will no longer be perceived as an externality, thus reducing the spillover under-investment effect.

Notice that the only market failure not addressed by the RJV is (a) – the undervaluation effect.

In order to better organise the literature on RJVs within this intellectual framework, Appendix 3.1 at the end of the chapter presents a formal model of RJV behaviour which draws together all these ideas.

1.3.2 Review of the Literature

This reviews the literature on Competition, Innovation and RJVs and, in particular, the contribution made to this literature by work undertaken in this TSER project. The latter works are indicated by having the names of the authors in bold. The review does not aim to be exhaustive, but rather to give an overview of the main developments in the field so that the reader can better understand the contribution made by the work of the TSER.

I will divide the review into a number of sections.

The first will examine the performance of RJVs, taking the number of firms in the RJV as fixed and assuming that firms act competitively in the product market. I will then examine the literature on the optimum and equilibrium size of an RJV, and the related literature on RJV membership. The third part will review the link between competition and RJV behaviour. The fourth part of this section will examine work on the evaluation of RJVs.

The final section of the review will cover some work done on the link between competition and innovation, but where there are no RJVs.

1.3.2.1 Performance of RJVs

A point of departure of many of the papers in the literature is the classic paper by d'Aspremont and Jacquemin (1988). They consider a model in which the products that firms produce are perfect substitutes. They employ a model in which R&D is non-stochastic and so both firms will discover for sure, and the research outputs are perfect complements. They assume that it is possible for firms to undertake some degree of R&D design co-ordination and information sharing in the non-cooperative equilibrium – so there can be a positive spillover between firms. However they also assume that this spillover is exactly the same when firms are in the RJV. They also assume that the RJV will always operate two labs. Essentially then all the decisions at Stages I and III of R&D decision-making are fixed, and the only decision they explore is that on the amount of R&D to be chosen. Thus the only role for RJVs here is on R&D co-ordination.

In the non-cooperative equilibrium this decision is made strategically, with R&D being chosen before output. Hence there are two effects at work. There is a strategic over-investment effect, and a spillover under-investment effect. The RJV will reduce the strategic over-investment effect, but internalise the externality and so increase R&D. The overall effect on R&D spending will depend on which of these two effects dominates. The classic result obtained by d'Aspremont and Jacquemin is that when the spillover parameter is less than 50%, the RJV will undertake less investment than in the non-cooperative equilibrium. The RJV will raise investment when the spillover parameter is greater than 50%, and will therefore obviously do exactly the same amount when the spillover is exactly 50%.

De Bondt and Wu (1997), Suzumura and Goto (1997) and Beath, Poyago-Thotoky and Ulph (1998), extend this model by allowing for the possibility that through better co-ordination and information sharing the RJV may have a higher spillover than in the non-cooperative equilibrium, though the spillover parameter is still exogenously specified in both the cooperative and non-cooperative equilibria. Now the RJV will obtain any given R&D outputs (levels of cost reductions) more cheaply than in the non-cooperative equilibrium. Indeed, compared to the non-cooperative equilibrium it may achieve greater R&D outputs with a smaller total expenditure on R&D. An RJV may achieve more R&D outputs than the non-cooperative equilibrium, even when the spillovers are less than 50%.

Roller, Tombak and Siebert (1997) allow for possibility that firms produce complementary products, and notice that this makes R&D investments strategic complements, but do not explore the possibility of voluntary information-sharing in the non-cooperative equilibrium. Empirical work by Cassiman and Veuglers (1998)

In a series of papers, Katsoulacos and Ulph (1998a,b & c) have extended the above framework considerably. They have recognised that the "spillover" that appears in the above models reflects two different decisions – research design co-ordination and information-sharing – and have endogenised both decisions in both the cooperative and in the non-cooperative equilibrium. They then recognise that it is important to make many other distinctions that are not always made in the literature. In particular in the model presented in Katsoulacos and Ulph (1998b) they allow for

(a) products to be complements or substitutes;
(b) process or product innovation;
(c) a very general degree of substitutability/complementarity between research outputs;
(d) the possibility that the RJV may choose to operate just a single lab.

Some of the main conclusions to emerge from this analysis were:
(I) When products are complements firms may be able to achieve full research design co-ordination and information-sharing in the non-cooperative equilibrium.
(II) RJVs may choose not to fully share information - and indeed will do so for anti-competitive reasons.
(III) In particular RJVs may choose to operate a single laboratory to avoid information-sharing.

These findings raise serious doubts about the welfare gains to be had from RJVs – a topic to which I will return later.

There are three main differences between the model set out in Katsoulacos and Ulph (1998b) and the framework developed in the previous section.

(A) In Katsoulacos and Ulph (1998b) no allowance is made for the possibility of licensing in the non-cooperative equilibrium.
(B) Katsoulacos and Ulph (1998b) assume that it is possible for an RJV to operate

a single lab and yet not have that lab share information. This may be a rather odd assumption, in that typically when an RJV operates a single lab, this is staffed by scientists from each firm. Indeed such an arrangement may be precisely a device to ensure that information-sharing is achieved within the RJV. In the framework set out in the previous section, I make the opposite assumption that with a single lab full information-sharing is achieved.

(C) Katsoulacos and Ulph (1998b) model research design co-ordination as a parameter that each firm can choose independently, and which affects the usefulness of their research to the other firm.

In the framework developed in the previous section I have argued that research design co-ordination is an essentially cooperative activity that requires the exchange of a great deal of information and mutual planning prior to undertaking any R&D, and that such co-operation would normally be precluded under competition policy. Within such a framework one of the great benefits of RJVs – and hence of competition policy which gives exemption to RJVs – may be precisely that it allows this research design co-ordination to take place.

In an interesting paper Klette and Moen (1998) reflect on the role of technology policy in promoting the development of general purpose technologies (GPTs) in which such complementarities are rife. They argue that there are number of strands in the theoretical literature that suggest that firms may indeed be able to undertake a considerable amount of co-ordination through normal market relationships, and provide evidence that this can indeed happen. However, they also point to arguments and evidence that suggest that this co-ordination is not necessarily achieved through normal market relationships.

This seems to me to be one of the key areas for further research – both theoretical and empirical. In order to fully evaluate the role of RJVs, we really need to know in more detail precisely how much and what kind of co-ordination is achievable through non-cooperative, non-market means.

While I think that the work referred to above has helped us develop a framework for thinking about RJVs which is a considerable advance on existing models, there are still a considerable number of weaknesses.

- In their work Katsoulacos and Ulph (1998a,b&c) do not explain how any information-sharing agreements within RJVs get enforced – particularly in the case where the RJV operates two labs. Recent work by d'Aspremont, Bhattacharya and Gerard-Varet (1998) explore the issue of information-extraction in greater depth – particularly for the case of intermediate discoveries.
- The model assumes that there are just two firms who comprise the entire industry.
- The analysis follows the earlier literature in assuming that firms will act competitively in the product market.

I now review some recent literature on the last two issues.

1.3.2.2 RJV Size and Membership

Suzumura and Goto (1974), Poyago-Theotoky (1995), De Bondt and Wu (1997) have allowed the possibility that there may be many firms in an industry, not all of whom join an RJV. They have examined the issue of whether the equilibrium size of RJV is above or below the social optimum. An important issue that naturally arises in this context is that decisions taken by the RJV will affect the firms outside the RJV, but will typically be ignored by the RJV – creating an externality. The papers differ in their stability notions. Suzumura and Goto (1974) simply examine whether a grand coalition comprising all firms would be stable against defections of a single firm. They find that if the RJV has no information-sharing advantage – and so has the same spillover as the non-cooperative equilibrium then the grand coalition is unstable. However when the RJV can also promote greater information-sharing amongst its members then the prospects for stability are increased. De Bondt and Wu (1997) look at coalitions comprising less than the entire industry and here examine two types of stability – no insider should wish to leave, and no outsider should wish to join. As in Suzumura and Wu (1974), coalitions are unstable if the RJV has no information-sharing advantage over firms outside the RJV, but if there is such an advantage, then stable RJVs may form. The size of the stable coalition depends on the spillover. The larger the spillover, the smaller is the stable coalition, since outside firms can free-ride on the cartel. They find that the equilibrium (stable) size of cartel may be above or below the optimum size. Poyago-Theotoky (1995) uses a different stability condition whereby the RJV can block entry. Now the equilibrium size of RJV is too small.

All these papers consider the case of a single group of firms in a single industry. Ulph (1991) examines two groups of firms located in different countries where, for as a consequence of previous R&D success, one group of firms currently has a technological advantage over the other. He considers a model in which, in a non-cooperative equilibrium, the firms in the technologically backward country would fall further behind, and examines whether the formation of an RJV by a subset of firms in this "backward" country could help regain a technological lead. He shows that this could happen but that, as in Poyago-Theotoky (1995) the equilibrium size of RJV could be below the optimum.

A somewhat related literature is that on RJV membership. Here, the aim is to explain the types of configurations of firms observed in RJVs. The most systematic attempt at modelling this is the recent paper by Roller, Tombak and Siebert (1997). As in d'Aspremont and Jacquemin (1988) there are just two firms, so the size of the RJV is fixed, and research outputs are perfect complements. As in d'Aspremont and Jacquemin (1988) spillovers are fixed so, as they note, there are no real opportunities here for RJVs to exploit complementarities. However, unlike d'Aspremont and Jacquemin (1988) firms can differ in their initial costs, and the products they produce can be complements rather than substitutes. They conclude that the gains from RJV formation are highest when: (i) R&D spillovers create free rider problems; (ii) duplicative R&D creates opportunities for cost-sharing; (iii) firms produce complementary products; (iv) firms are of fairly similar size.

While these findings are of some interest, and seem to be borne out by the data, there are a number of problems with this analysis.

(a) As Roller, Tombak and Siebert note - the RJV is unable to really exploit complementarities.
(b) While they discuss the gain from avoiding duplication, the R&D is perfectly complementary – so there is no real duplication taking place. Moreover the RJV always continues to operate two labs.
(c) As noted above, firms producing complementary products may have considerable incentives to share information and carry out co-ordination in the non-cooperative equilibrium, and this is not allowed for.
(d) Some caution has to be exercised in discussing how the size of asymmetries affects incentives to form an RJV. Asymmetries can be increased in many different ways, and these can have differential impacts on the incentives to join an RJV. At best one can get ceteris paribus conclusions about, say, increasing asymmetries keeping the mean value of initial costs constant - see for example Long and Soubeyran (1997).

1.3.2.3 Interaction Between RJVs and Product Market Competition

So far I have followed much of the literature in assuming that although firms might collaborate in the R&D stage of the game, they compete in the product market stage. An issue of considerable policy concern is that of cooperation in R&D might enable firms to cooperate in the output stage – see, for example, Suzumura and Goto (1994) for a discussion of this issue.

However since the emphasis has been on how RJVs may improve dynamic efficiency, this potential impact of RJVs on static efficiency has received has received little formal analysis. One paper which undertakes such an analysis is that by Martin (1995). He uses a model in which firms are involved in an ongoing process to develop some new technology/product. If firms have joined an RJV voluntarily, it can only be because their profits are higher inside the RJV than outside it. But then the threat to dissolve the RJV can be used as a trigger strategy to sustain higher prices while the RJV is still trying to discover the new technology.

As noted above the work by Katsoulacos and Ulph (1998 a, b & c) provides an alternative route by which RJVs may affect post-discovery profits – for they show that the RJV may not always fully share information. Whenever this happens it does so for anti-competitive reasons - the RJV wishes to prevent the market from becoming too competitive by having firms with identical costs/products.

A more recent paper by Beath and Ulph (1999) extends the framework used in all the literature to date by allowing an entry stage of the game to occur after the R&D decisions have been taken, but before the price/output stage of the game. The model is an extension of that used by Katsoulacos and Ulph (1998b&c). The idea here is that firms are located in different countries/markets. There are trade costs of a firm located in one market serving the consumers in the other market. If one firm alone discovers a new low-cost technology, and does not share this discovery with the other firm, then its technological advantage may enable it to overcome the trade cost disadvantage and enter the other firm's market. However, by sharing information, this removes the discovering firm's technological advantage, and may therefore prevent entry. Here then full information-sharing is used as a commitment device to prevent subsequent entry – even when this decision is made in a non-cooperative fashion outside the RJV. However, as Beath and Ulph (1999) note, this entry prevention is not really anti-competitive, since, because costs are lowered, welfare is higher than it would have been had information not been shared and entry taken place.

An interesting recent paper by Martin (1998) looks at the reverse linkage from product market competition to innovation and the performance of RJVs. Of course a major instrument of competition policy that bears on innovation and RJV performance are the exemption clauses that allow cooperation on R&D. But this ignores the many other instruments of competition policy like regulation. In his paper Martin explores the effects of having tighter regulation in the form of a lower guide price to trigger regulatory investigation. He employs a pure tournament model in which research paths are perfect complements. Research joint ventures are assumed to fully share information, although they cannot influence the extent of the (input) spillovers.

He shows that although tighter regulation lowers profits, it lowers pre-discovery profits more than post-discovery profits and so can increase the incentive to innovate. He also shows that excessively tough competition policy can have negative effects on welfare – since it encourages excessively rapid innovation. Welfare is highest when competition policy is moderately tough, there is an RJV operating two labs with high spillovers.

This is an interesting line of research, which warrants further work drawing on the RJV framework outlined in Section 1.3.2.

This brings us to an analysis of the work done on evaluating RJVs and RJV policy.

1.3.2.4 The Evaluation of RJVs and of RJV Policy

There has been a considerable amount of discussion of RJVs and of RJV policy, but relatively little in the way of a careful welfare evaluation – either theoretically or empirically.

Explicit theoretical welfare evaluations of RJVs have appeared in the papers by Kamien, Muller and Zang (1992), Suzumura and Goto (1994), Martin (1994 & 1998), De Bondt and Wu (1997). However these suffer from a number of problems.

Thus the papers by Kamien, Muller and Zang (1992), Suzumura and Goto (1994), De Bondt and Wu (1997) all draw on the original d'Aspremont and Jacquemin framework with spillovers that are exogenously specified; research paths that are perfect complements, substitute products, symmetric RJV equilibria. Thus, in relation to the framework developed in Section 2, they suffer from two major weaknesses.

(i) They fail to give full scope to the range of market failures that RJVs might address and the range of methods they might use to do so – such as research design coordination.

(ii) They do not explore the range of methods that firms might employ to undertake coordination and information-sharing in the non-cooperative equilibrium.

The first failure means that they mis-state the possible achievements of RJVs, while the second means that they mis-state the counter-factual as to what happens under the non-cooperative equilibrium.

Suzumura and Goto (1994) explicitly recognise the limitations of their framework for addressing some of the potential benefits and disadvantages of RJVs. For example they point out that RJVs are sometimes thought to be harmful in that they reduce the amount of innovation – without recognising that in some cases this is precisely the source of benefit from an RJV.

Martin (1994) provides a good account of the conflicting views of the possible benefits that RJVs might confer. However this just confirms the views set out in Sections 1.3.1 and 1.3.2. There are many different market failures that RJVs might potentially address – and that in order to have a full appreciation of the role they play, one needs a framework that recognises these many failures and the way in which RJVs may or may not address them. The welfare model that Martin uses to evaluate RJVs is somewhat different from those referred to above, in that his model is of a pure tournament and allows RJVs to operate either one or two labs. However, as in the previous papers referred to there is little recognition of the full role that RJVs might play, nor of possible alternative arrangements in the non-cooperative equilibrium.

The paper that comes closest to using the framework set out in section 1.3.2 to evaluate RJVs is that by Katsoulacos and Ulph (1998c). However, while it draws on the general framework of Section 2, the welfare evaluation covers a special case. Thus there are just 2 firms; they produce a homogeneous product, and their research discoveries are perfect substitutes. Thus there is potential needless duplication of research, but there is no scope for research design co-ordination to exploit complementarities. The RJV can decide whether to operate 1 lab or two labs, and whether or not to share information. Firms can choose whether or not to license information in the non-cooperative equilibrium.

In terms of information-sharing, notice that if firms choose to fully share information in the RJV, they will also licence in the non-cooperative cooperative equilibrium. Turning to the R&D coordination decision notice that when full information-sharing takes place then the RJV underinvests in R&D because of the under-valuation effect, while in the non-cooperative equilibrium there is strategic overinvestment. This leads to the following conclusions:

- When full information-sharing takes place then the RJV typically generates higher welfare than the non-cooperative equilibrium whenever the RJV chooses to operate a single lab. However, the non-cooperative equilibrium is typically welfare superior to the RJV when the RJV chooses to run two labs. This is because the combination of the under-valuation effect and the strategic over-investment effect tend to cancel out leading to the non-cooperative equilibrium producing a level of R&D spending that is closer to the social optimum.

- When information is not shared then the RJV can often do much worse than the non-cooperative equilibrium. This is because the overinvestment in the non-cooperative equilibrium means that the possibility that just one firm discovers (and so information is not shared) happens much less frequently than in the RJV.

As indicated, an important reason why RJVs perform rather badly is that, because of the undervaluation effect, they under-invest in R&D. As pointed out in Sections 1 and 2, RJVs alone cannot address this problem. This suggests that a combination of RJV and subsidy might be capable of achieving the welfare optimum.

Indeed a recent paper by Hinloopen (1998) has gone further and suggested that R&D subsidies by themselves can achieve the optimum. However this idea is developed in the d'Aspremont and Jacquemin (1988) framework where, effectively, there is only one thing to determine – the amount of R&D per firm. It is clear that in this context a single instrument – an R&D subsidy - can achieve the full optimum whether firms act cooperatively or non-cooperatively.

However in the framework developed here an R&D subsidy by itself will not achieve the full optimum – since it cannot induce the information-sharing and research design co-ordination. Katsoulacos and Ulph (1998a) investigate the implications of using subsidised RJVs, whereby firms only get the R&D subsidy if they join an RJV. They show that while a subsidy might have the beneficial effect of ameliorating the under-valuation effect; it may have two harmful effects. It could induce firms to operate two labs where they might otherwise have operated one, and so increase needless duploication.. It may encourage firms to join an RJV to claim a subsidy where, in the non-cooperative equilibrium they were getting the information-sharing decisions and R&D decisions more or less right. We need more work on the use of a mixture of instruments.

The importance of these results is that they show that when a full account is taken of all the possible forms of behaviour in both the RJV and in the non-cooperative equilibrium, then it is far from obvious that RJVs are necessarily superior to non-cooperative methods of organising R&D.

In particular the analysis shows that it is important to recognise that RJVs may have anti-competitive effects. This is in contrast to much of the previous literature which either simply presupposes that RJVs are no less competitive than non-cooperative outcomes. This is because the literature focuses either on non-tournament models in which both firms discover, or, as in Martin (1994, 1998) on tournament models in which the RJV is assumed to fully share information.

Of course one does not want to overstate this result, and a fuller evaluation of RJVs can only be undertaken once a much more systematic exploration has been undertaken of the full range of possible cases covered by the framework set out in Section 2. I will return to this point in the next section.

An interesting complementary study is that by Klette, Moen and Griliches (1998). This reviews the few (recent) empirical studies that have been undertaken to try to quantify the benefits of government sponsored programmes. These programmes often take the form of sponsoring R&D consortia (RJVs). In the light of these studies the authors try to develop a framework for undertaking such evaluations in the future. A number of important points emerge from their study.

- RJVs form for a number of reasons. In some cases the elimination of duplication is the primary motive, while in others it is the exploitation of complementarities. Any framework for evaluation has to recognise these.
- Some of the most important difficulties in undertaking empirical evaluations arise in determining the extent of true spillovers – i.e. unintended, unrewarded information leakages – as distinct from information transfers that are rewarded either through private payments or internalised through cooperative agreements. In essence this recognises that information transfers can be voluntary in both the cooperative and the non-cooperative equilibrium.
- They emphasise the importance of carefully establishing the counter-factual – what would have happened to firms had they not joined a particular programme. This corresponds to the discussion above of the importance of properly characterising the non-cooperative equilibrium.
- They emphasise that this problem has particular resonance in the case where the gains from the RJV might involve the exploitation of complementarities – since there is then an important issue as to whether firms might be able to exploit these through various private arrangements.

The thrust of this study is thus very similar to that emerging from the theoretical discussion above.

1.3.2.5 Innovation and Competition

A long-standing interest in the theory of innovation is the link between R&D competition and market structure (see also Section 2 below). In general both of these are endogenous, with market structure both determining and being determined by the outcome of R&D competition.

In particular, we know from the literature on tournament races[7] that there are two incentives at work determining the relative amounts of R&D that firms do: there is the profit incentive (sometimes known as the displacement effect) and there is the competitive threat. The former is typically greater for the follower, the latter for the

[7] See Beath, Katsoualcos and Ulph (1995) for an overview of this literature.

incumbent. To the extent that the profit incentive is the dominant incentive the outcome of R&D competition will be creative destruction or action/reaction. To the extent that the competitive threat is the principal incentive, the outcome will tend to be persistent dominance – though this is not guaranteed.

Theory predicts that when innovations are drastic then the profit incentive is the principal determinant of R&D, whereas for non-drastic innovations, it is typically the competitive threat.

Of course the outcomes of R&D competition are not determined by incentives alone. At least two other effects are at work.

The first is what is known as the "deep-pocket effect". For a variety of reasons, internal sources of funds – retained earnings – may play an important role in funding R&D. Thus incumbent firms with higher levels of retained earnings may have an advantage over non-incumbents in funding R&D. Ceteris paribus this effect would tend to produce persistent dominance.

The second effect is what is known as "success-breeds-success" – see Dasgupta (1986). The idea here is that for a given level of R&D spending, firms that have recently been successful at innovation have a higher probability of success than unsuccessful firms. This may be because techniques that have been successful in making one discovery will also work in making related discoveries. Beath, Katsoulacos and Ulph (1995) provide a useful overview of this literature. As Dasgupta (1986) notes there is empirical support for this idea, though it does not figure very much in the theoretical literature where it is often assumed that firms have identical R&D cost functions. Again ceteris paribus this factor would tend to produce persistent dominance.

Kaiser and Licht (1998) propose a theoretical and empirical investigation in the relationship R&D cooperation and R&D intensity (R&D investment relative to sales), the empirical work relating to German firm data. Like Katsoulacos and Ulph, they use the framework of d´Aspremont and Jacquemin (1988) and extend it to product as well as process innovation. The paper develops a three-stage oligopoly game for R&D cooperation, R&D intensity and product market competition. The firms decide in the first stage whether or not to conduct R&D in cooperation with other firms, in the second stage they determine the amount of R&D investment, and they finally compete in a Cournot-oligopoly product market.

Three testable hypotheses are derived from the theoretical model: (i) intra-industry knowledge spillovers make cooperative R&D more profitable, (ii) research joint ventures (RJV) are more likely to be formed if products are not close substitutes, (iii) cooperative R&D leads to higher effective R&D (i.e. R&D investment plus R&D spillovers). Yet the effect of R&D cooperation on the R&D spending of RJV members is unclear: on the one hand efficiency gains may allow to economize on R&D spending, on the other hand RJVs reduce negative externalities and may thus stimulate R&D investment.

These hypotheses are tested using waves 1 to 5 of the Mannheim Innovation Panel (MIP), and especially waves 1 and 5 which contain information on R&D within and without RJVs, and also allow to control for market structure, export market competition, diversification and various obstacles to R&D and innovation, such as financial restrictions, for example. The authors construct a new measure for inter- and intra-industry spillovers and use nested and multinomial logit models to study the determinants of the sequential decisions to conduct R&D, cooperate, and choose RJV partners. They use tobit models to estimate the effects of vertical and horizontal cooperation and of spillovers on R&D intensity.

They do not find large effects of R&D cooperation on R&D intensity. Neither do they find significant effects of horizontal spillovers on the propensity to cooperate with a competitor. However, vertical spillovers do have a strong impact on the propensity to form RJVs, suggesting that complementarities are the driving force behind RJV formation. Estimates also show that more diversified firms, and firms in more concentrated markets, spend more on R&D.

Besides technical improvements on the econometrics side, Kaiser and Licht suggest two ways in which there work could be improved. Firstly, vertical relationships should be modeled more explicitly than through the level of substitutability of the products. Secondly, the data set used contains a number of possibilities to model the ability of a firm to assimilate the know-how developed elsewhere, and this opens the possibility for refinements of the empirical approach.

1.3.3 Directions for Further Research

While the work undertaken in this TSER project has made important developments, it has equally identified many directions for further work. On the theoretical front we need to develop the framework sketched out in Section 1.3.2. There are a number of principal developments.

A) We need to understand much more fully the scope for R&D co-ordination through non-cooperative mechanisms.

B) More generally the literature has focused rather heavily on co-operation and complementarities between very similar firms – both being active in research and in the product market. We need to examine other types of complementarities and other types of institutions – e.g. links between universities and firms.

C) We need to extend the welfare evaluation to encompass the full range of possibilities allowed for in the model.

D) We need to couple the understanding of how firms behave in both the co-operative and non-co-operative equilibrium with an analysis of RJV membership. The question we really need to address is whether we should let private incentives alone determine which firms form an RJV, or whether we think that the strongest private incentives may not coincide with the highest social gains from RJV formation.

E) It would be a useful exercise to try to use the theoretical framework to more carefully guide the empirical gains from RJV formation.

These extensions all operate more or less within the existing model.

However there are two further areas for research which will require the development of significantly new models of RJVs.

I) As developed so far the theory treats R&D done by firms as a homogeneous entity – so all R&D is undertaken either independently or inside an RJV. What the existing theory has failed to properly grasp is the idea that firms are typically involved in a portfolio of research projects, and the issue they face is which projects they do alone, and which they do collaboratively.

II) Much of the literature focuses on the performance of RJVs once firms are already in an RJV. The smaller literature on RJV membership assumes that firms are fully informed about the firms with which they may or may not form a partnership. While it may be reasonable to think of firms in the same industry being fairly fully informed about each other, it is less clear that this assumption is valid when thinking about co-ordinating R&D across very different industries. Clearly a significant part of policy towards science parks, industrial districts is aimed at addressing these informational issues. I think the theory needs to take this more seriously.

1.3.4 Conclusions

As indicated in the text it is somewhat premature to draw firm policy conclusions from the work undertaken here.

Nevertheless some important points have emerged which should be taken into account in policy thinking.

- The existing analytical framework for thinking about RJVs has under-stated the potential benefits of RJVs in correcting market failures, by focusing rather heavily on the role of RJVs in coordinating R&D, and ignoring their role in research design co-ordination and in information sharing.

- The existing literature has also failed to deal adequately with the question of how far some of these benefits can be handled through private contractual means. There is scope for considerably more work on this – particularly in connection with research design co-ordination. Preliminary work in the context where research paths are substitutes and so the only research design issue is the number of labs to operate, suggests that non-cooperative outcomes can welfare dominate RJVs in situations where RJVs choose to operate independent labs.

- We have also seen that RJVs may not always fully share information. Whenever they fail to fully share information this is for anti-competitive reasons. In this context non-cooperative arrangements may be welfare superior. This is not because they are any better at information-sharing, but because they are less prone to under-investment and so situations where only one firm discovers are less likely to arise. This points up the importance of the interaction between the information-sharing decision and the R&D decision.

- By themselves RJVs will not solve all the market failures associated with R&D. In particular they do not address the under-investment effect. This is an important part of the reason why, in the results reported above, RJVs may be welfare dominated by non-cooperative arrangements. This suggests that more attention needs to be paid to combinations of policy instruments like subsidies and RJVs. However, as indicated, subsidised RJVs are prone to other problems as well, so the correct solution is not just a simply subsidy to RJVs.

1.4 Other Contributions over technology policy

Hall and Ham (1999) consider yet another instrument of technological policy: the patents system. Following the strengthening of US patents rights in the early 80s, it appears that the propensity of semiconductor firms to patent has considerably risen while at the same time firms in the semiconductor industry appear not to rely markedly on patent protection. The paper explores this apparent paradox by differentiating among types of semiconductor firms and analyzing their patenting activities since 1980.

The study consists of two complementary research components, interviews of patent managers, and drawing on the insights gained from the interviews an econometric of the patenting strategies of an unbalanced panel of 72 semiconductor firms over the period 1980-1994. This allows precise estimation of how the propensity of these firms to patent changes over time, and allows also to examine whether the changes are driven by changes in the mix of firms in the industry over time. A drawback is that large „systems“ manufacturers have to be excluded from the analysis because of the lack of reliable R&D data targeted at semi-conductor technologies.

The results demonstrate that US semiconductor firms are patenting aggressively, and that new entrants patent even more aggressively than pre-1982 entrants, ceteris paribus. The interviews show an increased reliance on patents by entrants and that strategic behaviour plays an important role. They suggest that the surge in patents relative to R&D spending may reflect important changes in the way these firms manage their patent portfolios.

Finally *Pavitt (1996)* expresses scepticism and dissatisfaction with the way the economics profession has handled the needs of the authorities in charge of technology policy so far. While he acknowledges that over the past 30 years related improvements in theory, statistical data and empirical analysis have strengthened the basis for science and technology policy by stressing the importance of technical change for economic performance, he considers that two important features of R&D activities in the OECD countries are still not adequately addressed in mainstream economics. One is the justification for public funding for basic research (but see David and Hall, 1999), and the other concerns the persistent international differences in R&D investment. An additional major gap is connected with the development of software technology.

Pavitt sees dangers of diminishing returns to the usefulness of economic research relying on established theory and statistical sources. Alternative propositions deserving serious consideration are in his opinion:

(i) the economic usefulness of basic research is the provision of mainly tacit skills rather than codified and applicable information;
(ii) in developing and exploiting technological opportunities, institutional competencies are as important as the incentive structures that they face;
(iii) software technology developed in traditional service sectors may now be a more important locus of technical change than software technology developed in high-tech manufacturing.

Pavitt concludes that if economic analysis is to continue to inform science and technology policy-making, it must pay greater attention to the empirical evidence and collect new statistics in addition to exploiting those available.

2. Indirect policies toward innovation: Product market Competition and Systems of Finance

Introduction

Although discussion over policies towards innovation tend to focus on th direct technology policies discussed above, indirect policies which affect the environment faced by organisations may be of far greater importance. This is especially so when one moves away from the early stages of the knowledge production function (R&D) and travels further down the product life cycle to the innovation/patenting stage and then to the diffusion of the technology outside the firm which first innovated. Other types of innovative behaviour such as managerial innovations (e.g Just In Time production) which are not considered as `technologies' by traditional policies may be particularly influenced by the market environment. We consider two types of features of the markets in which firms operate in some detail: product markets and financial markets. European governments have a major role in regulating both of these markets. In section 4 below we consider in more detail the labour market angle. In all these discussions one must be aware of the fact that markets influence and are influenced by innovation. The simultaneous determination of innovation and market structure has been a major area of concern for Network research.

2.1 Product Market Competition

The impact of product market structure on innovation has been a central theme of the economics of innovation since at least Schumpeter. There have been several contributions of the TSER Network to this debate. The traditional view that monopoly in the product market is needed to foster innovation (dynamic efficiency), even if it comes at the expense of short-run static inefficiency (monopoly deadweight loss). This view has come under serious challenge in recent years. Managers in monopolistic companies may become lazy and cease to put efforts into adopting and developing best practice.

Several studies have tackled the issue of innovation and market structure. In most datasets higher market share tends to be associated with more innovation. In the work of Blundell, Griffith and Van Reenen (1999) it is found that in Britain higher market share is associated with a greater probability of commercialising significant innovations. This is robust to the development of new econometric techniques to deal with reverse causality and individual fixed effects in count data models. However, what is good for the firm is not good for the industry. As competition decreases all firms in an industry are less likely to innovate as `Darwinian` forces become weaker. This result is confirmed in studies of French firms by Crepon and Duguet (1997a,b)

We expect innovations to enhance the market value of firms, but does is the effect different for different types of firms? Two comparative papers have been produced attempting to explain why high market share firms innovate more. For the UK Blundell, Griffith and Van Reenen (1999) argue that high market share firms receive greater rewards in the stock market because they have strategic incentives to blockade entry. Hall and Vopel (1997) have compiled a US database to examine the same issue and have found weaker, but broadly supportive results.

Bresnahan and Gambardella (1998) began a new project on the relationships between the growth of general-purpose technologies (GPTs -- i.e. computers, chemicals) and market structure in high-tech industry. The project has developed a model of the division of labor between an upstream sector producing the GPT and the downstream sectors using the GPT. Empirically some support for this theory has been uncovered by examining the evolution of industry structure in the chemical industry in the US, Europe and Japan by Arora and Gambardella (1997). The rise of upstream capital goods industries, the SEFs (specialised engineering firms) appeared particularly important as a source of technologies and know how for chemical and pharmaceutical plant. This stimulated innovation even though they were generally not embodied. This model has implications for emerging industries, such as software.

The paper by Economides (1998) addresses a policy problem that is somehow outside technology policy stricto sensu, but it provides a precise example of the kind of difficulty met by industrial policy at large, given the amount of information that government agencies should gather and process properly in order to avoid mistakes with far reaching consequences, a problem that was evoked in the papers of Dagenais et al., David and Hall, Klette et al., Klette and Møen.

The paper analyzes the effects of the implementation of the Telecommunications Act of 1996 on US telecommunication markets. The Act attempts to move all telecommunications markets towards competition, but Economides expresses concerns as to its actual implementation, because more than two years after its passage, there is very little entry and competition in local exchange markets. Moreover, in response to the apparent failure of this implementation there has been a wave of mergers in the telecommunications industry.

The primary example of failure of such deregulation attempts is New Zealand, where the telecommunications market was deregulated starting in 1987. The incumbent state-owned monopoly was privatized in 1990, and despite complete deregulation still dominates all telecommunications markets in New Zealand, acting as a practically unrestrained monopolist in its dealings with competitors. Other parts of the world are generally lagging behind in telecommunications reform but are also swept by the fast technical change in the sector.

The intent of the 1996 Act in the US was to promote competition and the public interest. Economides considers that it will be a significant failure of the US political, legal and regulatory systems if the interests of entrenched monopolists rather the public interest dictate the future of the US telecommunications sector, but states that if the present trend continues the intent of the Act will not become reality.

2.2. Financial Markets

Credit markets affect the ability of firms to raise finance for investments in general and innovation in particular. R&D may be particularly costly to finance from external sources due to its high risk and rewards, its long-term nature and the dangers of revealing sensitive information to rivals. Network researches have focused on three main questions concerning the importance of corporate finance for investment in R&D:

- Does internal finance matter for investment in R&D and physical capital?
- What can we learn from international comparative studies of the role of internal finance, banks and other financial institutions?
- Does the stock market value firms' patenting activity and investment in R&D (see section 3.2)?

The findings are summarized below.

Does internal finance matter for investment in R&D and physical capital? A number of studies by network researchers have addressed this question using detailed firm level, longitudinal data. Typically, the approach has started with well-established investment models and the focus of the analysis has been on the role of the firms' cash-flow. Harhoff (1998) follows this approach and he considers differences between investment in R&D and physical capital, and also differences between large and small firms. The analysis is carried out within three different models of investment: a structural Euler-equation and two non-structural models (the accelerator model and the error-correction model). He finds that a firm's cash flow is a significant explanatory variable for physical investment, but less so for R&D. It is, however, not clear whether this finding suggest that internal finance matters for investment in physical capital since the cash flow variable also may signal high expected returns on the investment and not only available finance. It is perhaps somewhat surprising that the R&D investment does not co-vary much with differences in cash flow, since one would expect that access to internal finance matters more for investment in R&D, given the informational asymmetries and lack of collateral for R&D investment. Harhoff also examines in some detail the performance of the structural investment model, and finds that it works well for large firms, but not for small firms.

The role of internal finance and different sources of external finance is studied in a somewhat different way by Harhoff and Korting (1997). They examine the role of lending relationships in determining the costs and availability of external funds, on the basis of data from a recent survey of 1400 small and medium-sized firms. In a descriptive analysis, they explore borrowing patterns and the concentration of borrowing from financing institutions. The authors use a regression analysis to identify the determinants of borrowing costs and of the availability of external funds. Using data on loan volumes, interest rates and collateral requirements, they find that relationship variables may have some bearing on the price of external funds, but more so on its availability. The interest rate on lines of credit increases strongly when firms enter a situation of financial distress, and credit availability deteriorates.

A third related study is Winter (1996), which investigates the influence of a firm's financial status on its plant-level investment and exit decisions. Firm-level financial status turns out to be significant for plant-level investment and exit decisions; in particular, the financial status variable improves the ability to predict plant closures, relative to standard specifications derived e.g. from learning models.

Kruniger (1997) considers the same Euler equation model of investment as Harhoff (1998), and he also compares its performance for physical and R&D investment. Kruniger explores whether the poor performance of this model can be explained by capital market imperfections.

International comparative studies of investment and corporate finance. Different European countries have very different institutional linkages between businesses on the one hand and banks and other financial institutions on the other. Models of investment in physical and intangible capital have been estimated by network researchers in order to compare across nations the impact of different financial regimes on investment incentives. Interest in comparative studies stems from the considerable differences between financial systems in different countries in terms of sources of investment finance, company ownership structures, the market for corporate control, and the relative importance of different financial markets and institutions.

The study by Bond et al. (1997a) investigates whether the impact of financing constraints on company investment spending differs between firms in Belgium, France, Germany and the UK. Many previous studies have found that investment spending displays "excess sensitivity to cash flow" for individual countries, and concluded that this evidence is consistent with the presence of financing constraints, but very few previous studies have presented comparative evidence. It is, however, widely perceived that there are important differences between the UK "market-based" system and the German "bank-based" system. In particular, it has been suggested that the arms-length relation between firms and suppliers of finance that tends to characterize the market-oriented system may be less effective at dealing with problems of asymmetric information and monitoring. If so, it is possible that financing constraints on investment would be more severe in the UK than in the continental European countries. The analysis by Bond et al. is based on company panel data sets for manufacturing firms in Belgium, France, Germany and the UK, covering the period 1978-89. These data sets are used to estimate a range of empirical investment equations, and to investigate the role played by financial factors in each country. A robust finding is that cash flow or profits terms do appear to be both statistically and quantitatively more significant in the UK than in the other three countries. This evidence is consistent with the suggestion that financial constraints on company investment spending may be relatively severe in the more market-oriented UK financial system.

The study just described focuses on investment in physical capital only, while the studies by Bond et al. (1997b) and Hall et al. (1998) incorporate investments also in R&D into their analysis. Bond et al. (1997b) consider empirical models of investment in R&D and physical capital for the United Kingdom and Germany, while Hall et al. (1998) present a comparative study between France, Japan and the US. Using firm level panels of R&D performing firms in United Kingdom and Germany, Bond et al. estimate identically specified models for the late 1980s and early 1990s in each country separately. In the preferred error-correction models and Euler equations there is no evidence that British companies are more financially constrained than their German counterparts. This is due to the fact that cash flow sensitivity is a feature only of non-R&D performing firms. They demonstrate this by examining a larger sample of 762 UK firms (R&D and non-R&D), and conclude that firms likely to encounter serious financial constraints do not seem to engage in R&D. Finally, smaller firms do appear to be more sensitive to cash flow, but this difference is, if anything, more marked in Germany than in the UK.

The analysis by Hall et al. (1998) is also based on firm level data from the three countries they consider, but the econometric framework they apply is somewhat different. They find that both investment in physical capital and R&D is more sensitive to changes in sales and cash flow in the United States than in France and Japan. They notice that their finding is consistent with the view that firms in France and Japan face softer budget constraints than in United States, but they also emphasize the preliminary nature of their conclusions.

Da Rin and Hellmann (1997) analyze the interaction between the financial system and industry growth, but with a more theoretical and historical approach compared to the other studies discussed above. They focus on `the role of banks as catalysts for industrialization'. When there are limits to contracting, and complementarities exist among investments of different firms, they show how coordination costs will emerge endogenously and their analysis reveal how banks can acts as catalysts provided that the banks are sufficiently large to mobilize a critical mass of firms, and provided the banks possess sufficient market power to make profits from coordination. Da Rin and Hellmann also show that the costs of coordination depend critically on the contracting instruments available to banks. In particular, allowing banks to hold equity reduces and sometimes eliminates the cost of coordination. Da Rin and Hellmann use the results to interpret the patterns of early industrialization of Belgium, Germany, and Italy in the late 19^{th} century. These countries experienced quick industrialization with the active involvement of large and powerful universal banks, which engaged in both debt and equity finance.

3. The effects of innovation on company performance

Introduction

One of the central tenets of the "new economics" of growth is that innovation is critical for productivity increases and growth. Yet the micro-foundations of this argument are underdeveloped. An important task is therefore to examine the way in which the productivity of companies or industries is affected by R&D, patents, innovation and other related factors.

This network has developed a wide range of studies examining the relationships between productivity, technology, innovation, and economic performance. We can classify these studies in four groups:

- Studies on the relationships between aggregate productivity (typically at the level of countries or industries) and technological innovation or R&D
- Studies on the relationships between firm-level productivity, investment, R&D, and other variables
- Studies focussing on the so-called "computer productivity paradox", notably the relationships between computer diffusion and productivity
- Other miscellaneous studies linking variables like innovation, R&D, patents, productivity to several institutional and economic factors.

We shall review these in turn.

3.1 Aggregate productivity studies

In the 1998 Urbino conference of this network Zvi Griliches presented a preliminary draft of his Kuznets Memorial Lectures. Particularly, he focused on section 6 of his Lectures on R&D and the productivity slowdown (Griliches, 1998).

Griliches examined the existing evidence on the productivity slowdown, and discussed various explanations. He noted that there are three major explanations. The first one is that the upturn in productivity growth is in fact around the corner, but it takes time for the big changes produced by the new computer and biotechnology revolutions to work themselves through the system. The second explanation is that the effects of these technologies are long-term. Hence, it takes time before we can see them in the statistics. The third explanation is that we simply do not know how to measure them. Griliches argued that measurement errors are probably not the whole thing, but nonetheless he emphasized that we do have serious measurement challenges ahead of us – e.g. how to account for productivity growth in services. He is also less convinced by the other two explanations. After all, he suggested, the computer revolution has been around for 20-30 years now.

In the Urbino conference this spurred a lively debate. Particularly, Paul David, whose "Computer and Dynamo" paper (David, 1990) had argued in favour of the first explanation, did not disagree with the need for better measurement. However, he noted that the problem is not how long does it take for the new technologies to induce productivity growth, but whether economies and societies more generally have been able to introduce complementary organizational revolutions. These are crucial in order to relax some of the constraints to productivity growth associated with computers and computer networks (e.g. telework).

The network produced a few other papers about aggregate productivity effects. Griffith, Redding and Van Reenen (1998) examined empirically the determinants of TFP growth in two-digit OECD industries in eleven OECD countries since 1970. They investigated the roles of R&D, education and trade in stimulating productivity growth directly and indirectly through technology transfer from the USA. They found that R&D is important in technology transfer, especially for smaller countries. For larger countries (Britain, France, Germany and Japan), R&D has a more direct effect through generating innovations. Moreover, they found that for these countries education facilitates productivity convergence to the USA.

In a related paper, Carlin, Glyn and Van Reenen (1998) examined the determinants of export market shares in a long panel of twelve manufacturing industries across fourteen OECD countries. They found that both relative labour costs and embodied technology are important, but the residual country-specific trends appear to be linked to "deep" structural features of the economies such as human capital investment and national ownership patterns.

The network also developed a few papers showing that investment or productivity growth are related to specific features of industry structure. Particularly, they can be associated with vertical specialization and division of labour and the role of an upstream sector of technology producers or knowledge-intensive business firms or industries.

Bresnahan and Gambardella (1998) developed a model that shows that the rise of a vertically specialized sector producing general-purpose technologies (GPT) is associated with the number of potentially different application of the GPT in an economy. By contrast, an economy featuring users of larger size will develop dedicated technologies produced in-house by the users themselves. Implicit in their analysis is that the expansion of the GPT sector can lead to greater investments by the downstream industries. Arora, Fosfuri and Gambardella (1998) empirically tested a similar proposition. Using data on the supply of chemical process engineering services by specialized chemical engineering firms, they showed that the expansion of the upstream sector leads to greater downstream investments in chemical plants.

The importance of division of labour is confirmed by Katsoulacos and Tsounis (1998) who examined the effects of information intensive business services (BS) on productivity growth in the Greek economy. Among other things, they found that: a) there is a strong association between the co-evolution of BS with communication services in the Greek economy; b) there is a correlation of the rates of growth of BS with the rates of growth of communication services; c) BS play an important role in explaining the rates of growth of TFP in the Greek economy; d) BS can be thought as a factor of production since they are important in explaining the variance of value-added in Greece, along with capital and labour.

One interesting implication of these studies is that what we normally label technological spillovers can in fact be produced by mechanisms based on the intermediation of an upstream industry. Put differently, spillovers may not just be "in the air", but they require well defined institutions to work. (See also Zucker et al., 1998). Policy implications would follow quite naturally.

3.2 Firm-level patents, investments, productivity and R&D

One important set of studies developed by this network focused on the relationships between variables like patents, R&D, investment and various measures of economic performance (productivity or else) using firm-level data. For instance, Hall and Mairesse (1998) have continued their research examining the progress in econometric modelling of investment at the micro-level. Their work compares the results based on the econometric techniques and investment models for panel data employed by Eisner and Oudiz 20 years ago to the econometric techniques and investment models representing at least a part of the state-of-the art today.

Hall, Jaffe and Trajtenberg (1998) continued the tradition of looking at the effects of patents and innovation variables on the market valuation of firms. Particularly, in this paper they introduce a citation-weighted measure of patent stocks to account for the knowledge asset of firms, and explore the impact of this variable on the market value of a comprehensive set of US manufacturing companies. This is an important innovation with respect to previous studies which use R&D or patent counts in market value equations. But R&D is an input, and patent counts do not account for the fact that the importance of patents as a measure of innovation is very skewed. Patent citations can correct at least in part this problem. They find that their measure of knowledge asset does explain part of the market value of firms, and it contains information beyond the usual R&D or patent measures.

The network also organized a conference (Paris 18-19, 1998) focused on empirical analyses of Innovation Survey Data, and particularly of the Community Innovation Surveys (CIS). Most studies in this conference dealt with one or two of the following issues: the determinants of innovation; the propensity to patent an invention; the links between innovation (and spillovers) and productivity growth. The conference also offered the opportunity to clarify two aspects about the use of CIS. First, there is a need to adopt more homogeneous frameworks across studies to get comparable conclusions across countries. Second, CIS provides information at a given point in time. This means that the intrinsic dynamic features of technological progress are missing.

3.3. Computers and Productivity

As hinted by Griliches in his Kuznet Lecture, and noted by Robert Solow's famous paradox that "one can see computers everywhere except in the productivity figures", the question of the relationships between information technology and productivity growth has become a crucial one. This network developed several studies on this issue, and organized a joint NBER-CREST conference on this topic (Nice, June 22-23, 1998).

One of the reasons why computers may not show up in the productivity figures may have been the over-emphasis on macro-economic aggregates. Examining micro data many studies have started to uncover important productivity effects. For example, Greenan and Mairesse (1998) made a first attempt to explore the relationship between computer use and productivity in French manufacturing and services industries. They matched information on computer utilization in the work place collected at the employee level in the years 1987, 1991 and 1993, with information on firm productivity, capital intensity and average wage available at the firm level. They found coherent and persuasive evidence that the computer impacts on productivity are positive and that the returns to the firm should at least be in the same range as the returns to the other types of capital. They also made the general point that econometric studies of the firm can be effectively and substantially enriched by using information collected from workers.

Licht and Moch (1997) developed a similar study on the use of information technology (IT) in Germany. They advanced two explanations for the computer productivity paradox, using two newly available datasets for the German service sector. They first showed that investment in IT has a stronger effect on the quality of services than on the productivity of the IT-using firm. This suggests that mismeasurement of the quality of new products and processes is one important reason for the inability to uncover the productivity effect of IT. Second, they showed that especially PCs (as opposed to mainframes) and the most recent generation of IT are a source of productivity growth. Thus, the type of IT that a firm uses is more important for productivity growth than its quantity. This also suggests that in order to realize the benefits from IT investment entirely, firms have to undergo a large restructuring of their business functions. As a conclusion, Licht and Moch (1997) seem to indicate that Griliches' emphasis on mismeasurement and David's suggestion of the lack of complementary re-organizations are both potential explanations of the problem.[8]

The relationships between computers and productivity have also been the subject of an extensive debate at the NBER-CREST conference in Nice, where several economists were asked to discuss their past research and experience on this topic. Among others, one issue that was raised was that even if new technologies pose important problems of statistical measurement, the origin of the productivity paradox is likely to be mainly an economic one. While initial investments in computers were primarily directed at automation of repetitive, labor intensive tasks, information and communication technology (ICT) investments today are disproportionately directed at enabling new ways of delivering value to customers though new ways of organizing work internally as well as new approaches to interacting with customers and suppliers.

Brynjolfsson (1998) examined a variety of empirical evidence to argue that ICT improve productivity by enabling complementarity organizational innovations. Considering numerous case studies, exploring large sample statistical evidence and examining studies

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[8] On the use of measures related to computers or IT drawn from the CIS innovation surveys, to explain productivity or the research intensity of firms, see also Harhoff (1997) and Crèpon et al. (1998).

that provide direct measurement of organizational complements, he concluded that, while there are strengths and weaknesses in all these individual studies, they paint collectively a very compelling picture where organizational complements play a critical role in enhancing ICT productivity.

The conference also debated other aspects about ICT, and particularly their effects on employment and wages. Chennells and Van Reenen (1998) surveyed the evidence on the effects of technical change on skills, wages and employment by examining the micro-econometric evidence at the industry, firm, plant and individual levels. They showed that there is a strong effect of technology on skills in the cross section which appears reasonably robust to various econometric problems. They also concluded that there is an effect on wages in the cross section, which is not robust, however, to endogeneity and fixed effects, and that there is not a clear relationship between employment growth and technology.

3.4 Other studies on productivity and research

The network developed various studies linking innovation, R&D and various measures of performance, to other economic and institutional conditions. These studies show that the relationships between innovation and productivity can be linked to several factors and characteristics of an economy.

In the Madrid workshop Bond presented a progress report on a joint work with Meghir and Windmeijer on the investment and productivity effects of takeover threats (Bond, Meghir and Windmeijer, 1998). The issue is important because especially in recent years takeovers and takeover threats have influenced various aspects of corporate performance and industry structure. Particularly, it is important to understand whether they reduce the incentives of companies to undertake long-term plans, and hence restrain company growth, investment and productivity. Bond, Meghir and Windmeijer (1998) examined the effects of takeover threats on investment and productivity first in a theoretical model and then in a large empirical study of UK manufacturing firms during 1975-1992. Their preliminary empirical results suggest that the threat of takeover has no effect on productivity, but has a negative effect on investments.

Another interesting set of studies initiated by the researchers in this network focused on the productivity of public research institutions, as well as the effects of public R&D grants or subsidies on private firm R&D investments and productivity. This is an important stream of research. In fact, while economists have developed a great deal of theoretical and empirical work on private R&D, we know very little (both theoretically and empirically) about the productivity of public research institutions (e.g. universities), and about the effects of public R&D grants and subsidies. This is a rather serious shortcoming of economic analysis if we consider that in the advanced economies between 40% to 60% of total R&D expenditures are publicly funded.

The productivity of public research institutions, and particularly of universities, has recently attracted the attention of some economists (e.g. Adams and Griliches, 1998). Within this network, Arora, David and Gambardella (1998) developed a structural model to estimate the production function of scientific publications using a data set on about 800 research groups that applied to a 1989-93 public research programme in biotechnology in Italy. The average elasticity of research output (quality-adjusted publications) with respect to the research budget is estimated to be 0.6; but, for a small fraction of groups led by highly prestigious scientists this elasticity approaches 1. These estimates imply that a more unequal distribution of research funds would increase research output in the short-run.

Arora and Gambardella (1998) used data on 1473 applications by US economists to NSF during 1985-1990, 414 of which were awarded a research grant. They ask whether the NSF grant was a critical resource for later publications or whether the NSF grant crowded out other resources and the publications would have been produced in any case. They found that this effect of NSF funding seems to be more pronounced at earlier stages of the career of economists.

3.5 Stock market values and investment in R&D and physical capital

Several studies by network researchers, in particular Bronwyn Hall and her co-workers, have focused on how the stock market values the knowledge assets of publicly traded firms. The analysis typically relates changes in the market value of stocks for various firms to their innovative activities, including R&D spending and patenting, while controlling for investment in physical capital and other activities. Most of the research has used data for the United States and the United Kingdom, but the research can be useful to validate various measure of innovation for use also for other countries. The research strongly suggest that R&D investments are valued by financial markets, but the relationship between R&D spending and changes in stock market values was strongest in the early 1980s and seems to have been steadily declining until the mid 1990s. Patents are informative about stock market values, and more so when patent counts are constructed with weights reflecting the patents' citations. The idea that more cited patents are more important and therefore more valuable is thereby confirmed by the econometric results. In her recent[9] survey 1, Hall concludes that the market value of the modern manufacturing corporation is strongly related to its knowledge assets, and that patent measures contain information about this value above and beyond that of the usual R&D measure.

Bond et al. (1997c) also focuses on the role of the stock market, but from a different perspective. They examine to what extent investment and productivity are affected by takeover threats, first in a theoretical model and then in a large empirical study of UK manufacturing firms for the period 1975 to 1992. Their preliminary empirical results suggest that the threat of takeover has no effect on productivity, but a negative effect on investment.

[9] See Hall (1998).

The Blundell et al (1999) study also examined this issue. They found a significant return in the stock market price of innovations and patents. Furthermore they found this pay-off was particularly large for firms with high market shares. Hall and Vopel found similar, but weaker results for their sample of US firms examining R&D as measure of innovation. One interpretation of this result is that high market share firms have a stronger incentive to pre-empt entry by innovating (since their market return is higher).

4. The effects of innovation on the labour market

Introduction

There is a growing concern in advanced countries that the position of less skilled workers has deteriorated, either through their ability to secure jobs and/or their ability to earn a decent wage. Some have linked this decline to modern computing technologies. This section surveys the evidence on the effects of technical change on employment (in total and by skill group) by examining the micro-econometric evidence coming out of activities associated with the TSER Network R&D, Innovation and Productivity. Most studies which use direct measures of technology rather than associating technology with a residual time trend. We first point to three basic methodological problems relating to endogeneity, fixed effects and measurement. To characterise our overview very crudely:

(i) There is a significant effect of technology on skills which appears reasonably robust to measurement issues and fixed effects

(ii) Product innovations appear to raise firm employment growth, but there is no clear evidence of a robust effect (either positive or negative) of process innovations or R&D on jobs.

(iii) There is a robust positive correlation of measures of technology with wages, but this relationship s not causal.

(iv) The problems of endogeneity, linking micro evidence to macro events and the theoretical mechanisms underlying the econometric relationships are still poorly understood.

The effect of the development of tools on the evolution of human activity has long been a principal concern for students of social behaviour. Marx viewed the development of the productive means as the key force in his theory of history. The identity of the dominant class was determined by their ability to best muster the development of technology. In neo-classical economics, technological progress is also regarded as the driving force behind economic growth, a notion that is reinforced by endogenous growth theory. Given its role in economic growth, technical progress leads to higher standards of living on average. But how are the benefits of technical progress distributed across society? Who gets a ‘share of the plunder’?

In the past, many commentators have worried that technology could lead to a ‘de-skilling’ of workers. The pin factory symbolises the destruction of skilled artisans and their replacement by workers who were required only to perform the most menial repetitive tasks (Braverman, 1973; Edwards, 1979). More recently, however, debates by economists have focused on whether modern technologies are generally biased towards more skilled workers. The participants are particularly vocal in the debate over the causes of the increasing inequality of wages and employment between the skilled and the unskilled. Although closely related to it, the existence of skill-biased technical change does not provide the explanation for recent changes in the wage and employment structure. To demonstrate that technology is biased towards more skilled labour is not sufficient (and some would argue not even necessary - see Leamer, 1994) to establish technical change as the dominant explanation for increases in inequality. We also have to consider the supply of skills, for example.

The plan of the section is as follows…...

4.1. Theoretical Guide: skill bias of technical change

We start with a general framework based within the context of a neo-classical model of production. For simplicity we consider the case of three variable factors (skilled labour, unskilled labour and materials) and two quasi-fixed factor (physical capital, denoted by *K*, and "technological capital", denoted by *R*). Consider a quasi-fixed translog cost function:

$$\ln C = \alpha_0 + \sum_h \sum_{i=B,W,M} \alpha_{hi} D_h \ln w_i + \sum_{i=B,W,M} \sum_{j=B,W,M} \beta_{ij} \ln w_i \ln w_j + \beta_q \ln q +$$
$$\sum_{j=B,W,M} \beta_{iq} \ln w_i \ln q + \beta_K \ln K + \sum_{j=B,W,M} \beta_{iK} \ln w_i \ln K + \beta_R \ln R + \sum_{j=B,W,M} \beta_{iR} \ln w_i \ln R$$

(1)

where C are the variable costs (`unskilled' blue-collar labour - *B*, `skilled' white collar labour - *W* and materials - *M*). The α parameters reflect own price effects. We allow these to differ in different 'units', indexed by D_h. (D = 1 if in unit *h*, etc). For example, we might allow the own price effects to vary in different industries or even different firms (fixed effects). The β parameters measure the effect on total cost of the other factor prices (*w*), the log of plant output (*q*), technological capital (*R*) and the fixed capital stock (*K*).

Since cost is homogeneous of degree one in prices, there are a series of restrictions as follows:

$$\sum_{j=B,W,M} \beta_{ij} = \sum_{i=B,W,M} \beta_{ij} = \sum_{i=B,W,M} \sum_{j=B,W,M} \beta_{ij} = \sum_{i=B,W,M} \beta_{iR} = \sum_{i=B,W,M} \beta_{iK}$$

(2)

These allow equation (1) to be normalised by one of the factors. Taking the materials price (w_M) as the unit of normalisation, we obtain a normalised translog cost function where costs (relative to materials price) are a function of the relative prices, output, capital, technology and their interactions. From Shephard's lemma, the variable cost share S_i for input *i* is given as:

Unskilled Workers

$$S_B = \alpha_B + \sum_{i=B,W} \beta_B \ln(w_i / w_m) + \beta_{Bq} \ln q + \beta_{BK} \ln K + \beta_{BR} \ln R$$

(3a)

Skilled Workers

$$S_W = \alpha_W + \sum_{i=B,W} \beta_W \ln(w_i / w_m) + \beta_{Wq} \ln q + \beta_{WK} \ln K + \beta_{WR} \ln R$$
(3b)

Note that the materials equation has been dropped because the cost shares sum to unity.

We can test for homotheticity of the structure of production (i.e. that the cost shares are independent of the levels of output and the quasi-fixed factors) by imposing the following restrictions:

$$\beta_{iq} = -(\beta_{iR} + \beta_{iK}), \text{ where } i = B, W$$

If these can be accepted, the cost share equations simplify to:

Unskilled Workers

$$S_B = \alpha_B + \sum_{i=B,W} \beta_B \ln(w_i / w_m) + \beta_{BK} \ln(K / q) + \beta_{BR} \ln(R / q)$$
(4a)

Skilled Workers

$$S_W = \alpha_W + \sum_{i=B,W} \beta_W \ln(w_i / w_m) + \beta_{WK} \ln(K / q) + \beta_{WR} \ln(R / q)$$
(4b)

The elasticities of substitution and complementarity can now be calculated. In terms of the technology variable, if the coefficients $\beta_{WR} > 0$ and $\beta_{BR} > 0$, we would say that technology is labour-biased. If $\beta_{WR} > 0$ and $\beta_{BR} < 0$, then technology is clearly skill biased.

The formulation is often further simplified using value added (*VA*) rather than output. In this case the dependent variable is the share of skilled labour in the wage bill, and the factor demand equation is simply:

Skilled Workers

$$S_W = \alpha_W + \beta_W \ln(w_W / w_B) + \beta_{WK} \ln(K / VA) + \beta_{WR} \ln(R / VA)$$
(5)

Again, skill biased technical change would be indicated by a positive coefficient on β_{WR}.

Versions of this structure are very common in the literature. It seems a natural one given the difficulties in accurately measuring a user cost of physical or technological capital (especially one that varies exogenously across microeconomic units). Sometimes the physical capital factor is allowed to be variable and only the technological component is fixed (e.g. Duguet and Greenan, 1997).

Many researchers have estimated equation (5) in employment shares rather than cost shares. Although less appropriate from a theoretical point of view, this clearly has the advantage that it allows a statistical decomposition of the effects of technology into a relative wage component and a relative employment component.

This is only a framework for organising our thoughts over the effects of technology in a well-known neo-classical framework. Other models suggest different rationalisations for the correlation of technology with cost shares. For example, the neo-classical model here takes factor prices as exogenous, which is clearly a questionable assumption since wage-setting is not conducted in a competitive spot market. Models of bargaining would suggest that workers may be able to 'capture' some of the rents from innovation. If skilled workers are more able to do this than unskilled workers (because of higher turnover costs associated with more skilled employees, for example), then the technology-cost share correlation could be driven by relative wage movements rather than relative employment movements. This underlines the importance of analysing movements in factor prices and quantities.

The literature on the effects of technology on wages has been primarily motivated by attempts to assess the productivity effects of computers on highly skilled workers. Note that a competitive labour market would only have one wage for each skill type, so the underlying model behind these correlations is not entirely clear. We offer a critique of the innovation-wage relationship elsewhere (Chennells and Van Reenen, 1998; Harhoff, 1999).

The impact on labour demand can also be derived from the structure outlined above. One problem with this, of course, is that much of the effect of innovation might derive from increased output, which implies estimating the production function directly. In fact, researchers have tended to estimate simpler equations of employment based on aggregating across all workers and estimating employment growth equations (see 2.3 below).

There are, of course, serious difficulties in extrapolating results from the micro-level to produce macro-level implications. We have focused on the demand side, but the equilibrium effects of technological change will also depend on what is happening in other areas of the economy, and in particular to the supply of more skilled labour. Furthermore, reallocations of output and employment will occur within and between sectors that will tend to complicate the aggregate effects. The micro-econometric evidence is only a small part of the story, and researchers should resist extrapolating too much from these partial equilibrium results.

4.2 The issue of skill bias and unemployment

In this section we consider what the implications of our model of skill biased technical change are for unemployment and jobs. There are a great number of complex interactions between innovation and employment but we begin with what we think is the most important route.

If technology is skill biased an exogenous increase in the stock of technological capital (a 'technology shock') will increase the demand for skilled labour relative to unskilled labour. This can be illustrated on the standard relative demand and relative supply diagram. As the relative demand curve shifts out, in equilibrium there is both a rise in the relative wages and the relative employment of the more skilled group.

Note that there is no unemployment in this model since the labour market clears. Now consider introducing some institutional limits to how far the wages of less skilled workers can fall. These could arise due to minimum welfare levels, minimum wages, trade unions or efficiency wage considerations. In this case there will be less of an increase in wage inequality, but there will be some unemployment for unskilled workers.

This is not a new idea. Solow (1966), for example, discussed it in his Wiskell lectures. More recently, the basic supply-demand analysis has become the dominant view of changes in the labour markets of the industrialised countries in the last 20 years, at least in the America. In the flexible labour market of the US, wage inequality has increased and unemployment has remained stable. In the relatively inflexible labour markets of Europe (outside the UK), wage inequality has been stable but unemployment has increased dramatically. Paul Krugman (1996) has christened US inequality and European unemployment as "two sides of the same coin".

The debate on these matters is fierce. As noted in the introduction, the existence of skill biased technical change and the question of whether technology is responsible for recent labour market trends are related, but quite distinct analytical issues. Explaining recent history is a far harder task than simply understanding skill bias. This is not least because of strong disagreement on the appropriate model of the labour market.

There are three key questions to be addressed.

Has the demand for skilled workers outstripped the supply of skilled workers? Or more accurately, has the demand/supply gap become greater over time?

If demand has accelerated relative to supply, is this due to technical change or some other factor, such as increased trade with less developed countries?

If the answer to both 1. and 2. is yes, how much of the change in unemployment and inequality can be accounted for?

Has the demand for skilled workers outstripped the supply of skilled workers?

Katz and Murphy (1992) and Autor, Katz and Krueger (1997) try to date the timing of the increase in demand for skills in the U.S. They use a weighted average of the growth of relative wages and employment, assuming that the labour market is in equilibrium with no unemployment. Given an assumption over the degree of substitutability between the skilled and the unskilled, it is possible to use a CES production function to estimate the relative employment changes. It is very hard, however, to date precisely the timing of the acceleration in demand, although both authors argue it exists (as does Machin, 1998, for the UK[10]).

More general methodologies have been proposed to take into account the unemployment in Europe and elsewhere. Nickell and Bell (1995), Jackman et al (1996), Manacorda and Manning (1997) argue that there has been relatively little increase in mismatch outside of the UK and US and that most of the increase in European unemployment has other roots.

Has the demand change been due to technical change?

There is greater agreement that, to the extent that demand has shifted towards the skilled, this is due to technology rather than trade. The methodologies used to reach this conclusion are based the fact that most of the change in skills has been a within industry phenomenon (see Berman et al, 1998, for more discussion of this debate).

How much can it account for?

This question needs a full general equilibrium analysis which has rarely been attempted (see Minford et al, 1997, for one attempt). Back of the envelope calculations in Machin and Van Reenen (1998) suggest that technological factors alone can only account for a third or less of the changes in the US and UK, but far more outside these two countries.

Katsoulacos (1996) argues that there is another question that should be considered. He puts forward the proposition that product innovation can increase labour supply. If we assume product innovation (in a general equilibrium context) has no effect on aggregate labour demand, one can still believe that the increase in the average quality and variety of goods stimulated by a faster rate of product innovation can change the leisure/work trade off. If wages are downwards rigid then this increase in labour supply could generate unemployment.

A problem with this argument is that participation and average hours worked have declined for men in the industrialised world since the end of the war. It is amongst women that participation has risen. Product innovations have clearly had a role in relieving women of the burdens of their traditional role as workers in home production. Examples would include technological improvements in domestic production (e.g. dish washers and micro-wave ovens) and in birth control (e.g. contraceptive pills). But (a) these are not the mechanisms Katsoulacos is focusing on, (b) there are a large number of other influences affecting female participation, (c) the implication that rising female

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[10] See Mishel and Schmitt, 1996, for a dissenting view

participation could be a cause of increased male joblessness is highly controversial (which is not to say that the GE effects are an important area are that is insufficiently researched).

4.3 Technology, homogenous labour and employment

The debate of the previous section is a crucial one for policy makers. Yet there is another strand in the literature which asks whether technology is responsible for falls in jobs *even when it is not skill biased*. Although a great deal has been written on this topic, the literature and the surrounding policy debate are littered with confusions.

Information and Communication Technologies (ICTs) have diffused rapidly in Europe over the last 20 years and unemployment has also risen. The temptation is strong to suggest that there is a causal link between the two. Yet waves of technology have passed over Europe in the past without creating persistent and structural unemployment. The debate over technological unemployment on the other hand has proved persistent. Similar arguments were being made in the 1960s over the introduction of automation, while in the 1930s Lord Kaldor (1932) commented:

"Today there is scarcely any political or journalistic observer of world affairs who does not attribute to the rapid growth of technical improvements one of the major causes of the present trouble".

Yet the fact remains that an examination of long-run unemployment trends shows no upward trend, despite the presence of technical change for several hundred years. If we examine U.K. and U.S. unemployment since the Nineteenth century we can see that the main difference is that unemployment was far more volatile pre-1945 than in the post war period. It is possible that technology has a temporary destabilising effect on employment, but it is difficult to believe that it is the major cause of the recent rise in European unemployment levels. Only technology combined with something else - such as wage rigidity - could be part of the cause.

What can economic theory tell us about the likely effects of technical change on employment? One form of technological change to consider is labour-augmenting process innovations. This case has been explored thoroughly in the literature. There are essentially two forces at work. For a given level of output, this type of technical change means that employment must fall since the same output can be produced with a lower level of inputs. To offset this, however, is the fact that output will increase as prices fall, because costs have fallen. This is the primary 'compensation mechanism' of technical change. It means that examining the impact of technology on output (the production function relationship) is fundamental to understanding the effects of technology on output.

In Appendix I we consider a simple model which shows how the effects of technical change work. This model leads us to the following results:

1. **Price elasticity of product demand.** The greater is the sensitivity of consumers to price changes the more likely it is that an innovation will raise employment. The higher is the price elasticity the greater the increase in output generated by an innovation.
2. **Substitution of capital for labour.** The easier it is to substitute the more likely it is there will be positive effects of labour augmenting technical change, since labour is now relatively cheaper than capital and the firm will substitute into labour. The opposite is true for capital augmenting technical change.
3. **Monopoly power.** If the firm has some degree of market power not all of the reduction in cost will be passed on in the form of lower prices. This will blunt the output expansion effect and make positive employment effects less likely.

Generalisations of the model lead to the consideration of further possible effects.

4. **Market share effects.** If the innovation does not diffuse immediately throughout the industry, the firm will have a cost advantage and so will tend to expand at the expense of its rivals. This will mean larger effects at the firm level in the short run. It also means that researchers should be careful in generalising from the micro-results to the economy level.
5. **Union effects.** If some of the efficiency gains from innovation are captured by unions in the form of higher wages (or reduced effort, etc), this will also blunt the output expansion effects. The results are uncertain if the union also bargains over the employment level (see Ulph and Ulph, 1994).
6. **Product Innovation.** Product innovations will tend to have stronger output expansion effects and are therefore more likely to result in employment increases (see Katsoulacos, 1984, for a fuller analysis)
7. **Economies of scale.** These will tend to magnify the positive employment effects. See Dobbs et al. (1987)

4.4 Econometric models

We discuss some econometric problems focusing on fixed effects, endogeneity and measurement. Consider the basic equation to be estimated as the stochastic form of equation (5)

$$S_W = \alpha_W + \beta_W \ln(w_W / w_B) + \beta_{WK} \ln(K / VA) + \beta_{WR} \ln(R / VA) + u$$
(6)

where u represents a stochastic error term. This could be justified by allowing the α_W to be random across units, or due to measurement error or optimisation mistakes. It is unlikely, however, that the error term is uncorrelated with other right hand side variables.

Some firms may have dynamic managers who employ both top quality workers and high quality technology. For this reason, controlling for **fixed effects** is important and researchers might estimate the equation in differences (or by including dummies if the time series is long enough):

$$\Delta S_W = \beta_W \Delta \ln(w_W / w_B) + \beta_{WK} \Delta \ln(K / VA) + \beta_{WR} \Delta \ln(R / VA) + t + e \qquad (7)$$

where Δ denotes the difference operator, t denotes time dummies, and e the error term. Unfortunately, estimating this type of model usually requires panel data, which is rare in the firm level work. This is one reason why most research has focused until recently on the industry level.

A second fundamental problem is dealing with the issue of **endogeneity**. Even when unobserved heterogeneity is removed, firms might still change their technology in response to a change in the make-up of skills available, rather than vice versa. If the 'technological' factor was truly fixed, this would not be an issue. But the factor is `quasi-fixed' meaning that it will move partially towards the long-run equilibrium in the short-run. Weak exogeneity (R is insensitive to current shocks this period, but may partially adjust next period) may be more plausible for R&D than for other technology proxies (such as computer use). The use of longer differences (used to mitigate such problems as measurement error) will exacerbate these problems of endogeneity. The only solution is to develop instrumental variables to deal with the fact that the technology and the skills decisions are being taken simultaneously. Unfortunately, such instruments are not easy to find, and researchers have been rightly reluctant to use the standard approach of using lags because of concerns that they are weak instruments.

A related issue is the interpretation of the coefficients on the relative wage terms. These terms are directly involved in the construction of the dependent variable. It is doubtful how much of the inter-firm or inter-industry variation in relative wages is due to changes in the price of labour, rather than due to changes in the quality mix of labour which is imperfectly captured by observable skill. An intellectually respectable solution would be to use credible instruments for relative wages. One commonly encountered short cut in the literature is to argue that time dummies will capture the real variation in wages, and to include these instead of the relative wage terms.

The third and perhaps the most basic issue, however, is the problem of **measurement** of technology. This is a very serious problem, since the technology input is a far more nebulous concept than the input of, say, labour, which in itself is difficult enough to measure. The traditional approach is simply to use time trends. The problem here, of course, is that the trends are likely to be picking up a lot more than just technical change, such as unmeasured price movements, changing demand conditions, cost shocks and so on. These criticisms are well known from the debate on how suitable total factor productivity (TFP) is as a measure of technology.

Researchers have turned to a variety of alternatives in seeking observable measures of technology. We can distinguish crudely between three types of measure, which correspond to inputs into the knowledge production function, outputs from the knowledge production function and subsequent diffusion of these outputs around the economy.[11] Inputs are generally measured by R&D activities. R&D expenditure has the advantage that it is measured in many databases over time, across countries and in a reasonably standard way[12] - at least by comparison with the alternatives. Also, R&D is measured in terms of a unit of currency, which provides a natural weighting, whereas other innovative measures are more qualitative. A big disadvantage of using R&D as the technology measure is the existence of spillovers. A firm might invest in large amounts of R&D without receiving any benefit from it, if the R&D does not produce any outputs (either in the form of innovation for the firm, or in the form of acquiring the ability to learn from other firms' innovations). There are long and unknown variable lags between the act of investing in R&D and reaping useful output from it.[13] The transmission mechanisms for knowledge to spill over from one firm to another are also poorly understood. For example, the R&D spending of Intel has dramatically affected the development of computer technologies used by other firms all over the world, but the process by which this knowledge has been absorbed by other firms is unclear, and rarely addressed in the literature.

Patents are a widely available and standard way to measure the outputs of knowledge. The problem with patents is that a large number of them appear to be of very low value and there is no obvious method of weighting them to take account of this.[14] In some countries expert innovation surveys exist, which can be viewed as a method of cutting off the lower tail of low value patents. The UK Science Policy Research Unit (SPRU) Innovation Survey is a good example of this, since industry experts were asked to list the most important innovations in their field, in order to weed out the innovations with little value. Output measures such as patents suffer from some of the problems of R&D – such as spillovers and variable time lags – and add new problems – such as the difficulties of dealing with count data.

Diffusion measures seem to be closely related to what is usually thought of as technology. A common example would be the use of computers in a firm. Researchers are usually faced with the problem of which technologies to include: what sort of computers (word processors, mainframes); whether also to include production-based technologies (lasers, robots, NC, CADCAM); how to weight the usage (the proportion of people using the computer is a common form of weighting). The most satisfactory

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[11] This roughly corresponds to the Schumpeterian triad of invention, innovation and diffusion.

[12] In OECD statistics most countries follow the guidelines of the Frascati manual (1993). Within countries accounting regulations often define how R&D is to be reported (e.g. in the USA under FAS and in the UK under SSAP13(Revised).

[13] Of course the same is true of the standard way in which the physical capital stock is measured. The main difference here is that the degree of uncertainty involved with R&D investments is much greater, and there is usually a method of benchmarking the physical capital stock in a particular year.

[14] Some current ideas include renewal fees, number of countries where the patent is registered, surveys of inventors and citations.

method seems to be constructing the capital stock of information technology (IT), although since IT is hardwired into more and more modern organisations, separating out this component becomes increasingly difficult. Measuring the diffusion of a particular technology is difficult in any time series context, since the passage of time changes the significance of using a particular type technology. For example, in 1978 an indicator of whether a computer was extensively used within the firm gave a very different signal to that same indicator in 1998. Diffusion-based measures of technology are more likely to suffer more from simultaneity problems than, say, R&D. Current changes to a firm's environment will have less of an effect on something like R&D than on the decision whether or not to postpone investing in more computers. This is primarily because of the greater adjustment costs attached to restructuring or canceling a research programme than in purchasing a new piece of hardware.

The measurement of skills is a less controversial issue, and the problems associated with it are well known. There are two main methods of measuring skills. Perhaps the most common in the literature is to use an indicator of occupation, often simply by dividing the population into manual (production) and non-manual (non-production) workers. Such categorisations can be criticised, since many non-manual occupations require very low levels of skill. Education-based measures are more closely tied to ideas of levels of human capital, but face the problem that even highly educated workers may not be employed doing very skilful jobs. Some authors have developed measures based on job content, where an occupation is broken down into different levels of task complexity (see Wolff, 1997). In studies that have compared them, these measures all tend to be highly correlated across industries (e.g. Gera et al, 1997). Nevertheless, there are real worries that the categories chosen are not comparable over time and across countries.

Another measurement issue relates to double counting. Innovative activities tend to be labour intensive and involve skilled workers. R&D is a good example, since typically about half of all R&D is staff costs and only 10% capital costs. This will automatically generate a positive correlation between the level of skilled (i.e. better paid) employees and the level of R&D. Correcting for this 'double counting' has been found to be important in the productivity literature. The problem reappears here in many guises.

Finally, there are issues to be grouped under 'selectivity'. The usual problems of sample response and survivor bias are encountered, but there are particular problems relating to the use of R&D expenditure. In most European countries, disclosure in company accounts of the amount of R&D carried out is not compulsory. This means that researchers have to be aware that excluding, or setting to zero, those companies which do not disclose any R&D is likely to introduce a selectivity bias.

4.5 Results from TSER Studies

4.5.1 Skills

4.5.1.1. Industry Level Studies

Berman, Bound and Machin (1998) use the UN General Industrial Statistics Database to provide some basic decompositions of the changes over time in the skill distribution across the manufacturing sectors of 14 different industrialised countries since 1970. In each country there has been an upgrading in the skill structure (as measured by the employment or wage bill share of non-production workers). This has been accompanied by an increase in wage inequality in some (notably the US and UK), but not all, countries.

They then decompose the change of skilled employment share into a `within industry' and `between industry' component.

$$\Delta P = \sum_i \Delta S_i \overline{P}_i + \sum_i \Delta P_i \overline{S}_i$$

Where P = proportion of skilled workers, S = share of industry *i* in total employment, a bar denotes a mean over time and the Δ is the difference over the same two time periods.

The between industry contribution arises because the less skilled industries (such as textiles) have been declining as a share of total manufacturing employment. This effect of industrial restructuring is relatively minor,, however. The vast majority of skill growth has occurred `within' industries. It appears that the within industry growth has occurred more in some industries than others. They find that chemicals, computers and non-electrical machinery and printing and publishing are particularly large contributors to the within component, and this tends to be true across all countries (the rank correlation coefficients tend to positive across countries). Since these are also industries which have has a lot of technical change, the authors argue that their results suggest that technological factors may be behind the upskilling evident in the data.

An important drawback of the Berman et al study (and the earlier studies which focused on the U.S.[15] using a similar methodology) is that there are no direct measures of technology. **Machin and Van Reenen** (1998) estimate a version of equation (7). They use 15 two digit manufacturing industries from 7 OECD countries (Denmark, France, Germany, Japan, Sweden, UK and US) between 1973 and 1991. The data was based on the OECD STAN/ANBERD dataset combined with occupational data from the UN dataset used by Berman et al. Information on educational sources was obtained by aggregating individual datasets from the different countries. This latter task was very time consuming and was done with the collaboration of fellow TSER colleagues in France, Germany and elsewhere.

Their measure of technology was R&D as a proportion of value added. There was a positive and significant association of skill upgrading and R&D intensity in almost every specification. This was robust to different measures of skill, conditioning on capital and output, using employment shares as the dependent variable, including industry wage

[15] For example, Berman, Bound and Griliches (1994) and Bound and Johnson (1992).

differentials as a control variable or using either first- or four-year differences. They conclude that direct measures of technical change are important in explaining the upgrading of the skill structure, although stress that technology accounts for different proportions of the change in different countries (for example, the proportion `explained' in the US and the UK is far smaller than elsewhere).

Goux and Maurin (1997) probe the decomposition of sectors into within and between components in more detail for France. They find that in contrast with most other countries most of the change in skill shares in France are due to between industry movements and these movements are driven by changes in domestic demand rather than import/export patterns. Part of the reason for this difference with the results from other countries is that the supply of qualifications has expanded very rapidly in the 1970-1993 period in France and was accompanied by falls in wage inequality. A second reason may be that they look at non-manufacturing sectors instead of just the manufacturing sector. The within sector changes tend to be larger in manufacturing than services (although as **Desonqueres et al,** 1998, and Autor, Katz and Krueger, 1998, show in the US and UK, at least the within sector movements also dominate).

Goux and Maurin (1995) complement their decomposition analysis with some direct measures of technical change. They estimate a version of equation (7) for higher and lower professional share of the wage bill between 1982 and 1993 for 35 sectors (aggregated from Enquete Emplois) but replace the technology variable (R/VA) by a set of industry fixed effects. They then regress these fixed effects against cross sectional measures of technical change drawn from the TOTTO surveys. Computer utilisation is found to be associated with significantly greater skill upgrading in these estimates. This is quite consistent with US and UK studies (e.g. Machin and Van Reenen). More surprisingly, however, they do find that a measure of the utilisation rate of industrial technologies (e.g. robots) has a negative correlation with skill upgrading. One suspects that these measures of diffusion may be subject to some sort of definitional problem. Industries with a lot of industrial technologies are likely to be more reliant on manual workers. Sectors with a growing number of white collar workers are more likely to have computers. Although R&D intensity is less likely to be endogenous (at least in the short run when it is relatively fixed) Machin and Van Reenen attempt to control for this problem by explicitly instrumenting R&D with government subsidies for R&D (assumed exogenous). They did not find evidence of endogeneity bias in their sample.

Fitzenberger (1997) uses an industry-level dataset matched with individual-level wage information for the German economy. He follows Leamer (1996a) by employing a Heckscher-Ohlin-Samuelson model to give his estimates some more structure than is usually the case in this literature. His results are noteworthy, since they support both trade and technology arguments. Skills come in three groups (low-skilled labor, skilled labor and high-skilled labor). Wages have been increasing disproportionately for the low- and high-skilled labor groups, though by very little if the U.S. experience is taken as a benchmark. Employment trends have been in favor of high-skill labor, exclusively. Fitzenberger shows that both import competition and total factor productivity have been increasing disproportionately in those industries which make intensive use of low- or high-skill labor. He interprets this result to be consistent with trade effects affecting low-skilled labor, and technology effects impacting mostly on high-skilled labor. In a recent extension of this work, **Fitzenberger (1999)** devises a structural model in which the centralized wage bargaining process in Germany is considered explicitly. His model is one of the first to actually open the black box of wage-setting. While the results of this estimation attempt are still preliminary, some success in linking centralized bargaining and union power to wage inflexibility is apparent in this paper.

The trade approach focuses on the sector bias of technical change. If technical change is faster in the skill intensive sectors then this `mandates' a growth in the skilled-unskilled wage differential. Fitzenberger cannot find a clear pattern in the data when he examines TFP growth across different sectors. Some work does suggest some sector bias towards the more skilled sectors in the US, but there is no consensus[16]. Part of the difficulty is undoubtedly in estimating TFP which is subject to a range of problems being an indirect residual from a postulated production function.

Falk and Koebel (1997) study labor demand in Germany. Four commonly provided explanations for the shift in labour demand for different skill groups are investigated: the substitutability of inputs; the own-price sensitivity for different types of labour; the effect of economic growth and the impact of technological change. During the period of 1977-1994, the rate of biased technological progress against unskilled workers seems to be large in the traded as in the non-traded goods industries. Furthermore, in three out of five sectors considered, technological change is biased towards high-skilled labour.

Steiner and Wagner (1997) analyze the economic factors which have contributed to the dramatic decline of the employment share of unskilled labor in German manufacturing, in particular the role played by the relatively rigid earnings structure. Potential effects of intensified international competition and skill-biased technological change on the relative employment and earnings position of unskilled workers are also discussed. They find that the substitution elasticity between unskilled and skilled labor is rather low. The decline in the employment share of unskilled workers attributable to an inflexible earnings structure therefore seems to have been modest compared to the trend decline in the skills ratio. Steiner and Wagner also find only modest effects from international competition and technological change on the employment share of unskilled labor.

Steiner and Mohr (1998) question the hypothesis of a trade-off between more jobs for unskilled workers on the one hand, and a less equal earnings distribution on the other. This paper builds on and extends previous work for Germany by Steiner and Wagner (1997) who find a rather low substitution elasticity between unskilled and skilled male labor for the whole manufacturing sector of about -0.3 and a trend decline in the skills ratio of about 3% per year. Given these estimates, the authors conclude that even reductions in the relative earnings of unskilled workers on a scale observed for the U.S. labor market would not have been sufficient to bring employment of unskilled workers in West German manufacturing back to previous levels. In this paper, we extend their

[16] For different conclusions see Sachs and Shatz (1994), Lawrence and Slaughter (1993), Haskel and Slaughter (1998), Desjonqueres et al (1998).

analysis for the manufacturing sector to the whole German economy and analyze the economic factors which have contributed to the dramatic decline of the employment share of unskilled labor in German manufacturing, in particular the role played by the relatively rigid earnings structure.

4.5.1.2 Enterprise Level Studies

Aggregation may be a serious problem for these industry studies, so we now consider analyses based at the level of the enterprise (both firm and plant).

Duguet and Greenan (1997) use an innovations survey to estimate cost share equations for a large panel of French manufacturing firms 1986-1991 in long differences (there are almost 5000 companies). They jointly model the 5 technical change variables (product improvements, new products, product imitations, process improvements, process breakthroughs) alongside the share equations (two types of labour and capital). So capital is treated as variable and innovations as quasi-fixed.

They find that skilled workers are not as easily substitutable for capital as unskilled workers. Furthermore, they find evidence for skill bias and argue that it comes primarily from the introduction of new products, although their results here are mixed. There appear to be differences in the different sorts of innovation but with not systematic pattern.

One problem with subjective innovations surveys is the comparability of the notion of innovation across different firms. Different firms may have of what counts as `innovation'. An interesting extension, given the increasing availability of this type of innovation survey (e.g. CIS), would be to use the longitudinal aspect of the panel when the question is asked to the same firms in future. If the same individual is questioned over time then differencing can remove the `permanent' component of the measurement error.

Greenan, Mairesse and Topel-Bensaid (1998) also use a large sample of French firms (about 11,000) producing in both the manufacturing and non-manufacturing sectors (combining the Enquete Structure des Emplois with the BIC). They have information for three years (1986, 1990 and 1996) and estimate a variety of long differenced models. They use an unusual measure of IT capital intensity derived from the firm's balance sheet expenditure on office and computing equipment. This includes computers but also less advanced equipment (such as photocopying machines). They are also careful to avoid double counting expenditure on IT personnel. Using four skill groups and a version of equation (7) they identify significant negative effects of IT capital on the share of blue collar workers, but only in the manufacturing sector.

Machin (1996) uses the British Workplace Industrial Relations Survey (WIRS) panel 1984-1990 of 402 establishments, which contains information on the presence of computing technologies. He distinguishes between the employment proportions of five occupational groups. The introduction of computers has a significantly negative effect on the least skilled groups and a significant positive effect on the most skilled group.

Machin's measures of computing are rather crude (basically a binary dummy). **Caroli and Van Reenen** (1998) extend the UK analysis by using a more sophisticated set of variables to measure the impact of computing. They also find that the establishments which have more intensive use new technology reduce the proportion of the least skilled workers to a much greater extent than other plants. A further finding is that plants who introduced major organisational changes in the early 1980s were more likely to shed unskilled workers in the later 1980s than plants who do not introduce organisational innovations. They compare these results to the Enquete Reponse, the French equivalent of WIRS. Following about 1000 of these establishments over time, they also find that the plants with the highest levels of technological and organisational innovation between 1989-1992 had the fastest falls in unskilled employment in the 1992-1996 period.

Another paper which stresses the importance of organisational influences is **Aguirrebriria and Alonso-Borrega** (1997). They use rich Spanish firm level panel data between 1986-91 (over 1000 firms). They are able to distinguish between 5 types of labour and three types of capital (fixed, R&D, and "bought-in" innovations). They estimate employment (not cost share) equations along the lines of equation (7) treating the capitals as quasi-fixed. The equations are first differenced and right hand side variables are instrumented by their own levels in t-2 using the Arellano and Bond (1991) GMM procedure. Since some of the innovation variables are zero they also use introduction dummies. Their most interesting result is that they obtain strong negative impacts of the introduction of technological capital on the least skilled group. Smaller incremental changes in the stock variables do not have significant impacts on the demand for skills. This paper is admirable for its attempt to deal with endogeneity and probe the innovation relationship more deeply that most other studies. Nevertheless, difference based GMM methods for dealing with endogeneity have come in for much recent criticism due to the `weak instruments' problem (e.g. Blundell and Bond, 1998; Mairesse and Griliches, 1997). Also the exact definition of "technological capital" is rather unclear in the paper.

Data constraints have hampered establishment level analysis in German studies. A notable exception is **Kaiser** (1998). She focuses on a sample of firms in the German business-related services' sector. Her employment measure is the managerial forecast of what she expects the change in net employment to be for each of four different skill groups over the next two years. Using ordered probit techniques a positive impact of current IT capital intensity is detected for employment growth of the most skilled group and a negative and significant impact revealed for the least skilled group. The main criticism of the study is the lack of any real longitudinal element to the data and the fact that employment is measured in qualitative rather than quantitative terms.

Summary

We end this sub-section with three general comments.

First, there does appear to be considerable support for the notion of skill-biased technical change from TSER research. This occurs across a range of studies, and these are usually robust to controlling for fixed effects. This is bolstered by findings from other research in the US (Doms et al, 1997, Dunne et al, 1997; Berndt et al, 1992; Autor et al, 1998, Mishel and Bernstein, 1998; Goldin and Katz, 1997; Bartel and Lichtenberg, 1987; Osterman, 1986; Adams, 1997; Wolff, 1996) and in other countries (Hansen, 1995, on Sweden; Gera et al , 1998, on Canada; Vainiomaki, 1998, on Finland).

Secondly, there have been few attempts to find instrumental variables to deal with the potential endogeneity of technology. Candidates could include government-induced schemes to alter the incentives to accumulate technological capital (such as R&D tax credits, government grants etc).

Thirdly, there are surprisingly few studies which try to analyse the mechanisms by which technological change translates into higher demand for skills. One mechanism is through organisational changes such as delayering, decentralisation and giving greater autonomy to workers. These organisational factors have been found to be important in the case study evidence and in the literature on the productivity paradox (investigating why computers have not raised measured productivity by as much as might have been expected). Some of the most interesting work discussed above suggests that this organisational restructuring could be the link between technology and labour demand (cf. Bresnahan et al. (1997)).

4.5.2 Employment

There are fewer econometric studies of the relationship between overall employment and technology. Those which do exist tend to be mainly descriptive in character and focused on specific industries (e.g. Dosi and Soete, 1983). The analysis in Blechinger et al. (1998) captures some of the salient points. An examination of the OECD STAN/ANBERD database (which covers manufacturing) reveals that the high technology industries (those with higher R&D intensity) expanded more quickly (contracted less slowly) than the medium or low technology industries.

TSER Research has focused on company level panel data.

Van Reenen (1997) examines 598 firms listed on the UK Stock Exchange. Companies are not required to disclose information about the skill composition of their workers. He examined a dynamic employment equation:

$$LnN_{it} = f_i + \Sigma_{k=0,\ldots 6}\beta_k\, INNOV_{it-k} + \alpha_1 lnN_{it-1} + \alpha_2 lnN_{it-2} + \gamma_1 ln(W_{it}) + \gamma_1 ln(K_{it}) + \delta' x_{it} + time\ dummies + v_{it}$$

(8)

Where N = total employment, $INNOV$ is a count of firm level innovations, W = average wage, K = fixed capital, f = a fixed effect and x includes other controls such as the number of industry innovations, i = firm.

This model is derived from the first order conditions for a CES production function. (see Appendix I). The user cost of capital is proxied by the fixed effects and time dummies. The innovation measures are drawn from the SPRU innovations survey (see section 4 above). These are headcounts of the first commercialisation of technologically important innovations identified by expert surveys in 1983, 1980 and 1970.

Equation (8) was estimated in first differences using the same standard GMM technique of Arellano and Bond (1991) that were used in the study by Aguirrebriria and Alonso-Borrega (1997) discussed above. Lagged employment was always instrumented and in some of the specifications firm wages and capital stocks were also treated as endogenous. The sample period runs 1976 through 1982.

Throughout the paper significantly positive effects of innovation were identified on firm employment. These were stronger for product innovations rather than process innovations. Over time the impact of innovations died away, presumably as other firms imitated the leading edge firm.

Martinez-Ross (1999) estimates a similar model for Spanish firms 1991-1995. She also finds it important to allow for second order dynamics in the employment equation. Her measure of innovation is drawn from a survey of Spanish firms were firms are asked if they have introduced new technologies, and if so, how many (similar to the Community Innovation Surveys). She criticises the Van Reenen study for assuming that the innovation measures were weakly exogenous. Instrumenting innovations by lagged innovations leads to a far lower (and insignificant) effect when compared to the OLS results.

The Van Reenen study argued that the rarity of SPRU innovations (compared say to the Spanish survey) would make lagged innovations an extremely poor instrument for current SPRU innovations. If patents only effect employment when they are commercialised as innovations, then past patent stocks become legitimate instruments. When using lagged patents as an instrument for innovations, he could find no evidence of endogeneity bias.

Blechinger, Kleinknecht, Licht and Pfeiffer (1998) use panel data from a large sample of Dutch firms in both the manufacturing (772 companies) and services sectors (836). They relate employment growth over the 1988-1992 period to characteristics of the firm in 1988. Essentially these controls include the size of the firm and indicators of technology. They found that office automation had a significantly positive effect in the service sector and production automation had a significantly positive effect in the manufacturing sector. The authors recognised the potential endogeneity problem. There are many unobservable reasons why firms may be growing faster in 1988-1992 and these shocks could induce firms to innovate in order to capture the higher demand. They try to control for these by including an inverse Mills ratio in the manner of Heckman (1979). This procedure is formally close to instrumenting the endogenous variable. It is still the case that one requires a variable that will shift the probability of innovating that is uncorrelated with the residual term in the employment growth equation. Unfortunately there are no obvious identifying instruments in this study and much then relies on the particular functional form.

The Blechinger et al study also examines the impact of the lagged proportion of R&D personnel on employment growth. Again, a positive effect of the innovation proxy is identified. Other studies using R&D have not found the same result. **Klette and Førre** (1998), for example, uses data from Norweigan manufacturing plants and industries to investigate whether R&D intensity is associated with above average employment growth. The data is extremely rich and comprehensive being essentially the population of firms with over 20 employees. R&D is measured as firm R&D intensity in the same line of business as the plant.

Klette found that R&D intensive establishments had lower net job creation than their less R&D intensive counterparts. This was robust to controls for size, sector and business cycle. Furthermore, the high tech sectors themselves fared worse in employment terms than other sectors (although not significantly so). A worry concerning his study is that the Norweigan economy suffered from a series of negative shocks arising from the oil-sector and banking sector. Nevertheless, Klette claims that his results are not driven by a few disastrous cases associated with these shocks but are a more general phenomenon. It is important to replicate Klette's extremely careful study in other countries to see if his results are a specific feature of a small open economy in crisis or a more general phenomenon.

A novel approach to the question of the impact of computers on employment is offered in **Entorf, Gollac and Kramarz** (1997). French individual workers are followed for 5 quarters in the Enquete Emplois. By matching these employees with other surveys (e.g. TOTTO, DMMO, EET) the authors can examine the employment profile of workers who use different forms of new technology and compare their employment trajectories with those who did not use these devices. Using multinomial probit techniques and controlling for a host of observed (gender, education, experience, part-time, region, occupation, establishment turnover and age, etc) and unobserved factors they find that computer use reduces the probability of unemployment in the very short run (one quarter) but not the long-run (one year). Although the authors make extensive attempts to control for selectivity one is still left wondering whether the results could be driven by the fact that employers are unlikely to give advanced tools to workers who are likely to leave in the near future. Still, this is one of the most sophisticated attempts to examine the problem in our current batch of research.

Summary

The TSER research findings are comparable with other parts of the literature on innovation and employment. Overall, there appear to be consistently positive effects of proxies for product innovations on the growth of employment (e.g. Konig et al. (1995), Entorf and Pohlmeier (1995), Smolny (1998) for German firms; Leo and Steiner (1994) for Austrian firms). The results for process innovations are very mixed – although usually insignificant, several examples of positive effects exist (e.g. Blanchflower and Burgess (1997) for UK and Australian plants; and Regev (1995) for Israeli firms). In an interesting study of French data, Greenan and Guellac (1996) find that process innovations have a strong positive effect at the firm level, but this washes out at the industry level. The story is reversed for product innovations. When measures such as R&D are used, negative correlations frequently arise. (e.g. Brouwer et al. (1993) for Dutch firms.). Hall (1987) find different effects for small U.S. firms (positive) than large U.S. firms (negative). The most plausible explanation for these results is that the effects of innovation depend critically on the type of innovations being produced

In general, existing employment studies have rarely been conducted with as detailed an eye to the econometric problems involved as those investigating wages and skills. This perhaps reflects the greater theoretical ambiguity involved in estimating the relationship (and policy interest in the microeconomic results). The econometric problems are particularly difficult in these studies however, and future work needs to address these more seriously.

4.5.3 Wages

While there is little disagreement about the phenomenon of rising wage inequality *per se*, the controversy on what drives these developments is continuing. Recent (and more detailed) surveys of the general literature have appeared in Levy and Murnane (1992), Autor, Katz and Krueger (1997), Bresnahan (1997) and the Spring 1997 symposium in the *Journal of Economic Perspectives*.

While the (potential) impact of technology on wages has only been one aspect of the TSER project "Innovation, R&D and Productivity", a large number of papers related to the topic of this survey has been presented at various conferences and workshops. This section discusses the evidence from some of these studies and their contribution to the literature.[17]

A large number of studies use industry-level data to study the relationship between wages and its determinants. Other studies employ firm or establishment level data. In most cases, a measure of average wages (either for all employees or by skill group) is used as the dependent variable in a wage regression. The objective is then to explore possible partial correlations of wage growth to measures of technology, export and import orientation and control variables. Panel data techniques are used in some studies to strengthen the case of a causal link between technology and wages.

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17 The set of studies considered here is not complete as of yet. The names of authors of TSER-related contributions are printed in bold in this section.

Machin and Van Reenen (1996) use Global Vantage data on firms from Italy, France, the U.K. and Germany to model the average wage as a function of lagged R&D per worker, the capital-labor ratio and other controls. Since R&D disclosure is subject to selectivity effects, the explicitly control for it. In this paper, a significant positive effect of R&D intensity remains, even after the selectivity controls and fixed effects have been introduced. In terms of their effect size, technology seems to be a more potent determinant of wages in the U.K. and Germany than in France and Italy.[18]

Van Reenen (1996) estimates average wage regressions in first-differened form, using Datastream data on about 600 U.K. corporations. The key right-hand side variables are counts of major innovations, introduced as a distributed lag. These measures turn out to have significant positive effects on average wages, even after controlling for potential endogeneity. Van Reenen interprets these effects as a form of rent sharing. According to this interpretation, innovations do not just raise profits at the firm level, but some of these rents are distributed to workers. Yet, some form of impact on the wage distribution may also be at work.

Chennells and Van Reenen (1997) study the development of wages in the U.K., using data on 900 British plants for 1984 and 1990 from the Workplace Industrial Relations Survey (WIRS). Unfortunately, they can only obtain matched data for a panel of 100 plants, since the original surveys were not designed for a panel data approach. They have relatively detailed data as to the use of micro-electronic technologies and computers and can control for a large number of potentially confounding effects (such as unionization, part-time work, firm size etc.). In standard OLS regressions, they find a significant effect of technology on wages, but this effect disappears once they use instrumentation to safeguard against endogeneity distortions.

Machin, Menezes-Filho and Van Reenen (1998) employ Datastream data on about 660 firms, covering the period from 1983-94. They observe in these data the directors' pay as well as total wages. Using GMM methods to safeguard against potential correlations between regressors and error terms, and using quasi-differencing to control for latent heterogeneity, they find a positive and significant R&D-earnings elasticity for workers and for directors.[19]

Greenan, Mairesse and Topiol-Bensaid (1998) conduct a mainly descriptive assessment of the links between computerization, wages and productivity growth in France. Their data originate from the SUSE (unified system of firm statistics) system and contain information on about 2,900 manufacturing and 2,500 service sector firms. Their

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[18] Note that the result on Germany is not at all inconsistent with the observation that there is been little wage dispersion in Germany (cf. Steiner and Wagner 1998). Quite to the contrary: if the unskilled in Germany have a greater chance of leaving employment, and if R&D intensive firms are particularly prone to shed unskilled labor, then wages will rise although the typical dispersion measures need not change by much.

[19] The latter elasticity is twice as high as the elasticity for workers' earnings. The difference between workers and directors may be partly driven by changes in the degree of diversification of the firm which are presumably correlated with R&D intensity. Cf. Rose and Shepard (1997).

cross-sectional results confirm results from a previous French study (**Greenan and Mairesse 1996**) as well as U.S. studies such as Lichtenberg (1995) and Brynjolfsson and Hitt (1995) which show a consistently positive relationship between productivity and the extent of computerization. In the time series dimension, the relationship between computerization and productivity vanishes again (as has been observed in other studies). More importantly for the purpose of this survey, changes in the skill structure of the firm are also correlated with computerization - the proportion of non-production workers rises with the extent of computerization. These results are qualitatively similar to those of Berndt and Morrisson (1995) and Autor, Katz and Krüger (1997). However, they have not been confirmed by all research teams. For example, Doms, Dunne and Troske (1997) do not detect such a relationship at the firm level.

Steiner and Wagner (1998) provide an assessment of wage inequality in Germany. They criticize earlier results and show that neglecting data issues (the inclusion of fringe benefits) in wage data can lead to the spurious conclusion that wage inequality has been rising. According to their results, earnings inequality in Germany has increased very little in the 1980s. Their decomposition analysis based on estimated earnings functions reveals that the relative stability of the German earnings distribution in the 1980s has not resulted from large compensating changes in the composition of the labour force on the one hand, and changes in the returns to human capital on the other. While both of these components have changed little in the observation period, the former rather than the latter component has contributed to the small increase in earnings inequality observed in the register data used in the study. Work by **Giles et al. (1997)** and **Gosling (1997)** confirms the result that Germany has been spared from increasing wage inequality. But Giles et al. also point to other interesting differences between Germany and the U.K. Over the life cycle, there is much higher wage growth in Germany than in the UK, and wage inequality is not increasing over the life cycle as it is in the U.K. Given these differences, the incentives for skill acquisition (in particular with firm-specific characteristics) ought to be more developed in Germany than in the U.K.

Büttner and Fitzenberger (1999) employ quantile regression techniques to use the information from the German wage distribution more fully than is typically the case. They argue that in labor markets with central wage bargaining wage flexibility varies systematically across the wage distribution: local wage flexibility is more relevant for the upper part of the wage distribution, and flexibility of wages negotiated under central wage bargaining affects the lower part of the wage distribution. Using a random sample of German social-security accounts, they estimate wage flexibility across the wage distribution by means of quantile regressions. The results support their hypothesis, as employees with low wages have significantly lower local wage flexibility than high wage employees. This effect is particularly relevant for the lower educational groups. On the other hand, employees with low wages tend to have a higher wage flexibility with respect to national employment.

Common Themes and Problems

The labor market developments at hand constitute major shifts, and it is difficult to argue that there is a mono-causal explanation available. Moreover, as the debate of the last few years has shown, the relevant question is not so much whether it has been increasing trade and capital flow liberalization or technology which caused the changes in labor demand patterns. Rather, the proper question is to ask which part of the change can be accounted for by these and potential other factors. What defeats any attempt to come to firm conclusions at this point, however, is a mix of methodological and of data problems.

Chennells and Van Reenen (1997) have already pointed to a number of problems that most these studies share, in particular those that consider technology as a potential contributor to recent labor market developments. The practice of identifying technology with a time is definitely outdated by now. More recent studies have attempted to use actual measures (such as R&D or the extent of computerization) which are directly related to technical progress. But since some of these may be determined endogenously, the results should be taken with a large grain of salt. Unfortunately, attempts to instrument these variables have not met great success - typically, the instrumented variables turn out to be insignificant. That does not mean that technology has no role in determining the structure of wages. It is well-known that the medicine of instrumentation applied here may in some case be too strong for the patient. If we have only have weak instruments (and finding strong ones is the classical problem in this approach), any information contained in the regressors may be sufficiently watered down to generate insignificant results. One should note that this is a problem common to all studies, may they concentrate on trade or technology. Moreover, technology may cause trade to grow, and vice versa, the threat of imports may spur firms to engage in technical change. Only few studies have tackled these complex relationships in some way.

A cautioning note regarding the operationalization of "skills" comes from the aforementioned study by Leuven et al. (1997). They essentially ask whether it is appropriate to use simple skill measures (e.g., educational degrees or work experience in the well-known Blau and Kahn (1996) study) for the purpose of cross-country comparisons. Arguably, the same question may be posed for long-term studies within a given country.

The choice of the unit of observation is another serious concern in this literature. On the one hand, aggregate data (at the industry level) is more easily available than firm or establishment-level information, in particular if international comparisons are attempted. But this convenience may have a price if one seeks to identify causal relationships. As Dunne, Haltiwanger and Troske (1997) point out, recent research suggests that the overall increase in wage inequality between workers in the U.S. is closely related to an increase in wage dispersion between establishments. In consequence, the preferred type of data to study and decompose changes to the wage structure should be at the establishment level.[20] However, the availability of European studies at the micro-level has been limited by data availability. The French statistical system has produced the qualitatively most

20 One of the problems that empirical work faces in many European countries is the lack of such data. Many national statistical systems have been astonishingly resilient against attempts to exploit their micro-data in more effective ways.

advanced datasets to tackle these problems, but much more could be done with additional data of this type.[21]

Finally, Leamer's (1996a/b) criticism of labor economists' work in this area (in particular of factor content studies) has left a visible mark in the research field. Attempts have been made now to better justify the estimation framework, using partial- and general-equilibrium models as the foundation. But the research is still very much in flux, and established positions that were still held by a majority of economists (such as the relative irrelevance of trade as a contributor to labor market developments) is now less palatable than it used to be. Quite to the contrary, it seems that the trade explanation (which looked defeated several years ago) has gained in acceptance, witnessed by the large number of recent studies focussing on the contribution of trade to labor market inequality. Many contributions are now set up as "horse races", allowing both trade and technological progress to assume an explanatory role in the respective multivariate analyses.

4.6.4 Conclusions

In this paper we have focused on studies in the TSER Network R&D, Innovation and Productivity which relate to the impact of technical change on skills, employment and wages. We identified studies which distinguished between different types of skills and those that focused on total employment. Most studies have been micro-econometric so relate indirectly to the macro question of the causes of aggregate unemployment.

In any survey it is difficult to reach definitive conclusions, aside from methodological ones. Nevertheless we hazard the following stylised description of our brief survey.

First, there is considerable evidence of a positive correlation of various measures of technology with the skill structure suggesting that technology is, on average, biased towards skilled labour. Secondly, the evidence on total employment is more mixed, with most measures suggesting a positive association (notably product innovation), but some others (notably R&D-based) being more negative. On balance, innovation at the micro level is probably associated with employment growth. Finally, although there is a strong correlation between wages and proxies for diffusion at the micro level, this is mainly spurious. High wages/high ability workers stimulate more technological diffusion. Giving someone a computer does not increase their wages.

The three main methodological problems with these results is the presence of unobserved heterogeneity, endogeneity and measurement problems. Most of the studies here have recognised the problem of heterogeneity and have turned to panel data where one can make attempts to control for fixed effects. There are well known problems in this but we feel that this is a huge improvement over earlier work examining cross sectional correlations.

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21 See Haegeland and Klette (1997) for a study which uses match establishment-worker data in Norway.

There are fewer attempts to deal with the issue of the endogeneity of technology. Some authors have relied on GMM approaches which identify based on an assumed serial correlation structure. A more satisfactory approach would be to use some of the empirical work on the determination of innovation. The large numbers of public policies towards stimulating innovation may offer some hope for identification in this respect. These policy changes may in many cases be regarded as natural experiments which exogenously shift the innovation measure independently of shocks in current employment and skills.

Another area for future work is the theoretical framework for analysing technology effect. The basic neo-classical model needs to be supplemented by a richer understanding of technological adoption in a tractable manner. There are a plethora of theoretical models; the task is to translate them into an empirically coherent form for implementation and testing. In particular, examining the role of organisational change in translating the effects of technology into labour demands should be a key area of future research (Caroli (1998)).

Finally, the links between micro-economic analysis and macro-economic outcomes are still very crude. We re-iterate that the existence of skill biased technical change is not the same as saying that technology is responsible for unemployment. Linking the empirical results here with simple GE models must be another important avenue of future research.

Appendices to Chapter III

3.1 A Formal Model of Research Joint Ventures

There are two firms. The products they produce can be either substitutes or complements. For illustrative purposes we can think of the demands being given by

$$p_i = a - x_i - sx_j, \quad i = 1,2, \quad j \neq i, \quad -1 \leq s \leq 1$$

where $x_i, \quad i = 1,2$ denotes the consumption of good i, and s denotes the degree product substitutability (s > 0) or complementarity (s < 0).

Each firm starts with an initial technology which gives it constant marginal costs of production $\bar{c}, \quad a > \bar{c} > 0$. The two firms spend money on R&D in order to make a discovery about some new lower cost technology. The probability of each firm' making this discovery depends solely on the R&D it does. Denote this R&D technology by the cost function $C(p), \quad$ where $p, \quad 0 \leq p \leq 1$ denotes the probability of discovery.

Assume
C (i) $\quad C(0) \geq 0; \quad C'(0) = 0$;
C (ii) $\quad C''(p) > 0. \quad 0 \leq p \leq 1$;
C (iii) $\quad p \to 1 \quad \Rightarrow \quad C'(p) \to \infty$.

Assumption C(i) allows for fixed costs, though I assume that these are sufficiently small that both firms would undertake R&D in any non-cooperative equilibrium.

If one firm alone makes a discovery it lowers its costs to $\underline{c}, \quad 0 < \underline{c} < \bar{c}$. Let $q = \bar{c} - \underline{c}$ denote the quantum of progress made. Assume that, through spillovers (i.e. involuntary information leakage), a fraction $\underline{\delta}, \quad 0 \leq \underline{\delta} < 1$ of this progress becomes available to the firm that has not made a discovery. Assume also that through voluntary information revelation, a fraction $\delta^{10}, \quad \underline{\delta} \leq \delta^{10} \leq 1$ of this progress can be made available to the firm that has not discovered.

If both firms make a discovery then the total quantum of progress made by each, t, is given by

$$t = \tau(q, r; \gamma)$$

where $r, \quad 0 \leq r \leq q$ is the amount of progress each firm receives from the other, and $\gamma, \quad 0 \leq \gamma \leq \infty$ is a parameter reflecting the degree of complementarity/substitutability of the research discoveries made by the two firms.

I assume that $r = \kappa . \delta^{11} . q$.

Here κ, $0 \le \underline{\kappa} \le \kappa \le 1$ is the degree of research design co-ordination between the research paths pursued by the two labs, and $\underline{\kappa}$, $0 \le \underline{\kappa} < 1$ is the minimum amount of co-ordination achieved haphazardly in the non-cooperative equilibrium. For expositional simplicity I will assume throughout the rest of the paper that $\underline{\kappa} = 0$.

$\delta^{11} = MIN\left[\delta_1^{11}, \delta_2^{11}\right]$, where δ_i^{11}, $\underline{\delta} \le \delta_i^{11} \le 1$ is the amount of information voluntarily shared by firm i if both firms discover. This formulation captures the idea that it is the mutual interchange of information that enables firms to benefit from each other's research.

This formulation highlights the fact that the benefit that one firm can make fro9m the progress made by the other depends on both the amount of information which they mutually exchange and on their ability to co-ordinate their research plans in advance.

A precise functional form for the function $\tau(.)$ is given in Katsoulacos and Ulph (1998). For expositional simplicity I just note two special cases on which I will focus throughout the paper.

Research Discoveries are Perfect Complements

This arises when $\gamma = \infty$, in which case

$$\tau(q, r; \infty) = q + r = q + (\kappa.\delta)q .$$

Thus to the extent that any firm can benefit from the progress made by the other, this just adds to the progress which it makes itself. This is the assumption that is made in virtually all the literature.

Research Discoveries are Perfect Substitutes

This arises when $\gamma = 0$ in which case,

$$\tau(q, r; 0) = MAX\left[q, r\right]$$

Notice that, given our assumption that $r \le q$ this implies that $t \equiv q$ so each firm's progress is independent of anything it might learn from the other. This captures precisely the idea that firms are just duplicating each other's discoveries.

Suppose that the market equilibrium is Cournot. Let $\pi(\alpha, \beta; s)$ be the Cournot equilibrium operating profits of a firm whose marginal costs are α when the marginal costs of the other firm are β and the degree of product substitutability/complementarity is s. For simplicity, in what follows the explicit dependence of profits on s will be suppressed.

Using this notation, we can then define the following profits conditional on whether or not each firm has discovered, and conditional on what R&D co-ordination and information-sharing decisions have been made.

(i) Neither firm discovers

Let $\pi^{00} = \pi(\bar{c}, \bar{c})$ be the profits of each firm and $\Sigma^{00} = 2\pi^{00}$ their combined profits.

(ii) Only 1 firm discovers, and a fraction δ^{10}, $\underline{\delta} \le \delta^{10} \le 1$ of information is shared

Let $\pi^{10}(\delta^{10}) = \pi(\underline{c}, \bar{c} - \delta^{10} q)$ be the profits of firm that has discovered;
$\pi^{01}(\delta^{10}) = \pi(\bar{c} - \delta^{10} q, \underline{c})$ be the profits of firm that has not discovered; and
$\Sigma^{10}(\delta^{10}) = \pi^{10}(\delta^{10}) + \pi^{01}(\delta^{10})$ be their combined profits.

$\pi^{10}(.)$ is a strictly decreasing function of δ^{10} if s > 0, and a strictly increasing function if s < 0. $\pi^{01}(.)$ is a strictly increasing function of δ^{10} whatever the value of s. $\Sigma^{10}(.)$ is a strictly concave function of δ^{10}.

(iii) Both firms discover.

Let $\pi^{11} = \pi(\underline{c}, \underline{c}) = \pi^{10}(1) = \pi^{01}(1)$ denote the profits of each firm if (a) both discover and research paths are perfect substitutes ($\gamma = 0$); (b) both discover, research paths are perfect complements ($\gamma = \infty$) but no co-ordination has taken place – i.e. $\kappa = 0$. Notice that these are also the profits that each firm would make if only 1 firm discovered but information as fully shared. Let $\Sigma^{11} = 2\pi^{11}$ be the combined profits of the two firms.

Notice that the function $\pi[\bar{c} - (1 + \kappa.\delta^{11})q, \bar{c} - (1 + \kappa.\delta^{11})q]$ is a strictly increasing function of $\kappa.\delta^{11}$. It follows that, when research discoveries are complements, the RJV would want to fully co-ordinate and fully share information. So let $\pi^{22} = \pi(\bar{c} - 2q, \bar{c} - 2q)$ be individual firm profits in this case and $\Sigma^{22} = 2\pi^{22}$ be combined profits.

Having thus specified the model, we can now examine both the non-cooperative and the cooperative (RJV) equilibrium.

0 Non-Co-operative Equilibrium

Since, by assumption, no research design co-ordination is possible, the only decisions that can be made are those on R&D per firm and on the sharing of research output information when only one firm has discovered. As usual we analyse these backwards.

A.III Research Output Sharing

What happens here depends very much on what assumptions are made, for example whether licensing is possible, whether it is possible for firms to share information freely, or whether information-sharing is impossible.

Consider first the possibility that licensing is possible.

Let $v^S(\underline{\delta}) = \pi^{10}(\underline{\delta}) - \pi^{11}$ be the minimum price which the licensor (seller) is willing to accept for licensing the discovery, and $v^b(\underline{\delta}) = \pi^{11} - \pi^{01}(\underline{\delta})$ be the maximum amount the licensee (buyer) is willing to pay for a licence. If goods are substitutes (s > 0) then $v^s(\underline{\delta})$ is positive and strictly decreasing, while if goods are complements (s < 0), it is negative and strictly increasing. $v^b(\underline{\delta})$ is positive and strictly decreasing.

Licensing will arise if $v^b(\underline{\delta}) > v^s(\underline{\delta})$, i.e. if $\Sigma^{11} > \Sigma^{10}(\underline{\delta})$. This is always satisfied when goods are complements (s < 0). If goods are substitutes (s > 0) then licensing will arise when the scope for exercising monopoly poser through withholding information is small. This will happen when the technical advance, q, is small and/or when intellectual property rights are not too tightly enforced – i.e. when $\underline{\delta}$ is large.

If we assume that the bargaining strength of the licensor is ϕ, $0 \le \phi \le 1$ then the licence fee is

$$F = \phi . v^b(\underline{\delta}) + (1-\phi) . v^s(\underline{\delta}) \qquad (1)$$

If licensing is not possible, but it is possible for information to be given away freely, then this will happen when goods are complements, but not when they are substitutes.

A.II R&D Co-ordination

It is useful to start with the case where in stage III firms give information away free of charge. Then the first-order condition for the symmetric non-cooperative equilibrium p is

$$(1-p)\left[\pi^{11} - \pi^{00}\right] = C'(p) \qquad (2)$$

The LHS is the marginal incentive to increase p and the RHS is the marginal cost.

The incentive here is the non-strategic incentive, since, with information freely shared, neither firm is trying to innovate ahead of the other. Notice that, as we would expect, the spillover parameter $\underline{\delta}$ has no effect on this equilibrium.

If information is not shared then the equilibrium condition becomes

$$\left\{p.v^b\left(\underline{\delta}\right)+(1-p)v^s\left(\underline{\delta}\right)\right\}+(1-p)\left(\pi^{11}-\pi^{00}\right)=C'(p) \qquad (3)$$

whereas if information is sold under license it becomes

$$F+(1-p)\left(\pi^{11}-\pi^{00}\right)=C'(p)$$

i.e.

$$\left\{\phi.v^b\left(\underline{\delta}\right)+(1-\phi)v^s\left(\underline{\delta}\right)\right\}+(1-p)\left(\pi^{11}-\pi^{00}\right)=C'(p)\,. \qquad (4)$$

The first term on the LHS of (3) and (4) is the strategic investment incentive since it reflects the gains that a firm obtains by innovating ahead of its rival, in a situation where only one of them can innovate. For example, in the case of licensing, it will be able sell at the fee F if the rival fails to innovate (and it does) but will avoid having to pay the fee F if it fails to innovate (and its rival does). So the strategic incentive is F whatever the probability of discovery.

As noted above, if goods are substitutes, the strategic incentive is positive and strictly decreasing in the spillover parameter $\underline{\delta}$.

1 Co-operative (RJV) Equilibrium

Again we solve the equilibrium backwards.

B.III <u>Research Output Information Sharing</u>

As noted above, if research discoveries are complements, then the RJV will choose maximal research design co-ordination ($\kappa=1$) in stage 1, and, given this will want to maximally share information when both firms discover, so $\delta^{11}=1$.

However, if only one firm discovers the RJV will share information only if $\Sigma^{11}>\Sigma^{10}\left(\underline{\delta}\right)$. So, if licensing is available, and if research paths are perfect substitutes - so effectively, there is no information to be shared if both firms discover - then the RJV performs no better than the non-cooperative equilibrium at research output information-sharing.

B.II <u>R&D Co-ordination</u>.

The analysis here has to be split into two cases depending on the number of labs which the RJV operates.

B.II.1 One Lab

If, at stage I, the RJV decides to operate a single lab, then no complementarities can be exploited, and, by assumption, information is fully shared. So the decision about how much R&D to do, is characterised as follows.

Let

$$V^1 = \underset{0 \le P \le 1b}{MAX} \quad P.\Sigma^{11} + (1-P).\Sigma^{00} - C(P)$$

be the expected present value of the RJV with one lab.

The f.o.c. for this is

$$\Sigma^{11} - \Sigma^{00} = C'(P)$$

or

$$2\left(\pi^{11} - \pi^{00}\right) = C'(P) \qquad (5)$$

Comparisons with the conditions (2) – (4) in the non-cooperative equilibrium are not particularly useful since they all involve operating two labs. So let us turn to that case

B.II.2 Two Labs

Suppose that, at stage I, the RJV decides to operate two labs. Then the outcome at this stage depends on whether or not research paths are complements, and on whether or not, at Stage III, information is fully shared when only one firm discovers.

Then

$$V^2 = \underset{0 \le p \le 1}{MAX} \quad p^2\Sigma^{11} + 2p(1-p).MAX\left[\Sigma^{11}, \Sigma^{10}\left(\underline{\delta}\right)\right] + (1-p)^2.\Sigma^{00} - 2C(p) \qquad (6)$$

is the expected present value of the RJV when it operates two labs and when research paths are perfect substitutes, while

$$V^2 = \underset{0 \le p \le 1}{MAX} \quad p^2\Sigma^{22} + 2p(1-p).MAX\left[\Sigma^{11}, \Sigma^{10}\left(\underline{\delta}\right)\right] + (1-p)^2.\Sigma^{00} - 2C(p) \qquad (7)$$

is the expected present value of the RJV when it operates two labs and when research paths are complements.

To more fully understand the implications for RJV performance, let me concentrate here on the case where $\Sigma^{11} > \Sigma^{10}\left(\underline{\delta}\right)$ and so information is fully shared at stage III. The analysis of the case where information is not shared when only one firm discovers is given in the Appendix.

Perfect Substitute Research

From (6) the first-order condition for RJV profit-maximisation is

$$2\{(1-p).(\pi^{11}-\pi^{00})\} = C'(p) \qquad (8)$$

To understand the implications of this, consider first the case where licensing is impossible, but goods are complements, so, in the non-cooperative equilibrium firms would be willing to freely share information. If we compare (8) to (2) we see then that the incentive to undertake R&D has increased because the RJV internalises the beneficial effects of information sharing on the profits of both firms. Thus the RJV does indeed ameliorate the non-strategic underinvestment effect - problem (b) in the initial list of market failures. Essentially it does this through internalising the externality – problem (g).

In all other cases the non-cooperative equilibrium will be characterised by (3) or (4) depending on whether or not licensing is possible. By comparing (8) with (3) or (4) we see then that the RJV has had two effect: (i) it has removed the strategic investment incentive - problem (c); (ii) as noted above, it has internalised the information-sharing externality – problem (g). The first effect will tend to reduce the amount of R&D the RJV does, the second to increase it, so it is not at all clear on balance whether the RJV does more or less R&D. This point that has long been recognised since the classic article of d'Aspremont and Jacquemin (1988).

Complementary Research

From (7) the first-order condition for profit maximisation now becomes

$$2\{p.(\pi^{22}-\pi^{11})\} + 2\{(1-p).(\pi^{11}-\pi^{00})\} = C'(p) \qquad (9)$$

The new term at the start of the LHS of (9) indicates that in addition to the effects mentioned above the RJV now has the additional benefit of ameliorating the under-exploited complementarities under-investment effect – market failure (f) in our initial list.

B.I <u>Research Design Co-ordination</u>

There are two aspects to research design co-ordination.

B.I.1 Exploiting Complementarities

If research paths are complements, then, by co-ordination of strategies, the RJV can design the research paths so as to maximise these complementarities, i.e., can set $\kappa = 1$. This has three effects.

By comparing (7) with (6) it has the direct effect of raising the expected profits of the RJV (if it operates two labs) for any given level of R&D. Thus it overcomes the under-exploited complementarities effect – market failure (e).

As noted above this has the further effect of encouraging the RJV to do more R&D – which further increases the value of operating two labs.

This brings us to the second research design issue:

B.I.2 Choosing the Number of Labs to Operate.

The RJV will make this decision by a straightforward comparison of V^1 and V^2. There are two effects at work here. To the extent that the research paths are complementary and the RJV maximally exploits these, this will increase the incentive to operate two labs.

The second issue is that of avoiding duplication – market failure (d). This issue is most acute when research paths are perfect substitutes and when the RJV chooses to share information. However, as noted by Katsoulacos and Ulph (1998a&b), even in this case, there is no automatic presumption that the RJV will necessarily choose to operate a single lab. If R&D were non-stochastic, then, in the circumstances just outlined, the RJV would certainly operate a single lab. Given the stochastic nature of R&D, however, there can be some benefit to operating two labs, since it increases the chances that at least one succeeds.

When the RJV decides not to share information, or, as noted, when there are complementarities then other factors come into play favouring the operation of two labs. Thus, in summary, in this section I have provided a model/framework within which to view the operation of RJVs. Within this framework we see how an RJV may be able to address market failures (b) – (g) outlined in the previous section.

Appendix 3.2
The micro-economics of technology and employment : a simple example

A special case of the translog cost function is when there is a constant elasticity of substitution between the factors (the translog allows for more general patterns of substitution and complementarity). To simplify the discussion we will work with this form. Write the production relationship as:

$$VA = T[(AN)^{(\sigma-1)/\sigma} + (BK)^{(\sigma-1)/\sigma}]^{\sigma/(\sigma-1)}$$
(A1)

Where K = capital, N = labour, VA = value added. T represents a neutral technology parameter, A is labour augmenting technology and B is capital augmenting technology. If a firm maximises profit then the labour demand equation is:

$$\log N = \log VA - \sigma \log(W/P) + (\sigma - 1)\log A$$
(A2)

The elasticity of labour demand with respect to a change in labour augmenting technical progress is given by:

$$\frac{\partial \log N}{\partial \log A} = \left(\frac{\partial \log VA}{\partial \log P}\right)\left(\frac{\partial \log P}{\partial \log MC}\right)\left(\frac{\partial \log MC}{\partial \log A}\right) + (\sigma - 1)$$
(A3)

or more succinctly,

$$\frac{\partial \log N}{\partial \log A} = \eta_P \mu \theta + (\sigma - 1)$$
(A4)

where the effect of technical change on labour demand is now written as a function of four factors: the price elasticity of product demand[22] (η_p), the mark-elasticity (a measure of market power, μ), the 'size' of the innovation as measured by its effect on marginal cost (θ) and the elasticity of substitution between capital and labour (σ) .

The interpretation of all of these results is quite intuitive and discussed in the text. Some points to note are that:

- When there is perfect competition (θ =1), and no substitution between labour and capital (e.g. if labour is only factor of production σ = 0) then for a normalised innovation (θ =1) the effect on labour demand will hinge on whether demand is

[22] We are assuming the elasticity between value added and output is unity.

elastic. If product demand is elastic (η_p>1) then employment will rise, if it is inelastic (η_p<1) then employment will fall.

- Since it is difficult to know the effect of any given measure of innovation on marginal cost, it is very difficult to compare different studies to determine the quantitative effect of an innovation – there is no natural scale of normalisation.

For further discussion of these points see Van Reenen (1997).

CHAPTER IV

CONCLUSIONS AND POLICY IMPLICATIONS

Introduction

In this chapter we examine what has been learned from the Network. We first focus on the policy lessons that have emerged from the research papers produced by members of the Network (section 1). Secondly we discuss briefly the key advances in the state of the art (discussed in detail in Chapter III). Many of these are also covered in the policy section so we focus on what has been learned for research methodology (section 2).

Innovprod was a thematic not a research network so clearly one of the crucial outputs is the way in which the European research infrastructure has been developed through joint scientific papers and dissemination of new ideas via frequent meetings. We discuss these advances in section 3.

One common theme that has emerged is the importance of the interaction between academic research and public policy. Policies provide researchers with areas of study interest but policies also can provide "experiments" which can be used to investigate different theories. For example, the introduction of R&D tax credits enables researchers to see if R&D is at all sensitive to changes in price. Such cost changes could come from other sources - a decrease in the wages of scientists due to a large exogenous in their supply (e.g. mass migration of Russian scientists to Israel in the 1990s, for example). Similarly the methodologies used by researchers to evaluate policies can be built into new policies to monitor their performance and delivery. More extensive use of randomisation, pilot studies, transparency and ongoing evaluation can benefit from the tools academics use and develop. The creation of `smart policies' which are capable of constant learning, improvement and self-evaluation could massively improve the delivery of improved EU welfare - productivity, employment and social solidarity

The structure of this chapter is as follows. Section 1 examines policy implications, section 2 looks at advances in method and section 3 describes research organisation.
The main policy recommendations are in italics.

1. Policy Implications

We follow the same structure here as in chapter III discussing first direct, then indirect policies affecting technology. We then discuss labour market policies.

1.1. Technology Policy

There is little reason to doubt that market economies do not deliver the optimal amount of R&D. In general the empirical work within the network and by others has confirmed the importance of positive externalities associated with innovation. Although in some industries there may be "too much" R&D and innovation the general assumption that some sort of policy to stimulate basic research is important has not been undermined by the empirical research. Indeed, the contribution of Griffith et al (1998) suggests that the pay-off to R&D may be even larger to most European countries as they are not technological leaders in most sectors (the productivity leader is usually Japan or the US). Thus R&D helps countries to learn from the leader through `catch up' as well as by pushing the frontier forward through innovation.

The upshot of this is that there is a good prima faciae case for interfering in the R&D market - the question is how? It should always be remembered that the costs of government failure may outweigh the benefits of reducing market failure. Even if in principle governments could do better than the market, in practice they might fail to do so.

Notice that we have focused on government policy towards the private sector. There is substantial basic R&D support through the university system and in government labs. This has received less attention (although the Arora et al, 1998, study is a start).

I summarise the conclusions rather boldly here.

Direct government subsidies have little measurable impact on economic performance

The surveys by Klette et el (1998) and Hall and David (1999) confirm that there is no robust evidence that R&D subsidies improve the performance of the companies who receive the subsidies. In Klette and Moene's analysis, for example, the firms actually do worse than their comparison groups. Hall and David focus on the evidence that publicly funded R&D crowds out private R&D through, for example, increasing the wages of R&D scientists.

Why is this? It may be that governments are picking out projects that have low private returns but high public returns (i.e. spillovers). Unfortunately the existing evidence does not support this interpretation either.

At least two possibilities remain. First, the methodologies used to identify the returns from public R&D are seriously flawed. It is true that there are very few properly conducted quantitative evaluations of technology policies. We have much more to say on this topic in section 2.

A more likely explanation, however, is that governments are poor at monitoring how well their R&D money is being spent. This is not simply because of the intrinsic problems with monitoring and evaluation, but it is because government bureaucrats simply do not have the same incentives and motivation t make spending money a success (which private sector agents do if the market is competitive). This leads us on to a policy alternative: fiscal incentives.

Tax incentives are effective in stimulating more R&D

This statement is controversial as the conventional wisdom in the 1980s was that tax incentives were ineffective in stimulating R&D. What has changed this view? Hall and Van Reenen (1999) summarise the evidence from the TSER Network and other sources. An important factor is a movement in research towards careful econometric studies which have tried to calculate the tax-adjusted cost of R&D across time, across companies and across countries. Early research generally focused on qualitative surveys of what people said instead of looking at what they actually did. A second factor is that most of the early studies focused on the USA in the early years of the 1981 Research and Experimentation credit. Subsequent research has widened the field of vision to take in European countries and look in the US over a longer period of time. It turns out that firms take a long time to adjust their R&D profiles and it is therefore necessary to look over a long time period (e.g. Bloom et al, 1999 show that the long-run effects of R&D tax credits are ten times as large as their impact effects). At first companies are unsure about the permanency of an R&D tax reform and may hold off making adjustments until they are sure that the change is not purely transitory.

The evidence from the TSER Network suggests that R&D tax incentives can stimulate more R&D, but there are costs.

First, part of the reason why there may be large effects is that R&D incentives cause a relocation of R&D activity from one country to another (Bloom et al, 1999). Member states who introduce fiscal incentives get higher R&D partly through tax competition with other member states. This is clearly sub-optimal from an EU-wide point of view as European countries fight each other for a finite number of R&D labs. This implies an important role for European co-ordination in tax setting policies.

A second problem is that the implementation of an R&D tax credit can have very perverse incentives. For example, consider the French system where the tax break is only applies to the incremental increase in R&D from the previous year (the base). In this situation firms may put off increasing their R&D as they know it will increase the size of their R&D base the next year and therefore their tax credit the year after.

Finally, some existing expenses may be re-labeled as `R&D' and real activity remains the same. These are distortions introduced into the tax system which may add to the wages of tax lawyers and accountants more than to innovative firms.

Research Joint Ventures solve many problems of R&D through design co-ordination and information sharing

Existing Research focuses on the role of RJVs through co-ordinating the amount of R&D performed. Often RJVs can reduce excessive duplication of R&D which arises in many theoretical models. New TSER research shows how the benefits of RJVs have been underestimated because RJVs are also involved in co-ordinating design (how many labs to keep open) and in sharing information.

It is also possible to show that RJVs may not always fully share information. Whenever they fail to do this it is for anti-competitive reasons and regulatory authorities need to be particularly vigilant in this regard. Where there is reason to suspect less than full information sharing, an RJV should either be blocked or pushed towards more information sharing.

1.2 Indirect Policies to foster innovation

Product market competition stimulates innovation

Micro-econometric work suggests that a powerful indirect policy in stimulating innovation is to remove barriers to product market competition. This goes against part of the "Schumpeterian" wisdom that R&D is higher in markets with less aggressive competition. It emerged from a series of empirical studies in different countries using different measures of innovation and competition. It is important to control for the reverse causality problem, of course, and the more recent studies have benefited from the recent methodological innovations in the analysis of panel data pioneered within the Network.

Competition authorities need to be vigilant because many have a tendency towards persistent domination. High market share firms have incentives to pre-emptively innovate, so left to themselves there is a tendency towards lower innovation in concentrated markets.

Regulators focus on price when they investigate abuses of market power and collusion. Our research suggests that structural policies against market power can also be justified on grounds of improved innovative potential.

Anglo-Saxon financial markets stimulate managerial efficiency through the takeover mechanism but reduce investment, especially in R&D

Even larger firms can be subject to financial constraints. We find that the financial systems in different countries have an important effect on the ability of firms to conduct R&D and other investments. We find that the UK system - many hostile takeovers, high dividend payouts, dispersed shareholders result in lower amounts of R&D and fewer firms performing R&D than in Germany.

On the other hand, an active takeover market does have benefits for productivity by forcing managers to work harder and use assets more efficiently. Thus there is a trade-off in promoting `shareholder value'. There may be less investment in long-term assets, but the use of these assets will be done more efficiently

1.3 Labour Markets and Innovation

Technology and skills are complementary with each other. Expanding skills through education and training will reduce inequality and unemployment. Blocking trade will make matters worse.

This result seems one of the few robust findings in the literature on technology and skills. This has several implications. First, policies which stimulate the supply of skilled labour are an effective way to increase the rate of technical change. Given the problems with many of the other policies and the benefits of human capital improvement for social inclusion this is perhaps the wisest form of technology policy.

Secondly, stimulating innovation through other policy measures will increase the demand for skills. If supply does not keep up then either wage inequality or employment inequality will rise. The deteriorating position of the less skilled in recent year is partially linked to just this phenomena. Exactly how much is still a matter of vigorous debate, but the Network has produced strong evidence that it is technology, rather than trade, which is responsible for a shift in demand against the less skilled.

There is no clear between employment growth and innovation at the micro-level .....

Overall there is some evidence that product innovations are associated with higher jobs growth and process innovation with lower jobs growth. The results are not very strong.

......and even if there was this would tell us nothing in terms of unemployment policy

As explained in the previous chapter (section 4.4) the unemployment rate has been stable over the very long-run even though technical change has taken place consistently. An innovation in a firm sets off a series of changes. Even if that firm shrinks in size the productivity increases make society as a whole richer. If the labour market is adaptable then the workers will be able to find employment in another company. In the short term there may be frictional unemployment problems, but longer run unemployment problems are not due to innovation per se.

The European unemployment problem does not lie in the system of innovation but in the way that labour market institutions interact with all shorts of structural shocks hitting the economy (the IT revolution being one among many). The system of wage bargaining, high regulation and benefits system are far more important than technology.

2. Research Methods

There are many methodological in the development of the Network

2.1 Development of European panel databases

Panel datasets are those where the relevant cross sectional units (e.g. enterprise, industry or economy) are observed for several periods of time. One of the major developments of the Network has been the creation and analysis of European panel datasets. Some examples of the data resources that have been created and used (and are available for other researchers):

- International database of skills, technology and production. This covers Britain, Denmark, France, Germany, Sweden , Japan and the USA. It is sectoral level and covers the years 1970-1992
- Firm data on employment, R&D and wages 1983-1990 (Britain, France, Germany, Italy)
- Firm data on investment, employment and R&D for the high tech industries (Britain, France, Germany, US, Japan, Belgium) 1970-1994
- Country-level panel data on calculating the tax-adjusted cost of R&D and fixed capital for Britain, France, Italy, Germany, Australia, Canada, Japan and the USA, 1979-1994

One of the key lessons is the importance of getting comparable measures of key variables. This involves deep research with the experts in each country to avoid pitfalls.

2.2 Econometrics of Panel Data

One of the most significant developments has been the tools for analysing longitudinal data.
Advances include:-

- Dealing with problems of `weak instruments' by developing system GMM estimators exploiting information in panel data more efficiently
- Dealing with innovation and patent count data (nonlinear GMM)
- Combining information from worker surveys with firm surveys

The models used are encrypted in software that is freely available to other researchers (e.g. Arellano and Bond's DPD-SYS software written in GAUSS can be downloaded free by anyone).

2.3 Evaluation of Policies

Compared to labour market research there is far less formal policy evaluation in the technology field. Evaluations tend to be qualitative rather than quantitative and are rarely made available to external researchers.

Creating an open platform evaluation database to enable learning from past evaluations is a priority

TSER researchers are developing and applying new tools for estimating the effectiveness of policy interventions. To do this effectively, however, policies should be introduced in such a way that learning is enhanced. For example, introducing pilot schemes with randomisation is common in US labour market policies and is being considered in technology policy.

Introducing random assignment in technology policy experiments and having these assessed by external evaluators would be a significant advance in understanding policy effectiveness

3. Research Organisation

The primary function of the thematic Network was to improve the European research capability. We have done this in many ways. The organisational structure of the Network was designed flexibly to allow researchers to follow many research paths, not just those originally envisaged by the co-ordinators. The Web-site contains a large amount of information which was used by the researchers for co-ordinating their activities www.ifs.org.uk

Naturally the projects begun under the Network are continuing and building upon the contacts formed during last three years. These are mainly research Networks such as GRIT co-ordinated by Professor David Ulph of UCL one of the project co-ordinators of INNOVPROD. There are also several applications under the new Framework involving researchers from this project such as E-TRIP (IFS, ZEW, CREST and OSLO).

There were three large annual conferences and 11 workshops over the three year period. Full details of all of these are given in the website.

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The Economics of Science and Technology: Micro-Foundations and Policy
University of Urbino, Italy: 5-6 June 1998.

Innovation, Competition and Employment
Mediterranean Agronomic Institute of Chania, Crete, Greece: 21-22 August 1997

The Economics and Econometrics of Innovation
European Parliament, Strasbourg: 3-5 June 1996

WORKSHOPS

Final workshop for the TSER Network
Brussels 26-27 March 1999

A joint workshop with MERIT is to be organised at the University of Sussex
Brighton, 19-20 February 1999.

A workshop on Innovation and Economic Change: Exploring CIS Micro Data is being organised at Delft. Delft, 12-13 February 1999.

Information and Communications Technologies, Employment and Earnings
Nice 22-23 June 1998.

Econometric Treatments of the Innovation Survey Data
INSEE/CREST 18-19 June 1998.

Competition Policy and Technology Policy
University College, London: 27-28 February 1998.

R&D Investment and Financial Conditions
CEMFI, Madrid: 24-25 October 1997.

Technology and the Organisation of Industry
University of Urbino, Italy: 20-21 June 1997.

Wage Structure, Skill Formation and Technical Change
ZEW, Mannheim: 21-22 March 1997

Unemployment, Job Creation and Technical Change
IFS, London: 8 November 1996

CHAPTER V

DISSEMINATION AND/OR EXPLOITATION OF RESULTS

As discussed above there are two ``results'' from the thematic Network. The first is the larger collaborative effort among European researchers. These are being exploited through the continuation of joint work, new applications for Networks, etc as discussed above.

The second is the research papers themselves. The main way that these results have been disseminated is through the submission and publication of papers in scientific journals as listed in the Annex. Another route is through other conferences and bilateral meetings. Members of the Commission have attended various workshops through the lifetime of the Network (e.g. Mike Rogers of DGXII in the final workshop in Brussels in March 1999). Finally, many researchers have published in national newspapers and other forms of media to talk about their findings.

It would be extremely tedious to list all the papers, their current status, etc. Part A. of the Reference section below list all the papers which have been associated with the TSER Network. I draw your attention to some highlights below

Some Examples of Dissemination			
Output	Partner Responsible	Description	Status
Special Issue of *Annales d'Economie et Statistique*, on "The Economics of Innovation"	BETA (Laisney)	Selected papers from the Summer TSER 1996 conference in Strasbourg	Published in 1998 Volume No. 49/50
Book and special issue of Review of Industrial Organisation on "Innovation Indicators"	Delft (Kleinknecht)	Selected papers from workshop in Paris 1998	Scheduled for 2000
Book on Information technologies and the labour market (MIT Press)	CREST (Laisney)	Selected papers from workshop in Nice 1998	All papers in, waitning for final referee report. 2000 publication date

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