Chapter 11

EVALUATING THE INDUSTRIAL INDIRECT EFFECTS OF TECHNOLOGY PROGRAMMES: THE CASE OF THE EUROPEAN SPACE AGENCY (ESA) PROGRAMMES

by

Patrick Cohendet[1]
B.E.T.A, Université Louis Pasteur, Strasbourg, France

Introduction

The aim of this paper is to present and discuss the experience in policy evaluation methods and practices related to large-scale technological programmes. The presentation will rely on the evaluation of the European space programmes, as an archetype of technological ("mission-oriented") programmes focused on a highly specific and narrowly predetermined end product (such as a launcher or a satellite).

Various methods have been used by major space agencies in the United States and Europe to measure the economic returns to space-related research and development. A number of approaches have been taken, including microeconomic analysis of specific technologies as well as macroeconomic modelling of long-term productivity gains. Most of these approaches have estimated very positive returns to investment in space. Since the 1960s, economists have tried to measure the economic impact of space programmes with a variety of tools. The levels of expenditure involved in these programmes are so high that public opinion is increasingly calling for an assessment of the tangible benefits accruing to the economy in return for the considerable sums invested. To this end, macroeconomic analysis combined with econometric tools has been used to assess the global impact of space expenditures (macroeconomic modelling, influence of R&D expenditures on a macroeconomic production function, etc.). A separate approach was used to evaluate the economic activity and employment directly induced by space programmes in the space industry and its suppliers (input-output analysis, use of economic multipliers). Other studies have focused on the impact of the use of meteorological or communication satellites on weather forecasting or activities related to telecommunications, as well as on the evaluation of space technology transfer policy (through the analysis of some of the markets created around or "fertilised" by space technologies). However, the wide variety of simplifying assumptions behind these models means that no single model can provide conclusive results. Moreover, many controversies remain as to the interpretation of the results. For instance, trying to justify large-scale programmes through the existence of some successful technological spinoffs (such as the "Teflon" case) was strongly criticised, and this has cast doubt on the evaluation procedures adopted.

This paper is one element in the methodological debate on the economic effects of large space programmes. It aims first to present the methodology designed by the Bureau d'Économie Théorique et Appliquée of the University of Strasbourg (B.E.T.A.) to evaluate what we consider to be the most specific economic effects of those programmes: the indirect industrial effects, also called the spinoff effects. As a practical example of the use of the methodology, we will describe the measurement of the economic impacts of projects implemented by the European Space Agency (ESA). This evaluation has two objectives: first, to obtain distinct quantitative figures that can be used to test the effectiveness of a particular programme in order to justify or not public-sector financial commitments by providing a minimum approximation of the indirect industrial effects of ESA contracts; the second objective is informative and prescriptive. It does not call into question the established status of the programme, but rather attempts to improve its effectiveness by analysing its economic, scientific and organisational impacts on those involved in the project and on their corporate environments. In other words, it depicts the behaviour and requirements of industry in relation to the management of the diffusion of technology and know-how.

In addition to the presentation of the B.E.T.A methodology, this paper will discuss some of the main issues and recommendations relating to the evaluation of government programmes designed to stimulate the economy, based on the lessons learned from evaluations of large-scale technological programmes. The main issues arise from the two main types of evaluation of large-scale technological programmes.

The first type, the evaluation of the "social" effects, addresses the direct use of the project's end product (does the use of a meteorological satellite really improve meteorological forecasts and how can we evaluate the economic impact of these potential improvements?). From this perspective, methodologies which follow more or less closely the classical "cost-benefit analysis" approach would seem to be adapted because it is generally possible to identify the activities (agriculture, transportation, etc.) affected by the programme. Then, for each type of activity, one could define variations of the demand curve that would lead to estimations of consumers' surpluses using a classical static comparative analysis. Use of this general framework raises a number of difficulties (what is the real nature of impact for each activity, how can the impact be accurately quantified, how can the relevant costs be assessed, how can alternative scenarios be assessed, etc.), but most of the techniques used have the same analytical perspective.

The second type, evaluation of the "industrial effects", addresses the problem of evaluating the spread of knowledge arising from the programme and its diffusion throughout the economy. These effects stem from the contractual relationships between the space agencies and the contracting bodies (firms and laboratories) that carry out the project. Evaluating these effects through conventional static comparative methods does not lead to satisfactory results: how can one identify the markets or activities which might have been "fertilised" by the industrial knowledge gained from the project when the routes and forms taken by the diffusion of knowledge are *a priori* totally unpredictable? The risk is that one would tend to select with a strong bias those markets where people "know that the impact is positive". The risk of bias is too strong but, even if such analysis were feasible, it would not capture the essence of the dynamics of the diffusion of knowledge. This is why we propose to develop, validate and improve methodologies based on direct interviews with the contracting bodies, which is where the process of dynamic diffusion of knowledge originates.

◊ The industrial effects are two-fold:

– First, the *direct industrial effects* comprise the effects which are directly related to the objectives of the project as defined in the contractual relationship between the agency and the group of contractors. These effects arise from the establishment and operation of an industrial infrastructure (launcher, satellite, etc.), mainly on account of the stimulation of activity (measured in terms of level of production and net job creation).

– Second, the *indirect industrial effects* correspond to the effects in terms of creation of new knowledge, transfer of technology, building up of new competences, quality improvements, acquisition of new processes, development of new markets, etc., that the contracting bodies derive from their participation in space programmes and that they are able to use elsewhere. The process expands beyond the frontiers of these contracting companies, spreading throughout the economy.

◊ The objectives of the evaluation of industrial effects can be manifold:

– First, the evaluation can focus on the measurement, for a given contractor, of the "outputs" of the knowledge process arising from his participation in a space project. According to the typology suggested by Schumpeter, these outputs can be classified in terms of new (or improved) markets, products, technologies, processes, patents, publications, etc. The methodology adopted by B.E.T.A is partly derived from this classification.

– Second, the evaluation can focus on the measurement of the learning effects within a given contracting firm. These effects include the building or reinforcement of corporate competences, the constitution of a critical mass of highly qualified employees, improvements in the acquisition, treatment or diffusion of new knowledge.

– Third, the evaluation can focus on the measurement of the learning process between contracting bodies. This aspect is becoming increasingly important in terms of the efficiency of the network of contractants in a programme. It is particularly relevant in the case of international programmes, such as the European space programmes, which are based on co-operation between firms from different countries. It is also important within the group of contractors the performances and problems specific to, say, SMEs or research laboratories.

– Fourth, the evaluation can focus on the diffusion of the knowledge gained by the contracting bodies to other sectors. This raises the critical issue of technological transfers from the space sector to other sectors, and to space from other sectors.

◊ In order to measure all these effects, we propose a very accurate methodology of direct interviews. The main features of the methodology are described in this paper (sampling procedures, identification and quantification of effects, etc.). However, two extremely important points relating to the methodology need to be emphasized:

– First, for various reasons (forgetfulness, confidentiality, human or material impossibility, etc.), many of the effects cannot be evaluated. This is why we propose to evaluate the "minimum results" – each time there is a doubt or where a range of values has to be taken into account, we will systematically record the lower limit.

– Second, the survey must be carried out in confidence between investigators and contracting companies. Not only will no individual results to be passed on to the agency in any form, but in addition, no confidential information should be passed from one contractant to another.

The paper is structured according the following plan: In Part I we attempt to define more precisely what is meant by the all-purpose term of "spinoff". Part II will be devoted to the problem of measurement, and especially to the studies carried out by B.E.T.A. in this field. Finally, some of the factors which play a role in the generation of spinoffs, as well as some issues of spinoff policy, will be reviewed in Part III.

Part I. Definition of a "spinoff"

The term "spinoff" is very often understood to mean technologies developed in the framework of space programmes and used in non-space activities. Space technologies are thus transferred and allow firms to make profits by helping them design and sell new products or services or to modify their production processes in order to enhance their efficiency. These effects, spreading throughout the economy through the sales of goods and services, purchase of licences, imitation, technical or scientific documents, etc., constitute the basis of what are commonly termed the long-term economic effects of space programmes.

However, in a much broader sense, the term spinoff is used to describe all the ways in which what has been learned in the course of one activity of a firm, in this case the space programme, is used by it or by another organisation in another context. In this sense, spinoffs should not be restricted to technology transfers: the introduction of new methods of management, changes in organisational structures, strengthening of collaboration between firms, the use of having worked in space applications as a marketing reference, the improvement of employees' know-how, could also be considered as spinoffs.

Thus a clear understanding of what is and what is not a spinoff is required. For this purpose, we will first compare spinoffs to the other types of economic impacts of space programmes. This will lead us to introduce the typology of spinoffs used by B.E.T.A. in its studies. Some examples, as well as some qualitative dimensions, will also be presented in order to emphasize the variety of cases that are covered by the spinoff phenomenon.

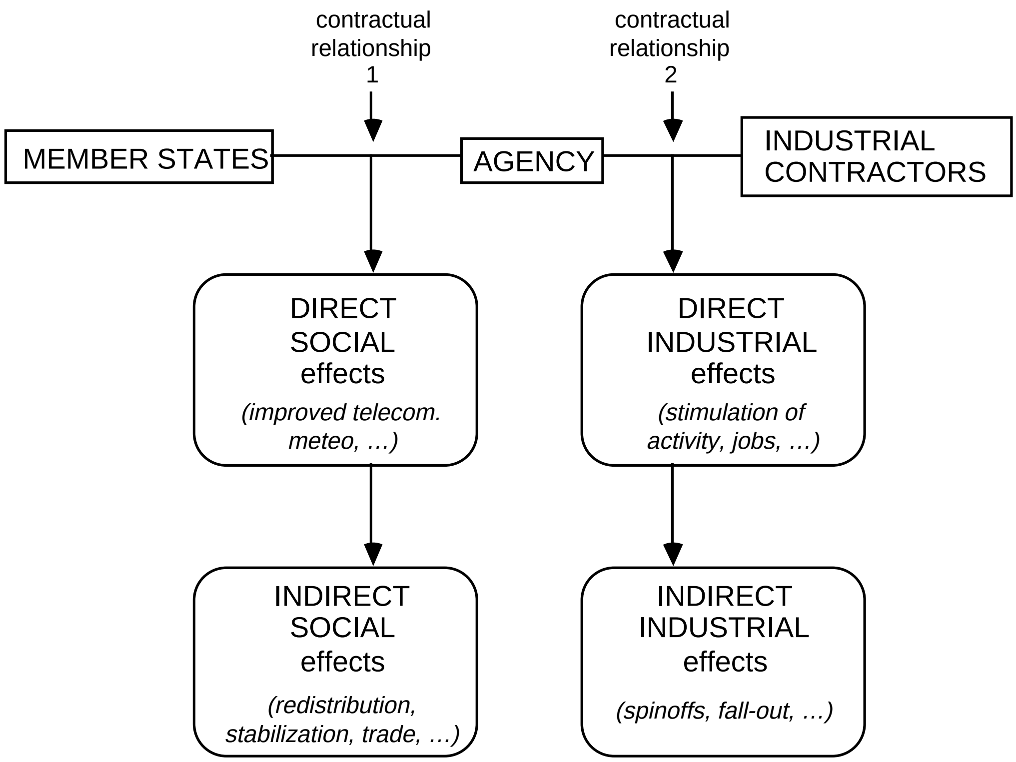
Spinoffs and the economic impacts of space programmes

The distinction between short-term and long-term effects, or between macro and micro effects are well known in the literature. However, there exists another approach, which is in many ways better adapted to the specific characteristic of space programmes.

To simplify, a large-scale technological development programme such as a space programme, with a significant financial involvement compared to the private R&D expenditure of the sector, generates two kinds of economic effect on the industrial structure: *direct* and *indirect.* Direct effects are those *arising from contracts performed within the set framework of the programme* (designers, constructors, suppliers of services and end-operators). Indirect effects are rather different in that they go *beyond the scope of the objectives of the contract* and subsequently spread throughout the economy as a whole.[2]

However, in attempting to define the nature of the full range of direct and indirect effects, we have to consider a specific characteristic of large-scale technological programmes. These programmes usually depend on a *two-fold contractual relationship*: on the one hand, between a government of a state (or of a number of states) and an Agency; on the other hand, between that Agency and a group of business contractors. Furthermore, each type of contractual relationship has its own sets of direct as well as indirect effects. For evaluating purposes it is important to distinguish between these two types: for any given contractual relationship, the related *direct effects* can be seen in terms of the *specific objectives* agreed upon between the parties, whereas the *indirect effects* correspond to *general objectives* (*e.g.* improvement of scientific knowledge, social equity, macroeconomic equilibrium, etc.). In the case of the European Space Agency, the related economic benefits are as follows (Figure 1).

Figure 1. Economic impact of space programmes



The contractual relationship between the Member States (the European countries participating in ESA) and the Agency (ESA) provides that the latter shall co-ordinate space activities with a view to establishing the operational facilities (launchers, satellites and ground control) needed to attain given political, scientific and economic objectives. In the economic sphere, the Agency is required, for example, to make operational meteorological satellites, which, by enabling more accurate weather forecasts, will lead to benefits affecting a large number of business sectors, such as agriculture, the construction industry, transport, and so on. Other economic objectives are clearly designated in connection with the implementation of telecommunication, remote sensing and earth sciences satellites. On the basis of economic objectives of this kind, stipulated in the contractual arrangements between the Member States and the Agency, we can identify a first category of direct economic effects corresponding to the benefits obtained by users of the services provided using the space infrastructure: *direct effects on the social community*, such as benefits derived from more efficient telecommunications systems, more accurate weather information, or extended knowledge of the Earth.

In addition to these direct effects, which need to be evaluated in terms of the specific provisions set out in the contracts, we can identify a whole range of *indirect effects on the social community* (or indirect social effects) that are also generated by the programme but which correspond to economic phenomena of a more general kind (cost redistribution effect in the case of structurally influential projects, possible environmental nuisance, income redistribution effects, etc.).

The contractual relationship between the Agency and the group of project contractors requires the latter to carry out – generally according to very stringent technical and quality specifications – the industrial projects laid down by the Agency. We can link to that relationship a set of *direct industrial effects* arising out of the establishment and operation of an industrial infrastructure, mainly on account of the stimulation of activity (measured in terms of production level and net job creation) stemming from orders for the construction of launchers, satellites or ground control centres.[3] Measurement of these direct industrial effects is often based on objective factors corresponding to marketable services on fully known markets.

The *indirect industrial effects* (often collectively described as "spinoffs" or "fall-out effects") include all the benefits in terms of technology, know-how, corporate image or business contracts, which Member State firms derive from their participation in ESA programmes and are able to use elsewhere (this constitutes a "first circle" of effects). The process then expands beyond these firms, spreading first to the customers and suppliers of the contracting companies and subsequently throughout the economy.

An extensive typology of spinoff

In economics, spinoffs are traditionally compared with externalities, and more precisely technological externalities. According to Griliches (1979; 1990), two kinds of externalities exist. In the first case, technologies developed or enhanced in a given sector of activity are embodied in marketable products, and the economic advantages related to this kind of externalities appear in the sale and purchase of these products on markets. Firms which sell or use these products are thus able to increase their incomes, while consumers benefit from new or better and more efficient products.

The second kind of technological externality corresponds to the spread of knowledge and its impact on the research endeavours and more generally the activities of other sectors. Knowledge can be transferred without direct links between sectors, and it is conveyed in many ways (personnel movements, reverse engineering, printed articles, news releases, patents, licences, colloquia, mergers and acquisitions of firms). This was the basis of the argument put forward by Nelson (1959) and Arrow (1962) to justify public R&D expenditure: because of these externalities, and despite the patent system, firms cannot appropriate all the benefits of their in-house research; therefore their incentive to innovate is insufficient. As a consequence, in the absence of public funds, the national R&D effort may be non-optimal.

There is no doubt that technological spinoffs are central in the case of space programmes which assume the role of leader in the technological development of an industry and even of a country as a whole. NASA has been trying to promote and develop spinoffs for many years, through the Technology Utilisation Programs, and similar initiatives have been taken more recently in Europe, at the international level through the ESA pilot projects as well as at the national level, for instance through the creation of the NOVESPACE company in France.

However as noted above, the spinoff phenomenon can be seen as much broader than mere technological transfers. B.E.T.A. has proposed a typology which takes into account the different forms that spinoffs can take. Before presenting it, two of its characteristics must be pointed out. First, only spinoffs affecting contractors of the space agency in charge of the programme(s) studied are taken into account.[4] Second, spinoffs concern the non-space-related activities of these contractors as well as the space-related activities, provided that these latter are not carried out for the space agency in question.

The typology is implicitly based on the analytical framework proposed by Schumpeter (linear model of innovation). According to Schumpter, new economic configurations have an impact on products, production and sales techniques, the market, and on company organisation and methods. Referring to this theoretical background, while needing to preserve an operational character, the B.E.T.A. classification distinguishes four categories of effects: technological, commercial, managerial and work-factor effects, respectively.

Technological effects

The fundamental – and even more the applied – research work carried out in the framework of the space programmes gives rise to technological innovations leading to the emergence of new product generations and sub-systems subsequently deployed by other space programmes. It also enables a technology developed in the space sector to be applied to other industrial sectors, resulting in the creation of new products – sometimes leading to a diversification of activity – and improved characteristics (quality, performance) of existing products.

These are the classical spinoffs referred to above. From Teflon materials or miniaturisation of electronic components for Apollo to ceramic materials for the coating of the space shuttle, NASTRAN computer software for structural analysis, programmable implantable medication systems, or the power controller for energy savings in engines, one can find numerous examples of such spinoffs in US industry (see also the annual Spinoffs reports from NASA or the qualitative part of the MRI, 1971, study). In Europe, there are no systematic surveys of these technology transfers; air-bag security systems for cars derived from gas generator technology, remote-control systems for professional TV cameras or various specialised electronic devices such as hybrid components are cases in point.

Commercial effects

Commercial effects basically take the form of increased sales of products or services that do not incorporate significant technological innovation. The space agency contractors are able to take advantage of new markets that open following the space programmes, for instance at national level (*e.g.* ground control stations). Furthermore, many of these firms have acquired a quality label associated with space activities, which is likely to give them considerable competitive leverage. On the commercial level, ESA programmes – more than other space programmes – also enable some contracting companies to form closer business ties which are then extended to foster joint activities outside the space agency framework. For instance, a company operating in the space market for connector technologies was in a position to join forces with Belgian and Swedish companies to bid for a EUREKA contract in order to solve the problems of connectors operating in a hostile environment (automated station for a North Sea oil rig).

Effects on organisation and methods

Another important contribution of the space programmes consists in the innovations in managerial and production methods they have inspired, for instance in terms of quality control, production techniques and project management. These innovations result from the high standards imposed by space performance and reliability specifications (principle of zero-fault in a hostile environment). Laser technology for cutting and welding electronic control units, control of EMI/EMC and ESD problems in electronic components production, or the design of review methods, are examples of techniques and methods developed or learned by firms in space programmes and then applied elsewhere.

These effects are also the consequence of the particular form of industrial network set up for space programmes, bringing together at different levels of responsibility firms originating from very diverse industrial sectors (although not originating in space applications, the generalisation of the PERT method initiated by the US Polaris programme is a good example of this effect). In the case of the ESA programmes, competence in project management is perhaps even more necessary since production is less concentrated than in the United States and is shared among firms from different countries.

Work-factor effects

The economic effects induced by ESA programmes are to a large extent related to "people". Space departments are often regarded as training schools for personnel as well as for managers. The induced work-factor effects are related in particular to the heightened qualifications and skills acquired by the personnel employed in these programmes, which enable them to feed expertise into company departments not directly concerned with space activities. For instance, the technical staff responsible for maintaining fluids and mechanical systems, UHF radio links, etc., on the Kourou site are trained to fit into a highly disciplined framework working to stringent standards. They are later employed on oil rigs, at chemical production plants or at nuclear power stations, and prove to be more aware than most people of the importance of quality and control.

In addition to promoting this permanent enhancement of skills, in certain firms space programmes support the creation, maintenance or growth of well-structured teams of specialists, scientists, engineers and technicians that constitute what can be called the "critical mass" of the firm. The technological potential represented by this critical mass is a decisive qualification for securing contracts relating to the increasingly complex systems of all sectors of industry.

For one major prime contractor in the European space industry, ESA programmes were the catalyst that enabled it to bring together in a single team technical skills that had previously been scattered throughout the different departments of the company. Another prime contractor freely confessed that one of its main considerations was to reach a critical size, through its contracts with the Agency, so as to be able to compete with American firms. Similarly, space firms in the smaller countries, by working for the Agency, are able to retain certain specialists in the space industry and even in the country itself, and thus form national centres of advanced-technology skills.

Some dimensions of the spinoff phenomenon

While some spinoffs are "spontaneous" *(e.g.* skills improvement) or quasi-immediate (use of space experience as a marketing reference), most constitute processes which: *i)* require a deliberate policy of the space firm (set up before its participation in a space project or once the results of the latter are known); *ii)* take time (several years may elapse before tangible results are observed); and *iii)* carry costs for the adaptation of the knowledge to its new environment (typically the case of technology transfers). These costs include in particular:

- ◊ the cost of acquiring new knowledge on market needs, opportunities, existing and potential competitors;
- ◊ the cost of adapting the technology to its new conditions of use, *i.e.* to the industrial and market requirements of recipient sectors;
- ◊ the cost of adapting the firm itself to this new technology or products (for instance, education and training of production and marketing personnel);
- ◊ the cost of giving up existing products that are replaced by new ones;
- ◊ the cost of giving up or not being able to discover alternative ways of research (opportunity cost);
- ◊ the transaction costs between the space firm and the recipient firm(s) in the case of external transfers.

As far as technologies are concerned, the diversity that characterises transfers derives first from the type of technology involved; whether it relates to products, production processes or methods and procedures. In practice, transfers often concern more than one of these three aspects (for example, certain technologies cannot be used for a product unless a special manufacturing process is also used).

Another element is the extent to which the transferred technology is formalised or codified, *i.e.* the precision with which it has been possible to define its characteristics and its conditions of use. This leads to another definition of "types of technology", where technologies are classified according to their degree (or level) of normalisation. To each type of technology associated with a level of characterisation correspond sets of possible forms of transfer and of modes of appropriability.

By way of example, the characteristics of a product or process covered by the sale of a licence are "frozen" and clearly defined: the licence provides a definition of the conditions of use of the product or process; it is thus explicit knowledge. Its transfer can be regulated by market mechanisms, even if in practice this is not always the case. This also applies to all products (including software) or processes which can be used by non-space sectors more or less as they stand. In contrast, the know-how possessed by specialists is a relatively indeterminate combination of scientific and technical knowledge, work habits and experience. By definition, this know-how resides in the heads and hands of specialists, and is very often tacit or uncodified. For instance, in a firm specialised in the design and building of electronic tubes for space applications, the ability to shape the special glass for given applications lies almost exclusively in the skills of a very limited number of specialists. It is difficult for these specialists to transfer their knowledge. Sometimes, different pieces of knowledge reside in the minds of different specialists, and only the combination of these various bits of know-how allows the firm to design or produce products.[5] In almost all cases, the only way to transfer this type of technology is to transfer the specialists.

Between these two extremes range a wide variety of "types" of technologies: precise and specific technical information on a particular aspect of a technology; management procedures and production or quality assurance methods, the main features of which may or may not be easy to identify or which may offer a valid methodology; algorithms or procedures used in computer programs; technologies of which some the conditions of use are fully understood by the space industry but for which the limits of applicability have not yet been established. It should be noted that a significant proportion of the technologies generated by the space sector relates to know-how and technical expertise.

Spinoffs may involve different actors interconnected according to different patterns of agreements. These forms of spinoffs are determined by the extent to which the technology is formalised – this conditions the scope for its transfer (for example, know-how realised only by staff transfer, obviously more easily done within a company) – and by the firm's technological, productive and commercial capabilities and strategic choices.

The following types of spinoff can be identified:

- ◊ transfers within firms, between two departments or divisions;
- ◊ the creation within a firm of a new department or division;
- ◊ the creation of a new firm, for example a subsidiary;
- ◊ transfers between a space firm and a firm in the recipient sector; in the case of the granting of a licence or patent, the market is sometimes divided up geographically or is shared on the basis of industrial sectors and/or the size of the customer's orders;
- ◊ the creation of a new firm in conjunction with a firm in the recipient sector (joint venture);
- ◊ technical assistance by the space firm in product development by a non-space firm.

In all such cases, a consultancy firm or organisation may be called in. Such firms may identify technological or commercial opportunities on behalf of the space firm or the transferee, liaising between them (technology brokers) or taking part in the transfer itself (contract research organisations).

Finally, it must be remembered that the actual transfer from the space to another sector is very seldom a "pure one-way" spinoff, from space to non-space application; on the contrary, it is usually one step in the overall process of technology development. For instance, a technology is developed in a non-space sector, then used in the space field where some of its characteristics are modified; it is then transferred back to the originating non-space sector or to another sector. There are also cases of synergies in which each sector is fertilised by the other. In practice, combinations of these patterns are common.

Part II. The measurement of spinoffs

This section will be mainly devoted to the presentation of the methodology designed by B.E.T.A. and its application to the ESA programmes. However, first we will emphasize some of the issues related to the evaluation of spinoffs and the problems encountered in this type of exercise.

Issues in measuring spinoffs from R&D and space programmes

As we noted in the first section of this paper, in the economics field spinoffs are usually compared with the two kinds of technological externality defined by Griliches.

The first occurs when technology is fully embodied in products, and is related to the price mechanisms as they are taken into account by the theory of the firm. This type of technological externality can theoretically be measured in terms of the producer and consumer surpluses generated by it, and derived from the representation of supply and demand curves. The producer surplus is basically equal to his profit, while the consumer surplus is the difference between what the consumer would be willing to pay for the product (represented by its demand curve) and the price he actually has to pay for it. Moreover, if the innovative product is, for instance, a machine used by another firm, the latter may also be able to increase its profits by lowering its production costs, and by the same mechanism the innovation entails increased profits for the downstream firms and finally in the surplus of the final consumer. The difficulty of measuring these effects will depend on at least three parameters: the complexity of the relationships between suppliers at each step of the production process; the ability of price indices used by evaluators to reflect the change in the quality of the product; and the competitive structure of the industry determining the distribution between buyers' and suppliers' surpluses.

The general diffusion of knowledge from one sector to the others, and the impact on these latter represents the second kind of spinoff or technological externality. To evaluate these effects directly, apart from the technical problems of measurement, one has first to identify either the firms or the sectors where they are localised and the features of the phenomenon itself (channels, direction and path).

In practice, it is often very difficult to identify separately the two kinds of externalities. Basically, two types of evaluation are to be found in the literature using the "classical" tools of economists: estimates of private and social return limited to a particular industry or sector; and regression-based estimates of the impact of R&D expenditures on economic activity. But other more qualitative approaches have also been used in this field.

The first "classical" approach is based on the theory of the firm and the consumer/producer surplus concept mentioned above (cost/benefit approach). Apart from some earlier studies in agriculture, one of the main applications is the work performed by Mansfield and his team (1977) on 17 cases of innovation.[6] These approaches suffer from many criticisms, and we will not attempt to review them all. Two points must nevertheless be stressed. In the case of new products, the proven and stable enough demand and supply curves required for quantification often do not exist. On the other hand, this method only indicates the social and private rate of returns for "successful" innovations, and thus may not be "representative".

The second approach is based on the use of the production function, linking output (for instance Gross National Product in studies at the macroeconomic level) to various production factors, basically capital, labour and R&D [the contribution of Solow (1957) can be considered as the pioneering work in the field; Denison (1985) and the works performed by Griliches' team are among the most representative references]. Most studies attempt to estimate the contribution of R&D expenditure to economic growth by measuring the contribution of the other factors and affecting the remaining influence to a "technical progress" factor, R&D then representing part or all of this factor ("residual factor models"). Other studies link the total factor productivity (excluding R&D) directly to the intensity of R&D investment (typically R&D to sales or added value ratios); the coefficient of regression between the two elements can be explained as the rate of return of R&D expenditures [see, for instance, Mairesse and Sassenou (1991) for a good survey on this topic]. Regression-based estimates raise a number of problems: measurement of output, capital and labour factors and especially R&D "capital", the short time frame of available data on R&D, the "scope" of the R&D effect actually captured by the measure (for instance quality changes are difficult to take into account), assumption of separability of the influence of the different inputs, lack of understanding of the innovation and diffusion processes [see again Griliches (1979) for a discussion of some of these points]. In the basic specification of these models, and insofar as spinoffs are to be evaluated in this way, it should be noted that if the study is carried out at the sectoral level, the interactions between sectors are not taken into account, whereas if it is carried out at the national level, it is not possible to distinguish "what is a spinoff of what".

Thus more recently, numerous studies have attempted to specify the transmission channels of externalities between sectors, trying to identify the "suppliers" and the "receivers" as well as the nature of the links between them. In other words, the problem is to evaluate the influence of the R&D of one sector on the activity of another. Different approaches have been proposed, some considering the influence on a given sector of the R&D of all other sectors, others considering the influence of a weighted amount of R&D of the other sectors. In this second case, the weighting function is based on different assumptions (proportional to the input-output flows of intermediate consumption between sectors, to the flows of patents, to empirically determined flows of "innovations", to a "technological distance" for instance, based in the United States on SIC or NSF classifications, etc.). The results of these analyses are sometimes used in more sophisticated specifications of the production function for the purposes mentioned above; others stand alone, such as patent statistics, bibliometrics, reviews on inter-industrial flows of innovations (Mohnen, 1989). The latter are closer to the approaches that are not strictly based on consumer/producer surplus theory or production function analysis, but which often place more emphasis on the qualitative aspects of spinoffs (case studies, financial investment models, studies on skills and competences, etc.).

In this very large family, one growing stream follows the more radical criticism of the basic assumptions underlying the classical tools, such as the concept of the production function, and calls into question, for instance, the hypotheses of perfect competition, rationality of choice, technology akin to information, non-increasing returns, etc. In particular, attention is drawn to the tacit, localised and path-dependent characteristics of technologies (with learning processes playing a fundamental role), and to the interdependence between technological development and organisational forms (internal to firms, interactions between administrations and firms, networks of firms) in shaping the evolution of the economy. This approach thus emphasizes the dynamic analysis of the processes of wealth creation rather than that of resource allocation in a fixed context implicit to mainstream economics (for recent synthetic studies by authors representing this "non-orthodox" view, sometimes referred to as evolutionary economics, see Dosi *et al*., 1988). From this standpoint, the scope of spinoffs or indirect effects of R&D expenditures, and especially public R&D programmes such as space programmes, needs to be broadened; the B.E.T.A. typology of indirect effects provided in the first section of this paper is in some ways close to this kind of "evolutionary" approach. Nevertheless, in this field, the diversity of evaluation methods has so far prevented the development of a standard, universally applicable methodology.[7]

In the field of space programmes, various estimates of the spinoff phenomenon have been made using the methodologies briefly described above. Most were conducted in the United States. The production function approach was for instance applied by MRI (1971, 1988)[8] to NASA programmes; cost-benefit calculations were completed on some secondary applications of NASA programmes (MATHEMATICA, 1975), and on the NASA Technology Utilisation Program (see, for instance, MATHTECH, 1977; Johnson and Kokus, 1977). A large body of studies focused on the NASA TU programme, using miscellaneous indicators (cost-benefit related approaches, sales and cost reductions for users of NASA technologies, statistics on commercialisation of patents or licences; see again Johnson and Kokus, 1977; and Chapman *et al.*, 1989). Most of these studies are described in Hertzfeld (1985). We will now present the analyses completed by B.E.T.A. in this field (B.E.T.A., 1980; 1988; and B.E.T.A./H.E.C., 1989).

The B.E.T.A. methodology

General presentation

The main features of the methodology designed by B.E.T.A. can be summarised as follows:

- ◊ the evaluation is limited to the indirect effects/spinoffs affecting ESA contractors;
- ◊ it is based on first-hand data, obtained through direct interviews with the managers of the ESA contractors, and carried out by B.E.T.A. staff;
- ◊ the inventory of indirect effects is thus of a microeconomic type, but since the sample of firms can be considered as statistically significant, the result may be extrapolated to the whole set of ESA contractors;[9]
- ◊ the objective of the evaluation is two-fold: *i)* qualitative, since it aims to describe the spinoff phenomenon in more detail; *ii)* quantitative, since it aims to provide a minimal estimation of its importance;
- ◊ the scope of the spinoff phenomenon studied corresponds to the typology proposed in Part I above.

The economic indirect effects studied by B.E.T.A. correspond to the different learning processes undergone by firms during their work for ESA, affecting them in many varied ways (widening of scientific, technical and “organisational” knowledge, innovation in products and procedures, new links with new external organisations, etc.), and applied to activities other than ESA contracts (space- or non-space-related activities). In fact, while the economic effects of large R&D programmes are likely to spread to the whole economy, it seems clear that the phenomenon of “wealth creation” first appears in the organisations contracting with ESA, where they obviously have their origin and first concrete application in economic terms. Such a choice implies that the B.E.T.A. methodology does not allow the estimation of the long-term effects of ESA programmes on the economy as a whole.

The procedure followed was to make as exhaustive an inventory as possible among ESA contractors of the indirect effects resulting from ESA programmes and to identify the various forms these may take. For this purpose the typology of indirect effects presented in Part I was refined and gave rise to the following classification (Table 1).

Table 1. B.E.T.A. classification of spinoffs

TECHNOLOGICAL EFFECTS	COMMERCIAL EFFECTS
Derivatives from ESA products New products Diversification Product improvement	International co-operation New sales networks Use of ESA as a marketing reference
EFFECTS ON ORGANISATION AND METHODS	**WORK-FACTOR-RELATED EFFECTS**
Quality control Project management Production techniques	Formation of a critical mass of specialisats Improvement of workforce skills

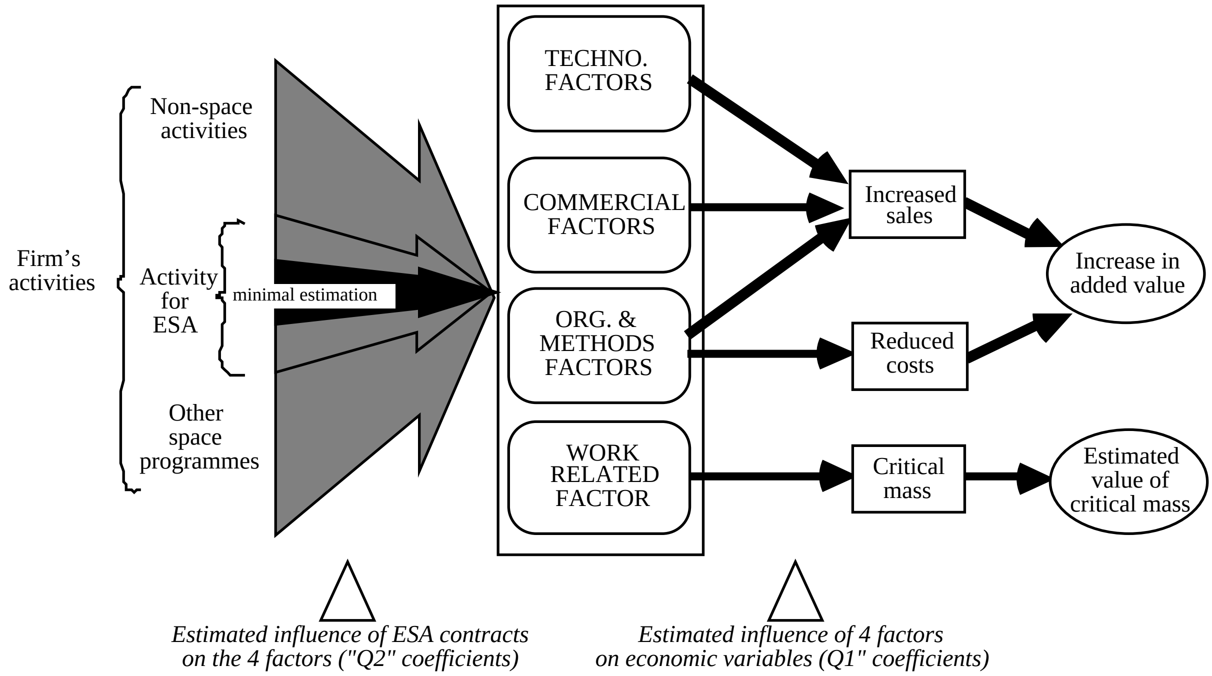
Quantification of the effects

The final unit of measurement used to express indirect effects on a firm is the value added (the sum of the firm's wages and profits), together with the estimated value that results from setting up and maintaining highly skilled design and production teams (defined above as the "critical mass"). The quantification exercise thus consists in determining how the work carried out for ESA programmes affects these two parameters; the process is illustrated in the diagram below (Figure 2). The contracts that firms obtain from ESA, like all their other activities, affect the four basic factors corresponding to the four types of effects described earlier (technological, commercial, organisation and methods, and work-factor-related effects). These in turn contribute to increasing the volume of sales and reducing costs and thus, under some circumstances, to increasing the firm's added value. The work factor also specifically affects the critical mass, which is estimated in a broad fashion on the basis of the payroll of the staff concerned.

In the case of *quantification by sales*, the managers interviewed were asked to estimate, as a percentage, two sets of coefficients:

- ◊ Those (Q1) accounting for the parts played by the three factors, respectively Technology (Q1T), Commercial (Q1C) and Organisation and Methods (Q1OM), in influencing sales; their sum must be equal to 100per cent. Q1 does not therefore refer exclusively to the firm's ESA activity.
- ◊ Those (Q2) accounting for the parts played by ESA contract work in each of the three factors above (respectively Q2T, Q2C and Q2OM); they must be between 0 and 100 per cent. They are very often based on objective data such as the share of ESA funding in the development of the product in question. The industry representatives also specify the exact nature of the influence of ESA contracts expressed by Q2 in each of the three categories.

Figure 2. Principle of quantification of indirect effects



These figures are, of course, relative to the sales of the product which constitutes the indirect effect in question. The final result is obtained by multiplying these two sets of coefficients by the increase in added value caused by the increase in sales:

TECHNOLOGICAL EFFECT: Sales x rate of added value x Q1 x Q2T

COMMERCIAL EFFECT: Sales x rate of added value x Q1C x Q2C

ORGANISATION AND METHODS EFFECT: Sales x rate of added value x Q1OM x Q2OM

It is also possible to extend the scope of the evaluation by including those suppliers of ESA contractors who helped to make the products among the items which constitute indirect effects as defined (in this case, the complementary of added value to sales is discounted). However, the distinction between technological, commercial and organisation and methods effects is no longer relevant, since the suppliers do not benefit from an ESA experience, but only from sales opportunity. This gives:

EFFECT FOR SUPPLIERS: Σ[SALES x Q1 x Q2 x (1 – rate of added value)]

In the case of *quantification by cost reduction,* the data are quantified using savings on inputs, lower reject rates or savings in production time. This is calculated:

◊ directly, by adding up the savings made thanks to methods acquired under ESA contracts;

◊ indirectly, by multiplying the following data: amount of savings made thanks to a particular method and percentage of influence of ESA experience in implementing that method (Q1).

In the case of *quantification of the critical mass*, for reasons of homogeneity, the quantification is made in monetary terms by taking into account the average cost of an engineer working in the space division. The effect thus measures the minimum cost the company would have had to bear in order to qualify for space contracts if it had not been able to benefit from ESA contracts.

The data were quantified by the representatives interviewed in three stages:

- ◊ estimating the firm's critical mass in terms of the number of people in the space sector; managers often provide at the same time a distribution of the number of specialists by field of technology;
- ◊ estimating the share of the critical mass which is created or maintained by ESA contracts; industry representatives either give overall estimates in percentage terms or examine the given fields of technology one by one;
- ◊ multiplying the number of people making up the critical mass by the average cost of an engineer for the company.

Finally, additional information relevant to each of the indirect effects identified was collected (technological areas giving rise to it, application areas in which it occurred, time lag, etc.), so that the results could be analysed in detail.

This relatively complex procedure is designed to meet two essential requirements. First, it must be possible to isolate the specific contribution made by ESA contracts from the firm's other activities, so as to allow for the fact that technologies or production methods often stem from developments made in a number of different programmes over a period of time.[10] Secondly, the purpose of the study is to provide a minimum estimate of the volume of indirect effects rather than to set a precise value on them (given, for instance, that some items may be overlooked). Consequently, the corporate managers taking part in the survey were asked to assess the influence of ESA contracts in terms of an estimated range, of which only the lower figure was used for the final calculation.

Findings of the ESA programme evaluations

Overall results

Under this heading, we will describe the results of different evaluations performed by B.E.T.A. since the late 1970s, bearing on the indirect economic effects of ESA programmes. The overall results are arrived at by adding the effects observed with respect to the contractors and their suppliers (see explanation above): it is the total value of indirect effects identified by B.E.T.A. These are shown in Table 2.

This result can be expressed in the form of an overall economic spin-off coefficient, representing the ratio between the total value of the indirect effects generated by the ESA contractors surveyed and the total payments made by ESA to those contractors during the period covered by the study. It means that, on average, for the sample of firms studied, every 100 units paid by ESA to industry results in a minimum indirect economic benefit of around 300 units via the ESA contractors forming the sample.

Table 2. Overall results of the B.E.T.A. studies

	ESA 1980	ESA 1988	Canada 1989
Period covered	64-82	77-91	79-93
Number of firms in the panel	128	67	10
Total indirect effects	7 551 (MAU 86)	12 680 (MAU 86)	256 (MAU 89)
• among ESA contractors	6 023 (MAU 86)	9 214 (MAU 86)	189 (MAU 89)
Ratio effects / contracts	2.9	3.2	3.5
Indirect effects outside space sector	50 %	21.1 %	24.4 %
Indirect effects on exports	28.2 % (out of ESA Member States)	12.8 % (out of ESA Member States)	66.4 %
Nature of the effects (% of contractors' effects)			
Technological	25	32	40
Commercial	27	8	18
Org. & Methods	19	6	18
Work factor	29	54	24

Moreover, this figure should be seen as a conservative estimate, for at least three reasons. First, as mentioned above, the study takes no account of the long-term effects on society as a whole; second, some effects inevitably escape the interviewers while others are impossible to quantify (only 60 to 70 per cent of the identified effects were quantified); third, the option taken for the quantification exercise was to always retain the lower boundary of the figures provided during the interviews.

Nevertheless, this coefficient may prove somewhat confusing, because a single figure cannot express the wide variety of indirect effects studied,[11] and may give the false impression that all the economic effects of space programmes are covered. Another shortcoming of this kind of presentation is that readers could be tempted to compare it with results from other studies based on completely different approaches such as, for instance, those based on the use of production function analysis. For these reasons, the detailed analysis provided below is undoubtedly more interesting. However, it should be noted that the overall results obtained from the three studies carried out by B.E.T.A. are quite similar; this suggests that there is a certain homogeneity between the European and the Canadian "performances" as regards indirect effects, despite the different characteristics of the space industries studied. Incidentally, it also proves that the method developed by B.E.T.A. is both repeatable and transferable to a certain extent.

The results set out in the rest of this paper are expressed in terms of added value, given that they correspond to the fraction of the effects observed at the level of the contractors. We will also focus on the ESA 88 study results.[12]

Breakdown by type of indirect effect

The indirect effects for the contractors can be broken down into different categories according to their nature; within each broad category, "sub-categories" can be distinguished.

The main part of the indirect economic benefits from the ESA programmes relates to product technology, together with the enhanced potential of the design and production departments of the companies involved. In contrast, the commercial and organisation and method effects are relatively slight, whereas the four types of effects carried more or less equal weight at the time of the 1980 study. It should be noted that, in the case of Canada, the breakdown shows that technological benefits are clearly dominant, the three other effects being close to one another in size (the "Canadian critical mass" being supported by Canadian or US programmes).

The *technological effects* generated by the European space programmes increased considerably during the period considered, confirming the trend observed at the time of the previous B.E.T.A. study. We also found a time lag of about five years between the marketing of a product and the ESA programme from which its technology was wholly or partially derived (the "incubation" phase for know-how applied to new products).

The *commercial and managerial effects* increased very slightly during 1977-91, but were in sharp decline compared with 1964-82. There a number of explanations for this two-fold trend: the fading novelty of the ESA connection; the stability of the network of companies working in the space sector up to 1986-87 (restricting opportunities for fresh contacts); the emergence of new programmes tending to reinforce co-operation at the European level (EC programmes, growing internalisation of the aerospace industry); the fact that the production methods imposed by ESA were by then common and were not being renewed, and so on.

The *work-factor effects* increased in step with an evolutionary trend in the space industry. In most of the companies surveyed, we found an ongoing process of structural expansion of the space activity, with the original space project team becoming a "Space Department", then a "Space Division" and in some cases, a self-contained subsidiary. This work-factor effect is, of course, linked to ESA expenditures and it can reasonably be expected to continue tp grow in step if the three major programmes scheduled by the ESA (Ariane 5, Columbus and Hermes) are completed, since they should enable the European space industry to cross an important technological threshold.

Further analysis

Thanks to the different qualitative information received from the managers interviewed in connection with each case, it is possible to analyse the results from different standpoints. One approach consists in classifying the induced effects according to the space technological speciality from which they derive, and the space technological speciality (if the effect remains in the space sector) or the industrial sector where they take shape. In other words, a distinction is made between indirect effects within and outside the space sector. Another view proposes classifying the indirect effects according to the type of firm in which they were generated. We will examine this second type of results in Part III of this paper.

Effects within and outside the space sector

The results of this analysis are summarised in Table 3. Although they remained constant in value terms, the effects recorded outside the space sector accounted for a smaller proportion of the total indirect effects than was found in the 1980 study (20 against 50 per cent). This trend seems to correspond to the process of building up a major European space industry during the last 10 to 15 years, which caters mainly for the "commercial" space market – as reflected in the increase in the size of the highly skilled workforce and in the impact of the technological effect (sales to the private sector of systems developed in the course of ESA programmes).

Table 3. Indirect effects outside the space sector/ESA 88 study

21.2 per cent of total indirect effects

ORIGIN		FALL-OUT APPLICATIONS	
Space technology area	% total effect	**Industrial activities**	% total effect
On-board equipment	31.1	Aeronautics	31.3
Production & testing equipment	19.6	Defence	29.5
Power supply & storage	11.7	Data processing	8.1
Ground equipment	9.6	Electronic equipment	7.8
Design & methods	9.0	Telecommunications	6.5
Telecoms systems	6.5	Medical equipment	5.8
Structures and mechanisms	5.9	Transport	4.5
Propulsion	3.8	Energy	2.8
Thermal control	1.6	Design engineering	1.8
Attitude & orbite control	0.9	Others	1.9
Optics	0.3		------
	------		100
	100		

The indirect effects observed inside the space sector reveal that there is very little synergy between the different technology areas. Most of the effects are concentrated in areas where there is a "commercial" space market, satellites or launchers ordered by Arianespace (telecommunication and propulsion technologies and the like). Outside the space sector, the majority of the indirect effects are generated in the aircraft and defence construction divisions of ESA contractors. In fact, many of the companies in the space industry, especially the largest ones, are usually active in both sectors. The technology areas most likely to generate indirect effects outside the space sector are those whose applications cover several industrial sectors and can be more readily transferred. In contrast, those applications that fall more specifically within the space sector generate fewer indirect effects. These findings confirm the existence of a synergy effect between sectors which have similarities at both the technological expertise and organisational levels ("technological clusters" analysis). It also appears that some companies encounter organisational obstacles to converting from an innovation-oriented space activity characterised by increasingly complex systems and very small scale of production, to a commercial non-space type of production based on standardized products to be produced in large series. These difficulties are mostly related to readapting a corporate culture ruled by the observance of quality standards that are often too strict for direct application to a non-space activity (see Part III).

Technology transfers (or "classical" spinoffs)

We were able to extract from the database on indirect effects those effects that are more traditionally called spinoffs, *i.e.* technology transfers. They are clearly set apart from other indirect effects by the fact that they require technological content, a non-space recipient sector and a deliberate policy on the part of the firms making the transfers. The analysis, undertaken solely from the point of view of the transferring party (the ESA contractors), leads to the identification of 133 cases of technology transfer based at least in part on knowledge acquired by firms working on ESA programmes. The results are shown in Table 4.

Table 4. Technology transfers: some results (ESA 88 study)

Number of transfers	133
Total value of transfers	2 179 MAU 86
to contractors	1 345 MAU 86
Transfer coefficient (transfers/estimated payments)	0.6
Technology transfers as a % of total of indirect effects	17.2 %
Internal transfers	84.8 %
External transfers	15.2 %
Product technologies	61.2 %
Process technologies	10.3 %
Procedures	20.8 %
Others	7.8 %

Transfers represent 17.2 per cent of the total indirect effects, and the bulk involve product-linked technology (61.2 per cent), with or without adaptation of the technology concerned, and project or quality control procedures (20.8 per cent). So, space transfers give rise above all to new products, while on the other hand, few production processes developed for space purposes are transferred between firms.

The space technology fields that generate most transfers are those relating to on-board equipment (32 per cent) and to production and test equipment (24.5 per cent). The main recipient sectors are again aeronautics and the defence industry.

A very large proportion of space technology transfers are internal (85 per cent of the total), *i.e.* in the direction of other activities of firms working in the space field. The majority of external transfers (the remaining 15 per cent of the total) are towards sectors further removed from the space industry (transport, electronics), sometimes in the context of international co-operative projects.

Part III. Managing spinoffs: Key factors and policy issues

In this section we will look closely at the mechanisms of spinoffs and at the factors determining their success or failure.[13] If we leave aside important, but rather obvious, factors, such as the need for the "existence of a market" or of an "efficient management of technology transfer projects", it appears that the elements presented here play an important part in the existence and success of spinoffs. Corroborating evidence of the significance of these factors was obtained by correlating empirical studies, especially B.E.T.A. studies carried out for ESA, and the replies to a questionnaire sent to European space firms (this analysis is detailed in B.E.T.A., 1989). We will not classify these factors by order of importance: recent developments in the Contingency Theory of Organisational Innovation show that the performance of an organisation in terms of innovation, covering differents aspects such as administrative and technical issues (Mintzberg, 1979), product and process (Utterback, Abernathy, 1975), or radical versus incremental innovations (Schumpeter, 1934), depends more on the conjunction of several factors (relation of "congruence") than on each type taken separately [see, for example, Damanpour and Evan (1984) for an analysis of innovation as a multidimensional phenomenon].

Some factors have a general influence on the transfer of space technologies to other sectors, and mainly concern *structural* elements of the industrial network potentially involved in such a phenomenon. Others specifically affect internal spinoffs (within a single firm or company) or external spinoffs (between firms), and are linked more to the *behavioural* dimension of the transfer inside and between the industrial structures at stake, emphasizing the role of individual capabilities and the communication between them. Their importance varies according to the different types of spinoffs as defined in Part I. In relation to these key factors, we will present some policy actions taken at the micro or macro level in order to provide the conditions for successful spinoffs.

Structural factors

The technological complexity of space activities

The argument here is based on a "congruent" property according to which the higher the level of complexity of the technology, the more important the potentiality of transfers. A complex technology and all the R&D efforts associated to it should generate more technical ideas, and consequently more potential sources of innovation. From this point of view, both technologically and organisationally, the space industry ranks among the most complex areas of activity, whatever the indicator used to express this complexity [number of elements and linking as in Ayres (1987); R&D intensity representing the effort required to reduce the uncertainty in technological development as in Hugues (1988) or Lambert (1991)]. Thus, space technologies theoretically have the greatest potential for solving the less complex organisational and technical problems encountered in other sectors. Nevertheless, if this assertion may sometimes be accepted when thinking of technology, it cannot be accepted so easily if we think in terms of products and processes. Space technologies and products are very often seen as too sophisticated and over-qualified for commercial application; space staff suffer from the same criticism, being considered unable to design commercial products using current technologies.

The technological proximity of the receiving sector

The adaptation work, and associated costs, required by transfers from the space industry will be less (and the volume of transfers that much greater) where the transfer is towards sectors which have features in common with space technologies. Two aspects should be distinguished: the generic (common to several industrial activities) or specific nature of the space technologies concerned; and the technological proximity of the space and recipient sectors.

These two aspects, and particularly the second, lead to the application of the technological bunching strategy (also called "technological cluster"), generally defined as a systematic search for combinations between different sectors of technological activity. At least two phases have to be distinguished for the control of the combinatory feature of the different technologies (Zimmermann, 1986). One is the management of a minimal scope of know-how during the constitution of the space technology; the other corresponds to the exploitation of the technological similarities between the space sector and the recipient needs. Several studies show that the larger the span of technological specialities controlled by the firm, the higher the control level of a transfer involving different sources of technology. Furthermore, Teece (1988) shows that all along the technological transfer process, in addition to the complementary feature of the different shapes of know-how in the firm, more logistic and downstream skills such as marketing and distribution problems are also important. The situation of the space activity is unusual and covers the main fields of scientific knowledge on which industrial activities are founded. From this point of view, the space industry is privileged in terms of its strategic situation for transfers of technology.

For instance, it is interesting to note that space activities have developed more frequently among large companies initially involved in aeronautics and defence systems. Many similarities exist between these activities and the space department. Many of the technical solutions included in the first generation of launchers in Europe had their origin in aeronautic and defence knowledge. The quantitative results of the B.E.T.A. studies on the performance of the European space industry provide a significant illustration of this phenomenon, as shown in Part II.

The nature of the firm

Two interconnected aspects are covered here: the size and the position of the firm inside the network of R&D programmes in which the technology originates. We emphasize that these two structural dimensions influence the industrial learning process of the firm, and hence the type and amount of spinoffs that it is able to generate.

Previous studies based on the combinatory feature of technologies lead us to believe that large companies are in a better position than small ones because of their wider scope of know-how.

However, the highest capacity to generate technological synergies is certainly reinforced by the financial capabilities for new ventures. Financial aspects could play an instrumental role in transfer strategies when the latter imply high costs of technological adaptation for the user. For Porter (1980), for example, the size of the firm is important in the implementation of an R&D programme where large scales of production are at stake.

The results of the B.E.T.A. studies provide partial and somewhat contradictory elements on this point. The B.E.T.A. team studied to what extent the size of firms affected the likelihood of their generating indirect effects, and took particular notice of the results of small and medium-sized firms, divided into two types: "general" firms, with a staff of under 1 000 employees on all types of work (25 firms in our sample), and "space" firms with a staff of under 100 engaged in space work (30 firms in our sample).

It is clear from the study that these two classes of firms generate proportionately more indirect effects than the overall sample of firms (coefficient of 3.5 and 4.1, respectively, for the two types of SME), and that these effects are generated largely outside the space sector (34 per cent and 61.2 per cent, respectively). These firms also produce more commercial effects, but tend not to form a critical mass of employees. It should be noted that the "space" firms include a number of large firms engaged in space activities on a relatively modest scale. These firms appear, however, to generate the most indirect effects, particularly outside the space sector, no doubt because of the interaction of technological and organisational factors and because they have the money to finance space technology transfers.

It would seem that a "contingency" vision is required to find a significant relation between size and technological efficiency, pooling different influencing factors such as the size of the company, the existence of a scope of activities and the firm's internal communication system. In any case, interpretations can be drawn in this direction from our empirical results. An interesting complementary point in relation to this question is indicated by the second feature determining the nature of the firm; that is, its position in the industrial network set up for space programmes (in this case ESA programmes).

For this purpose, the correlation between the level of responsibility of ESA contractors and the indirect effects they generated was analysed to see whether there was a link between the various functions performed by firms and the indirect effects on them (Table 5). ESA contractors were divided into four categories: prime contractors, system developers, equipment developers and service providers.

The prime contractors, and to a lesser extent the sub-system developers, tend to concentrate their efforts on the space market and are required to maintain a highly skilled workforce. They also gain experience in managing complex international projects, experience that can subsequently be put to good use in other programmes. Prime contractors tend to diversify more (creation of new activities or a new division), no doubt because their size and financial position allow them to do so. The firms generating the most significant indirect effects, especially outside the space sector, are the equipment developers. They are generally innovative, medium-sized or large firms with a small space department, using generic technologies to manufacture components and they are quite capable of moving on to mass-production. They are in "direct contact" with the technologies, and therefore most of the indirect effects they generate are related to technology or production processes. Tese firms tend to be large companies with a "small" space activity or small firms integrated in a large network, thus corroborating the importance of the factors of size and variety of know-how for a strategy of transfer.

Finally, few indirect effects are observed among service providers because these firms usually make use, in the context of ESA programmes, of skills already developed elsewhere. The type of transfers realised by the service companies confirms the importance of their position in the network, whereas approximatively 80 per cent of their transfers are linked to administrative innovations such as methods and quality control procedures in relation with their participation in ESA work (studies, consultancies, assistance and maintenance).

Table 5. Analysis by contractors' level of responsibility (ESA 88 study)

	INDIRECT EFFECTS (% of total)	**RATIO** indirect effects / contracts
PRIME CONTRACTORS	36.6	2.0
SYSTEM DEVELOPERS	36.1	2.3
EQUIPMENT DEVELOPERS	22.5	3.9
SERVICE PROVIDERS	4.8	1.8

Decision-making procedures and financial criteria

The last feature of the structural factors to have some impact on the transfer of technological knowledge concerns the framework structuring the company's decision-making process, and the place that a transfer can take in that framework. The traditional decision-making framework is based on financial analysis, *i.e.* the comparison of flows of returns and flows of expenses through such criteria as return on investment or net present value. While the majority of investment projects are analysed inside the company on this basis, technology transfers are often perceived as "extraordinary" projects. As its rentability is not immediate and is seldom easy to express in terms of financial gain, a "non-orthodox" project can be viewed as inadapted to the usual decision-making framework of the firm. Therefore, a strategy of transfer could be a source of problems *vis-à-vis* the firm's financial authority; this handicaps and restrains the development of this type of project.

According to the managers interviewed, the more the technology is formalised, or specified, the easier it will be to determine its impact on the technological choices of the receiver, and then to give figures for potential markets. In the case of the purchase of a patent on a product, evaluation appears easier in the sense that classical parameters for criteria can be deduced (production cost, market size, expected profit, etc.). However, if the technology is less formalised, containing some form of tacit knowledge, the real impact of its transfer on the reconception of the receiver's products, on the resources required for its production, and on the markets it will allow the firm to reach, will be difficult to determine. More generally, it would seem that for the majority of technology transfers, strong uncertainty bears on the financial gains. Several market studies are sometimes required to demonstrate the commercial interest of a transfer. These studies require approval at the highest level of the hierarchy, and very often the R&D department or engineers/scientists initiating the project are unable to provide enough evidence for a non-routinised activity.

The rationality of the manager justifying the relevance of these criteria corresponds to a substantial rationality, *i.e.* emphasizing the financial results of a choice. In fact, a different representation of that rationality could provide a more appropriate framework for accounting for the positive aspects of a transfer within the decision-making procedure. This is what Simon calls "procedural rationality" in which the elements of appreciation of a project go beyond the strictly financial dimensions to incorporate some of the qualitative features of the investment (higher flexibility, organisational learning, new technological opportunities, etc.). We can observe that most of the time, the existence of a policy of technology transfers in a company depends on the consideration of qualitative aspects in the decision-making process, *i.e.* the introduction of procedural elements into the traditional financial framework. To summarise, spinoffs will depend on the firm's ability to reconcile, in determining its transfer investment policy, conventional cost-benefit criteria (expected profits, time taken to achieve a return on investment, etc.) and more qualitative criteria (new technological openings, acquisition of expertise, company image, etc.).

This last category of factors, linked to the usual framework of decision making in the firm, shows how individual and behavioural dimensions are necessary in order to go beyond what is commonly allowed by the structure. Two different aspects of the problem of transfers exhibit strong interactions with the human factor. One concerns the notion of technology itself and emphasizes its tacit dimensions having some impact on the process of transfer of knowledge. The other is related to the role of communication, both formal and informal, in the development of new ideas within the organisational framework.

Individual and behavioural factors

The problem of transaction costs

According to the theory of transaction costs developed by Coase and Williamson, collaboration between different organisations induces some costs, generally related to the meetings required for the negotiation and the fulfilment of contractual forms, and leads to a lengthening of the reaction time required for elaborating a decision (de Jong, 1988).

One direct and important application of this development to the problem of technological transfers is that the transmission of the information related to the technology and the body of knowledge "all around it" is often the most costly operation. As mentioned in a new development of this theory by Teece (1980; 1982), transfer of technology is not only the exchange of a "commodity" or a piece of codified information, it also includes a large proportion of non-explicit know-how and knowledge.

In this respect, the translation of the technological know-how into a language understandable by the technology user proves to be a serious obstacle. Therefore, in considering the tacit or non-specified part of the technology, a strategy of transfer between two organisations requires either a similar learning process to enable the user to build up the same information, or important efforts for the supplier to formally specify the know-how embodied in the technology and make it explicit and comprehensible for external organisations.

The process of expliciting the technology certainly represents an important source of transaction costs and can be avoided in large companies which can organise internal transfers by simply moving people around or, as we have observed in the European industry, by diversification corresponding to the creation of a new department with employees of the organisation or, indeed, by the creation of a new company by engineers. A "mix" of these three different solutions is often observed, such as in cases where specific task-forces are created involving staff from both the supplying and receiving companies. The most advanced form of this type of collaboration is probably a joint-venture strategy.

The organisational dimension

Some of the arguments described above point to several significant difficulties encountered when implementing a strategy of technological transfer from one organisation to another. It sometimes results that a company will initially attempt to organise an internal transfer in order to avoid some of the transaction costs. This choice is corroborated by our evaluation of the space industry which indicates that 85 per cent of transfers are internal to companies. However, if some of the barriers to transfer can be overcome in this way, others persist due to the organisational dimension. The causality link between technology development, to which spinoffs contribute, and organisational structure, has been the subject of a huge literature. An evolutionary perspective on spinoffs, and more generally on the diffusion of the technologies, indicates two kinds of barrier to transfers.

The first concerns the degree of decentralisation of an organisation required in order to provide new issues in the utilisation of the technology. This argument emphasizes a relationship where the organisation has an impact on technological performance. Thus, in the phase corresponding to the *development of the technology* in the industrial organisation, it appears that some properties in the organisational structure (existence of vertical links, degree of decentralisation of decision making) condition not only the stimulation of new ideas by cross-fertilisation between the various fields of activity of the firm, but also have an impact on the transaction costs mentioned above.

In particular, "mutual adjustments" – informal communications between people in the organisation – seem to play an important role in the dynamics of new technological developments (Mintzberg, 1982). On the other hand, a multi-product company will generate "economies of scope", that are savings due to "shareable inputs" (in particular intangible inputs such as knowledge), common to several activities or with the possibility of affecting them to different projects (*e.g.* engineers) (Teece, 1980; 1982; Levy and Haber, 1986). Organisations using matrix structures, often seen as the attribute of innovative organisations, combine informal relations and economies of scope. A study of European firms in the space sector would seem to confirm that this phenomenon occurs when these firms follow a matrix organisation as opposed to independent departments. The MBB-ERNO company considers that using this strategy its total critical mass was reduced by one-third. However, it is interesting to note that according to the majority of the managers interviewed, the matrix shape is not necessary and other types of structure have the properties described above.

A second type of barrier exhibits an inverse relationship between technology development and organisational structure: new technical features require organisational modifications with tighter couplings (the dynamics of standardization). Thus, in the phase of the *application growth* of the technology, the ability of the space firm that created the technology to adapt to the industrial environment in the recipient sector (*e.g.* mass production, quality requirements, marketing strategies) is crucial. In other words, for a transfer to be successful, the organisation must be adapted to more commercial features in terms of quantity, price and timing, and thus be able to move its expertise from complex products to production programmes. This often results in a shift from an aim of maximising the technical performance characteristics of a product to one of holding down costs.

As a consequence, a firm specialised in producing small series of complex products (*e.g.* space and avionics), is forced to introduce standardization rules to diffuse technical progress in large production series in order to reduce production costs. However, irreversibility phenomena prevent such a diffusion from occuring in the absence of major changes in the firm. The justification for the irreversibility stems from both the technical and commercial aspects. On the one hand, the know-how necessary to design industrial prototypes does not correspond to a continuous search for optimisation in order to reduce time and consumption of inputs in the production process. On the other hand, the high cost of qualified workers, as well as the existing commercialisation structures, are inconsistent with the manufacturing rule of large series for which a commercial valorisation of innovation is at stake rather than permanent innovation *per se*. For Intzberg (1982), an organisation based on complex mechanisms between people using mutual adjustment rather than standardization rules (autocratic form) will have to become a structure based on the standardization of the production process (divisionalised form) in order to commercially exploit a technological success. However, the dynamics between different types of structure conditioning technological transfer encounter several types of inertia.

Issues of spinoff management policies

Obviously, there is no "recipe" for spinoffs, and the following comments are intended as "guidelines", enriched by some quantitative results from an empirical test on the European space industry. On this basis, several management decisions can be taken at the micro level within the company in order to stimulate the spinoff phenomenon. Each of the key factors described above can lead to specific actions, although the set of possibilities is more or less bounded by structural elements. For instance, it is difficult to rapidly change the nature of the firm, its size or its scope of activities. But it would seem, according to experience of transfers in the realm of industry, that the first step consists in a willingness to improve linkages in order to initiate spinoffs. Various methods can be used to do this without disrupting the structural features on which the firm is based.

Some examples of firms' policies

Firms' policies can take the shape of an individual role (opinion leader, product champion or gatekeeper) or, at a higher level, a task-force, a project team or a matrix structure. Generally, the objective is to place the company in an environment which is more receptive to new opportunities. Some examples of microeconomic decisions implemented to initiate an active policy on transfers can be observed in the European space industry. Several interesting examples of such a strategy are provided by the German space industry. In order to stimulate a valorisation of technologies, companies such as MBB-ERNO or DORNIER have created "transfer units", or simply special teams within the staff responsible for systematically identifying the potential applications of space technologies. MBB-ERNO set up a technology application division in 1989, in which approximately 50 per cent of the development projects originate in space activities. Members of the staff of DORNIER hold "synergy board meetings" on a monthly basis with the aim of promoting cross-fertilisation between different technologies developed inside the company, identifying internal technological opportunities and determining what is needed on the demand side of the technology in the different departments of the company.[14]

With a higher level of implication of the organisation, the French company AEROSPATIALE has set up a systematic “swarming” strategy by creating a “New Products” department with the objective of maximising the valorisation of the technologies partly born in the space sector. The specificity of the micro-strategy of the German companies is the opening of the organisation as a whole to the environment, mainly in relation to external transfers. Once the technological opportunities have been identified, an assessment of the market for potential applications is required.

Some cases of industrial organisation entirely devoted to the realisation of transfers can be observed. ELAB in Norway provides a good example of such a company. Belonging to the SINTEF Foundation (Engineering Research Foundation), ELAB is a laboratory carrying out research in electronics and computer science for the rest of the industry. The different bodies of knowledge cover the realms of acoustics, telecommunications, telematics and physical electronics, all organised in a matrix structure crossing these home-based scientific fields with several research projects such as satellite, communication and environmental protection systems. In accordance with the matrix organisation structure (Galbraith, 1977; Davies and Lawrence, 1978), the concept of matrix swing characterising a moving role of authority is illustrated in this company. Indeed, at the beginning and end of a project, the authority is mainly in the hands of the general manager due to the functional priorities; the project moves to the project manager during the realisation phase.

Finally, an interesting illustration of how internal transfers can be improved by a change in organisational structure is provided by the Swedish company ERICSSON. In a first phase, a matrix organisation was adopted in the ERICSSON Radar Electronics Department in order to start the development of two new activities (antennas and hybrid electronics), due in particular to the growing space activity of the company. However, the separate evolution of these two home-based technologies has led to an organisational mutation. Indeed, while for the antenna activity the technological challenge has remained unchanged over time (prototype or small series), the hybrid function has become increasingly standardized, and this is true of all the project applications of the company. In order to implement the process of standardization coming from an internal transfer of the hybrid technology, but also because of an intensive strategy of diffusion outside the company, the hybrid activity became a new department of the company with its own organisation and hierarchical structure. This autonomisation process, characterised by the department’s break away from the matrix structure, was mainly guided by scale effects in order to guarantee a successful transfer of the technology.

The role of public spinoff policies

Many interesting micro experiences could be noted in the European space industry, but these tend to be isolated actions and are insufficient to provide an optimal rate of diffusion for space technology. Help is often needed on both the supply and the demand sides. On the supply side, in addition to the creation of a special unit, a study by external experts of the potential applications of the firm’s technologies could have a substantial impact. The same is true for the demand side: persons familiar with space technologies could examine with potential users whether their technical problems could be solved by technologies from the space sector. One justification for the intervention of a neutral and external entity comes from the “asymmetric” nature of the technical information to be transferred. According to the paradox of information pointed out by Arrow, a situation of transfer can be characterised as follows. In some cases the recipient has to purchase information, the real value of which will not become apparent until it has been acquired, whereas the proposer must possess clear evidence of ownership of the technology (patents, licences, commercial agreements), before he will agree to divulge it.

One solution to this paradox, arising from the diverging interests of, on the one hand, the social optimum of systematic diffusion and, on the other hand, the private optimum of the firm, has to be found by adding a third-party organisation to provide a balance. A policy of technological transfers will have the tricky task of making these two objectives converge, turning the private technology into a quasi-public good, without colliding with the private objective of the providing company. In addition to the problem of protection for the supplier, the role of this third-party organisation is to translate the objective characteristics of the technology so that they can be understood by the receiver, who sometimes comes from a totally different technical environment.

Following this argument, it seems clear that there is room for involvement of the public sector to improve the linkages between potential providers and receivers, to reduce transaction costs through the provision of financial support, and even to provide some guarantees during realisation for the protection of the technological advance (property rights, patent policy). However, as firms wish above all to retain total control over their “home” technologies, the span of action for a public policy of transfers would probably be strictly limited due to resistance from private companies to sharing responsibility for the technology.

The NASA TU programme is a well-known example of such a policy, although it partly aims at supporting spinoffs from NASA technologies. In Europe, various initiatives have been taken. Apart from the current ESA pilot project which should help the Agency to move away from a rather “passive” attitude *vis-à-vis* spinoffs to the design and adoption of a clearly established strategy, two actions are worth mentioning here because they represent two different approaches. An example of a “classical” approach (using technology brokers) is provided by NOVESPACE, a subsidiary of the French CNES. This organisation publishes a newsletter reviewing the space technologies available at CNES or in French space firms; it thus acts as an intermediary, bringing the supply and demand sides into contact, without becoming involved in the spinoff projects by sharing risks or acting as a technical supporting organisation.

A typical example of sharing responsibilities is provided by the Swedish Board for Space Activity. Ceated in 1986, it was set up to fund new technological developments or commercial applications and was funded partly by the government (40 per cent) and partly by the three biggest companies in space (SAAB – ERICSSON – VOLVO) (20 per cent each). In the early 1990s, the Board’s budget amounted to some Skr 100 million and was used to provide subsidies to each of the three companies to promote their positioning on future markets. Each application from the companies is submitted to an executive committee composed of members of both the government and the firms. Various technological projects such as spinrock for SAAB, microwave equipment communication for ERICSSON and propulsion systems for VOLVO have been developed, funded by the Swedish Board for Space Activity.

Conclusion

Using different methodologies, the B.E.T.A. studies reviewed here and other estimates performed in the United States present optimistic conclusions regarding the existence and the importance of spinoffs from space activities. Some authors, comparing the benefits from pure R&D activity with transfer projects, even emphasize the interest of the latter strategy. However, we should treat with caution studies that lead to the conclusion that a transfer programme is more profitable than current R&D activities: one is a consequence of the other and, indeed, before directions for transfer can be explored, the original R&D programme has to be carried out. More than an alternative programme, the transfer strategy leads to an increase in the value of the knowledge accumulated by firms in their R&D departments. From this standpoint, the spinoff phenomenon is a very interesting field of observation and research for economics and management specialists, because public and private interests are mixed, and are sometimes conflicting ("socialisation" of the technologies for the whole economy *vs.* protection of information on technology to ensure leading corporate position). One essential challenge of the private as well as public management of spinoffs is to make these interests compatible.

Many research projects need to be carried out in order to develop an analytical framework able to take into account the variety of spinoff phenomena and the complexity of the channels through which they have an impact on economic activity and, on this basis, design methodologies that can provide accurate measurements. In this respect, recent advances in evolutionary economics could help to shed new light on spinoffs, by considering them as one of the factors shaping technico-economic development instead of treating them as isolated phenomena.

Such a change in the research perspective could contribute to overcoming two types of criticism to which studies on spinoffs are very often exposed. The first is the tendency to justify space activities by their spinoffs, whereas the growing importance of space activities as an autonomous economic sector leads us increasingly to find justification for these activities in what we have defined as their direct effects. On the other hand, studies on spinoffs often give the impression that the space sector is seen as the only innovator of new technologies which are later used in the rest of the economy. In fact, experience shows that the space industry is where technologies developed elsewhere are assembled and improved. This is why we should perhaps consider space-sector spinoffs in terms of their complementarity and interactivity with other sectors rather than in terms of impacts justifying space programmes.

NOTES

1. The author gratefully acknowledges the help of Monique Flasaquier during the translation of this text into English. The paper is based on a revised version of the article "Measuring and Managing Spin-offs: The Case of the Spin-offs Generated by ESA Programmes", by L. Bach, P. Cohendet, G. Lambert, M.J. Ledoux, in J. Greenberg and H. Hertzfeld (eds.), *Space Economics*, AIAA, Vol. 144, 1992.

2. In this respect, it is important to note that the definition of direct and indirect effects proposed here is slightly different from definitions according to which direct effects are those affecting the participants of the space programme and indirect effect are those affecting the other organisations.

3. These effects are sometimes called short-term economic effects in US studies.

4. As described later in this paper, this typology was designed for the purpose of evaluations based on direct interviews with firms in one way or another statistically representative of the size of the space programmes (*e.g.* the space agency contractors). For this reason, spinoffs affecting the whole economy (spill-over effects) cannot be taken into account since, by definition, it is not possible to form a statistically significant sample of organisations having benefitted from these "second-order" spinoffs (only case studies can be provided about this more global phenomenon, unless econometric tools using statistical data are used).

5. This phenomenon forms the basis of the concept of "critical mass effect".

6. The private return takes into account the surplus of the producer (income from the innovation less costs of producing and marketing the new products as well as costs of carrying out the innovation) and the profits that would have been made if the innovation had not occurred; the social return takes into account the consumer surplus, the research expenditures of related unsuccessful innovators and the profits (losses) of imitators (unsuccessful competitors).

7. Pieces of the puzzle can be found in J. Irvine and B.R. Martin (1980), "Impact of Scientific Research in the Area of Radio-astronomy on the Skills of Specialists"; in M. Callon *et al*. (1991), "Impact of French AFME Administration Programmes on Networks Mixing Firms and Other Organisations"; or P. David *et al.* (1988), "Payoffs from Big Research in the USA".

8. Results obtained with this approach were also used in macroeconomic models in M.K. Evans (1976); D.M. Cross (1980); or ECON (1983), in order to estimate the impact of space industries on aggregate economic indicators such as prices, employment or balance of trade.

9. Note that the result obtained from this calculation is still different from macroeconomic evaluation.

10. Other studies used sales and costs reduction for assessing some of the indirect effects of NASA programmes, but without such a refined search for the "fatherhood" of the effects (see, for instance, R.L. Chapman *et al.*, 1989).

11. This variety of cases is also linked to the variety of the nature of the effects; for instance critical mass effects may be considered as of a different nature than other effects. The reader can easily take into account this remark by computing the figures provided using a different approach to that taken here.

12. Results from the Canadian study are extensively analysed, in B.E.T.A./H.E.C. (1989).

13. We will mainly focus on the factors affecting "classical" spinoffs (transfers of technology), since the other effects are not specific to the spinoff phenomenon. Effects such as strengthening of co-operation, opening up of new markets or formation of critical mass can be analysed on the basis of the theory of the strategic management of firms, the theory of organisations or the theory of R&D management which go beyond the frame of this paper.

14. DORNIER and MBB-ERNO are now part of the DAIMLER-BENZ group.

REFERENCES

ARROW, K. (1962), "Economic Welfare and the Allocation of Resources for Invention", in R. Nelson (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors,* reprinted in K. Arrow (1985), *Collected Essays,* Vol. 5, *Production and Capital*, Blackwell, Oxford..

AYRES, R.U. (1987), "Complexity, Reliability and Design: Manufacturing Implication", Working Paper, IIASA, Laxenburg, Austria.

B.E.T.A. (1980), "Economic Benefits of ESA Contracts", Final Report for ESA, June.

B.E.T.A. (1988), "Study of the Economic Effects of European Space Expenditure", Results (Vol. 1) and Report on Investigation Theory and Methodology (Vol. 2), Reports for the European Space Agency, ESA Contract No. 7062/87/F/RD/(SC).

B.E.T.A. (1989), "Analyse des mécanismes de transfert de technologies spatiales : le rôle de l'Agence Spatiale Européenne", Rapport final pour l'Agence Spatiale Européenne, Paris.

B.E.T.A./H.E.C. (1989), "The Indirect Economic Effects of ESA Contracts on the Canadian Economy", Final Report for the Canadian Space Agency, Contract 67SPS-9-0001/01-SS, Montréal.

CALLON, M., P. LAREDO and V. RABEHARISOA (1991), "Des instruments pour la gestion et l'évaluation des programmes technologiques : le cas de l'AFME", in J. de Bandt and D. Foray (eds.), *L'évaluation économique de la recherche et du changement technique*, Presses du CNRS, Paris.

CHAPMAN, R.L. *et al*. (1989), "An Exploration of Benefits from NASA "Spin-off'", Chapman Research Group Inc., Littleton, Colorado, USA.

CROSS, D.M. (1980), "The Economic Impact of NASA R&D Spending, An Update", Report for NASA – NASW-3345, Chase Econometrics Ass., Philadelphia.

DAMANPOUR, F. and W.N. EVAN (1984), "Organisational Innovation and Performance: The Problem of Organisational Lag", *Administrative Science Quarterly*, No. 29, pp. 392-409.

DAVID, P., D.C. MOWERY and W.E. STEINMUELLER (1988), "The Economic Analysis of Payoff from Basic Research: An Examination of the Case of Particle Physics Research", CEPR Publication No. 122, Stanford University.

DAVIES, M. and P.R. LAWRENCE (1978), "Problems of Matrix Organisations", *Harvard Business Review*, May/June, pp. 131-142.

DE JONG, H.W. (1988), *The Structure of European Industry*, 2nd edition, Kluwer Academic Publishers.

DENISON, E. (1985), *Trends in American Economic Growth, 1929-1982*, Brookings Institution, Washington, DC.

DOSI, G., C. FREEMAN, R. NELSON, G. SILVERBERG and L. SOETE (eds.) (1988), *Technical Change and Economic Theory*, Pinter Publishers, London and New York.

ECON Inc. (1983), “Assessment of the Economic Impacts of the Space Station Program”, NASA Space Station Task Force.

EVANS, M.K. (1976), “Economic Impact of NASA R&D Spending”, Chase Econometric Associates Inc., Balacynwydpa.

GALBRAITH, J. (1977), *Organisation Design*, Addison-Wesley, Reading, MA.

GRILICHES, Z. (1979), “Issues in Assessing the Contribution of R&D to Productivity Growth”, *Bell Journal of Economics*, 10(1), pp. 92-116.

GRILICHES, Z. (1990), “The Search for R&D Spillovers”, Working Paper, Harvard University.

HERTZFELD, H.R. (1985), “Measuring the Economic Impact of Federal R&D Investment in Civilian Space Activities”, Workshop on The Federal Role in R&D, National Academy Press.

HUGHES, K. (1988), “The Interpretation and Measurement of R&D Intensity – A Note”, *Research Policy*, No. 17.

IRVINE, J. and B.R. MARTIN (1980), “The Economic Effects of ‘Big Science’: The Case of Radio-astronomy”, in T.D. Guyenne and G. Lévy (eds.), *Economic Effects of Space and other Advanced Technologies*”.

JOHNSON, F.D. and M. KOKUS (1977), “NASA TU Program – A Summary of Cost-Benefit Studies”, Denver Research Institute.

LAMBERT, G. (1991), “Complexité microéconomique et diffusion technologique à partir d'un grand programme de R&D”, in J. de Bandt and D. Foray (eds.), *Évaluation de la Recherche et du Changement Technique*”, Presses du CNRS, Paris.

LEVY, D.T. and L.J. HABER (1986), “An Advantage of Multiproduct for the Transferability of Firm-specific Capital”, *Journal of Economic Behavior and Organisation*, Vol. 7, pp. 291-302.

MAIRESSE, J. and M. SASSENOU (1991), “R&D Productivity: A Survey of Econometric Studies at the Firm Level”, *STI Review*, No. 8, pp. 9-43, OECD, Paris.

MANSFIELD, E., J. RAPOPORT, A. ROMEO, S. WAGNER and G. BEARDSLEY (1977), “Social and Private Return from Industrial Innovations”, *Quarterly Journal of Economics*, 77, pp. 221-240.

MATHECH Inc. (1977), “A Cost Benefit Analysis of Selected Technology Utilisation Office Programs”, NASA, Washington.

MATHEMATICA Inc. (1975), “Quantifying the Benefits to the National Economy from Secondary Application of NASA Technology”, NASA, Washington DC.

MIDWEST RESEARCH INSTITUTE (MRI) (1971), “Economic Impact of Stimulated Technology Activity”, Report for NASA.

MIDWEST RESEARCH INSTITUTE (MRI) (1988), “Economic Impact and Technological Progress of NASA Research and Development Expenditures”, Report for the National Academy of Public Administration, Washington DC.

MINTZBER, G H. (1979), *The Structure of Organisations*, Prentice-Hall, Englewood Cliffs, NJ.

MINTZBER, G H. (1982), *Structure et dynamique des organisations*, Les Editions d'Organisation, Paris.

MOHNEN, P. (1989), "New Technologies and Interindustrial Spillovers", paper presented at the OECD International Seminar on Science, Technology and Economic Growth, Paris, 5-8 June.

NELSON, R. (1959), "The Simple Economics of Basic Scientific Research", *Journal of Political Economy*, Vol. 67, pp. 297-306.

PORTER, M.E. (1980), *Competitive Strategy*, Free Press, New York.

SOLOW, R. (1957), "Technical Change and the Aggregate Production Function", *Review of Economics and Statistics*, 57, pp. 312-320.

SCHUMPETER, J.A. (1934), "The Theory of Economic Development", *Trans Redvers Opie*, Harvard University Press, Cambridge, MA.

TEECE, D.J. (1980), "Economies of Scope and the Scope of the Enterprise", *Journal of Economic Behavior and Organisation*, 1, pp. 223-247.

TEECE, D.J. (1982), "Towards an Economic Theory of the Multiproduct Firm", *Journal of Economic Behavior and Organisation*, 3, pp. 39-63.

TEECE, D.J. (1986), "Capturing Value from Technological Innovation: Integration, Strategic Partnering, and Licensing Decision", paper presented at the Conference on Innovation Diffusion, Venice, March.

UTTERBACK, J.M. and W. ABERNATHY (1975), "A Dynamic Model of Product and Process Innovation", Omega, Vol. 3, No. 3.

ZIMMERMANN, J.B. (1986), "Les stratégies d'accords inter-industriels", in *Les stratégies d'accord des groupes de la CEE, intégration ou éclatement de l'espace industriel européen*, LAREA, "Europe industrielle et technologie", programme of the Commissariat Général au Plan, Paris, pp. 4-35.