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# Study about the economic benefits of Astronomy

## Surveying the perceived economic impact of European Southern Observatory's Very Large Telescope

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**DISCLAIMER**

This thesis represents the sole opinion of the author. The work leading to the completion of the thesis was conducted independently from ESO – European Southern Observatory, and ESO bears no responsibility for the content or conclusions.

## RESUMO


Ao longo desta dissertação afloram-se os benefícios económicos que a Astronomia poderá originar no desenrolar da sua actividade científica e tecnológica.

Embora a histórica contribuição da Astronomia para a civilização humana seja óbvia, encontraram-se relativamente poucos estudos dedicados aos efeitos económicos desta ciência.

A dissertação debruça-se sobre os efeitos de médio e longo prazo que projectos de Astronomia poderão gerar nas organizações que colaboram nesses projectos. Foi realizado um inquérito a organizações fornecedoras do ESO no âmbito do projecto VLT – Very Large Telescope. Os principais impactos declarados em relação à actividade do ESO foram:

. 58,(3)% das organizações que responderam ao inquérito realizaram esforços de investigação e desenvolvimento de forma a cumprirem os pedidos do ESO;

. 80% dessas organizações estreitaram a sua relação com o ESO como consequência da colaboração no projecto VLT;

. 71% das organizações identificaram benefícios de imagem, que ficou associada à capacidade para colaborarem em projectos de fronteira tecnológica;

. O "saber fazer" dos trabalhadores de 65% das organizações foi reforçado com a participação no projecto VLT;

. 58% das organizações declararam que os projectos em Astronomia nos quais estiveram envolvidas geraram novo conhecimento;

. 64,8% das organizações respondeu que o projecto VLT contribuiu para a sua excelência tecnológica.

O inquérito contou com a participação de 31 empresas e de 10 instituições dedicadas à investigação e desenvolvimento (I&D). Em termos gerais, o impacto percepcionado pelas empresas é inferior ao impacto percepcionado pelas instituições de I&D.

O presente trabalho também aborda a eventual transferência de conhecimento da Astronomia para a indústria, através de tecnologias e criação de empresas. São dados exemplos retirados de diferentes áreas da Astronomia, nomeadamente da óptica adaptativa, astronomia no comprimento de onda do raio-X e optomecânica.

A transferência de conhecimento também se pode realizar através dos recursos humanos que transitam entre organizações. O presente trabalho reproduz evidência que a indústria valoriza e contrata recursos humanos com formação e experiência em Astronomia.

Os dados empíricos reunidos e tratados neste trabalho acerca do impacto do ESO nos seus fornecedores poderá complementar a actual investigação acerca da intitulada "Grande Ciência", bastante focada na física de partículas (CERN) e espaço tomado num sentido lato (ESA e NASA). Ao estar concentrado num projecto de Astronomia pontual, o presente trabalho terá o potencial para averiguar com precisão o impacto da Astronomia, por si só.

No fim, o objectivo do presente trabalho será alcançado se este contribuir para uma discussão objectiva das políticas públicas em ciência e tecnologia, nomeadamente as politicas públicas que apoiam a Astronomia e aquelas que promovem a participação da indústria em projectos da "Grande Ciência", Astronomia incluída.

## ABSTRACT

Throughout the present dissertation one explores the economic effects derived from the scientific and technological activities of Astronomy.

Despite the obvious historical contributions of Astronomy to human civilization, one does not find much organized information about the economic effects of this Science.

The present dissertation is focused in the medium and long term economic impact that procurement activity of Astronomy projects has in organizations which collaborate in these projects. An inquiry was made to organizations that supplied ESO in the framework of VLT – Very Large Telescope project. Overall, the main impacts associated with ESO's procurement activity are summarized as follows:

. As many as 58.(3)% of all respondents made R&D efforts in order to answer to ESO's demands;

. 80% of all respondents deepened their relation with ESO as consequence of their contract(s) within VLT project;

. 71% of respondents spotted image benefits, associated with high tech projects;

. Workers' know how of 65% of respondents improved with the participation in the VLT project;

. 58% of respondents declared generation of new knowledge in consequence of their involvement in Astronomy;

. 64.8% of respondent organizations perceived that their technological / R&D excellence was enhanced with their participation in the VLT project.

The survey was completed by 31 companies and 10 R&D organizations. In general, the perceived impact by companies is lower than that of R&D organizations.

The present work also takes a look to the knowledge transfer between Astronomy and Industry by the means of technologies and spin off companies. Examples were taken from different areas of work in Astronomy, specifically, adaptive optics, x-ray astronomy and opto-mechanics.

Other mean of knowledge transfer is through human resources who transit from Astronomy organizations to Industry. There is evidence that industry values and employs high skilled human resources coming from Astronomy.

One thinks that the empirical evidence gathered and analyzed about ESO's impact on its suppliers will complement the present literature on Big Science, until now focused in particle physics (CERN), and space in a general sense (ESA and NASA). This work is focused in a single astronomy project, being able to scrutinize with precision the impact of Astronomy, individually taken.

In the end, the objective of this study is fulfilled if it is able to contribute to an objective discussion of science and technology public policies, namely public policies which support Astronomy as well as those which promote industry participation in big science projects such as astronomy projects.

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**LIST OF ABBREVIATIONS**

ADI: Agência da Inovação (Portuguese Innovation Agency)
BETA: Bureau d'Economie Théorique et Appliquée (University Louis Pasteur, Strasbourg)
CCD: Charge-coupled device
CERN: Centre Européen pour la Recherche Nucléaire
DESY: Deutsches Elektronen-Synchrotron
EBIDTA: Earnings before Interests, Depreciations, Taxes and Amortizations
ESA: European Space Agency
ESO: European Southern Observatory
ESRF: European Synchrotron Radiation Facility
FCT: Portuguese Foundation for Science and Technology
GDP: Gross Domestic Product
HgCdTe: Mercury Cadmium Telluride
ICT: Information and Communication Technologies
IP: Intellectual Property
IYA09: International Year of Astronomy 2009
MSc: Master (Master of Science)
NASA: National Aeronautics and Space Administration
p: Significance level
PhD: Doctorate (Doctor of Philosophy)
PPARC: Particle Physics and Astronomy Research Council
r: value of the correlation coefficient
R&D: Research and Development
SPSS: Statistical Package for the Social Sciences
SME: Small and Medium Enterprises
UC: University of California
US: United States of America
VLT: Very Large Telescope
WWW: World Wide Web

# 1. INTRODUCTION

## 1.1 Motivation

Common sense tells that curiosity is one of the drivers of humankind in our quest for knowledge. In the same line, it was curiosity that drove me to engage in the realms of the Master of Curricular Development by Astronomy. At that time, I believed that the program would allow me to answer to some of the questions I have been wondering since I started to read about the Cosmos (for instance, by the hand of Carl Sagan). And it did!

Presently, I feel that it is time to give back and the way I found for doing it is to apply my background in Economy in the study of the Science Astronomy. It seems to me it will be a good way of closing this academic adventure, by combining the scientific domains to which I dedicated more time until now.

Pointing an economic perspective into Astronomy uncovers some aspects of the Economics of Astronomy: the inputs, the way this Science processes them and its outputs. In this context, my choice will be to focus on the study of the impact of this Science in the economic activity. One may call it an economist bias but I think that when one studies a human activity it will be a good practice to infer whether this activity is, in *lato sensu*, useful in economic terms. Although I believe that the intellectual richness of the knowledge generated by this Science is…astronomic, one still has the challenge of knowing the contribution of this activity to human economic growth and development. Furthermore, in times when the scrutiny on public funding is established, I concluded that, while the study of research policy and of the impact of science are quite explored areas of research, there is few work dedicated specifically to the impact of Astronomy and Astronomy related projects. If the hypotheses posed in this work are confirmed, I'll be fulfilled with my tiny contribution to make the case of companies which are investing in the participation in Astronomy projects as well as of public policies which support Astronomy and the involvement of the industry in Astronomy endeavors.

Other way of giving back is to spread the word about what I learnt with this Science. Wrapping my experience in a language to which my fellow economists and managers are used to and showing the present work may attract their attention to this field of knowledge. This attempt to spark an interest for Astronomy in uncommon and new publics is coherent with the outreach objectives of the Master program I'm in: sharing knowledge and teaching skills which, ultimately, will facilitate the promotion of Astronomy.

## 1.2 Question mark

To the vast majority of people, including myself, Astronomy, among other associations, remembers our oceanic discoveries, brings majestic images, takes our imagination to distant places or feeds our feeling of smallness. When one digs further into the problems astronomers want to solve, one is confronted with exotic information and matters that seem not having relevance in our daily live. Astronomy questions, such as how the present Universe was formed and is evolving or how stars are born, seem more appropriate to a minority of scientists with intellectual goals than to solve practical and more mundane needs. So the following question might arise: What do we, as Society, gain with Astronomy besides cultural realization? Narrowing the question: What does our Economy gain with Astronomy activities?

### 1.3 Defining Astronomy

But, what is Astronomy after all?

The word Astronomy comes from the Greek "Astron" = star and "Nomos" = law. A quick search on the web would give a myriad of definitions for this natural Science. One chooses the explanation given by the International Year of Astronomy 2009 (IYA09)[1]: *Astronomy is the study of all celestial objects. It is the study of almost every property of the Universe from galaxies, stars, planets and comets to the largest cosmological structures and phenomena.*

So, since its origins Astronomy studies the space beyond the Earth and all its contents, which includes our planet. Poetically said: *It is the study of all that has been, all there is and all that there ever will be. From the effects of the smallest atoms to the appearance of the Universe on the largest scales* (IYA09, 2009). It is not casual that Arab tradition dubbed it as the Mother of all Sciences.

Figure 1: The earth through the view of an artist, Margarida Teixeira, 2000

Astronomy is one of the oldest fields of knowledge, pairing human evolution since primordial times. Astronomy conquered the status of Science as soon as astronomers, combining observations and theory, were capable of understanding and explaining what they observed and of previewing future events (Ferreira et al, 1997).

One quotes again the IYA09 information in order to transmit a slight idea of the contemporaneous achievements of this Science: *One hundred years ago we barely knew of*

[1] http://www.astronomy2009.org/

*the existence of our own Milky Way. Today we know that many thousand millions of galaxies make up our Universe and that it originated approximately 13.7 thousand million years ago. One hundred years ago we had no means of knowing whether there were other solar systems in the Universe. Today we know of more than 200 planets around other stars in our galaxy and we are moving towards an understanding of how life might have first appeared.* These discoveries have presumably motivated and, at the same time, have been facilitated by technological progress. This mutual causality process will be explored later on this work.

Astronomy has always been associated with visual observations of the sky. This fact was true one hundred years ago, when we studied the sky using only optical telescopes and photographic plates. Today we observe the Universe from Earth and from space, in all wavelengths of the electromagnetic spectrum, from radio waves to gamma rays, using cutting edge technology (IYA09, 2009).

Nowadays, the field of professional astronomy may be divided in observational and theoretical branches[2]. Observational astronomy is focused on acquiring data from observations of celestial objects, which is then processed and analyzed using principles of several Sciences like Mathematics, Physics, Chemistry or Biology. Theoretical astronomy is oriented towards the development of computer or analytical models to describe astronomical objects and phenomena. The two fields complement each other, with theoretical astronomy seeking to explain the observational results, and observations being used to confirm theoretical results.

On this work, one will focus on observational astronomy and the means it requires to be developed.

As stated, Astronomy is a multi–disciplinary science, applying or testing concepts derived from other Sciences. Other important feature is that is an international Science in scope, being developed by a network of scientists around the globe who research through a combination of many disciplines and sub-fields using different approaches, such as ground-based telescopes, space based observatories, robotic probes, theoretical calculations and simulations. The observational structures are large, powerful, complex (and expensive), trying to match the thirsty curiosity of scientists as well as to overcome the faintness and distance of astronomical objects. It would be useful to keep in mind these characteristics of Astronomy to better understand the point of this work.

### 1.4 Defining benefit

Before trying to answer to the primary question of this work, one finds useful to clarify the concepts behind it. This conceptual enlightenment will help the reader to understand how these concepts are interpreted in this work.

So, one thinks that Society gains with certain human activity (in this case, Astronomy) when this activity contributes to the welfare of Society. Welfare is defined by economists by the well being of an individual or a Society[3].

A way of inferring whether certain human activity or project contributes to the welfare of Society is to study its impact on Society. Taking into account the European Commission's guide to cost benefit analysis of investment projects, "impact" is a generic term for describing the changes or the long term effects on society that can be attributed to a project

[2] http://www.iau.org/public/careers/
[3] http://www.economist.com/research/economics/

(European Commission, 2008). These changes are perceived through the variation, caused by that project or human activity, of certain indicators of the welfare of a region, country or other system where that project or human activity is implement or occurs.

One may think in economic impacts as the changes in economic variables caused by the project or the human activity (Pinho et al, 2008). Examples, at a Macroeconomic level, are variations in employment, in the product (or income) generated or in earnings (wages). One assumes that such variables are indicators of the welfare of a society.

By the other hand, one may analyze the social impacts, typically described as changes in the quality of life or comfort of society due to a certain project. For instance, changes in travel conditions or quality of the environment due to the introduction of a collective transport in a city (Pinho et al, 2008). Directly associated with the well being of a Society, social impacts are wider in scope and generally include intangible effects. Since they usually result of perceptions, they are harder to identify and to translate in monetary units. This is one reason for the choice of focusing this study in the economic effects of Astronomy.

At this point, one dares to define benefit as an impact of certain project or human activity that leads to improved welfare in a Society. Referring specifically to scientific research, Nelson defined benefit as an increase (resulting from scientific research) in the value of the output flow that the resources of society can produce (Nelson, 1959). Both definitions are connected: improved welfare and increased value mean more satisfaction from Society's point of view. And Society is made of individuals.

Recalling the basics of Economics, classical economists try to capture satisfaction through the concept of "utility" of a good or a service to an individual (consumer theory). They try to measure the economic value of a good or service based on what people want – their preferences and choices (theory of the value). People express their preferences through the choices and tradeoffs they make, given certain constraints, such as those on income or available time[4]. Thus, economic value is measured by the most someone is willing to give up in other goods and services in order to obtain a good, service, or state of the world. In a monetary economy, the maximum amount of money that a consumer would be willing to pay for a good or a service is an accepted measure of economic value, that is "willingness to pay". By relating the quantity demanded and the price of a good, we can estimate the demand function for that good.

A good's market price does not measure its economic value. The market price only tells us the minimum amount that people who buy the good are willing to pay for it. When people purchase a marketed good, they compare the amount they would be willing to pay for that good with its market price. They will only purchase the good if their willingness to pay is equal to or greater than the price. Usually people are actually willing to pay more than the market price for a good, and thus its value exceeds the market price. This excess is called the consumer surplus. The consumer surplus measures the net economic benefit to individual of purchasing certain good or service.

By the same token, classical economists try to capture value on the producers' side (producer theory). Producers of goods also receive economic benefits, based on the profits they make when selling a good[4]. Economic benefits to producers are measured by producer surplus. The supply function tells how many units of a good that producers are willing to produce and sell at a given price. If producers receive a market price higher than the minimum price they would sell their output for, they receive a benefit from the sale—the producer surplus. Thus, benefits to producers are similar to benefits to consumers, because they measure the gains to the producer from receiving a market price higher than the minimum price they would have been willing to sell the good for.

[4] http://www.ecosystemvaluation.org/

Resuming, one may measure the impact of a project or human activity by trying to capture the variation in consumer surplus plus producer surplus due to that project or human activity. If the variation is positive we are facing benefits to Society (that we have to compare with the amount of costs).

Note that it is worth to distinguish between a good, defined as something that satisfies a human need (Neves, 1993) and a resource, something that doesn't satisfy directly a human need but it is necessary to produce a good (Neves, 1993), for instance labor or capital. One may latter conclude that one is free to see the output of Astronomy both as a good, for example the pleasure one may have in reading an article about our galaxy, or as a resource, if there are outputs from the Astronomy, for example technology, that help us to produce other goods.

At this point, one concludes that one may analyze benefit of a certain good, project or activity from several perspectives. Benefit at an individual level, translated in more satisfaction to a person, for example, due to the increase of the consumer surplus of citizens who see the opening of a planetarium in their city and will pay less to watch a stellar show.

Benefit at a microeconomic level, for instance, new products or cost savings that certain activity (for example, research and development) may generate to companies, translated in increased profit.

Benefit at a macroeconomic level: one has already seen that certain projects or activities are sources of economic growth (positive variation in the income/product of an economy) and employment. An adequate illustration of this kind of benefits is the work developed by Solow on his studies on growth theory and on research and development. He concluded that research and development (R&D) and, consequently, innovation are drivers of new products & industries, productivity and economic growth (Nelson, 2003).

Soon one will be clarified about the perspective taken by this work in order to answer to the primary question and about the reasons for that choice.

At this point, one is able to answer that Society/Economy gains with Astronomy if this human activity generates economic benefits to Society (as defined above). Pretty holistic hem?

One may guess that the hurdle of this work is not defining the concept of economic benefit but rather to identify the eventual economic benefits of Astronomy and to accounting them. That will be the goal of next chapters.

## 2. LITERATURE REVIEW

The assessment of the economic benefits generated by Science is a work that has being developed in a structured way by an increasing number of researchers interested in deepening the knowledge about the connections between Science, innovation and economic development. This field of study, pioneered by Nelson in his primordial article "The simple economics of basic scientific research" in 1959, has inspired research policy. Among the historical reasons for the increasing interest in the impact of Science, the need of assessing the costs and benefits of public funded science is the most unanimous. Basically said, public or government funded research comes from tax payers.

Doing science is expensive and requires resources. Considerable government funds are spent on research in universities, institutes and elsewhere (Salter et al, 2001). Is common sense that governments face numerous competing demands for public funding. In reality, Science is not always seen as high political priority. For instance, for many people the benefits associated with public spending on, say, health or education is more obvious than those from research (Salter et al, 2001). In periods of constrains in public expenditures, like the present times, there is an increasing pressure for scrutiny and accountability of research in order to allocate priorities (Martin et al, 1981). These priorities may take into account the politically desired needs of innovation and economic growth (Gulbrandsen, 2009).

At the same time, scientists and research funding agencies argue that more is needed to accomplish scientific and technological objectives and they try to persuade governments to invest more (Salter et al, 2001).

At international level, for instance, in the context of transnational science projects, public funding agencies want to know what types of industrial benefits these government-funded large scale scientific projects can generate. Their reasoning is that this information could help them to better utilize their national industrial home base (Nordberg, 1994).

Hence, one assists to recurrent debates on why government should fund science, at what level and which science.

Martin and Irvine give a curious insight of three motivations to fund certain Science: *it is a branch of science that contributes a great deal to our understanding of other areas of science - it is more "fundamental" than others; it helps human beings understand and make sense of their natural and social environment - it is culturally significant; it provides vital ingredients for material progress and welfare – it is of economic importance.* As illustration, one recalls that the scope of this study is on the latter criteria, considering that, with regard to Astronomy, the former two criteria are assumed as given.

By the above introduction, one guesses that the main focus of the literature review and of this work is Science, scientific research and their impact in Economy. This is also due to the fact that the object of this work is the Science "Astronomy". This clarification may be considered a good starting point to define Science as well as research.

## 2.1 Definitions

### 2.1.1 Science and research

Nelson states that the activity of science is the search for knowledge. Being scientific research defined as *the human activity directed toward the advancement of knowledge: facts or data observed in reproducible experiments (usually, but not always, quantitative data) and theories or relationships between facts (usually, but not always, equations)* (Nelson, 1959). Alternatively but in the same spirit, Michael Hähnle in his dissertation about R&D collaborations between CERN and Industrial Companies quoted Kline and Rosenberg who, in their article "An overview of innovation", define Science as *the creation, discovery, verification, collation, reorganization, and dissemination of knowledge about physical, biological, and social nature.* Kline and Rosenberg suggest two components of Science: the current totality of stored human knowledge about nature; and the research process by which that knowledge is corrected and enriched. When the first component fails to supply the necessary information, one goes on to the second component. Since the present study is mostly interested in evaluating the impact of the human activity toward the advancement of knowledge in Astronomy, one may find useful to dedicate a few lines to the research process and the types of research.

### 2.1.2 Basic research as opposed to applied research

Literature distinguishes between basic or fundamental research, that is, experimental, observational or theoretical work that has no practical application in mind, and applied research, that is, research directed to practical problem solving.

Basic research is by nature exploratory. More precisely, *it is oriented towards the production of pure epistemic utilities required by the scientific community* (Hähnle, 1997). For instance, as said before, astronomers research the properties of celestial objects. Taking one of its fields as example, galactic and extra galactic astronomy is oriented towards the identification of the fundamental properties of galaxies and the understanding of how these complex structures were formed, evolve and interact. The mission of research in galactic and extra galactic astronomy is clearly not oriented towards immediate industrial applications. However, large-scale research centers like the ones that feed this field of Astronomy also have to carry out applied research in optics, electronics, data processing, and other areas in order to build the scientific machines necessary for pursuing their original mission (Hähnle, 1997). One will necessarily get back to this fact later on. Inside the fuzzy borders of basic research, one may find "curiosity-oriented" research: undertaken primarily to acquire new knowledge for its own sake, and "strategic" research: undertaken with some instrumental application in mind, although the precise process or product is not yet known (Salter et al, 2001). Once again, recalling its mission, one may affirm that Astronomy is on the extreme side of "curiosity-oriented" research. Due to its nature and objectives Astronomy may be classified as very basic research (Salter et al, 2001).

Moving from the applied science end to the basic science end of the spectrum, the degree of uncertainty about the results of specific research projects increases, and goals become less clearly defined and less closely tied to the solution of a specific practical problem or the creation of a practical object (Nelson, 1959). Other feature that Nelson distinguishes in these two types of research is that while the direction of an applied research project must be closely constrained by the practical problem to be solved, the direction of a basic research project may change markedly, opportunistically, as research proceeds and new possibilities appear.

Applied scientific research is related with invention, defined by Nelson as the human activity directed toward the creation of new and improved practical products and processes. Invention is clearly a goal directed activity and it is usually referred as a possible output of applied research.

Other important definition is that of technology, interpreted as the activity of applying knowledge, skills or techniques to practical purposes, that is, using knowledge, skills and techniques in order to make or produce something (Nordberg, 1994). Once again, technology is commonly referred as a possible output of applied research. One will see that it is plausible to be also motivated by basic research like Astronomy.

## 2.2 Assessment of basic research impacts

It's consensual that the task of assessing the impacts of basic research is challenging. Firstly, because the products of scientific endeavor may take a variety of forms: new scientific knowledge; new scientific problems or new practical ideas; or techniques of more direct benefit to society (Martin et al, 1981). Martin and Irvine say that *though perhaps difficult to measure, there can be no doubt that there is an output of some kind from Science*.

Secondly, due to the alternative ways human knowledge may be expressed or transmitted. Human knowledge can be codified (for example, in the form of publications, inventions) but, many times, as Teece states, it has a tacit component since it is embodied in researchers (Nordberg, 1994). The transference of this kind of knowledge is hard to detect and to measure.

Other reason for the difficulty of assessing the results of basic research is that fundamental knowledge, for example, natural "laws", facts or mathematical formulas, tends to be widely shared by (economic) agents, that is, its use by another individual does not reduce its availability to those who made the discovery (CED, 1998). It is difficult to deal with and to value this kind of ubiquitous knowledge.

In addition, significant advances in scientific knowledge are often not directly and immediately applicable to the solutions of practical problems (Nelson, 1959). Hence their effect in Economy can take a long time to happen.

Summing up, although the role of basic research assets is essential, often they represent only a small component of the entire socio-economic value chain of a product or a service (OECD, 1997), being hard to distinguish the individual contribution of each factor of production.

Economic benefits from basic research can take the form of directly useful knowledge but also other less direct economic benefits such as competencies, techniques, instruments, networks and the ability to solve complex problems (Salter et al, 2001). These benefits are mostly indirect, often subtle, heterogeneous, thus difficult to track or measure with precision. The authors add that the complex and often indirect contributions of basic research vary greatly across scientific fields and industrial sectors. There is great heterogeneity in the relationship between basic research and new or improved goods, services or quality of life.

Consequently, no simple model of the nature of the economic benefits from basic research is possible (Salter et al, 2001).

One concludes that benefits can only be approached through a multi-faceted process including examination of direct and indirect benefits, spillover spin offs, economic and social returns, cluster effects, short and long term impacts (OECD, 1997), retrospective examination of specific cases, etc.

In the next pages one will have the chance to see in more detail the solutions and pathways taken by researchers in the quest for assessing the impacts of research and its outputs.

### 2.2.1 Macroeconomic studies – growth models

Macroeconomists have been curious about the economic impact of research and development. The focus of these works is the influence of research and development in the macroeconomic variables (such as economic growth, employment, wages, etc.) in a local, regional or broader Economy.

Macroeconomic studies use econometric and statistical tools such as economic models and production functions. They can also use activity and job creation models (with employment multipliers) based in input-output models (Nordberg, 1994).

The objective of this field of Economics is to calculate the portion of economic growth accounted by technological innovation in general, and by research in particular (Salter et al, 2001). This field of research analyzes the contributions of production factors, such as labor and capital, to economic growth.

Early growth models, pioneered by Solow, treated technological change largely as a residual — as the portion of growth that could not be explained by labor and capital inputs. Technical change was treated as part of the general productivity increase and played no independent role in explaining growth (Salter et al, 2001), that is, it was assumed as exogenous.

Newer models in growth theory, like the ones developed by Romer, have attempted to take into account technology as an endogenous factor, introducing a variable for "technical progress". Quoting Salter and Martin in their review of macroeconomic studies: *they vary in their conclusions but all suggest a key role is played by technology in generating economic development.*

By reading the review of Salter and Martin, one may get the idea that growth models are opaque with regard to the causality effects between basic research and technological progress. Nevertheless, going one level up, Salter and Martin inform that new works on growth theory highlight the spillover effects of technological development. For example Romer tends to see spillovers as the main mechanism underlying growth patterns, suggesting that the encouragement of spillovers through government institutions may be fruitful from a policy perspective (Salter et al, 2001). One will get back to the concept of spillover later on.

### 2.2.2 Macroeconomic studies – demand side studies

In a less theoretical perspective but making also use of quantitative analysis based in input-output and economic forecasting models, demand side studies are focused in accounting the economic impact of certain project, program or human activity. The cause of the impact is the spending or expenditure caused by that project. Possible proxies of economic impact are: the value of goods and services produced due to a certain project; employment generated; and earnings, defined as the sum of all wages paid in the framework of that project (FAA, 2008). These studies rely heavily in the financial flows that the project in appreciation originates.

The logic behind these studies is that expenditure of certain project produces 3 types of impacts (FAA, 2008):

(1) Direct impacts - the project's expenditures on inputs and labor;

(2) Indirect impacts - involve the expenditures (in goods, services and labor) made by project's suppliers in order to provide inputs to the project. This impact quantifies the inter-industry trading and production necessary to provide the final goods and services;

(3) Induced impacts - are the successive rounds of increased household spending resulting from the direct and indirect impacts (for example, a project or supplier worker's spending on food, clothes dry-cleaning, or any other household good and service).

Simplifying, in demand variations (caused, for instance, by an investment project) one faces a multiplier effect: the money that the project spends locally is spent again by those who receive it. The multiplier represents the number of times the money spent by the project cycles through the economy, generating additional income and jobs before it effectively leaves the system through savings, taxes, and expenditures made outside the region (UCB, 2007). The objective of these studies is to estimate the multiplier effect.

Several Universities have been applying this logic in their attempt of measuring the economic impact of their activities, namely, research and development. These studies show a large, positive contribution of academic research to economic growth (Salter et al, 2001).

As illustration, one underlines the exercises made by US Universities, for instance University of California:

An impact study for the University of California found that in 2000/2001 for every $1 it spends in California's regional economy, UC generates a total of $1.30. The study recalls that the economic "multiplier" on research activity is much higher than that on consumption, since that research activity leads to productivity gains. The study concluded that approximately 1.3% of the growth in California's Gross State Product over the next decade can be attributed to productivity gains resulting from UC research activities. The study predicts that productivity gains derived through UC research will contribute an estimated $5.2 thousand million to the growth in Gross State Product and create more than 104,000 new jobs between 2002 and 2011 (UC, 2003).

University of California – Berkeley study on the impact of this University found that the overall output multiplier for UC Berkeley spending was 1.44 in 2005/2006, which means that for every dollar the University spent an additional $0.44 in indirect and induced spending was generated. The study also found that the University helped create almost nine jobs for every $1 million in direct expenditures, or about 0.4 indirect jobs for every direct University job (UCB, 2007).

A major pitfall of these studies is that they do not separate applied and basic research spending neither different fields of investigation. It would be interesting to know the multiplier effect of Astronomy research on these Universities. A weakness of demand side studies is that they focus only in spending not caring about the non-financial outputs, intangible benefits (for instance, enhanced knowledge or skills, productivity gains through innovation, caused by research) or indirect benefits of research.

### 2.2.3 Innovation related studies

These studies assume that fundamental research has an important economic impact beyond the social and cultural dimensions. Taking the example given by Hähnle, he states that *knowledge concerning the universe is important for its own sake, and the education of students, which occurs in many academic research projects, is socially important as well. However, the support of fundamental research in scientific fields such as mathematics, astronomy, physics or biology yields significant economic benefits* (Hähnle, 1997).

The main hypothesis of these studies is that fundamental research fosters technological development and innovation among industry.

One may define innovation as the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations (OECD, 2005). The minimum requirement for an innovation is that the product, process, marketing method or organisational method must be new (or significantly improved) to the firm. This includes products, processes and methods that firms are the first to develop and those that have been adopted from other firms or organisations (for instance, research and development centres). The Oslo manual continues, stating that innovation activities are all scientific, technological, organisational, financial and commercial steps which actually, or are intended to, lead to the implementation of innovations. Given this wide definition, one might reach the conclusion about the hurdles of setting a direct link between fundamental research and innovation.

This line of research is dominated by microeconomic studies, that is, their focus is the economics of a particular firm, market or industry. A general view of the main findings of some of these works will be presented.

Why not starting with the thoughts of Nelson, one of the precursors of this line of research? The work of Nelson called attention to the benefits for the firms (and Economy) of basic research (for example, reduced search costs, unexpected applications). Nelson gave a justification for government support of basic research, namely the existence of external economies.

In Economics, externalities (or spillovers) are costs or benefits, not transmitted through prices, incurred by a party who did not agree to the action causing the costs or benefits. A benefit in this case is called a positive externality or external benefit, while a cost is called a negative externality or external cost[5].

Nelson says that basic research efforts are likely to generate substantial external economies. External economies result from two facts: research results often are of little value to the firm that sponsors the research, though of great value to another firm, and second, that research results often cannot be quickly patented (Nelson, 1959) and thus protected. External economies open a gap between marginal private benefit (of the firm) and marginal social benefit (of all) from basic research. That is, the private return of the investment in basic

[5] http://stats.oecd.org/glossary/detail.asp?ID=3215

research for a firm is less than the social return of that investment. This may lead companies to under invest in basic research in relation with the socially desirable.

Nelson adds that two other factors, working in the same direction, must be mentioned: firstly, the long lag that very often occurs between the initiation of a basic research project and the creation of something of a marketable value. Secondly: the very large variance of the profit probability distribution of basic research projects.

The big assumption of Nelson is that the use of existing knowledge by one firm in no way reduces the ability of another firm to use that same knowledge. The marginal social cost of using knowledge that already exists is zero (Nelson, 1959). Translating, the knowledge that results from basic research is a public good.

One should clarify that, in Economics, a public good is a good that is non-rivalrous and non-excludable. Non-rivalry means that consumption of the good by one individual does not reduce availability of the good for consumption by others; and non-excludability means that no one can be effectively excluded from using the good (Varian, 1992). Unlike private goods, a public good can be used simultaneously by any number of individuals without anyone's use diminishing its supply. For example, one person's use of a scientific formula does not exclude another person's use, nor does it diminish the formula in any way. This general characteristic has many implications, one of the most important of which, like underlined by Nelson, is that it makes private ownership of a public good difficult and inefficient in economic perspective. Because an individual or firm cannot easily reap all of the benefits of the scientific formula (or other potential outcomes from basic research), these private market actors tend to under invest in basic research activities from society's perspective (CED, 1998). As a result, a gap emerges between the prevailing level of private investment in basic research and the level that would maximize the benefits to society at large. Economists identify this gap as a market failure and point to government intervention as necessary to fill this funding gap and exploit the positive externalities of basic research (CED, 1998).

This line of though inaugurated the "informational" approach of basic research, interpreting, like Arrow did, that the output of basic research was in the form of information that was costly to produce, but virtually costless to reproduce or transfer and reuse, and therefore had the properties of a public good and deserved public support (Pavitt, 2001).

Following this line of though, there are numerous empirical studies whose objective is to calculate the private and social rates of return of basic research in industry or of public basic research. They compare spending of basic research with the economic returns associated with the products and processes attributed to the basic research in question (Salter et al, 2001). The difference between private rate of return and social rate of return may give a clue about the spillovers of the studied basic research. Martin resumes in a lecture that for industrial R&D, social rate of returns calculated by these works round 40% and 60%, typically the double of private rate of return, between 20% and 30%. By the other hand in studies about publicly funded R&D, rates of return typically go up to 20% and 50% (Martin, 2007). The social returns of basic research are often particularly high due, in part, to the wide dispersion of fundamental knowledge, which frequently leads to additional discoveries and applications in diverse fields (CED, 1998).

Mansfield made substantial progress in measuring the benefits of basic research (Salter et al, 2001). This author focused on recent academic research. That is, research within 15 years of the innovation under consideration. Using a random sample of 76 US firms in seven industries (information processing, electrical equipment, chemicals, instruments, drugs, metals, and oil industries) he obtained estimates from company R&D managers about what proportion of the firm's products and processes over a 10-year period could not have been developed without the academic research.

He found out that about 11 percent of these firms' new products and about nine percent of their new processes would have been developed with a substantial delay without the findings of recent academic research. With the help of these figures, Mansfield estimated the rate of return from academic research to be 28%. In parallel, he registered that the percentage of new products and processes based on academic research varied across industries. The highest percentage could be observed in the drug industry, which has an obvious interest in the large amounts of medical, biological, and pharmaceutical research carried out, for example in universities, and the lowest percentage was found in the oil industry. Mansfield concluded that the industry differences can be explained, to a considerable extent, by differences in R&D intensity among firms. The percentage of a firm's new products based on academic research seems to be directly proportional to the percentage of its sales devoted to R&D (Hähnle, 1997). More recently, Mansfield published the results of a follow-up study. He found that academic work was becoming increasingly important for industrial activities (Salter et al, 2001).

Beise and Stahl replicated Mansfield's survey in Germany with a much larger sample of 2,300 manufacturing firms. They found that approximately 5% of new product sales could not have developed without academic research. They also showed that academic research has a greater impact on new products than new processes. Additionally they showed that small firms are less likely to draw from universities than large firms (Salter et al, 2001).

As research is being made on the externalities of basic research researchers are, at the same time, dedicating themselves to the study of individual cases of direct benefits coming from fundamental research. As illustration, one may be elucidated by the historical case of the development of the transistor which is considered one major technological breakthrough of the 20th century (Hähnle, 1997). Fundamental to the development of the transistor in 1947 was the prior use of the quantum mechanics model for explaining the behavior of electronic band structures in semiconductors (Nelson, 1962).

The transistor came about because fundamental knowledge had developed to a stage where one could understand complex phenomena that had already been observed for a long time. The breakthrough came from work dedicated to the understanding of fundamental physical phenomena, rather than from work dedicated to methods of producing a useful device (Lederman, 1984).

The broad utilization of this innovation began with the commercialization of micro-electronics in the 1970's. In other words, the direct economic and cultural benefits of the development of the transistor were realized more than 20 years after the development of the first specimen and about 40 years after the publication of the underlying scientific model. This fact gives evidence to the time lag between academic findings and their industrial utilization.

Also regarding to the basic science of quantum physics, Lederman and Carrigan have identified transistors, computers, lasers, television, nuclear energy and biotechnology instrumentation as the most important technologies that have resulted from quantum physics research. They concluded that these developments have contributed to about 20% of the U.S. Gross National Product up to the start of the 1980's (Nordberg, 1994).

Nowadays, there are researchers who prefer an "evolutionary" approach to the economics of basic research. Relatively few economists today would support the purely informational approach (Salter et al, 2001).

The informational approach assumes a direct link between research and technological development and between technological development and innovation. This simple linear model of innovation does not take into account the complexities of innovation, which, as described by the chain link model of Kline and Rosenberg is a complex system with distinct inputs (not only research but also, for example, "trial and error", marketing research, customer feedback) and outputs interacting between each other and characterized with loops between causes and effects. In the end, timescale from research to innovation can be long. In consequence, Martin identifies a number of problems when trying to measure impact of research (Martin, 2007):

(1) Causality problem – is not clear what benefits can be attributed to what cause

(2) Attribution problem – is not clear what portion of benefits should be attributed to initial research or to other inputs

(3) Evaluation timescale problem – premature measurement may result in policies that over-emphasize research which brings short-term benefits

Furthermore, in its pure version, informational approach underestimates the value of research output. This view assumes that the output is information available without a cost, in a codified form, but to understand information one almost always requires knowledge. Salter and Martin remember that information only becomes knowledge and therefore valuable when users have the capabilities to make sense of it – absorptive capacity; without these, information is meaningless (Nightingale, 1997; Pavitt, 1998). That capacity to understand and use the results of basic research performed elsewhere requires considerable investment in institutions, skills, equipment and networks (Callon, 1994). So, the diffusion has a cost. That's why Callon affirms that basic research has attributes of public good but is not a free good.

This new approach emphasis the importance of tacit knowledge generated by basic research, for instance, embodied in the researchers and in scientific networks.

Salter and Martin state that the development of tacit knowledge requires an extensive learning process, being based on skills accumulated through experience and often years of effort.

It is natural that its defenders give importance to the development of skills, networks of researchers and new capabilities on the part of actors and institutions in the innovation system in order to promote the diffusion of knowledge (Salter et al, 2001). They recommend a focus on the learning capabilities generated by public investments in basic research in order to apprehend the economic benefits of such investments (Rosenberg, 1990; Pavitt, 1991; Pavitt, 1998).

As an illustration of this approach and making a bridge to the subject of the next set of innovation studies one may refer the inspiring work of Martin and Irvine on the spin offs from basic science: the case of radioastronomy (Martin et al, 1981). They named 3 major forms of economic benefit associated with the so called big science (like radioastronomy, as one will see):

(1) development of original, fundamental scientific ideas which can inspire radically new innovations

(2) technological benefits to firms supplying equipment to scientific researchers

(3) training of high skilled researchers who then go on to utilize their skills in R&D at the frontiers of technology, thus creating economic benefits for their subsequent employers.

They dubbed the first two benefits as "technological spin offs" and the third one as "man power training benefits". Then they looked at the case of radioastronomy in Great Britain to examine how important these benefits are. In the end, they found that, for the case in analysis, the technological spin offs were not of great magnitude. Instead, the impact of radioastronomy in industry was concentrated in the researchers, who acquired high tech skills in radioastronomy and then went to apply them in industry. One will get back to this study in the following sub chapter.

### 2.2.4 Big science

The next step in the present literature review will be to highlight the fundamentals of studies on the so called "big science". Comparing with the referred works on basic research impact, is not the economic logic behind the studies that changes, rather it is the object of the studies. And the object is big science.

Big science is a Science that in order to fulfill its scientific mission need to be supported by highly complex and large-scale research facilities. The research mission thus creates a highly demanding engineering need that comes with a structure and a schedule (Autio et al, 2004). In order to meet their scientific goals, big science projects need to build large-scale installations that routinely employ highly sophisticated, even frontier-pushing technologies and scientific knowledge.

In big science projects many instrument components are needed in large quantities and new industrial technologies may provide increased performance compared to existing technologies and thus are desperately needed for the never ending scientific quest for new discoveries (Vuola et al, 2006).

Autio, Hameri and Vuola underline that such large-scale installations, recently dubbed the "Modern Cathedrals" by the Economist Magazine (Carr, 2002), constitute a substantial market for advanced technologies and scientific equipment. In Europe alone, the annual value of the market created by big-science procurements is estimated at 2 thousand million Euros (EC, 1997).

Because of the means they require, the most frequent examples of big science projects are in space research, fusion research, high energy physics and in astronomy (Martin et al, 1981). One notices that big science projects combine fundamental research with an often extremely demanding engineering task (Autio et al, 2004). They are also a fruit of a most diverse collaboration within a network of academia, public organizations, and industry (Autio et al, 2003).

The corollary assumption is that such projects, fed by multimillionaire budgets and concentrating resources on few major research facilities with equipment generally demanding significant R&D at the frontier of technology (Martin et al, 1981) create significant economic impact.

What are the drivers of this economic impact?

One may divide the economic effects of a research center in three categories (Bianchi-Streit et al, 1984):

(1) Primary economic effects – result from the primary aim of the research centre, when this centre produces innovations itself such as new energy sources, telecommunications satellites, etc. Primary economic effects are more characteristic of applied research centers. In contrast, for instance, Astronomy projects' primary aim is very basic research and practical applications of its results can be rarely foreseen. Despite this fact there are cases of technologies that, although not being the main target of the work of basic research centers, were developed by them and successfully transferred to industry. In annex 1 some examples of astronomy spin offs are named.

(2) Secondary economic effects – are the benefits for partners from collaborating with big science centers. One refers to the "famous" externalities or spillover effects. Most of them are intangible positive effects. One may identify a myriad of opportunities for externalities from big science centers. A major part of the scientific equipment necessary for carrying out the research by big science centers is supplied by industry. Often the specifications and requirements are beyond the know-how currently available and thus represent a challenge

for the manufacturer. Positive effects, such as new products, quality improvements and productivity increases may occur.

Big science centers often require sustained R&D efforts from their industrial suppliers, efforts that may potentially transform the technology base of the supplier company. Big science also can act an important first customer for emerging technologies (Autio et al, 2003).

One may guess that a big science centre, with its multiple skills, diverse assets and technology validation practices generate a most fertile ground to foster scientific and technological learning in companies and boost industrial innovation (Vuola et al, 2006).

(3) Multiplier effect – as viewed before (in the sub chapter dedicated to demand side studies) this effect occurs in all public investments, like the case of big science projects, which create additional demand. It is because of the multiplier effect that the direct spending of Big Science projects in procurement and salaries also stimulates the economy and creates employment in the short term.

One may gladly find that flourish empirical studies, mostly in space research and high energy physics, whose aim is to estimate the economic impact of big science in these 3 perspectives. Let’s have a look to some them.

#### 2.2.4.1 Primary economic effects - Technology transfer

With regard to the development and transfer of technologies by big science, Mathematica measured the transfer of technology from NASA. As case studies, they used cryogenics, integrated circuits, propulsion, and software development. This study reported new product developments and cost reductions (Markus, 1994). Mathech also studied nine innovations resulting from technologies used by NASA. They estimated a benefit-cost-ratio of four for pace-makers intended for cardiac disease patients (Markus, 1994).

Chapman et al also studied the economic impact of "spin-offs" from NASA. These were defined as the secondary use of major research and development efforts. The direct NASA-furnished technology amounted to about $12 thousand million in sales. Excluding them, Chapman et al reported that sales and savings resulting from the studied spin-offs resulted in about $20 thousand million in total. In addition, roughly 350,000 jobs were created or maintained between the years 1978 and 1986. Chapman et al interviewed 400 suppliers and studied 441 separate instances of NASA-sponsored or provided technology. They were led to the conclusion that 83% of the cases resulted in benefits in terms of savings or sales. Of total sales and savings, 46% were generated in transportation, mostly in aviation. The corresponding share in industrial manufacturing and processes was 27% and 9% in medical applications. The rest covered a number of other technological domains. In about 15% of all cases, a product, process or an entire company would not have come to existence without the furnished technologies (Markus, 1994).

Literature on benefits from high-energy physics research supports the findings on transfer of technology from big science. Imrie identified short, medium and long-term benefits from high-energy physics. These included areas such as new materials and mechanical engineering techniques and medical instruments like positron emission tomography and radiotherapy. On-line computers and modular data-acquisition systems were also reported to have an impact. Superconductivity and instruments for other scientific disciplines were often found to have roots in high energy physics research (Markus, 1994).

Barbalat has made a review of advanced technologies and applications arising from high energy physics. He concluded that one rapidly developing new area appeared to be environmental protection, such as sewage and flue gas treatment using industrial accelerators (Markus, 1994).

As a last example one may not forget that the revolutionary world wide web (WWW) aroused from CERN. In its website[6] CERN states that the WWW was originally conceived and developed to meet the demand for automatic information sharing between the network of scientists working in different universities and institutes all over the world. The basic idea of the WWW was to merge the technologies of personal computers, computer networking and hypertext into a powerful and easy to use global information system.

As illustrations of primary economic effects from astronomy, one may consult in annex 1 examples of technologies and businesses emerging from this science.

#### 2.2.4.2 Secondary economic effects

Along the study of the impact of big-science increased interest has been directed to secondary economic benefits, that is technological innovation, learning and other spillover effects.

BETA studied the indirect micro-economic effects of expenditure by the European Space Agency - ESA for the periods 1964-1976 and 1977-1986. BETA concluded that the ratio of indirect benefits of estimated ESA payments to the contractors was in the first study 2.9 and 3.2 in the second study. The studies included supplier sample sizes of 128 and 67, respectively. The benefit-ratio was calculated by first estimating the impact of the already awarded ESA contracts and their impact on the foreseen future company sales. It should be noted that figures refer only to the indirect benefits to ESA suppliers. Figures do not refer to industries in general or the overall economy. In this study the benefits were divided into four categories:

(1) Technological benefits - included diversification, new ESA products and sales of modified or new products based on ESA technology;

(2) Commercial benefits - included possible market expansion, the use of the ESA reference for marketing purposes, and commercial collaboration with new companies or research institutes;

(3) Work factor or labour related benefits - included maintaining qualified personnel, the "critical mass" to preserve the necessary technological know-how;

(4) Organizational benefits - included improvements in production methods, quality control, cost savings and management techniques.

In the later period of the study, the most important effect was in the area of technological benefits. They accounted for 43% of all indirect benefits. These were followed by work factor benefits (41%), commercial benefits (9%) and organizational benefits (7%) (Markus, 1994).

In the area of high energy physics, Schmied et al studied the secondary microeconomic impact of CERN expenditure during the periods 1955-1973 and 1973-1982. The supplier sample sizes were 127 and 160, respectively. Benefit coefficients, called utility to CERN

6 http://public.web.cern.ch/public/en/about/web-en.html

ratios, of 4.2 and 3.5 were reported, respectively. Economic utility was here defined as the sum of increased annual sales and cost savings. Schmied identified a number of different benefits. These included annual sales increases, new companies created, the use of CERN as a product test-bed, maintaining production capacity and inter-company collaboration. Furthermore, cost savings, product innovations and quality improvements were reported. The use of the CERN reference for marketing purposes was also acknowledged. Schmied gives the breakdown of the types of benefits reported in the first period of CERN study. Here, 46% of the net utilities consisted of technological benefits and 45% commercial benefits. The remaining 9% were cost savings (or organization and methods benefits) and preservation of production capabilities (or work factor benefits). On average, it took less than 3 years to generate the secondary effects (Markus, 1994).

Autio et al in their study on the technology transfer and technological learning through CERN's procurement activity document the findings on CERN's spill-over benefits, focusing on the technological, market and organizational learning benefits that accrue to CERN's supplier companies as well as on their performance outcomes during the period 1997- 2001. They surveyed 629 companies, technology intensive suppliers to CERN. They concluded that many corollary benefits are associated with procurement activity. As an example, as many as 38% of the respondents developed new products or services as a direct result of the supplier project; 13% started new R&D units; 14% started new business units; 17% opened a new market; 42% increased their international exposure; and 44% indicated significant technological learning (Autio et al, 2003).

Thinking in Astronomy, one returns to the already mentioned case study "Spin off from basic science – the case of radioastronomy" by Ben Martin and John Irvine. The authors looked at the case of radioastronomy in Great Britain to examine how important technological spin offs and man power training benefits are. After doing interviews to staff of the radioastronomy observatories, the authors identified 4 cases of possible technological spin offs from radioastronomy (Martin et al, 1981):

One might occur in the area of communications, more precisely, in capital equipment suppliers. The hypothesis was that companies responsible for the construction of telescopes and implementation of the antennas might have had medium and long term benefits from collaborating in these projects;

Other involved instrument suppliers, namely, in the field of parametric amplifiers, which seemed to have derived substantial economic benefit from collaborating in these projects;

Another concerned the transfer of radioastronomy equipment to areas such as medical physics, and in particular to tumour detection technology;

The last case involved the transfer of radioastronomy techniques, for instance, the precise measurement of distances and the use of radio signals for the purposes of very precise navigation.

The results of the interviews with the companies involved in these cases did not confirm their hypothesis. They concluded that the economic benefits have been limited.

Nevertheless, punctual benefits were identified, that is worth to point, namely, in the communication industry: radioastronomers were responsible for the idea of big dishes and for demonstrating that big dishes could detect very weak signals; Radioastronomers contributed to the increase of know-how in the use of big dishes; Companies involved in the construction of the dishes gained experience that was applied in subsequent projects. With regard to the second possibility of spin off , the instrument supplier shared that the turnover (financial benefits) received within the project helped them to build a basis for future growth; the contact with the radioastronomy telescope stimulated them to develop a new range of products and create new market opportunities; they used the nearby radioastronomy facilities to test new products quickly and rigorously; there was a considerable transfer of knowledge in the field of microwave technology since radioastronomers were at the very forefront of that technology. Other identified benefits were related with the transference of radioastronomy techniques: the precise measurement of distances has been used with some success to detect movements of the earth's crust in earthquake zones; the use of radio signals in navigation has been used in the military field.

By the other hand, interviews to radioastronomers and companies were unanimous to reveal that the more substantial economic gains from radioastronomy have taken the form of manpower-training benefits.

Martin and Irvine wanted to explore this clue and sent questionnaires to the former postgraduate students from the two British radioastronomy observatories in order to know the numbers and percentage of radioastronomy students moving to R&D places in industry as well as to know the skills students acquired during their experience in the observatories and how useful these skills are in the present professional occupations.

The conclusions were that at the time of the survey former PhD students dedicated 32.7% of their time to R&D functions (government and industry); 20% of the PhD students worked in industry. With regard to former MSc students, they dedicated 38.7% of their time to R&D (government and industry); 35% of former MSc worked in industry.

About the developed skills, it is useful to know that postgraduate training in radioastronomy involves a variety of tasks ranging from the construction of receiver equipment (sophisticated electronics), the use of this equipment on a radio telescope, to the development of computer programs and mathematical techniques for processing and analysing data.

Responses of former students working on R&D in industry and government at the time of the survey show that there are benefits emerging from training in radioastronomy. Data show that not only several general skills have been found useful – for example, individual initiative, capacity to undertake original scientific work and the ability to communicate effectively – but so have other skills more specific to radioastronomy. Of the former PhD students working in industry at the time of survey, no less than 85% have found their training in computing "useful" or "very useful", 65% their electronics training, 50% their expertise in radio systems and 40% their knowledge of radio astronomy techniques. Furthermore, some of the skills associated with big science research, such as organizational and supervisory ability, and the ability to work as a member of a team, have also been mentioned as useful.

Finally, the survey shows that most students entering industry or government have spent grand part of their working years in high technology areas related to their previous training. Altogether, radioastronomy students have spent 11% of their subsequent careers in computing R&D, 8% in telecommunications and radar R&D, and 5% on wave propagation problems.

Based on these evidences the authors of the study argue that is the close relationship between the skills acquired by radioastronomy students and their subsequent utilization in certain areas of high tech R&D that is responsible for the greatest impact of radioastronomy. In the end, one may conclude by this study that astronomy generates person embodied economic benefits. These benefits are the high skills that researchers in transit from Astronomy to industry apply in companies, fostering innovation.

Still in the field of human resources, one may find empirical evidence that reinforces the conclusions of this case study, again in Great Britain. One refers to the study in 2003 of the career paths of PPARC PhD Students. PPARC means Particle Physics and Astronomy Research Council. This study was based in questionnaires sent to all former PhD students in these scientific areas, more precisely, to former students whose PhD awards terminated between 1995/96 and 1998/99.

The study found that PPARC PhD students are highly employable. Only 4% of respondents were unemployed and actively seeking work. This study shows that 48% of former students were employed in the private sector, 35% in universities and 12% in other government and public organizations.

Three quarters of those employed in the private sector worked in the following sectors: financial services; business services; and computer software design, solutions and management. Those employed in the financial services sector were engaged in banking and investment/fund management activities. Those employed in the business services sector worked mainly for companies providing management consultancy services (often information technology related). Other employers in this sector are companies providing legal services and engineering consultancy services. Only a small minority of those employed in the private sector worked in manufacturing (13% of those employed in the private sector).

With regard to R&D tasks, approximately half of respondents said that they were still engaged in scientific research (either directly or indirectly through the management of research). Only 19% of those employed in the private sector were still engaged in scientific research compared to 97% of those employed in universities and 64% of those employed in other public organizations. 63% of the respondents who said that were still engaged in research but in areas outside PPARC domains work in the private sector. Respondents engaged in research undertake a wide variety of research from financial modeling to more traditional research and development for the defense and aerospace sectors.

The study concluded that the high level mathematical, computer modeling and information technology skills possessed by PPARC PhD students are transferable to several types of careers. In particular, the skills of PPARC PhD students appear to be valued by private sector companies in software-related industries, financial services and business services.

Summing up, this study gives evidence that industry recognizes the benefits of employing high skilled human resources coming from Astronomy.

One may argue that the fact that particle physics students and astronomy students are not distinguished by the study is a pitfall for the objectives of this work. Although these very basic research areas are related, particle physics does not fall in the scope of this work. It is true but this fact is minimized when one finds that the majority of respondents took their PhD in an area related to Astronomy and Planetary Science. A smaller number (roughly a third) worked on research related to Particle Physics. Materializing the subject and type of PhD undertaken by researchers, one finds that 48% of the respondents took a PhD in Astronomy, Astrophysics and Cosmology, compared with 16% who took a PhD in Planetary Science and Solar Research including Space Physics and with 34% of the respondents who took a PhD in Particle Physics. 2% of the respondents took a PhD in other areas.

#### 2.2.4.3 Multiplier effect

Taking the multiplier effect as a base, Evans studied the effect of a continuous $1 thousand million increase in NASA expenditures since 1975. He estimated that it would have translated into an increase of $22 thousand million in US Gross National Product by 1984. In addition, it would have created 1.1 million new jobs (Markus, 1994).

Bezdek and Wendling reported a multiplier effect of 2.1, the ratio of total to direct output, on NASA procurement in 1987. It generated some $18 thousand million in total industry sales and $3 thousand million in business profits. About $6 thousand million was generated in tax revenues and some 200,000 private-sector jobs were created. The highest impact in selected industries was in electronic components with sales of $500 million and multiplier effect of 5.9. Electric lighting and wiring equipment amounted to about $43 million and had an effect of 4.8. Electric, gas and sanitary services amounted to about $610 million and had a multiplier effect of 4.5 (Markus, 1994).

The multiplier effect, local stimulation of the economy and employment, has been studied for the DESY project and for the Superconducting Supercollider project in Texas, long term economic benefits were identified in both cases (Markus, 1994).

## 2.3 Key findings of the literature review

Reading the present literature review one easily concludes that there is an agreement regarding the contributions of basic research to innovation and economic development.

There is a time lag between basic research projects and the effectiveness of their economic benefits.

One may distinguish various types of contributions of public funded research to economic growth (Salter et al, 2001):

| |
|---|
| Increase of the stock of useful knowledge |
| Training of skilled graduates |
| Creation of new scientific instrumentation & methodologies |
| Formation of networks and stimulating social interaction between innovation agents |
| Increase of the capacity for technological problem-solving |
| Creation of new firms |

Table 1: Types of contributions of public research to economic growth

The type and "strength" of the benefits varies accordingly to the scientific field of the basic research and across the industries that might benefit from it. Ultimately, these impacts of basic research should be analyzed in a case by case basis in order to allow a clearer view of the effects.

Since most of the economic benefits are intangible they are hard to measure. Surveys and case studies are the preferred methodological approaches.

A basic research project may origin primary economic effects, secondary economic effects and the multiplier effect.

Regarding the secondary economic effects or spillovers, one may identify 3 mechanisms (that are interrelated and may overlap) through which economic value-added could be achieved (Autio et al, 2004):

(1) Financial benefits - direct financial impact of the supplier contract; financial impact of optimizing production capacity;

(2) Innovation benefits – increase in sales due to new or improved products; better quality systems; costs savings through process improvement;

(3) Commercial benefits - increase in sales due to marketing reference value associated with being a supplier to a big-science center.

Suppliers of big science projects are the first economic agents to benefit from them and tend to be the ones that get the major economic benefits from these projects.

There are negative outcomes of basic or public research projects, which consist of the opportunity costs due to resource allocation.

Up to know remains the doubt whether it is accurate to emulate these findings on the case on analysis, Astronomy.

# 3. CONCEPTUAL FRAMEWORK

## 3.1 The Economics of Astronomy

A way of inferring whether Astronomy activity produces economic impacts and what kind of impacts are originated is to dedicate some time to the Economics of Astronomy, that is, interpreting Astronomy as an human activity, one might ask what "production factors" this activity needs to reach its goals, how it works and how it processes these factors and, finally, what are the expected results. This exercise might also bring light to how this human activity is integrated in the economic system and how it relates with other subsystems and agents.

First of all, Astronomy needs human resources. Remembering what was said in a previous chapter about the tasks of Astronomy, this science needs highly skilled researchers in fields that go from mathematics, physics, information technology to engineering, for instance, electronics, communications and mechanics. In astronomy projects, which employ, for instance, master and doctoral students in astronomy, these specialists acquire skills in research and development at the frontiers of knowledge (Martin et al, 1981). One hypothesis is that if and when these human resources go to industry they will apply the acquired skills, benefiting the companies which employ them: even students from very basic fields such as astronomy may move into industry and make major contributions (Salter et al, 2001). Thus, one might consider the training of skilled graduates as a main output of Astronomy.

As stated before Astronomy is a rich field of application of other sciences. Thus, one must mark the knowledge produced by other sciences as an input of Astronomy. For instance, the study of astronomical objects relies heavily in the knowledge of wavelengths spectrum of the radiation emitted by these objects, knowledge developed in physics. Spectrometry is used by Astronomers to measure the chemical composition and physical properties of astronomical objects or to measure their velocities.

By the other hand, being the field of application of other sciences, where the produced knowledge is tested and perfected, Astronomy might inspire the advancement of these Sciences. As illustration, just think in the theoretical concept of relativity, coming from physics, which was proved in Astronomy.

Since the first ages of Astronomy its scope and complexity have expanded. For instance, the objects of study have evolved from the closest planets of the solar system to the distant galaxies and exotic structures like quasars. One might argue that one of the drivers of this evolution is being technology development. As illustration one may think in the scientific progress in Astronomy fostered with the help of telescopes, the application of photography and detectors, the possibility of observing astronomical objects in various wavelengths or with the advent of computation and space missions. Hence, one may consider technology as an input to Astronomy. By the same token, Astronomy's scientific challenges might push the limits of technology motivating technological progress. If successfully transferred to industry, these technologies might be drivers of innovation.

One may conceptually synthesize the Economics of Astronomy, with its inputs and outputs, as follows:

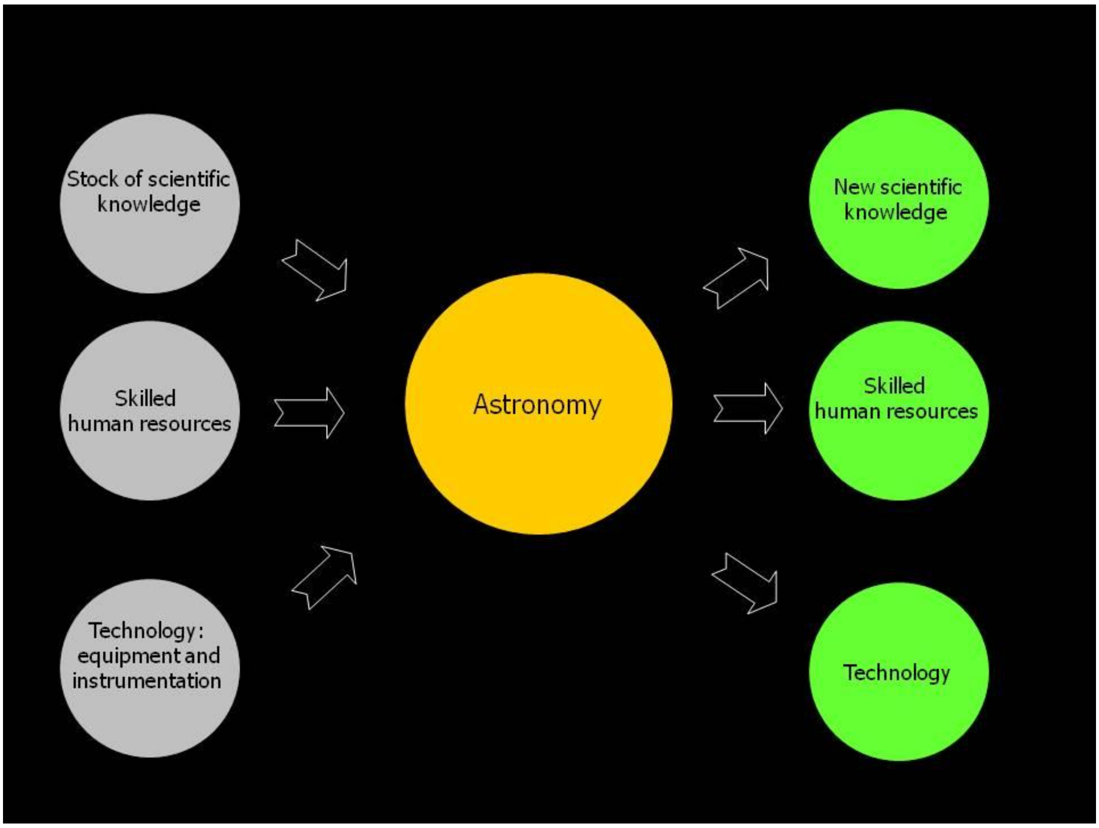


Figure 2: The Economics of the Astronomy

Now, in the perspective of the interactions with other agents, one expects that the new scientific knowledge will benefit complementary Sciences and will contribute to human development through culture and education. With regard to training of skilled human resources, there is a hypothesis that these specialists flow into related industry applying the acquired knowledge in these industries and contributing for their competitiveness. At last, technologies developed in the framework of astronomy projects might be transferred to industry, being a possible source of innovation. One might find significant interactions with other agents on the input side too. Namely, with suppliers, during the implementation of the infra structures and development of instrumentation and technologies while setting the "production line" of Astronomy and while making science. Taking into consideration the reviewed literature, this backward linkage might be a fertile mean of diffusion of innovation, through mutual learning, between Astronomy projects and suppliers.

At this stage, one believes that there is a reasonable basis to establish a set of hypotheses concerning the economic impact of Astronomy:

(1) Being a big science, Astronomy has a positive impact in the Economy through its procurement activity, namely by the means of the secondary economic effects of Astronomy projects. Secondary economic effects of Astronomy projects are significant;

(2) Astronomy produces economic benefits in the form of technologies transferred into industry and spin off companies emerged from this science;

(3) Astronomy generates person embodied economic benefits.

The present work consists in one attempt of testing the first supposition. Although not being the focus of this work, publicly available examples of technology spin offs from Astronomy, shared in annex 1, give clues about the second proposition. Also, in sub chapter 2.2.4.2 one may find citations of secondary information coming from studies which address the third hypothesis.

## 3.2 Methodological approach

In the literature three main alternative methodological approaches are taken to study the impacts of basic research: econometric studies, case studies and surveys.

Usually, econometric studies are associated to the attempt of predicting the impact of basic research in macroeconomic variables. Econometric studies focus on large-scale patterns, providing an aggregated, big picture of statistical regularities. Salter and Martin affirm in their literature review that econometric studies are useful in estimating the rate of return of research. However they are unable to trace the impact of research through the process of technology development, innovation and commercialization (Salter et al, 2001). Since the scope of econometric studies fall beyond the hypothesis that this work is attempting to test and demand resources not available to the author of this work, this methodological approach is not an option.

Case studies involve picking up a certain research project, a technology, company or a research organization and then monitoring and trying to explain its evolution and implications in relation with other agents. Case studies can also be made in an ex-post perspective, based on an attempt of tracing all historical inputs to a certain innovation; Salter and Martin consider that case studies are the best tool to examine directly the innovation process and changes over time. However they are expensive to administer and can take a long time to analyze. In addition, cases studies yield only a narrow picture of reality, thus they are difficult to generalize (Salter et al, 2001).

Even if it is not the aim of this chapter, it is worth to note that results of case studies show that research produces substantial spillovers, namely geographical, linked to localization effects and reflecting personal interactions, connected with person-embodied nature of much of the knowledge. Salter and Martin quote that these spillovers contribute to development of agglomerations or clusters (Feldman et al, 1994) and shape a region's capacity to innovate (Saxenian, 1994). Notwithstanding, case studies tend to focus mainly in successful innovations.

Finally, surveys question companies, for example suppliers of a certain big science project, about the impacts of the collaboration with big science on their business. Surveys analyze the extent to which collaboration with research projects constitutes a source of innovation for firms. They only focus in one particular case but tend to be effective in the evaluation of the impacts, namely the secondary economic benefits. In the end, this methodological approach will be the chosen one for testing whether secondary economic effects of Astronomy projects are significant.

This choice tries to balance the objectives of the present study with the available time and resources for this work. By going ahead with this methodological approach one also relies on the findings of the related literature that show that analogue approaches achieved satisfactory results while studying other big science projects, namely the CERN case.

After searching for organizations whose mission is astronomy research and consulting the supervisors of this work, one reaches the conclusion that ESO - European Southern Observatory would be a good candidate to be a case for study.

# 4. ASSESSING SPILLOVER EFFECTS OF ASTRONOMY

## 4.1 Why ESO

ESO – European Southern Observatory[7] is the European organization for astronomical research in the southern hemisphere of planet Earth. Is an inter-governmental organization with 15 member states, including Portugal, which joined it in 2000 and Brazil, which joined it recently.

The original aim of ESO, whose organization started to be discussed in 1953, was to allow member States to work together to build and operate advanced astronomical facilities which were beyond the capabilities of individual countries. In particular, it would allow European astronomers' access to the parts of the sky best visible from the southern hemisphere.

ESO's main mission, laid down in the 1962 Convention, is to provide state-of-the-art research facilities to astronomers and astrophysicists, allowing them to conduct front-line science in the best conditions.

The annual member state contributions to ESO are approximately 135 million Euros and ESO employs around 700 staff members. Portugal's contribution to ESO annual budget reaches 1% to 1.5%, sensibly 1.5 million Euros[8].

Operationally, ESO runs three observing sites in the Atacama Desert region of Chile: La Silla, Paranal and Chajnantor.

La Silla site is equipped with several optical telescopes with mirror diameters of up to 3.6 meters. The 3.58 meter New Technology Telescope, which started operations in 1989 was the first in the world to have a computer-controlled main mirror, a technology developed at ESO and now applied to most of the world's current large telescopes. The ESO 3.6 meter telescope is now home to the extrasolar planet hunter: HARPS (High Accuracy Radial velocity Planet Searcher), a high precision spectrograph.

Paranal site hosts the Very Large Telescope array (VLT). VLT is constituted by an array of four telescopes, each with a main mirror of 8.2 meters in diameter.

Chajnantor site is assisting to the construction of ALMA - The Atacama Large Millimeter/submillimeter Array. ALMA is the largest ground-based astronomy project in existence. ALMA will comprise an array of 66 twelve meter and 7 meter diameter antennas observing at millimeter and submillimeter wavelengths (it's a radioastronomy project). ALMA project is a partnership between Europe, East Asia and North America, in cooperation with Chile. Construction of ALMA started in 2003 and it will start scientific observations around 2011.

The next project of ESO is to build the European Extremely Large optical/infrared Telescope (E-ELT) with a primary mirror 42 metres in diameter. The E-ELT is the largest optical/near-infrared telescope in the world. It is expected that construction begins around 2010, with the start of operations planned for 2018.

ESO's "science machines" generate huge amounts of data at a very high rate. These are stored in a permanent science archive facility at ESO headquarters, in Germany. The archive

[7] All the information about ESO, reproduced in this chapter with the courtesy of ESO, is available on its webpage: www.eso.org

[8] Source: FCT space office

now contains more than 1.5 million images or spectra with a total volume of about 65 terabytes. Consequently, ESO's "production" allows a torrent of scientific work. In 2009, more than 650 refereed papers based on ESO data were published.

By reading ESO's biography, one easily concludes that ESO organization is a driver of Astronomy. That was the main reason to present this project to ESO, proposing collaboration in the framework of which the Organization would be considered as a case for study concerning the secondary economic benefits of Astronomy.

ESO is focused on the design, construction and operation of large and powerful, ground-based observing facilities for astronomy in distant and inhospitable places. Hence, one believes that ESO projects are well suited to the label of "Big Science", possibly generating economic benefits that are generally found in Big Science projects.

In order to build and to operate its facilities ESO needs to buy large quantities of high technology equipment to industry and to develop scientific and industrial R&D collaborations. One expects that these collaborations might generate economic benefits to partner organizations. ESO's projects involve work from a broad spectrum of industry sectors, for instance, transports and logistics, civil engineering, optics, electrical engineering, computing, telecommunications, electronics, mechanical engineering, opto-mechanics or opto-electronics sectors. In addition, ESO outsources many support services to industry. These include building maintenance and repairs, information technology support services and data processing operations.

The fact that ESO's industrial relations cover several unrelated sectors minimizes the risk of industry specific biases while analyzing hypothetical impacts. In parallel, the fact that ESO applies dominantly competition-based supplier selection policies and that ESO projects involve a large number of small and large companies tends to avoid biases in the analysis towards certain countries or companies, individually considered.

It's useful to remember that ESO maintains close connections with a wide network of research groups at university and at R&D institutes in the development of scientific instruments, offering opportunities to do frontier research to astronomers and to scientists of complementary fields.

## 4.2 VLT project as reference

ESO gently accepted to help in the endeavour of checking the secondary economic benefits of Astronomy projects.

One decided to take the procurement activity of a particular project as a reference because, when one knows the origin, it is easier to trace and explain the effects, if any. Furthermore, choosing one particular project downsizes the large number of ESO's suppliers to survey, without compromising the significance of the sample, since all ESO's projects require considerable procurement activity.

The chosen project was VLT project, due to two main motives: presently it is viewed as the flagship facility of ESO and VLT has been in routine scientific operations since 1999 (when the first of the 4 telescopes started their work) which is thought enough time to suppliers perceive the effects of the collaboration with ESO. As viewed in the literature review, economic impact of collaborations between companies and basic research (discounting the immediate financial benefits) normally take time to occur.

VLT[9] is the world's most advanced optical instrument, consisting of four unit telescopes with main mirrors of 8.2 meter diameter and four movable 1.8 meter diameter auxiliary telescopes. The telescopes can work together, in groups of two or three, to form a giant "interferometer", the ESO Very Large Telescope Interferometer (VLTI).

The 8.2m diameter telescopes are housed in compact, thermally controlled buildings, which rotate synchronously with the telescopes. This design minimises any adverse effects on the observing conditions, for instance from air turbulence in the telescope tube, which might otherwise occur due to variations in the temperature and wind flow.

The auxiliary telescopes are mounted on tracks and can be moved between precisely defined observing positions from where the beams of collected light are combined in the VLTI. The auxiliary telescopes are self-contained in their ultra-compact protective domes, and travel with their own electronics, ventilation, hydraulics and cooling systems. Each auxiliary telescope has a transporter that lifts the telescope and moves it from one position to the other.

VLT includes large-field imagers, adaptive optics corrected cameras and spectrographs, as well as high-resolution and multi-object spectrographs. VLT covers a broad spectral region, from deep ultraviolet (300 nm) to mid-infrared (24 μm) wavelengths.

These facts are relevant since they show that astronomy facilities are constituted by computer-controlled telescopes but also by instrumentation that allows astronomers taking full advantage of the received cosmic data. Instrumentation is developed and calibrated to detect and process pre chosen signs, according to specific scientific goals. As an illustration one may name the instrument X-shooter. This instrument is a multi-wavelength (Ultra Violet to near infrared) medium resolution spectrograph. It started operations in 2008. X-shooter is designed to detect and analyse the properties of gamma-ray bursts, the spectra of low metallicity stars, X-ray binaries, distant quasars, galaxies and nebulae.

Many of these instruments have been built in collaboration between ESO and consortia of R&D university centers.

The VLT has stimulated a new age of discoveries, with several notable scientific firsts, including the first image of an extrasolar planet (eso0842), tracking individual stars moving around the supermassive black hole at the centre of the Milky Way (eso0846), and observing the afterglow of the furthest known Gamma-Ray burst.

Once presented the VLT, conditions are gathered to go on with the empirical assessment of the spillover effects derived from its procurement activities and discussion of the results.

### 4.3 Assessing VLT's spillover effects

The assessment of VLT project's spillovers will be made applying a survey to organizations that collaborated with ESO in the framework of this project. The main objective of the survey was to ask organizations about their perception in relation with hypothetical economic benefits derived from their collaboration with ESO. Afterwards answers to the survey will be analysed on a statistical stand point and the findings will be discussed.

ESO gently helped to go on with the task, sharing information about all procurement orders that had been materialized since the beginning of VLT project until the beginning of January

[9] All the information about ESO, reproduced in this chapter with the courtesy of ESO, is available on its webpage: www.eso.org

2010. The long list of orders gives information about the order number, date of order, name of the vendor organization, the vendor post address, the vendor city, the vendor country, the name of the contact person of the organization and amount of each order.

The database contains 1,603 orders, amounting 52,629,845 Euros in total. One may conclude that in terms of procurement budget the VLT project is a heavy weight. The value of single orders ranges from 4 Euros to 19 million Euros. Orders were executed by 453 organizations.

As an appetizer, one may analyze how the value of orders evolved annually which will give an idea of the procurement activity of VLT project during the time:

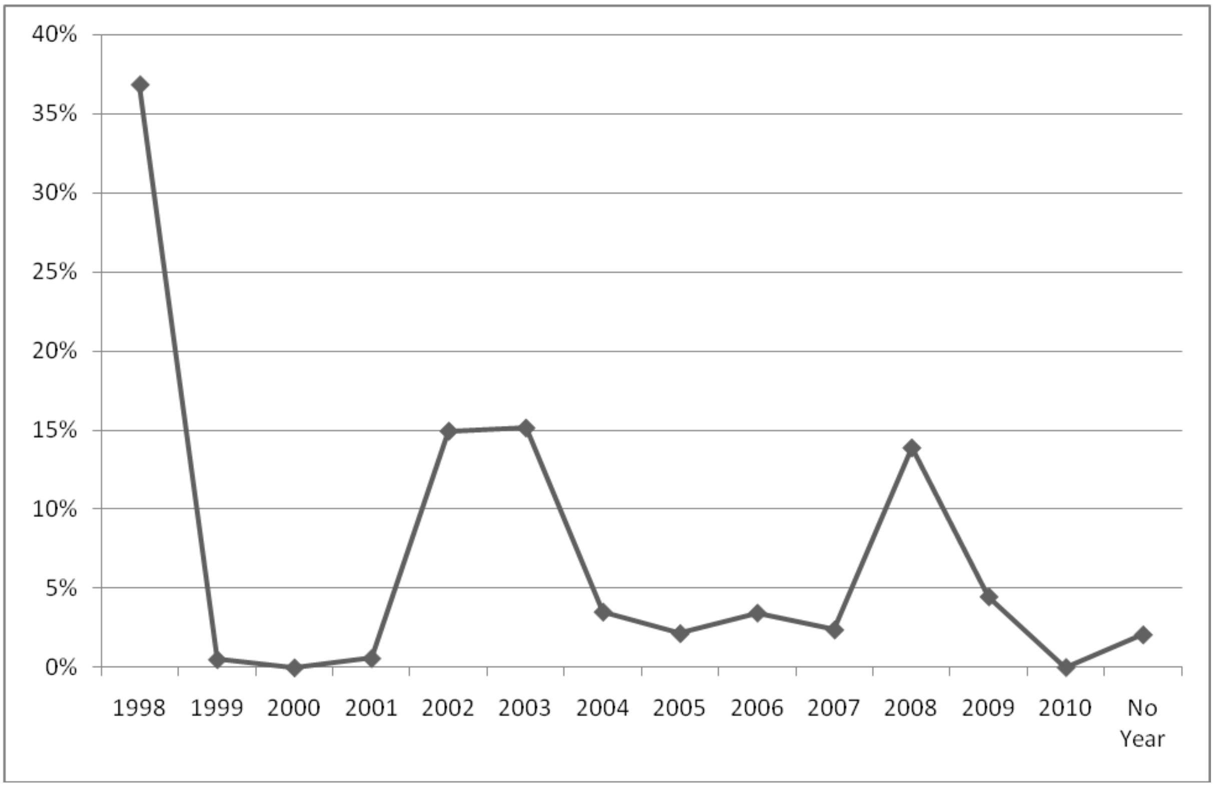


Figure 3: Annual chronology of the value of VLT's orders

The gross of the orders, in terms of value, was given in 1998, as natural, in the beginning of the project. The value of orders in 1998 amounted 19,373,549 Euros, 37% of the total value of orders. The second and the third years with bigger value of orders were 2003 and 2002, with 7,968,572 Euros (15.14%) and 7,863,730 Euros (14.94%) of orders given respectively. Followed 2008 with 7,308,612 Euros of orders, corresponding to 13.89% of the value of total orders. Note that there are orders amounting 1,095,981 Euros (2.08%) that were undefined in terms of date. So, they don't count for this chronological analysis. Other aspect to keep in mind is that the date of the order does not necessarily correspond to its fulfillment. That is, implementation of contracts is made after the register of the order, originating a time lag between the date of the order and the works that may bring externalities to organizations which collaborated with ESO.

After gathering orders by organization, one decided to eliminate organizations whose total orders did not exceed 20,000 Euros during the period under consideration. This criterion was applied because it was deemed unlikely that significant economic effects (namely learning effects) would occur within very small-scale contracts or purchases. In an analogue study, concerning technology transfer and technological learning through CERN's procurement activity, Autio et al eliminated companies whose total orders did not exceed 25,000 CHF, sensibly 18,750 Euros, at present currency exchange rate. Other reason to reduce the number of organizations under analysis is the time and resources constraints of this study. After applying this criterion 94 suppliers remained in the list. Of these, one individual service provider was excluded after the verification that it is a member of ESO. The correspondent order has the value of 30,000 Euros. During the search of suppliers' contacts, one found that two of the companies were recently acquired by one major multinational company. In consequence, one gathered the value of the orders corresponding to the former companies and treated them as one solely organization. Other finding was that one company was a division of other, bigger company, present in the sample too. One corrected the duplication by merging the respective value of the orders of both companies in only one organization. In the end, the population one will study is constituted by 91 entities, with corresponding orders of 51,252,485 Euros. That is, these 91 suppliers cover 97% of the total budget for VLT project.

In contrast with similar studies (for instance, CERN contract), one didn't exclude from the list research institutes or research centres of Universities, fundamentally because R&D centres and Universities are economic agents too, with impacts in the local, regional or national Economy (Salter et al, 2001). This work has already exemplified in chapter 2.2.2 studies made by Universities which highlighted their contribution to economic development. Also, this decision is based in the opinion that R&D organizations tend to be managed with the aim of maximizing quantity and quality of scientific production (in contrast with companies, whose objective is to maximize profits). So, there is a chance that they identify impacts caused by their collaboration with ESO, with consequences in their scientific and economic ecosystems.

Adding up, similar studies exclude logistics, transport or civil engineering companies with the argument that these firms are not high technology suppliers. Unlike these studies one also didn't exclude the referred sectors because the present study is not only focused in technological learning but also in commercial, marketing and organizational learning that collaborations with ESO might originate.

Other characteristic of the population under scrutiny is that there was not a prior separation between organizations which engaged in development contracts and organizations which supply "off the shelf" products. This is due to the fact that, with the given information, one has no secure way of screening different types of agreements. One hopes that both the research on companies' business and the analysis of the survey help to infer the impact of the collaboration with ESO in function of the types of contracts.

Following, one will give a deeper description of the population. One thinks that is a useful exercise in order to get the first impressions of the ecosystem of an Astronomy project as well as of the interactions and impacts that it generates in industry and R&D organizations.

### 4.3.1 The Population

The Population is constituted by 91 organizations which have activity in a variety of technical specializations. Although frontiers between specializations are faint and in many organizations different specializations overlap, one dares to classify organizations taking in account the following areas of business:

| |
|---|
| **Astronomy** – one refers to astronomy services, for instance, to celestial mapping studies; number of hours of observation in other telescopes; or to work linked with instrumentation conception, namely the establishment of requisites or the design of instrumentation |
| **Communications** – production of communication components such as cables, conductors |
| **Computer hardware** – computers, servers, hubs |
| **Electronics** – production of electronic material and components, for example, sensors, consoles, boards, dyads, motors |
| **Electronic Engineering** - design and implementation of electronic systems, for instance control systems, actuators or metrology systems |
| **Energy** - electricity production and distribution, building of electricity infra structures |
| **Instrumentation** – development of specialized customized equipment. In astronomy it requires expertise from optics to mechanical engineering, control and electronics |
| **Management** - consultancy in project management |
| **Mechanical engineering** – design and production of mechanical components, high precision mechanics |
| **Optics** – fabrication of lasers, fiber optics and optic components |
| **Opto-electronics** – delivery of opto-electronics systems and devices such as detectors and imaging devices (for instance, cameras, CCD – charge coupled devices) |
| **Opto-mechanics** – one refers mainly to the activities of design and implementation of telescopes and their structures |
| **Software** – development of specialized computer programs |
| **Textile structures** - membrane structures for buildings |
| **Transports and logistics** – one refers to the task of transporting telescope big structures from suppliers to Chilean desert |

Table 2: Areas of business of the Population

The distribution of the number of organizations according to their main business/activity is shown in Figure 4:

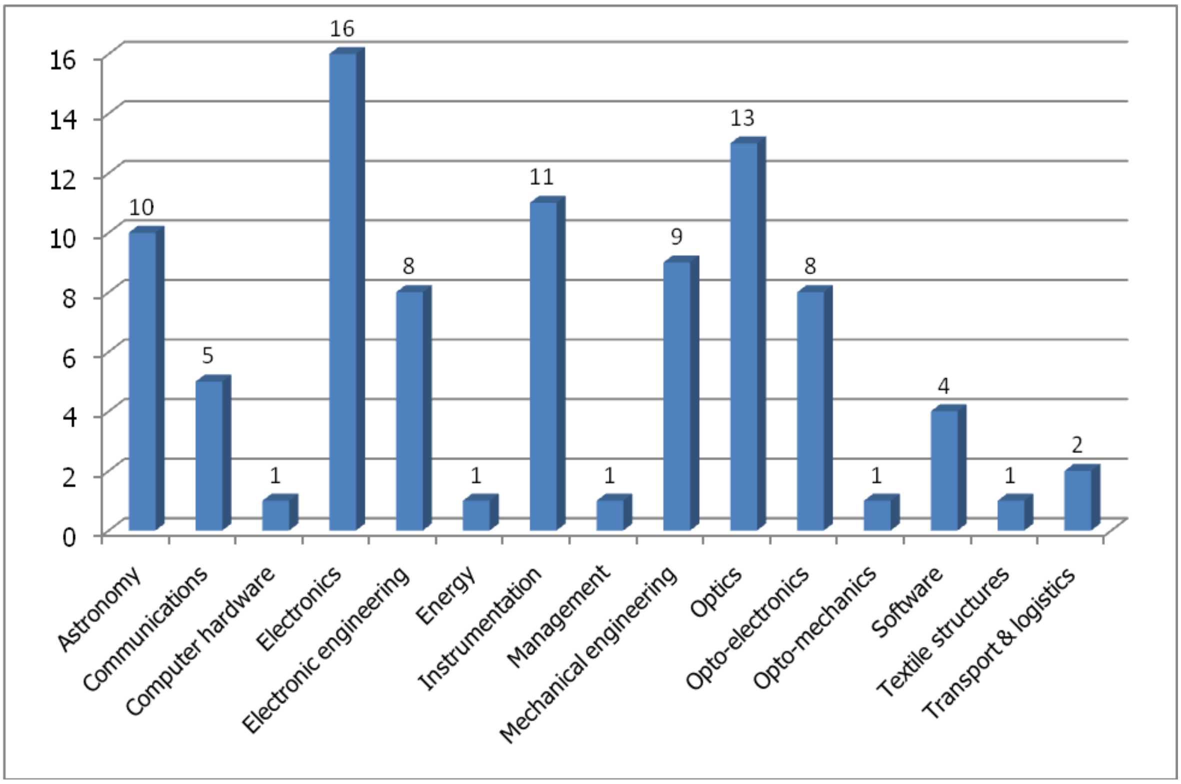


Figure 4: Number of organizations according with their business

The distribution of businesses/specialties according with the value of orders is shown in Figure 5:

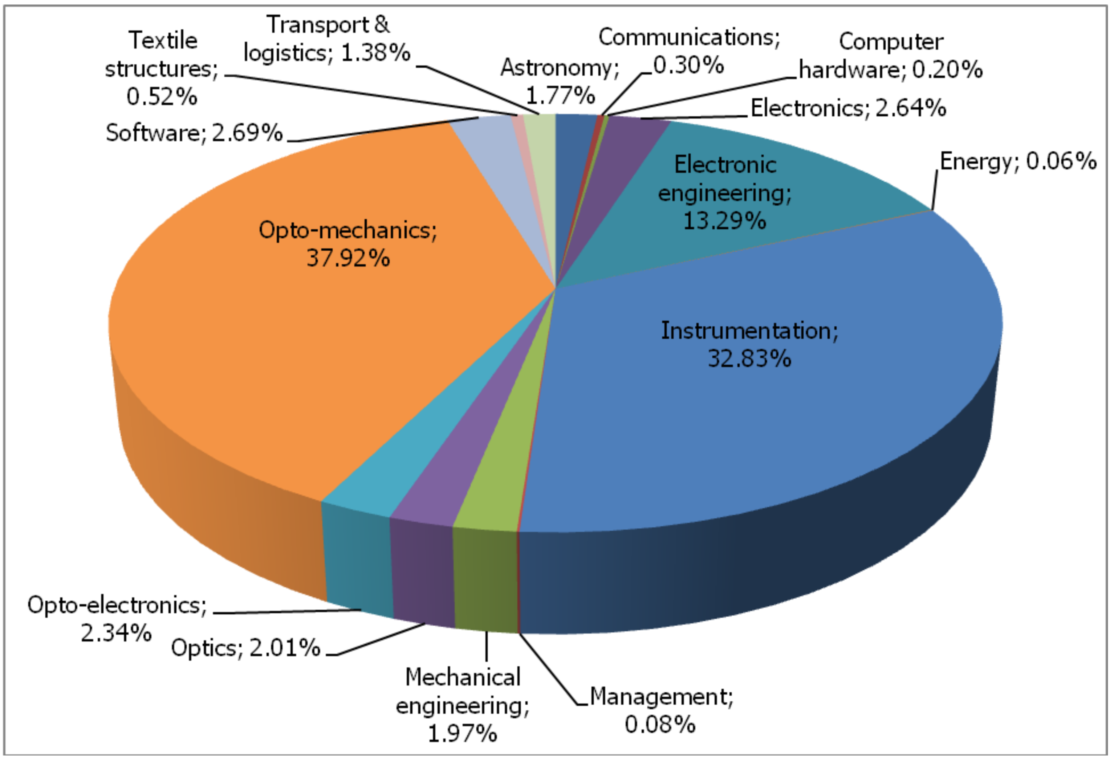


Figure 5: Weight of specialties in the sample in terms of orders' value

One verifies that the population is constituted largely by organizations coming from high technology sectors. Recalling the literature, if one considers “Energy”, “Management”, “Textile structures” and “Transports and logistics” as non high technology areas, one will conclude that these sectors only make a fraction of the population, in terms of number of organizations, 5 in 91, and value of orders, 2.04% of the total value of orders. Anyway, one imagines the technically demanding task that it was to transport telescope’s big structures from suppliers’ sites, located in Europe, into Chilean desert.

With regard to the budget of each organization of the population (sum of the value of all orders asked to each organization), it ranges from 20,394 Euros, minimum, to a maximum of 19,433,585 Euros. The median of budget’s distribution is 50,000 Euros.

The distribution of the number of organizations according with their budget is shown in Figure 6:

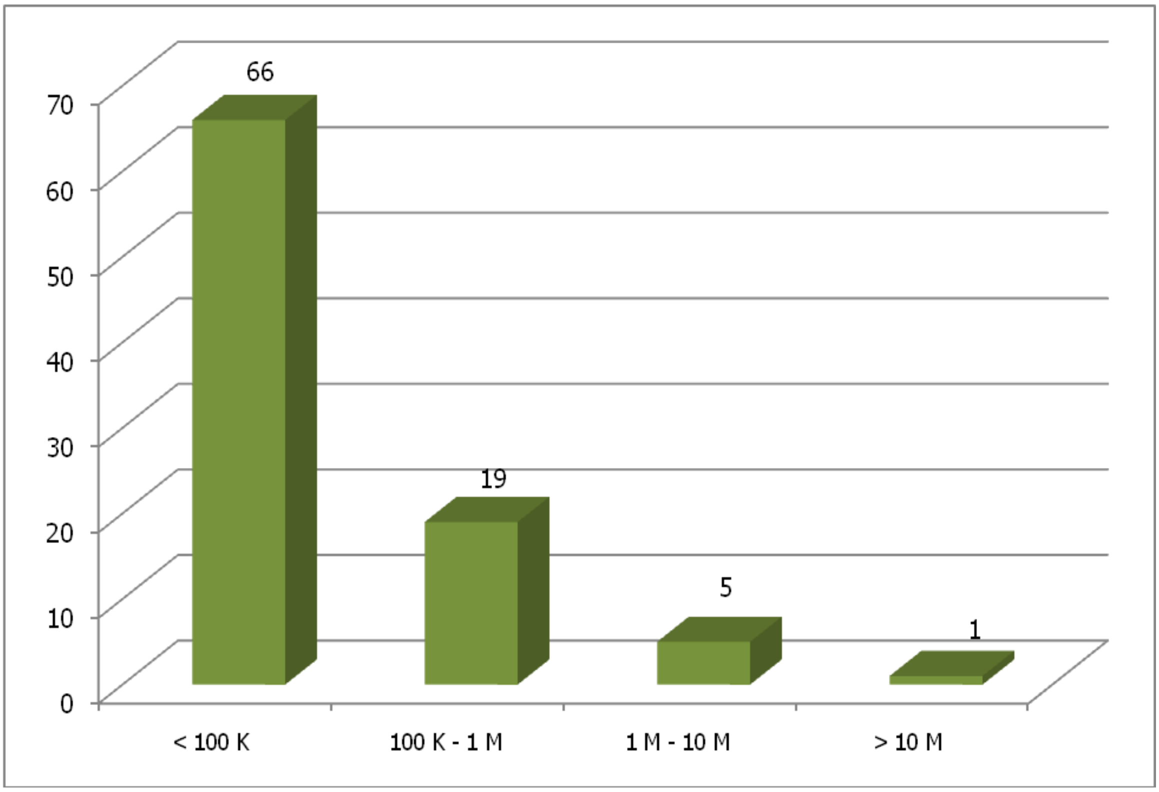


Figure 6: Distribution of the number of organizations according with their budget

The contribution for the total budget coming from the various ranges of budgets is shown in Figure 7:

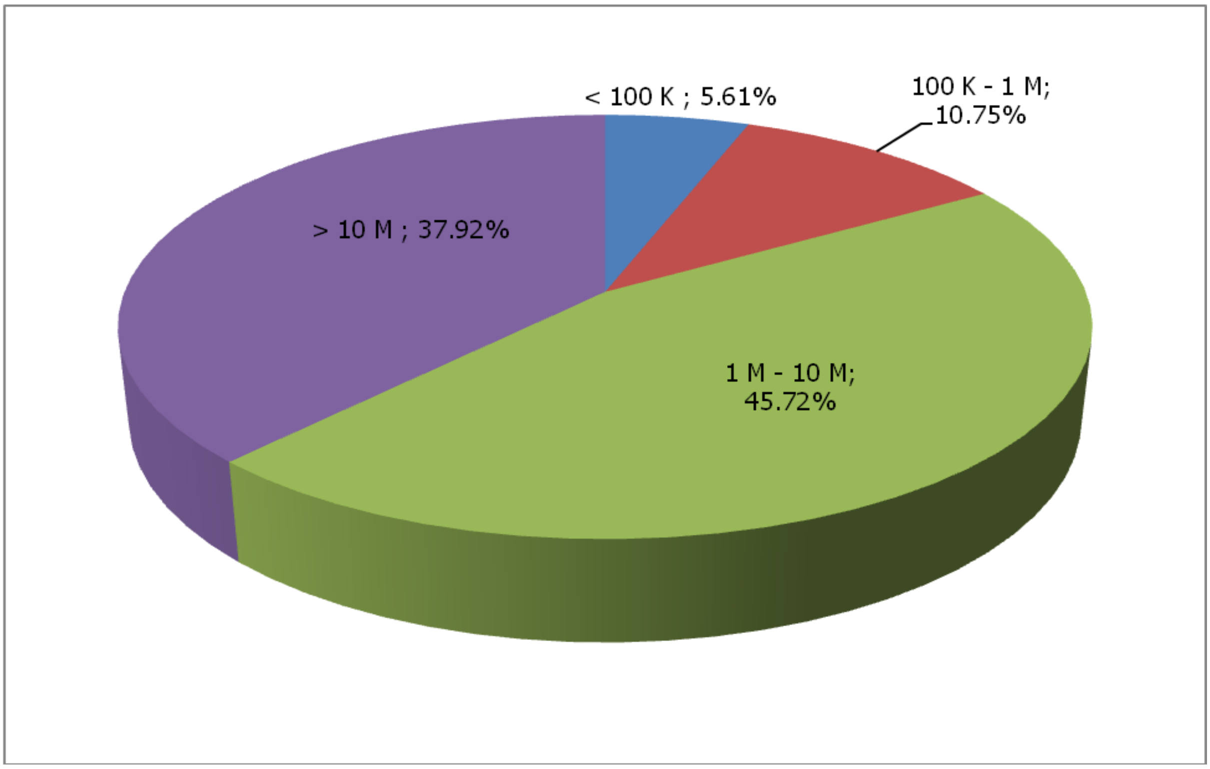


Figure 7: Weight of the ranges of budgets in the total budget

The distribution of organizations according with their budget shows a disparity in terms of the financial value of the work being done by organizations: a small number of organizations is responsible for the most of the budget to implement and run VLT, more precisely, 6 organizations (6.59% of the sample) are responsible for 83.64% of the total budget of the sample. This fact suggests there is an increased probability that these organizations interact and learn with ESO, due to the value of their budgets (which may reflect long, complex and development projects). On the other hand, this fact might lead to a situation where only few organizations identify medium and long term benefits from collaborating with ESO.

The available information in the file given by ESO allows a geographical view regarding organizations and the respective budgets. This view is relevant in the context of the discussion among researchers whether there are or there aren´t spillovers based on geographic proximity. Reviewed authors state that organizations and firms located near research centres or other firms and universities tend to benefit from the activities of their neighbours due to externalities. These externalities are derived, for example, from procurement contracts or R&D collaborations made easier due to proximity, or to the multiplier effect (Nadiri, 1993). Salter and Martin refer that Katz has concluded that research collaboration within a country is strongly influenced by geographical proximity; as distance increases, collaboration decreases, suggesting that research collaboration often demands face-to-face interaction (Salter et al, 2001).

Below, one may find in Figure 8 the number of Organizations of the Population by country:

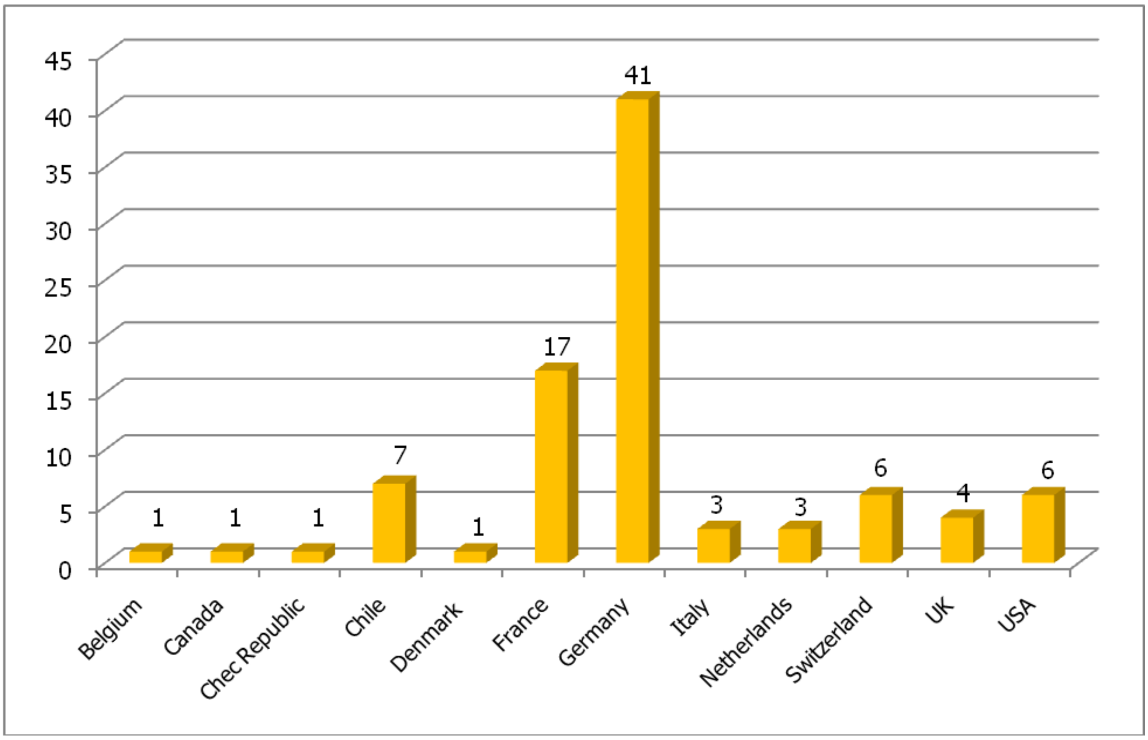


Figure 8: Number of Organizations by country

Figure 9 shows the relation between represented countries in the sample and their relative weight in the budget:

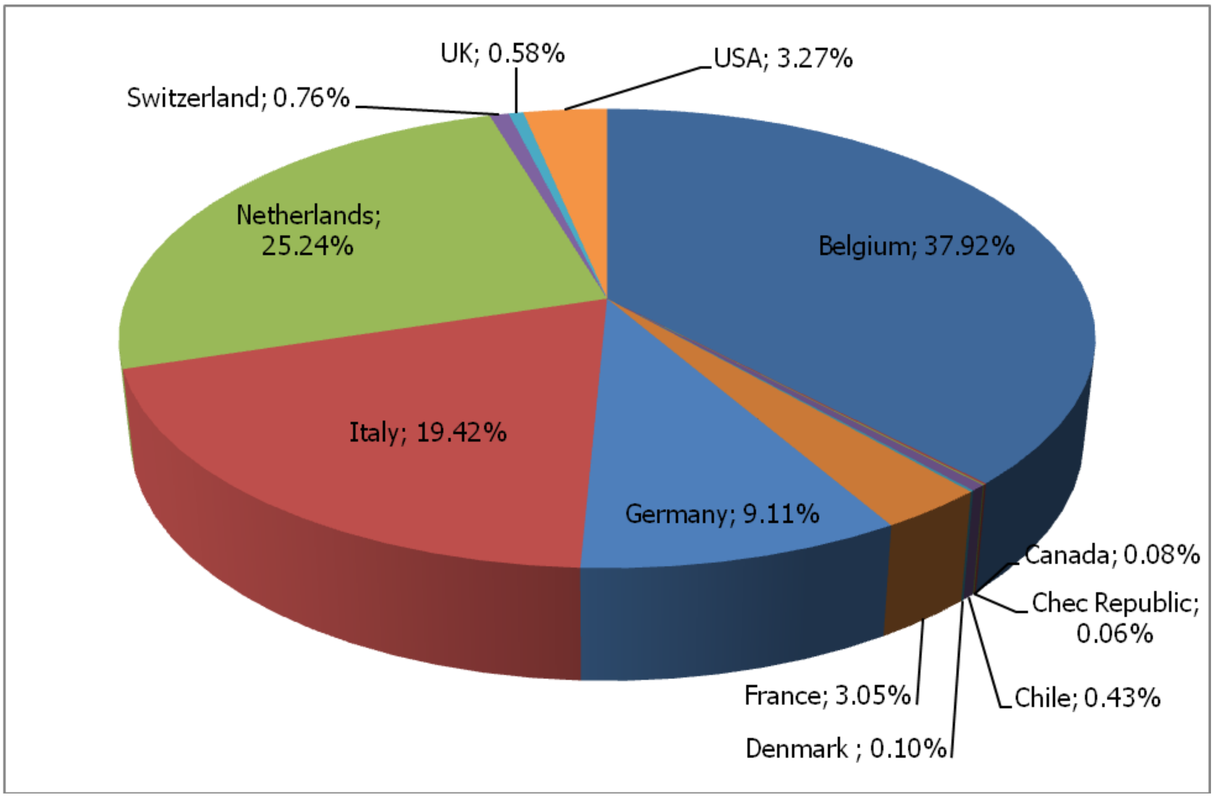


Figure 9 : Weight of the countries in the budget

Note that the country of origin is defined as the geographic site of the company to where the procurement order was sent. As many companies are multinational companies, the geographical location of the company that received the order might not match with the geographical location of the headquarters of that company or with the geographical location of the site where the major part of the manufacturing or assembling took place.

Since the headquarters of ESO is in Germany and the telescopes are located in Chile one might wonder whether companies of these countries were in good position to receive a substantial slice of the budget. Although Germany is the country with the largest number of Organizations, 41, it is the fourth country in terms of budget, with 9.11% of the total budget of this population. Chile is represented by a small number of Organizations, 7, and constitutes a small percentage of the budget too, 0.43%. Europe is responsible for 96.22% of the budget. These facts might be justified by the procurement policy of ESO, based in competitive contests. These facts also underline the international context where this type of projects occurs. In addition, probably the chosen countries have already developed high tech competencies that gave them competitive advantage. Note that Portugal, although being a member of ESO, is not represented in the Population under study.

Discussion has being made whether big science organizations, like ESO, ESA or CERN should, in principle, limit invitations to tenders to organizations established in member states or attribute a pre established share of the budget to member states in function of their contribution to the overall budget of the organization. The reasoning of "quota" defenders is that this procedure, by exposing member state Organizations to technically complex challenges, may incentivize high tech industry in these member states. This procedure could also be viewed as a form of financial return to the contributions of the member states. People who are against argue that this type of procedures limit competition thus medium and long term innovation.

Other important factor for the relation and type of interactions with ESO is the mission of the Organizations which collaborate within the VLT project. One is able to check through Figure 10 the number of companies of the Population, comparing with the number of research and development organizations (private or coming from Universities):

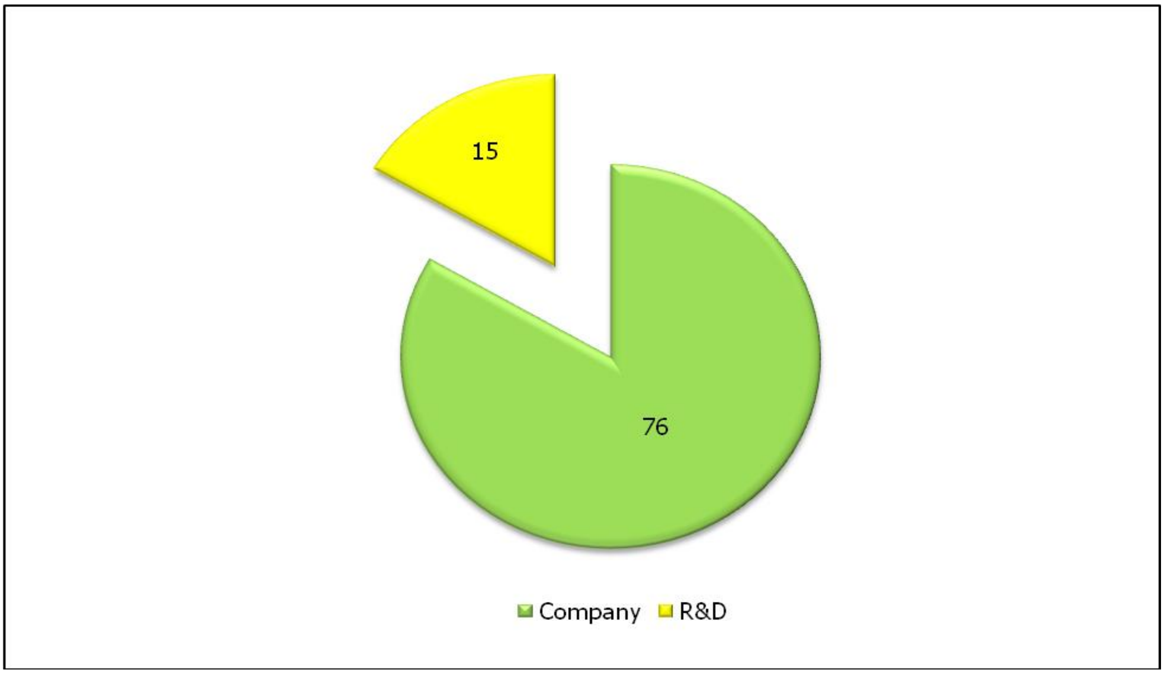


Figure 10: Number of companies vs number of R&D organizations

Below, one may find in the Figure 11 the comparison between the total value of orders executed by companies and the total value of orders executed by R&D centres of the sample by country:

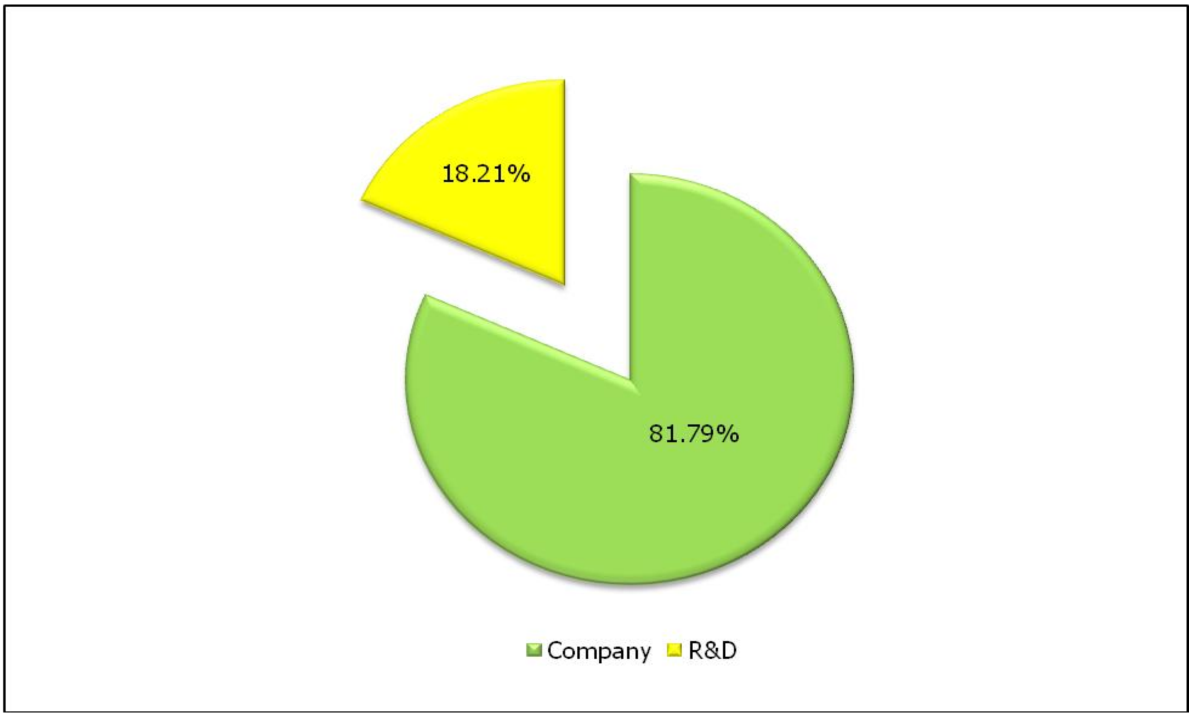


Figure 11: Companies vs R&D organizations in terms of budget

The population is constituted by 76 companies, representing 81.79% of the value of the budget, that is 41,921,088 Euros whereas 15 R&D organizations are included, corresponding to 18.21% of the value of the population, that is 9,331,397 Euros. Note that among R&D organizations there are four whose mission is applied R&D, serving as interface between national Universities and Industry. The budget of these organizations reaches 8,371,267 Euros, the big portion of the budget dedicated to R&D centres. The other 11 organizations develop more fundamental research in their areas of domain: 10 dedicate their research to Astronomy and 1 to instrumentation for several scientific purposes. Figures show that Astronomy projects although being a source of basic research, rely heavily in industry collaboration. A fact to keep in mind is that for certain subprojects within VLT project organizations are organized in consortia, for instance companies and R&D centres, due to their complimentary skills. So, they work together, fostering mutual learning effects. One example is the development of a specific telescope, whose conception and design were performed by a R&D centre and whose assemblage, motorization and tests were made by a company.

### 4.3.2 The survey

The survey targets the collaborations between organizations and ESO, aiming to check whether organizations recognize benefits found in the literature and to get a feedback from these organizations about the degree of importance of the identified benefits. The survey is inspired in the work of Autio et al regarding technology transfer and technological learning through CERN’s procurement activity (Autio et al, 2003), in the work of Michael Hähnle regarding R&D collaborations between CERN and industrial companies (Hähnle, 1997) and, at last, in the work of Markus Nordberg on contract benefits and competence-based supplier strategies (Nordberg, 1994).

The survey, entitled "Survey on the impact in your organization in doing business with ESO", is divided in two parts. The first one is focused in organizational data. Since there is a relevant number of large companies in the sample and because the study is concerned about organizational learning, for which the relevant teams of workers are the ones which collaborate directly with ESO, one requests the respondents to indicate (if the organization is divided in business units) the name of the business unit where they work and its activities. A business unit is an organizational substructure focused on a given product family and/or a given market.

In the first part of the survey one asks about the number of collaborators working in the organization or business unit. One also asks information aimed to infer the percentage of collaborators who work in astronomy projects, who have an astronomy background and who work in R&D.

One also inquires about financial information trying to get an idea, in a direct way, of the influence of astronomy in the revenue and earnings of the organization. Also one asks in this part o the questionnaire about the level of R&D expenses in the organization and the portion that corresponds to astronomy projects.

Knowing, by the experience of similar works, that there may be issues suppliers feel reluctant to disclose because they fear that this act will jeopardize their competitive advantage (Hähnle, 1997), one tried to avoid asking detailed information or data that might be considered confidential. The focus was on information one could get on reports and accounts of organizations or on data that is usually publicly available, like revenues or expenses.

Remembering what Salter and Martin said about the impacts of public research, the number of active business spin offs of a research domain is a good indicator of its impact in Economy. In this survey, one will have the chance to ask organizations which supply ESO whether they are spin offs of R&D centres related with Astronomy.

The second part of the survey is concentrated in the impacts of collaborations with ESO. Recall that the focus of the survey is on the benefits that accrue to ESO's supplier organizations by virtue of their relationships with ESO. In consequence one asks suppliers to indicate the degree of significance of a series of benefits, structured in 4 groups of benefits. The selection of benefits was based in the findings of the literature and in the typology of benefits used in previous analogous studies, for example the one developed by Markus Nordberg (Nordberg, 1994):

(1) Performance outcomes:

| |
|---|
| Financial income / profit generated by the contracts |
| Optimization of process or manufacturing/production capacity |
| Development of new products / services |

Table 3: Performance outcomes

(2) Marketing and commercial benefits:

| |
|---|
| Increased number of contracts with new costumers |
| Increased number of contracts with previously unknown costumers |
| Increased number of contracts with similar costumers (Astronomy or Big Science) |
| Establishment of a long term relation with ESO |
| Marketing / image benefits (for example, association with high tech or Big Science projects) |
| Market learning (about customers, their needs, market trends) |
| Access to industry networks |

Table 4: Marketing and commercial benefits

(3) R&D and technological benefits:

| |
|---|
| Transfer of technology from ESO (for example, instrumentation, patents, techniques / methods) |
| R&D learning (new ideas, knowledge, skills, methods) |
| Access to scientific or technological networks |
| Sharing of R&D or innovation risks |
| Development of new knowledge (for example, technology, publications) |
| Application of new patents, copyrights or other intellectual property rights |

Table 5: R&D and technological benefits

(4) Organizational benefits:

| |
|---|
| Improved technical skills / know how in your Organization's collaborators |
| Improved project management skills (for example, contract control) |
| Improved processes or manufacturing methods |
| Improved organizational practices (for instance in production, marketing, procurement, R&D) |
| Improved compliance / quality assurance |
| Increased collaborator's motivation |

Table 6: Organizational benefits

In addition to this series of hypothetical benefits, one gives respondents the opportunity to indicate benefits that were not identified prior to the survey.

In complement to this question, one tries to know whether the identified benefits are contributing for the development of projects outside Astronomy.

Other way of inferring the impact of collaborations with ESO is to analyse suppliers' efforts in order to successfully accomplish ESO's objectives.

Thus, one asks suppliers the level of significance of a series of hypothetical efforts:

| |
|---|
| Investment in new process equipment |
| Investment in new testing equipment |
| Training of collaborators |
| Visits to ESO (or other costumers) |
| Hiring new people |
| Implementation of new procedures |
| Bibliographical research |
| Market research |
| R&D |

Table 7: Efforts to comply with ESO's requisites

In the same logic of the last question, one gives respondents the opportunity to indicate efforts that were not identified prior to the survey.

At last, one concludes the survey with an aggregating question, that is, one tries to know the overall impacts on organization's wealth resulting from the collaboration with ESO. This question also works as a controlling question since it repeats and generalizes effects stated in other questions and because it invites respondents to imagine the results of the organization if there was no collaboration with ESO. The overall impacts are resumed in the following table:

| |
|---|
| Growth in revenue (sales) |
| Growth in number of collaborators |
| Technological / R&D excellence |
| Innovation / Competitiveness (Product, Process, Organization, Marketing) |
| Net value of your Organization |

Table 8: Overall impacts

In the questionnaire the fundamental questions are closed-type ones because the scope of the study does not require going deeper in details (in these cases informal interviewing is more appropriate). Closed types questions allow to obtain comparable data as well as to control answer biases since possible answers are standardized.

In the questions where respondents are asked to mark the degree of importance or significance of a certain effect, one uses a 5-point Likert scale. Likert-scales are commonly used in these types of studies (Nordberg, 1994).

One should note that questions concern contracts or transactions derived of projects related with Astronomy. Although the questions are about astronomy projects in general, one gave VLT project as an example in order to remember respondents that their Organization collaborated in that one. This reference aimed to increase the probability of accuracy and reliability of responses. Other requisite of the survey should be to save as much as possible time to respondents while filling the form. After several essays, the estimated time to fill the second part of the survey, being in the authors' opinion the fundamental part of the survey, was less than 10 minutes to a person who was directly involved in VLT project.

After designing and approving the survey, the next step was to frame it in the most simple and intuitive form to respondents. The form should also be clear about the implications of the survey. That's why the questionnaire starts with a short explanation of the purpose of the study and with a confidentiality clause. The questionnaire was prepared in English and in Spanish in order to minimize the potential for misinterpretations.

Then, a web questionnaire[10] was designed in order to allow respondents to complete the survey through the web and at the same time to concentrate all the answers in a database.

### 4.3.3 Results of the survey

The following lines will tell us the story of the inquiry to organizations. After signing a confidentiality agreement regarding the use of information provided by ESO about contractors of the VLT project, the file containing the supplying orders within VLT project was received in 29th June 2010.

Since the database does not indicate contacts (neither email addresses nor telephone numbers), the solution was to search for them in the web. The first reference was obviously the name of the organization. The complementary reference was the name of the contact person indicated in the orders. This organizations' representative was viewed as a potential respondent of the survey or as someone able to indicate the most suited person to answer to the survey since he/she had knowledge of the VLT project and/or ESO.

For organizations with several contact persons, the criterion was to try to contact the person who managed the order with biggest budget. This option derived from the assumption that the person who managed the biggest VLT order would be more acquainted with the VLT project and/or with the customer ESO. The budget for each contact person was calculated by summing the total value of the orders that corresponded to a certain contact person. The second-best was to try to contact the person named in the most recent order, decreasing the probabilities of not catching her/him due to an organization leave, for example.

[10] One may check the web questionnaire at https://spreadsheets.google.com/formResponse?formkey=dG9jY2FYUTRzMTlZVzlyN0RuSXNic0E6MQ&theme=0AX42CRMsmRFbUy05ZGE0Y2Q5ZS0zNTRmLTQzNmMtYjM5ZS1hN2Y0YjkzMmI4NDY&ptok=5474133415195354278&ifq

Luckily, one found in the web the email address of several organizations' representatives. In the remaining cases (the majority of them), one called to the organizations by phone in order to find the contact person. The phone calls begun with a presentation of the study and its objectives, then one asked for the contact person. In the cases where the contact person was not in the Organization anymore, one asked for the person responsible for the liaison with ESO. When one was able to speak with the targeted representative, one presented the study and its objectives and asked for collaboration. In addition one asked for the email address of the representative in order to send a message which explained the study, showed the survey and made the written request to fill it. In the cases where the person in the other end of the line was not able to give an accurate information one asked for a general or department email contact (for example, sales department).

One may say that one dialogued with commercial people/costumer managers mostly when the contacted organizations supply standard products. The contact person corresponded to technical people or project manager in the case of orders which implied development projects. Finally one was able to talk with the top management of organizations in the case of Small and Medium Enterprises (SME). Anyway, the large majority of contacted people knew ESO and knew that their organization had business or scientific relations with ESO.

After this initial approach by phone, one was able to send the first complete email in 15th August 2010. Note that, after the initial approach, 32 organizations were contacted by email without a previous phone call or without a previous talk with the direct representative in the relations with ESO. On the other hand, one made the first approach by phone in 59 organizations. The first round of emails ended in 28th August 2010.

The email message identifies the researcher and contextualizes the survey, describing the objective of the study. A hyperlink for the on-line version of the survey was included in the message. The email message informs the organization about the way one got their contact, as an ESO's supplier. The email message also informs about ESO's contacts, giving the organization the possibility of checking with ESO the veracity of this study. As a hypothetical stimulus to take part in the survey the potential respondents were promised a copy of the results' report. The deadline given for filling the survey was the end of August (for organizations contacted by email in middle of August) and the beginning of September (for organizations contacted by email in the end of August).

Between the second and the last weeks of September the remaining potential respondents were approached in two successive rounds by telephone (or email, when one was unsuccessful in trying to reach them by phone). Follow up emails were sent in order to reinforce the importance of their collaboration for the present survey since they were the organizations with more weight in terms of VLT's budget. Taking into account the feedback meanwhile received by the organizations, one also informed the remaining organizations that the survey was divided in 2 parts. The first part concerned financial and organizational data. The second part tried to catch the perception the organization had in relation with hypothetical impacts that the collaboration with ESO generated or was generating. One informed that, for the study, the most important part of the survey was the second one. One added that the second part would take sensibly 10 minutes to answer. About the first part of the survey, one recommend respondents to let them in blank when they concluded that certain answers were hard to get or sensible for the Organization, namely in terms of confidentiality.

A new deadline was set to the period between the end of September (for the organizations contacted in the second week of September) and the beginning of October (for the organizations contacted later in September) with the justification that the objective of the research was to start the statistical work in that period.

After the end of the new deadlines a final effort was made through a fourth round of phone calls directed to the thirteen organizations with biggest budgets. The line of conduct was that one would stop the survey only when the number of answers was sufficient to grant the significance of the study (as defined bellow). That milestone was accomplished in 30th September 2010. The last answer before the statistical work was received in 27th October 2010. That means that the data was collected between 17th August 2010 and 27th October 2010.

Following, one may check a graphic that describes the chronology of valid answers to the survey:

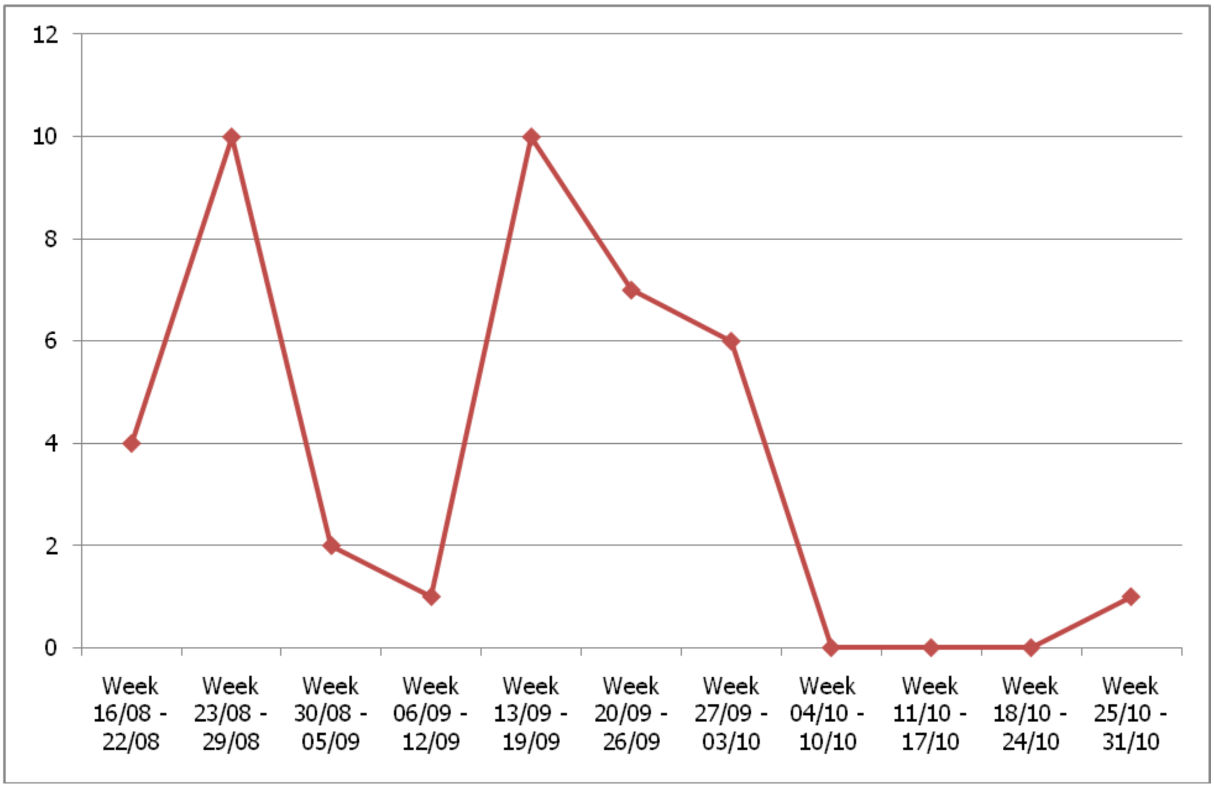


Figure 12: Weekly chronology of valid answers in the survey

In total, 43 organizations responded to the survey. Two of the participations were not considered valid because they consisted only in a null submission of a form. That is, both submissions did not have any answer to the form. Hence, the survey received 41 valid answers. This corresponds to a response rate of 45.05% of the sample, which can be considered fair for a survey of this nature. The response rate compares favourably with earlier similar surveys, the response rate of which usually hovers around 10% (Autio et al, 2003). For instance, the supplier company survey made by Autio et al in their study on the technology transfer and technological learning through CERN's procurement activity had a response rate of 24.4% (154 companies out of 629 companies), which the authors considered good. It is also noteworthy that the respondent organizations represented a total of 28,558,816 Euros in sales to ESO, representing 56% of the total budget allocated to the base population of this study.

Note that two inquiries were carried out by the author of this study while on a phone call (with the due authorization of the Organizations). Organizations' representatives alleged lack of time to complete the form by themselves. The solution was to ask them on the phone the questions of the survey.

At this point, one should grant that the number of answers allow a reliable projection of the results. The chosen relevance criterion is that respondents should represent more than 50% of the base population for each group of organizations which result of the stratification one makes in the framework of the statistical analysis. This criterion aims to avoid the occurrence of single, particular or few observations when making stratifications of the responses. Single, particular or few observations in a certain group of analysis may lead to biased or false extrapolations.

In the statistical analysis one will want to know if and how externalities occurred per type of organization which collaborated with ESO. The natural division is between companies and R&D organizations. Out of the 76 companies of the sample, 31 responded to the survey which corresponds to 41% of companies present in the base population. The budget covered by these companies totals 19,866,899 Euros, which represents 47% of the budget allocated to companies. These values are close to 50%. In relation with R&D centres, 10 out of 15 organizations responded to the survey, which corresponds to 67% of the R&D organizations present in the population. The budget covered by these organizations totals 8,691,917 Euros, which signifies 93% of the budget allocated to R&D organizations. Note that the group of 10 R&D centres that responded to the survey contains 3 organizations that develop applied research, representing, in terms of number, 75% of the subgroup of interface organizations and 98% in terms of value, whereas 7 organizations have a mission that is focused in fundamental research in Astronomy, representing 64% of this subgroup in terms of number and 49% in terms of value of orders.

Other pertinent categorization of the sample for statistical purposes is to group organizations per level of allocated budget. Recurring to the budget size categories already mentioned in section 4.3.1, one may divide the respondents as follows:

| | **< 100 K** | **100 K – 1 M** | **1 M – 10 M** | **> 10 M** | **Total** |
|---|---|---|---|---|---|
| **Number** | 26 | 10 | 5 | 0 | 41 |
| **% Number** | 39% | 53% | 100% | 0% | |
| **Total budget** | 1,212,374 Eur | 3,912,268 Eur | 23,434,174 Eur | 0 | 28,558,816 Eur |
| **% Total budget** | 42% | 71% | 100% | 0% | |

Table 9: Breakdown of respondents according with their budget in the VLT

One verifies that in the category of organizations which have allocated a budget with a value less than 100,000 Euros, the number of respondents is 39%, less than 50% of the number of organizations of this category in the sample. On the other hand, if one analyses the respondents on the perspective of the value of their budget, the respondents represent a percentage closer to 50%, more precisely, 42%. In the categories of budgets between 100,000 Euros and 1,000,000 Euros and between 1,000,000 Euros and 10,000,000 Euros the number of answers and respective budgets of respondents are more than the required 50%. In relation to the category of budgets bigger than 10,000,000 Euros there were no answers. This is no statistically worrying because this category is constituted by only one firm. One may say that the category itself is a particular case. In the end, one may conclude that, in relative terms (that is, in terms of number of observations in relation to the size of the population), observations are slightly biased towards larger procurements.

One could try to analyse spillover effects by country but chose not to make any breakdown of information for this variable. The complexity of industry makes the task of determining exactly which country benefits from the spillovers a challenging one. This is particularly true for multinational suppliers (Bianchi-Streit et al, 1984). Furthermore, this objective falls out the purposes of this study. Notwithstanding, the curiosity about the country of origin (as defined in section 4.3.1) of the respondents may be fulfilled in the following figure:

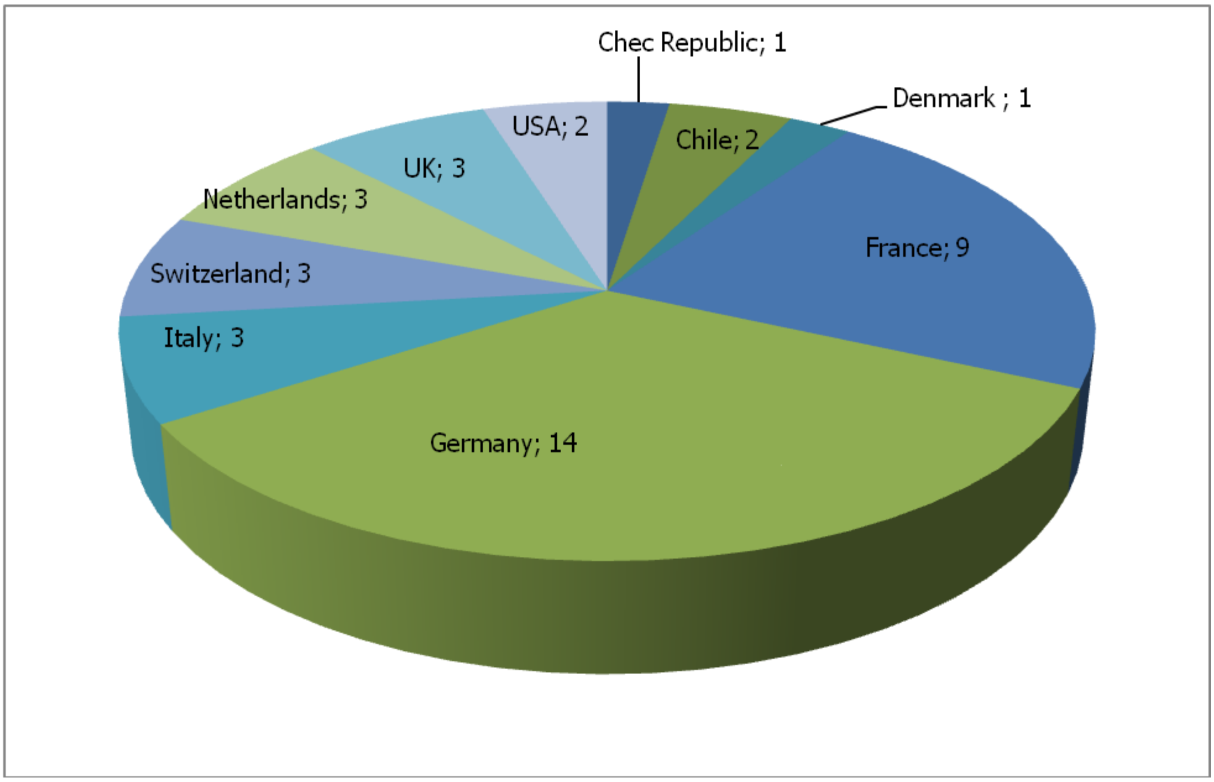


Figure 13: Distribution of respondents according with the country of origin

Regarding the countries of the organizations included in the sample, one did not receive answers from Belgium neither from Canada. In all other countries one got a significant feedback, if one takes into account the number of respondents but mostly the corresponding value of orders for each country. The exception is Chile, which gave 2 answers (out of 7), corresponding to 30% of the value of the total orders made for this Country.

Other relevant breakdown is by technical specialization of the respondent organizations. At this phase, one had the opportunity to verify whether the initial classification (based in an analysis of the organizations' websites) was correct. One took as reference the answers given to the survey's question number 1.3 "Main activities of your organization or business unit". One confirmed with reasonable certainty that the initial classification of the organizations per technical specialization was accurate.

One may check it in the table below:

| | **Number** | **% Number** | **Total budget** | **% Total budget** |
|---|---|---|---|---|
| **Astronomy** | 6 | 60% | 417,140 Eur | 47% |
| **Electronics** | 6 | 38% | 748,604 Eur | 55% |
| **Electronic Engineering** | 4 | 50% | 6,569,830 Eur | 96% |
| **Instrumentation** | 6 | 55% | 16,419,443 Eur | 98% |
| **Mechanical Engineering** | 4 | 44% | 517,478 Eur | 51% |

| | | | | |
|---|---|---|---|---|
| **Optics** | 5 | 38% | 523,735 Eur | 51% |
| **Opto-electronics** | 5 | 63% | 1,089,383 Eur | 91% |
| **Software** | 3 | 75% | 1,335,781 Eur | 97% |
| **Textile structures** | 1 | 100% | 268,568 Eur | 100% |
| **Transport & Logistics** | 1 | 50% | 668,854 Eur | 95% |
| **Total** | 41 | | 28,558,816 Eur | |

Table 10: Breakdown of respondents according with their specialization

By looking at the respondents' technical specializations one concludes that there are specializations that are not represented in the observations. One refers to Communications, Computer hardware, Energy, Management and Opto-mechanics. In consequence, these specializations won't be taken into account in the statistical analysis of the breakdown by technical specialization. All the other specializations have significant representations, both in terms of number of respondents and value of the corresponding orders.

Next one will check the time when orders were given to respondent organizations. Isolating the value of orders given to organizations which completed the survey, one concludes that they represent the gross of the value of orders given within VLT project between 2001 and 2009. The exceptions were years 2005 and 2007 where orders to respondents corresponded respectively to 38% and 41% of the total value of orders given within the VLT project in these years. Worth of note is that the first 3 years of the project, 1998 to 1999, are not represented in the observations. That happens mostly because the organization with biggest budget in the VLT (corresponding to one single order of 19 M Euros in 1998) didn't respond to the survey. In the following table, one may verify, for each year of the VLT project, the weight of the value of orders belonging to respondents in the total value of orders of the VLT project:

| | **1998** | **1999** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **No year** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **% Yearly Budget** | 0% | 0% | 0% | 96% | 96% | 99% | 61% | 38% | 69% | 41% | 93% | 80% | 0% | 79% |

Table 11: Weight of respondent orders in total value of orders, for each year

The following graphic highlights the chronology of the value of orders given to respondents during the period of implementation and operation of the VLT:

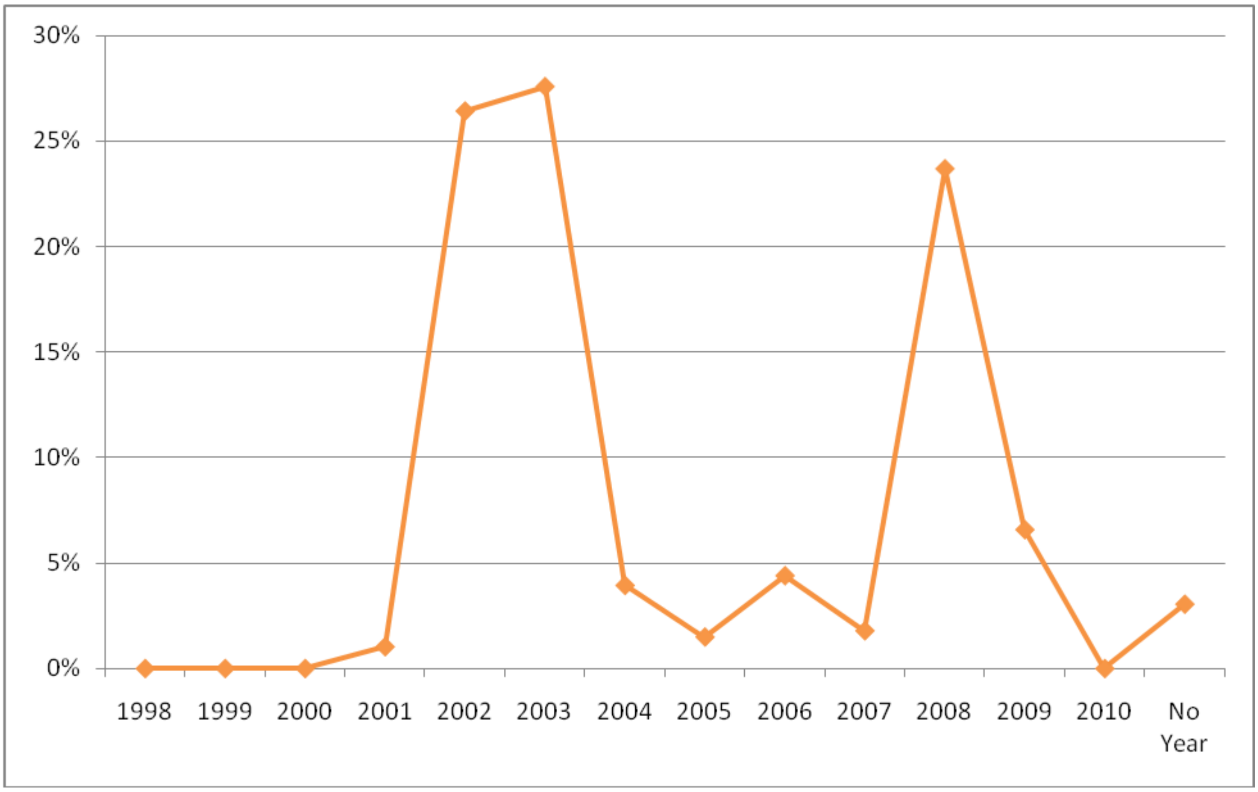


Figure 14: Distribution of respondents' orders in VLT time frame

One realizes that 28% of orders given to respondents, in terms of value, were made in 2003. The second most abundant year in terms of value of orders is 2002, with 26% of the total orders given to respondents. The third year is 2008, with 24%. One concludes that 89% of orders, in terms of value, were given in the time period spanning between 2002 and 2008, which one considers satisfactory regarding the accuracy of the answers to the survey executed in 2010. Markus Nordberg states in his work that the literature on European Space Agency and CERN benefits suggests that it takes between two and four years to see the benefits resulting from the contracts placed by a research organization like ESA and CERN (Nordberg, 1994). He continues, affirming that the same literature also found that events further back in time, more than six or seven years, are hard to recollect due to the so called "memory effect" (Nordberg, 1994). After statistical analysis of survey's data, no evidence was found regarding the influence of time in impact evaluation by respondents. Results of statistical tests are available in question 7 of annex 4 of this work.

In the end, one believes that the empirical coverage is sufficient and representative of the base population.

One will dedicate the next lines to the 21 organizations which, although not responding to the survey, were kind enough to give a feedback and to justify, by email or by phone, why did not fill the form. The reasons for not answering the survey give clues about the type of relation these organizations have with ESO and the impacts this relation may originate. One may resume the justifications as follows:

. 3 organizations informed that the work asked by ESO was a long time ago. They do not have means to remember or identify impacts of that work because people who were involved in the referred contract left the organization and/or the organization did not get more contracts from ESO after the referred contract. These organizations, 2 R&D centres and one company total 510,064 Euros in terms of budget for the VLT, corresponding to 1% of the value of orders covered by the population.

. 6 organizations did not collaborate because they found that had to disclose confidential information in order to answer to the query;

. 6 organizations stated that they sell to ESO standardized products not requiring more interactions than the ones developed in the framework of a regular commercial relation; of these, two organizations stated that they are distributors of other organization. Their work is limited to a pure commercial relation. These 6 firms total 476,855 Euros in terms of budget for the VLT, corresponding to 0.93% of the value of orders given to the base population. The firm with biggest budget received 162,622 Euros in orders.

. 5 organizations informed that the collaboration with ESO consisted in small works with no impact in their business. These 5 firms total 241,134 Euros in terms of budget for the VLT, corresponding to 0.47% of the value of orders. The firm with biggest budget received 69,202 Euros in orders.

. 1 organization communicated that they their relation with ESO is purely scientific, without any commercial interest and cash-transfer. Even though they work together with ESO on major instrument developments, these collaborations are executed as scientific collaborations, not on a contractual / business basis. The budget of this R&D organization for the VLT totals 55,336 Euros.

The information given by these organizations may be used as a qualitative contribution, complementary to the statistical analysis that one will present in the following chapter.

### 4.3.4 Results analysis

It is time to analyze the information shared by respondents. One will divide this exercise in two parts. In the first part one relies on the data gathered on the first part of the survey. In the second part one will compile and try to interpret the answers given in the second part of the inquiry.

#### 4.3.4.1 Warming up

The first part of the survey aimed to get organizational information from respondents. This organizational information may allow a direct and objective accountancy of hypothetical influences of Astronomy activity, such as development of spin off businesses, employment of Astronomy graduates or weight of Astronomy projects in respondent organizations. Other information one would like to get is the dimension of organizations, their core business and technological intensity in order to permit a richer breakdown and interpretation of the second part of the survey, more subjective by nature.

During the interaction with targeted organizations one realized that the information requested in the first part of the survey implied analytical accounting and possibly more time than the 10 minutes one initially previewed as the time necessary to complete the second part of the survey. These may be the reasons why contributions and valid answers in this part of the survey are lower than those of the second part of the survey. Other handicap is that several organizations, although naming the business unit which delivered the service to ESO (answer number 1.1), indicated data (for instance, number of collaborators or revenues) that correspond to the organization as an all. One guesses that this situation occurred in 4 cases. Evidently, this does not allow an analysis of the weight of Astronomy projects or employees with regard to the business unit that delivered the service. One made the decision of treating the organizational data as it is, that is, taking as reference the organization as an all and, for the second part of the survey, assume that the responses refer to the evaluation of impacts in the business unit that delivered the service (and not in the umbrella organization), where the hypothetical organizational learning might have taken place.

Anyway, one believes that the gathered organizational data gives a reasonable light about respondents and allows a first glance on the weight of Astronomy in their organizations.

One starts by scrutinizing their origin, that is, whether they are spin offs. One recalls that the term "spin off" was defined as an organization founded on the findings of a member or by members of a research group at an already existing organization. As one may consult in the following graphic, one verifies that 33 respondents stated that they are not spin off organizations while 8 organizations declared to be spin offs:

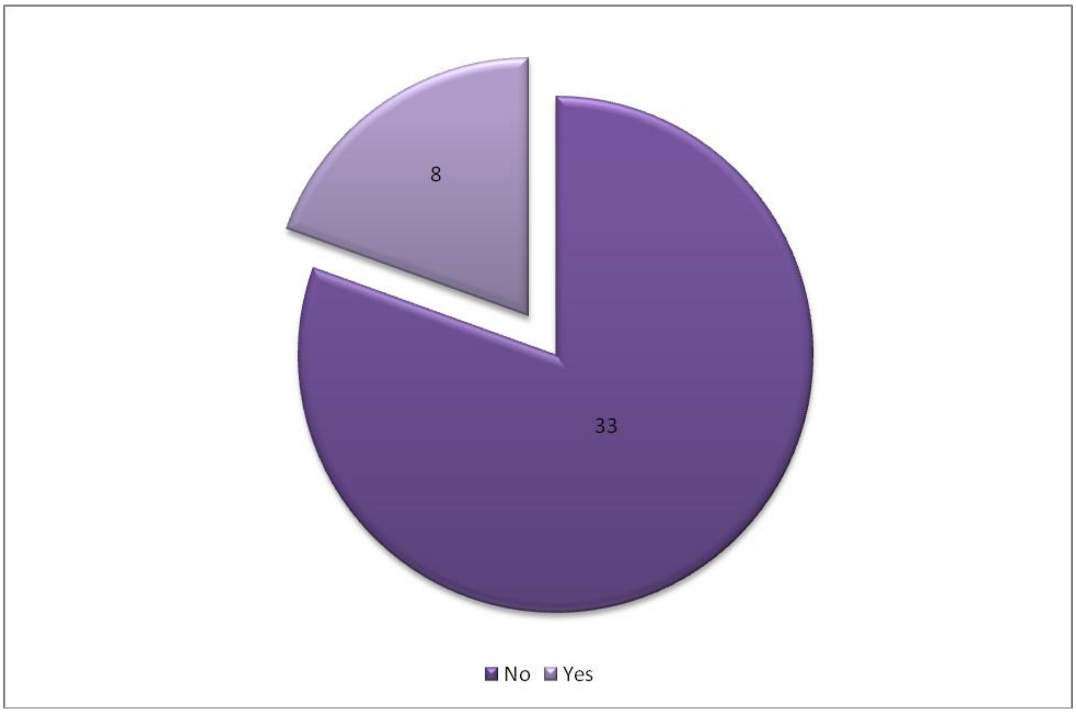


Figure 15: Answers for the question "Is your organization a R&D centre or a University spin off?"

These spin offs were originated in several scientific and technological fields: 3 were formed in physics organizations and 2 come from opto-electronics, more precisely, one from military R&D and other from HgCdTe detectors development. There is one company that was founded in an optics R&D centre and other that comes from ICT – information and communication technologies, namely, from innovations in image processing. Only one organization has its roots in Astronomy. Coincidence or not, this organization is the only self denominated spin off that is a R&D centre (not a company). They are now specialized in instrumentation. One reaches the conclusion that this survey did not detect much spin offs. Furthermore, although reported spin off companies came from scientific fields close to Astronomy activities, the truth is that none had origin in Astronomy.

One important indicator of the type of organizations one is dealing with is the number of persons they employ. Next table resumes the headcount of respondents. Note that 4 organizations did not answer to this question:

| | ≤ 10 | ]10, 50] | ]50, 250] | > 250 | Total |
|---|---|---|---|---|---|
| **Number of organizations** | 3 | 17 | 11 | 6 | 37 |

Table 12: Distribution of respondents according with the number of workers

If one crosses this information with the 2009 revenue declared by organizations, one is able to deduce their dimension according, for instance, with the parameters defined by the European Union. In this exercise one will apply the definition to all respondents, ignoring their mission, that is, whether they are enterprises or R&D centers.

Notice that relying on the small and medium enterprise (SME) definition[11], an enterprise is qualified as micro if it employs less than 10 workers and at the same time has a turnover of less than 2 million Euros. On the other hand, an enterprise is qualified as small if it employs less than 50 workers and generates a turnover of less 10 million Euros. Medium sized enterprises employ less than 250 workers and generate a turnover of less 50 million Euros. Big enterprises are the ones that do not fit in these requisites.

Returning to our analysis, one may check the distribution of respondents with regard to the declared turnover in the following table[12]:

| | ≤ 2 M Euros | ]2 M, 10 M] | ]10 M, 30 M] | ]30 M, 50 M] | > 50 M | Total |
|---|---|---|---|---|---|---|
| **Number of organizations** | 4 | 13 | 3 | 1 | 4 | 25 |

Table 13: Distribution of respondents according with their turnover in 2009

One should observe that 16 organizations did not respond to this question. Taking into consideration the referred SME definition, one concludes that among respondents one finds 2 micro enterprises, 8 small enterprises, 2 small R&D centres, 1 medium enterprise, 4 medium R&D centres, 5 big companies and 2 big R&D centres. In one case was not possible to apply the SME definition because the organization did not disclose the number of workers.

Since the number of workers who collaborated in Astronomy projects is also available for the majority of organizations (9 organizations did not respond to this question) one is able to calculate their weight in the total number of workers of the organization or business unit. Hereby, one shows the distribution of organizations according with the weight of workers directly connected with astronomy projects:

| | 0% | ]0%, 5%] | ]5%, 10%] | ]10%, 20%] | ]20%, 30%] | ]30%, 50%] | ]50%, 75%] | ]75%, 100%[ | 100% | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number** | 4 | 6 | 3 | 4 | 2 | 6 | 1 | 0 | 6 | 32 |

Table 14: Distribution of respondents according with their staff working in Astronomy

The table indicates that 4 organizations declared not having in 2009 workers dedicated to Astronomy projects. Out of the 6 organizations which declared to have all their workers dedicated to Astronomy 5 are R&D centres whose mission is to generate knowledge in this Science. The remaining organization is a company. This result may be justified by the fact that this company is a micro enterprise, where probably all the workers intervene in all the projects. Taking off R&D organizations, companies with bigger percentage of workers allocated to Astronomy appear in the range between 30% and 50% of the total number of workers, consisting in 2 unclassified companies (in terms of dimension), one small company, one micro enterprise and 2 big companies. Of these last ones, a company is dedicated to

[11] One may consult the SME definition at http://ec.europa.eu/enterprise/policies/sme/facts-figures-analysis/sme-definition/index_en.htm

[12] In the calculation of the turnover one applied the following exchange rates: 1 EUR - 640 CLP, 1 EUR – 0.76 USD, 1 GBP – 1.18 EUR

electric engineering and other to instrumentation. In total, 18 companies declared having collaborators working in Astronomy projects in 2009. Of these, 14 companies have more than 5% of their workers allocated to Astronomy projects.

One will complement the above information with the depiction of the 2009 revenue originated by contracts or transactions related with Astronomy projects in order to get an idea of the degree of association between the business of respondents and Astronomy. The next table resumes the distribution of organizations according with the percentage of revenue derived from Astronomy in 2009 with regard to their total revenue in 2009:

| | 0% | ]0%, 1%] | ]1%, 3%] | ]3%, 5%] | ]5%, 10%] | ]10%, 30%] | ]30%, 50%] | ]50%, 75%] | 100% | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number** | 1 | 5 | 3 | 3 | 4 | 4 | 2 | 1 | 2 | 25 |

Table 15: Distribution of respondents according with their revenue coming from Astronomy

This question was not filled by 16 organizations. Once again, one notices that the 2 organizations which declared that their revenue in 2009 was totally generated by Astronomy projects are fundamental R&D centres. In 16 organizations astronomy contracts represented less than 10% of their revenue in 2009. In 6 organizations 10% up to 50% of their revenue depended on Astronomy contracts in 2009. 3 organizations are companies, of which, 2 big companies dedicated to instrumentation. These ones reported that 20% of their revenues came from Astronomy. In one case they reported 4 active contracts in 2009. In the other case, they reported 5 contracts. With regard to the R&D centres, one develops applied research. This organization reported that 27.5% of its turnover came from Astronomy contracts. In 2009 they were involved in 4 contracts. Additionally, one interface reported that 60% of its revenue in 2009 was derived from Astronomy contracts. They informed that in 2009 they had 20 active contracts related with Astronomy. In the end, 16 companies declared turnover coming from astronomy projects. Of these, 8 reported that more than 5% of their revenue came from astronomy projects.

At this point, one finds useful to include in the discussion the data about the number of active astronomy contracts in 2009 declared by respondents. Note that 15 organizations did not respond to this question. Hereby, one shows the distribution of organizations per number of astronomy contracts in 2009:

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 11 | 15 | 20 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Number of organizations** | 3 | 3 | 5 | 3 | 2 | 3 | 1 | 1 | 2 | 1 | 1 | 1 | 26 |

Table 16: Distribution of respondents according with the number of contracts in Astronomy

In resume, one finds that 3 companies reported that they did not have active contracts running in 2009. Also, 20 organizations run less than 10 contracts. It is no surprise that the 3 organizations with biggest number of active contracts are all fundamental research organizations. Assuming that the reported revenue came entirely from active contracts, one notices that the average turnover of respondents generated by active countries in 2009 was 594,622 Euros. This result is influenced by the data of 3 big companies and one big R&D centre which disclosed Astronomy revenues in the order of more than 10 million Euros and, at the same time, reported few active contracts.

One note to the indicator EBIDTA – earnings before interests, depreciations, taxes and amortizations, which was asked in questions 3.4 and 3.5. Unfortunately, the survey only received 4 valid answers to work with, all coming from companies. These few answers indicate that in these companies, EBIDTA coming from Astronomy represent around 10% of total EBIDTA in 3 companies and around 70% in one company.

Wrapping up the above information, the survey shows that 15 companies, approximately half of the total number of companies which participated in the survey, had a business connection with Astronomy projects in 2009. A quarter of the respondent companies had a sound link with Astronomy projects, meaning that they applied at least 5% of their workers to astronomy projects, which, by their turn, generated at least 5% of revenues in 2009. Mixing these conclusions with the fact that, of the 8 companies which supplied ESO in 2009 for the VLT project (recall that, orders in 2009 represented 7% of total orders of VLT project given to respondents), only 3 answered and quantified revenues coming from Astronomy projects in 2009 (that is, although 5 companies did not give information about revenues in 2009, one knows that they had business interactions with ESO), one feel confident to conclude that, independently of the time respondent companies collaborated with ESO within the VLT project, in 2009 a relevant number of companies (at least 20) were still developing business related with Astronomy projects.

Having in mind the hypothesis that Astronomy generates person embodied economic benefits, one took the opportunity of contacting ESO supplier organizations to ask them, through question 2.3, how many collaborators with education in Astronomy or with professional experience in Astronomy they have. The answers may help to deduce whether respondents recognize advantages, in terms of person embodied benefits, in hiring qualified people coming from Astronomy. Taking off the 8 organizations which did not participate in this question, the results tend to indicate that respondent organizations do not recognize advantages in hiring people coming from Astronomy since, out of the 33 respondents, 20 companies reported that they do not have workers with that background. If one considers that R&D organizations in this field tend to employ researchers coming from Astronomy, it might be clarifying to isolate this type of organization from companies. Applying this filter, one concludes that only one of the 10 R&D organizations said that it does not have workers with Astronomy background. There is one organization that did not answer to this question. The remaining 8 naturally reported workers with Astronomy background. 6 organizations reported that half of the workers have astronomy degree or that more than 75% of collaborators have it (2 organizations to be precise). The R&D centres with relatively less workers coming from Astronomy are 2 interfaces: one (a big interface) estimates less than 1%, whereas the other notices 1/3 of the workers. With regard to the group of companies, 4 reported workers with background in Astronomy: 1/4 of the workers of a micro enterprise, in the area of optics, come from Astronomy; 2 big companies, one in the area of instrumentations and other in the area of optics report that respectively 5% and 3% of their workers have astronomy background. The biggest company that responded to this question, coming from the area of instrumentation, with around 2,800 workers, responded that 30 collaborators have astronomy background.

Usually, one presumes that organizations which collaborate with Astronomy are technologically intensive. Does this presumption apply to the present case? One may infer technological intensity through one of its drivers: R&D. One has the means to verify the relevance of R&D to respondents through the number of collaborators who work in R&D and through R&D expenditures in 2009 reported by organizations. With regard to R&D workers, one may check in the following table their weight on the total number of workers of respondents:

| | 0% | ]0%, 5%] | ]5%, 10%] | ]10%, 20%] | ]20%, 30%] | ]30%, 50%] | ]50%, 75%] | ]75%, 100%[ | 100% | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number** | 7 | 1 | 5 | 5 | 4 | 3 | 4 | 0 | 6 | 35 |

Table 17: Distribution of respondents according with the percentage of R&D workers in total workers

6 organizations which participated in the survey did not respond to this question. One verifies that 28 organizations have at least 1% of their workers allocated to R&D. 7 organizations (all of them companies) have none worker allocated to R&D. Curiously, against ones expectations, the majority of organizations that have 100% of their staff allocated to R&D are companies, namely, one business unit (spin off company) dedicated to optics, one micro enterprise and other company both dedicated to software (probably software

development), and other company (a spin-off company) dedicated to opto-electronics. Only two R&D organizations reported having their staff entirely dedicated to R&D. Expunging R&D institutions, which naturally have a large portion of their workers dedicated to R&D, one underlines that 18 enterprises (out of 25 respondent companies) employ at least 5% of their staff in R&D. One highlights four cases: one micro spin off enterprise, with business in optics, applies 75% of its human resources in R&D; one electronic engineering company applies 58% of its human resources in R&D; one small company and other enterprise, both in the optics business, employ 60% and 45% of their staff in R&D.

Next, one complements the features about the number of workers with data regarding R&D expenditures of respondents. One revealing exercise is to check the distribution of respondents taking into account the portion of the R&D expenditures in their revenue:

| | 0% | ]0%, 1%] | ]1%, 3%] | ]3%, 5%] | ]5%, 10%] | ]10%, 30%] | ]30%, 50%] | ]50%, 75%] | 100% | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number** | 3 | 2 | 3 | 0 | 2 | 7 | 3 | 1 | 1 | 22 |

Table 18: Distribution of respondents according with the percentage of R&D expenditures in their revenue

Out of the 22 respondents (19 did not collaborate in this question), 3 organizations reported that they did not have R&D expenses in 2009. 5 organizations reported that their R&D expenses were less than 3% of their revenue. 14 organizations communicated R&D expenses higher than 3% of their revenue. Amongst these 14 organizations, 8 come from the business side.

If one takes as reference that the European Union set the objective of increasing R&D expenses up to 3% of GDP – Gross Domestic Product, one may say that most of respondents are on the good way to this target. This indicator reinforces the last one on the conclusion that the majority of respondents, more precisely, 28 organizations, of which, 10 are R&D centres, are intensive in R&D. One guesses that this evidence is justified by the core business of the majority of organizations that responded to the survey, strongly connected with scientific and technological challenges. Note that, for the purposes of this work, a R&D intensive organization is defined as having at least 5% of its workers dedicated to R&D or applying at least 3% of its revenues to R&D expenditures.

With regard to the 5 organizations whose R&D expenses make more than 30% of their revenue, the one with biggest weight of R&D expenses is one applied research centre, with R&D expenses overcoming the amount of revenues. Two companies also belong to this group, one micro company and one small technological enterprise, featuring R&D expenses corresponding to 40% of their revenues. Two fundamental R&D organizations report R&D expenses equivalent to 35% and 60% of their revenue. Of these, the applied research organization informed that only 0.13% of the R&D expenses in 2009 were dedicated to Astronomy. The first of the other two R&D organizations reported that they dedicated their R&D entirely to Astronomy whereas the second affirmed that Astronomy R&D corresponded to 67% of their R&D. The micro enterprise dedicates 1% of its R&D to Astronomy whereas the small company dedicates 5% of its R&D to Astronomy.

Next table shows the distribution of organizations according with the weight of Astronomy in their R&D expenses (17 organizations did not respond to this question):

| | 0% | ]0%, 1%] | ]1%, 3%] | ]3%, 5%] | ]5%, 10%] | ]10%, 30%] | ]30%, 50%] | ]50%, 100%[ | 100% | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Number** | 8 | 2 | 0 | 3 | 3 | 2 | 0 | 3 | 3 | 24 |

Table 19: Distribution of respondents according with the weight of Astronomy in their R&D expenditures

Looking upon this indicator with more detail, one verifies that out of the 24 respondents, 8 organizations declared that they did not have R&D expenses in Astronomy. Organizations which dedicate more than 3% of their R&D expenses to Astronomy are split in half in terms of mission, that is 7 are companies and 7 are R&D centres. If one distinguishes the 6 organizations with more of 50% of their R&D expenses dedicated to Astronomy, one notices that one is a company, related with electronic engineering, which invests 60% of its R&D in Astronomy challenges. All the others are fundamental R&D organizations, as expected. Taking off the already mentioned R&D organization, with 67% of its R&D dedicated to Astronomy, one organization dedicates 80% of its R&D to Astronomy and the remaining 3 are fully dedicated to Astronomy R&D.

#### 4.3.4.2 Evaluating the impacts

This important chapter consists in an attempt of examining the results of the inquiry. One should remember that the survey asks ESO's suppliers to score hypothetical medium and long term impacts coming from their participation in astronomy projects, namely in the VLT project.

Impacts' examination is dominated by descriptive statistics, specifically, by the disclosure of scores' frequencies in each question. In complement to frequencies analysis, comparisons between groups of respondents were made. In addition, relationships between different impacts were studied, namely through correlation analysis of benefits, efforts and results. Adding up, one tests the statistical significance of differences in the valuation of astronomy impacts by different groups of respondents. One also developed a factor analysis of the hypothetical benefits of participating in Astronomy projects. One may check in annex 4 the question marks, assumptions, steps, and outputs of statistical exercises.

In the statistical description of the survey, besides the observation of frequencies of the scores (on a 5-point Likert scale) for each variable, the mean value and the corresponding standard deviation were calculated. The mean value is the sum of the observations divided by the number of the observations. By its turn, the standard deviation expresses how much variation there is with regard to the mean of the observations. A low standard deviation indicates that observations tend to be close to the average, whereas high standard deviation indicates that the data is spread out over a large range of values. The standard deviation is calculated as the square root of the variance.

Also, the standard error will be indicated for each variable. The standard error of the mean value is a statistic that estimates the variability one expects of the different sample means if taking repeated samples of the same size from the population. The standard error reflects how much sampling fluctuation a statistic will show. In general, the larger the sample size, the smaller the standard error. This statistic is calculated by dividing the standard deviation of the observations of a sample by the square root of the number of observations.

With regard to potential benefits coming from suppliers' relationship with ESO (taking the VLT project as reference), as one has seen in the section 4.3.2, they were grouped in 4 categories: performance outcomes, marketing and commercial benefits, R&D and technological benefits and organizational benefits. One will check the result of the survey for each type of benefit belonging to these categories, followed by a wrap up which compares the different benefits. The same method is applied in the analysis of potential efforts as well as in the scrutiny of perceived results of supplier's linkages with ESO.

#### 4.3.4.2.1 Benefits

(1) Performance outcomes:

. Financial income / profit generated by the contracts:

Figure number 16 indicates responses regarding this outcome:

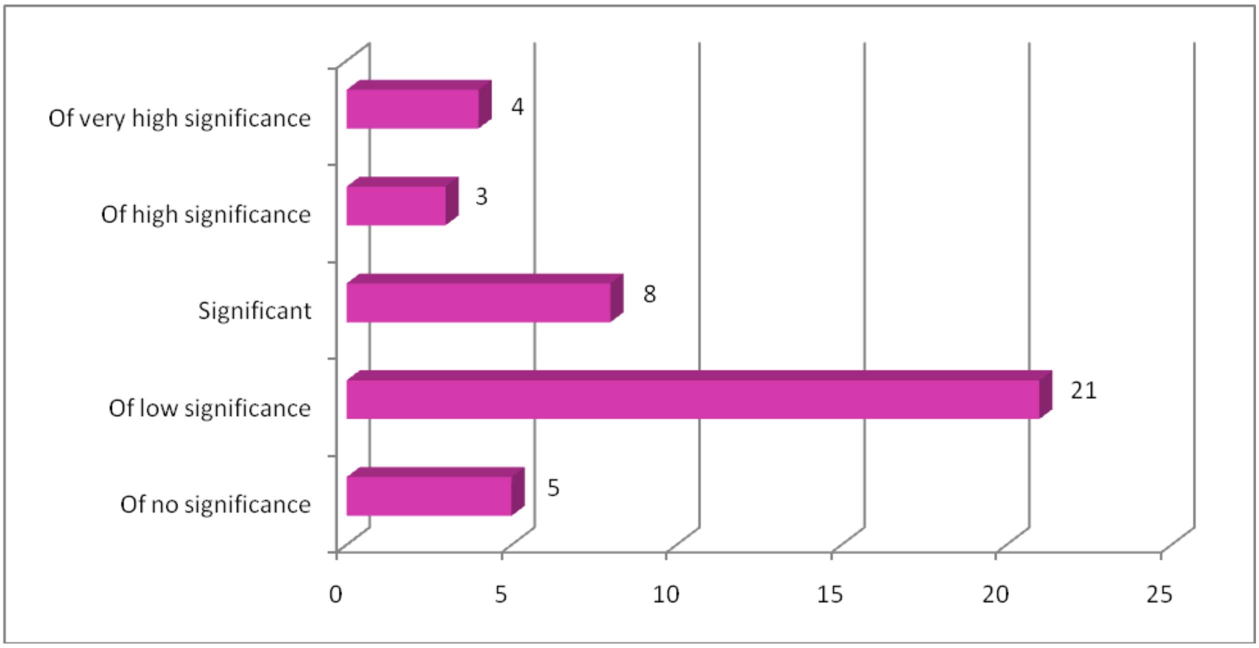


Figure 16: Frequency of answers for the question about financial income / profit generated by ESO contracts

As can been seen, the majority of respondents, 26 to be precise (63% of respondents), consider that the contracts with ESO were or are generating low or no profit. The average score of the responses is 2.512 (below the level for significant = 3) with standard deviation (σ) of ± 1.121. The standard error (σM) is fixed in ± 0,175 which means that for different samples of 41 observations taken from the population of ESO VLT's suppliers whose total orders are bigger than 20,000 Euros, the mean score is predicted as 2.512 ± 0.175.

A possible explanation of this result may be the fact that 17 organizations whose answer indicates low or no profit had budgets inferior to 100,000 Euros. The underlying assumption is that this budget is considered not relevant for their business. One should be careful with this assumption since statistical analysis did not capture evidence of a relation between budget and impact evaluation by respondents. Results of the statistical analysis are available in question 2 of the annex 4.

Continuing with the description of data, one notices that 3 organizations which declared low or no profit had budgets above but close to 100,000 Euros. One of these last organizations declared that the percentage of revenues coming from Astronomy with regard to total revenue was low. One organization of the group of low or no profit had a budget close to 270,000 Euros but communicated that, to the date of the survey, the referred contract was the only one that they had with ESO. In addition, 3 respondents out of the 26 one is analysing had budgets between 400,000 Euros and 1 million Euros. 2 of the latter informed that Astronomy projects have low contributions for their total revenue. The third of these last organisations is a big multinational. The remaining 2 organizations (out of the 26 which communicated low or no profit) have budgets higher than 2,500,000 Euros. They did not give sufficient data to allow an attempt of understanding their answer.

One should highlight that although organizations, mostly companies, do not recognize significant financial income or profit coming from Astronomy projects, at least 20 companies (out of 31 respondent companies) had business relations with Astronomy projects in 2009, as can be seen in sub chapter 4.3.4.1.

. Optimization of process or manufacturing/production capacity:

This question aims to know whether respondents see that the relation with ESO enabled them to improve the efficiency of the existing production process or allowed them to employ production capacity that was not used before. The latter benefit may be connected with the quantities of a certain product or service ordered by the client. The first benefit is more related with technical breakthroughs caused by a project. Note that if a certain order of a client implies producing quantities of a product above the manufacturing capacity of the organization, the same organization may be motivated to optimize or increase the capacity of its production process. In the end, one suspects that, as in the first of these performance outcomes, the factor that may influence responses is the amount of projects (and their value) that respondents have with ESO. One calls attention to the lack of statistical significance of this factor, as seen in question 2 of annex 4. Next figure shows the results for the 40 responses obtained regarding this outcome:

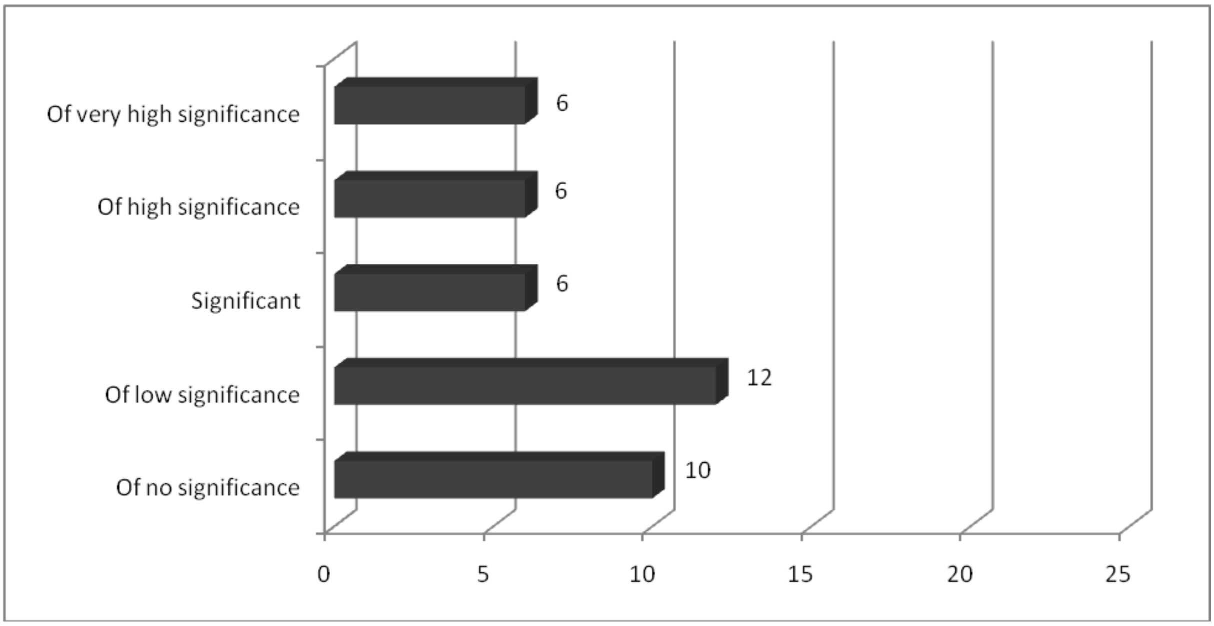


Figure 17: Frequency of answers for the question about optimization of process or manufacturing capacity

As shown in the figure, more than half of respondents (22 out of 40) did not identify process or production utilization improvements originated by projects with ESO, leading to an average scoring of 2.65 (below the level for significant = 3). Answers are spread among the 5 possible scores, leading to an σ of ± 1.406. The σM is equal to ± 0.222.

Guessing that the driver of this result could be the value or orders from ESO, one verifies that 15 organizations whose answer indicates low or no benefit had budgets inferior to 100,000 Euros. One organization has a budget close to 100,000 Euros. Two organizations had budgets close to 250,000 Euros. Of the latter, one organization states that revenues coming from Astronomy represent 1% of its total turnover. Other communicated that, to date, the referred contract was the only one that they had with ESO. The respondent with largest contract with ESO (in terms of budget) also answered that the significance of this benefit is low. Note this respondent stated that the revenues coming from Astronomy represented 7% of total revenue in 2009.

Complementarily, one may analyse the answers given by organizations which have bigger budgets with ESO. One concludes that half of the 10 organizations which have budget between 100,000 Euros and 1,000,000 Euros scored this benefit as significant or higher. In the same token, half of the organizations which have budgets higher than 1,000,000 Euros and answered to this question scored this benefit as significant or higher. This even result does not clarify the reader about the veracity of the assumption that the driver of this result is the value or orders from ESO.

By curiosity, one finds that 4 respondents out of the 6 which answered that this benefit has very high significance are R&D organizations. By the other hand, 5 out of the 6 organizations which answered that this benefit has high significance are companies.

. Development of new products / services:

This question tries to infer whether organizations developed new products or services in consequence of their supplies to ESO. The results are indicated below:

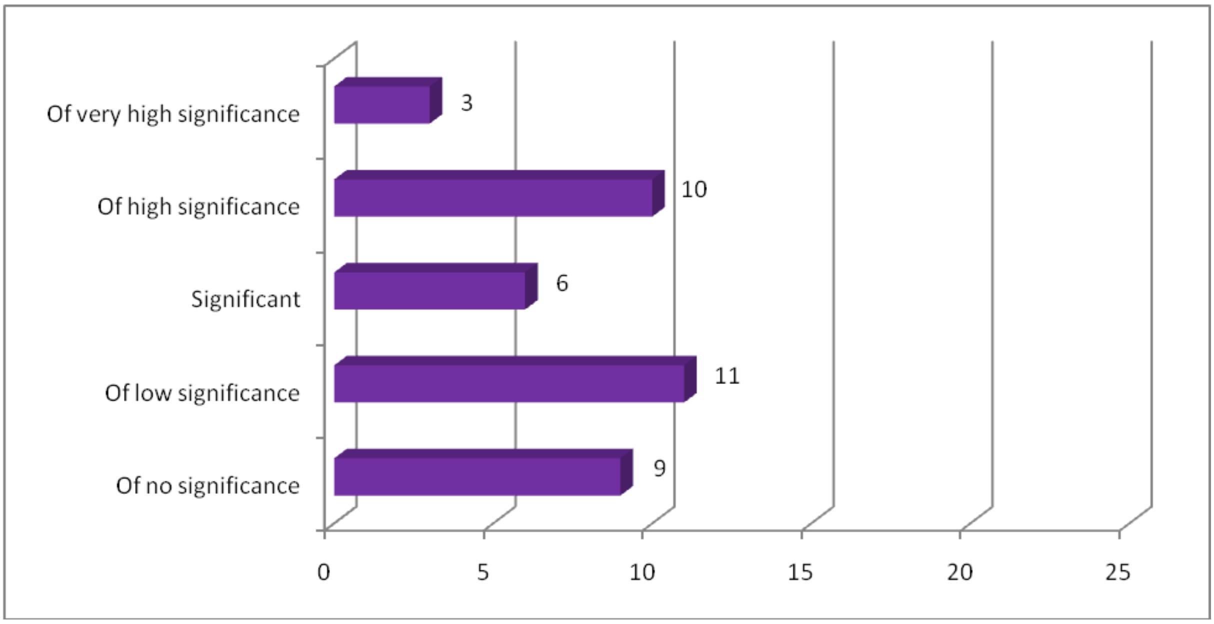


Figure 18: Frequency of answers for the question regarding the development of new products / service

This question was answered by 39 organizations. Even though the average of scores is fixed in 2.667 (below the level of 3), 49% of respondents considered this benefit at least significant, being a sign that 49% of respondent suppliers were able to develop new products or services in consequence of their projects with ESO. This might be considered a relevant percentage, if one thinks that projects with ESO were, in essence, supplying contracts. The σ of ± 1.305 indicates a significant dispersion of observations. The σM is equal to ± 0.209.

This outcome is particularly important in the case of companies since they have the mission of commercially exploring products or services. Hypothetical innovations introduced by companies derived from their relation with Astronomy projects might be captured by this question. One concludes that 40% of the 30 respondent companies, that is 12 companies, scored this benefit as at least significant. 23% of these 30 companies attribute a high significance to this outcome. 7% of these 30 companies give a very high significance to this benefit. Other interesting result is that only one of the 4 respondent R&D organizations attributed to this outcome a high or very high significance.

Although new products and services can be stimulated by several factors, technological challenges (for instance, demands brought by ESO) may be an important driver. Correlation analysis revealed a statistically significant, strong linear association between the present benefit and the following efforts: training ($r=0.558$, $p=0.001$), visits to ESO ($r=0.523$, $p=0.001$), market research ($r=0.527$, $p=0.002$) and R&D ($r=0.694$, $p<0.001$). Stats are available in question 8 of annex 4. Other possible driver is innovation through R&D, commonly sparked by technology intensive businesses. One indirect way of getting a sense whether new products or services were originated by innovation through R&D is to check whether the 12 companies which stated having developed new products or services are R&D intensive organizations or come from technological intensive sectors. One company is not R&D intensive. In 4 cases one has not the necessary information to classify them. One knows that the remaining 7 (59%) companies are classified as R&D intensive companies. This might make the case of innovation synergies between R&D strength and connections with Astronomy projects. At this point, one should refer that it is not statistically proven that the likelihood of R&D intensive organizations recognize impacts of Astronomy projects in new products and services is bigger than that of non R&D intensive organizations. Results for this statistical exercise are shown in question 4 of annex 4.

Since in high technology projects (like the VLT) a big piece of the procurement contracts are for unique, tailor made products, remains the doubt whether respondents thought in their supplies as new products or services, taking them as a reference in the answer to this question, or considered supposed new products or services besides the ones delivered in the framework of the VLT.

(2) Marketing and commercial benefits:

. Increased number of contracts with new costumers:

This first market related outcome aims to know whether suppliers' relation with ESO is a good source of market development through new costumer acquisition. Results for this question are exposed below:

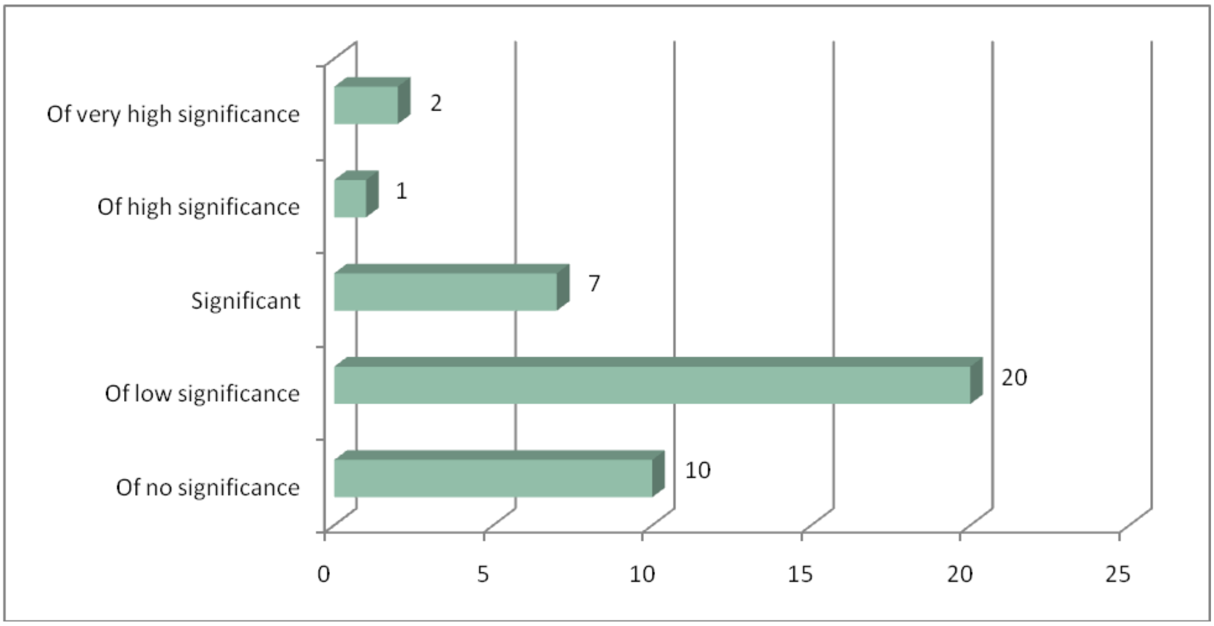


Figure 19: Frequency of answers for the question regarding the number of contracts with new costumers

This question was answered by 40 organizations. The scoring average is 2.125 with a standard deviation of 0.992. The σM is fixed in ± 0.157. One notices that only 25% of respondents consider this benefit relevant. The group of respondents that answered favourably to this question is constituted by 6 companies and 4 R&D centres. There is no pattern regarding the dimension of organizations too, since 5 of these respondents are small organizations, 2 are medium organizations and 3 are large organizations. The only recognized pattern is when one looks to the core business of companies which found this benefit significant: 3 out of 5 (60%) organizations which do business in optics said that they started to deal with new costumers in consequence of their relation with ESO. The same happened with 2 out of 4 (50%) of organizations in the mechanical engineering business as well as with the only respondent working in transports and logistics. Anyway, this fact is not sufficient to counter balance the clear evidence that respondent organizations consider that their relation with ESO does not add value in their ability to conquer new costumers. In addition, statistical analysis present in question 3 of annex 4 relativizes this fact since there is no strong evidence that impacts' evaluation by respondents is influenced by their specialization.

. Increased number of contracts with previously unknown costumers:

This question attempts to capture organizations' views about the capacity of enlarging their market horizon trough their relationship with ESO. By observing the next figure one concludes that relations with ESO are quite neutral in this aspect:

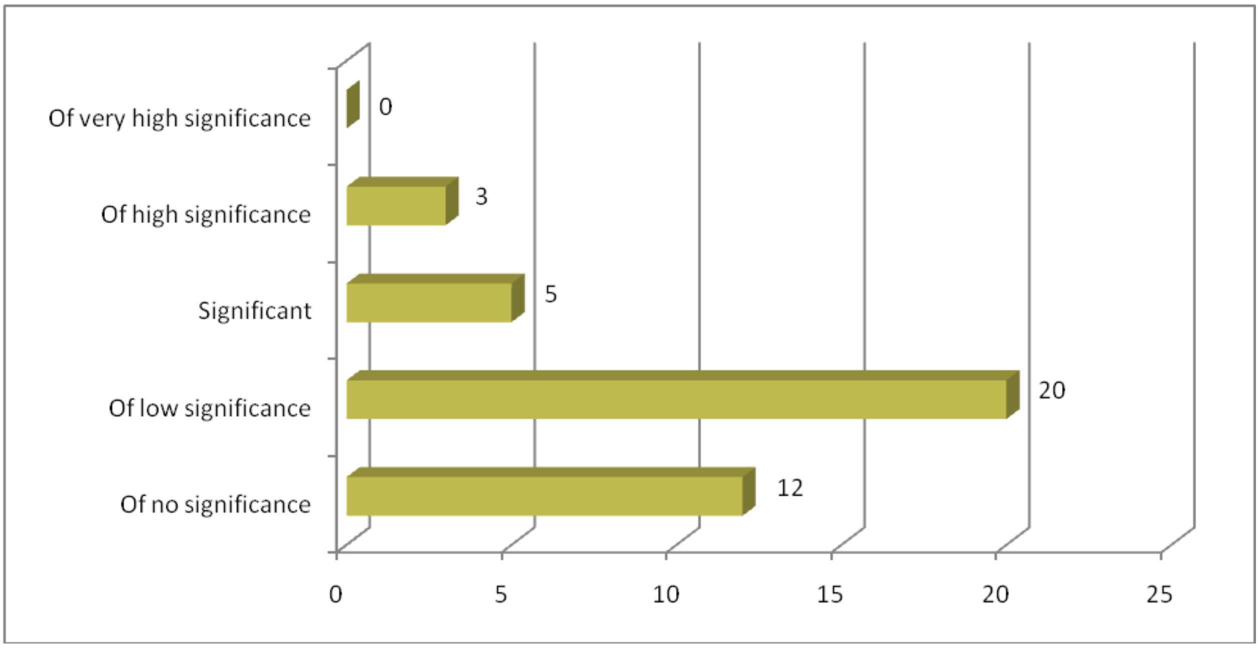


Figure 20: Frequency of answers for the question about contracts with previously unknown costumers

The graphic shows that only 8 organizations out of 40 respondents consider this benefit at least significant. The mean score is 1.972 with a standard deviation of 0.862. The σM is fixed in ± 0.136. Dividing respondents by type of organization one verifies that R&D centres, traditionally less commercially focused or skilled (hence with more margin of market learning when working with an organization like ESO, which is connected with industrial networks) didn't give much importance to this outcome: 4 out of 9 R&D respondents declared that this outcome is at least significant. One of them, in the field of instrumentation, valued this outcome as high significant. Other, dedicated to Astronomy, valued this outcome as very high significant. With regard to companies there is no pattern in the organizations which answered favourably to this question: two are small companies and the other two are big companies. By the results of this question, one guesses that or respondents have a deep knowledge of their potential markets or there was not much communication amidst ESO's suppliers nor perceived networking activities in the framework of VLT.

. Increased number of contracts with similar costumers (Astronomy or Big Science):

Results improve when one analyses suppliers' perception about the probability of gaining contracts from big science costumers due to their relation with ESO. Next figure shows the stats for this question:

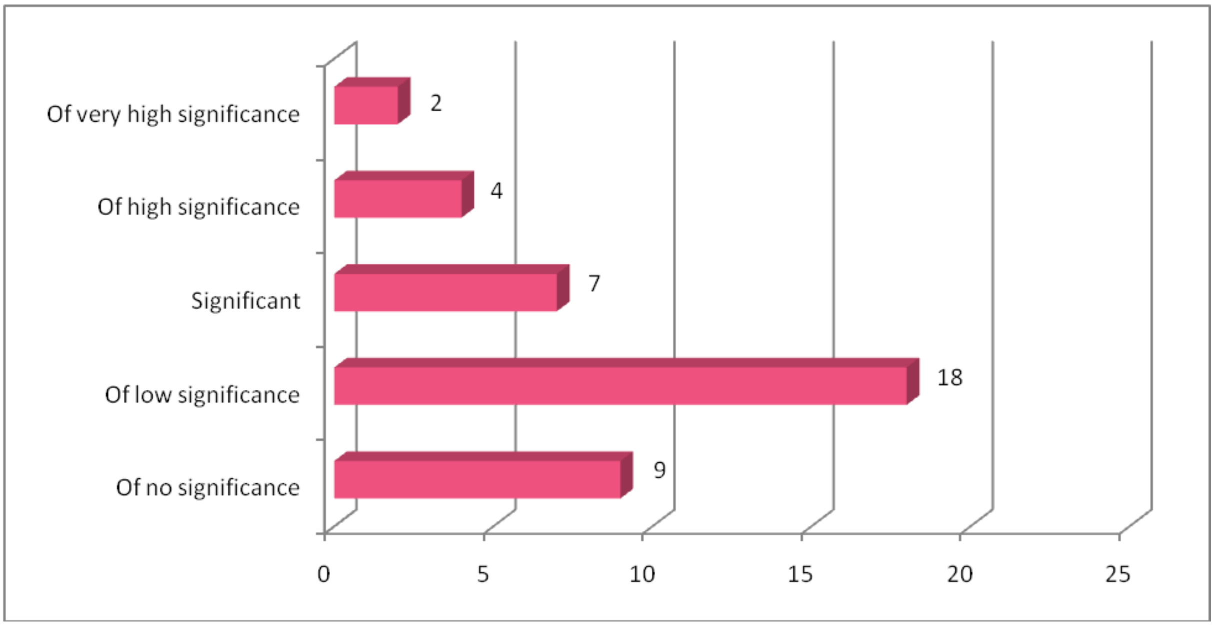


Figure 21: Frequency of answers for the question about contracts with similar costumers

The average score of this question is 2.3 with a standard deviation of 1.091. The σM is rounded to ± 0.172. One verifies that 13 out of 40 respondents consider this benefit was relevant for them. This group of respondents represents 32.5% of the total number of respondents. It is constituted by 8 companies and 5 R&D centres (out of 9 R&D centres). The prevalence of favourable answers in R&D centres may point to their capacity of capitalizing the scientific networks where they develop work together with ESO.

All 4 R&D organizations that responded favourably to the last question maintained their perception in this question. The same happens with two companies.

Characterizing favourable answers according with respondents' specialization, one does not identify any pattern. The weight of respondents' specializations is dominated by 6 categories, each one with 2 representatives, namely, mechanical engineering, electronic engineering, opto-electronics, optics, instrumentation and astronomy. One respondent develops software.

Wrapping up the first 3 first questions related to marketing, which have in common their focus in costumer awareness, one verifies that 6 organizations consider that these impacts are all relevant. Four of these organizations are R&D centres, which represent 44.(4)% of total R&D centres that responded to these questions. This result may confirm that R&D centres feel that their costumer awareness has potential to increase.  One also notices that these 3 benefits connected with costumer awareness are highly correlated between themselves, as the chart of question 8 of annex 4 reveals.

. Access to industry networks:

How about the influence of the link with ESO in the probability of getting access to industry networks? The survey shows that this influence is not important for most of respondents since the average scoring of this question is 2 with a standard deviation of 0.922. The standard error reaches 0.144. Let's see the breakdown of responses in the next figure:

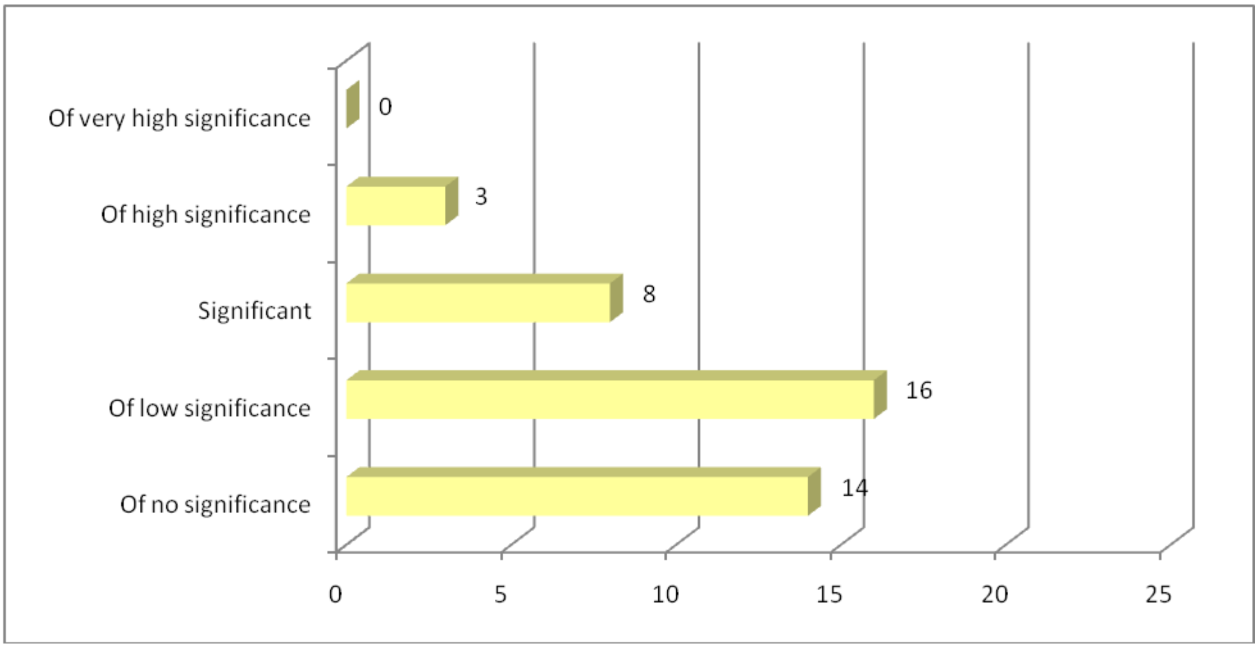


Figure 22: Frequencies of answers regarding the question about industry networks

30 respondents out of 41 stated that this benefit has low or no significance. 11 respondents attributed significance to this outcome, of which 3 valued it as high significant. This group of respondents is constituted by 4 R&D organizations (40% of total R&D respondents) and 7 companies. Of the 4 R&D organizations, two also evaluated as significant the 3 precedent customer related questions. The same happened with 2 companies. It is interesting to know that 3 of the respondents work in Astronomy which correspondents to half of respondents with this specialization. The same happens in the electronics field. These facts, despite not statistically significant (see findings of question 3 of annex 4) may lead to the impression that ESO is a relevant gateway to industry relations in the fields of astronomy and electronics. With regard with other specializations one may think that the effectiveness of ESO as a node in industry networks could be fostered. An alternatively interpretation is that suppliers already belong to more or less informal industry networks. It is a proven fact that suppliers organize themselves in consortia (constituted both by R&D and commercial organizations) to answer to ESO's tenders.

. Market learning (about customers, their needs, market trends):

The results for this market related outcome are shown in the figure below:

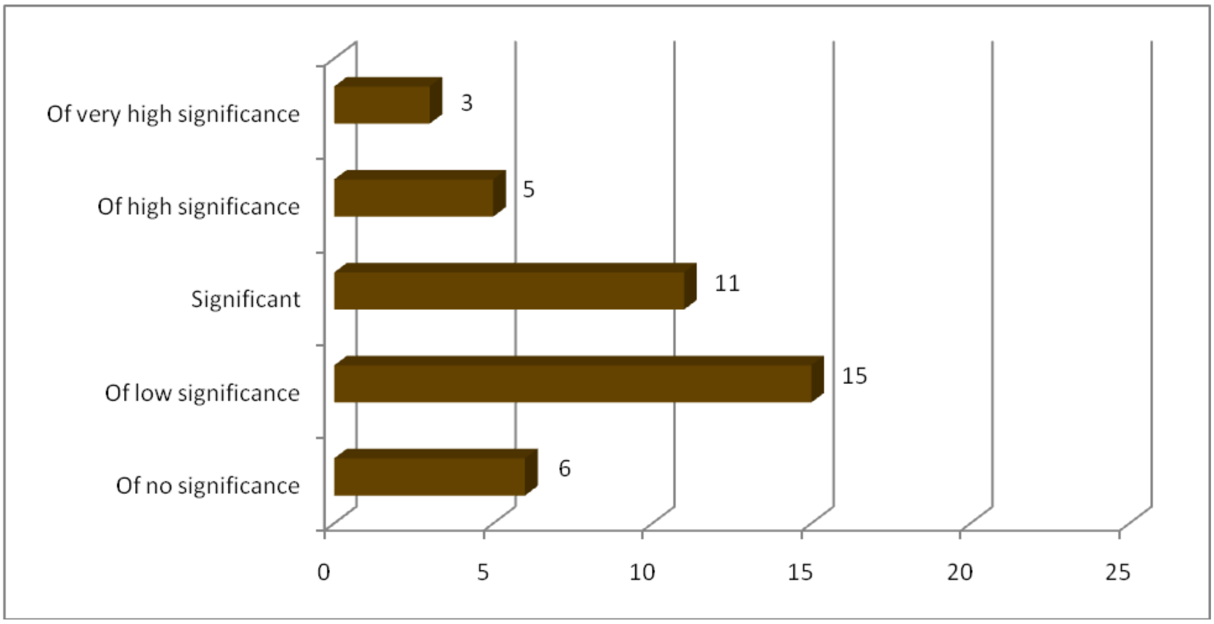


Figure 23: Frequencies of answers regarding the question about market learning

Slightly less than half of the respondents, more precisely 19 out of 40 respondents, indicated moderate to strong market learning. 15 respondents indicated weak to moderate market learning. 6 respondents thought that they did not derive any market learning benefits from their ESO contract. These findings lead to an average scoring of 2.6 with a standard deviation of 1.128. The standard error of the mean is 0.178.

Regarding the nine R&D centres that responded to this question, 5 valuated positively this benefit. This result might be explained by the fact that R&D centres were able to exploit synergies with ESO's experience with industry. Although dedicated to fundamental astronomy, ESO, as a big science organization, has probably developed considerable activities in procurement and liaison with industry. This synergy might be relevant in organizations with relatively less market experience such as R&D centres.

Analysing the respondents from the specialization point of view, one verifies that 4 out of 5 organizations which work in opto-electronics declared that they value this benefit. In parallel, 5 out 6 organizations specialized in instrumentation attributed relevance to this outcome. These stats, although not statistically significant (see findings of question 3 of annex 4), point that the referred fields of specialization might be a fertile ground for market learning.

Market learning can signify learning about the costumer one is dealing with. That is, gaining knowledge about its requisites, business model, needs, etc. So, when companies refer to market learning they might be thinking in what their learnt about ESO in the framework of VLT. Eventually, the acquired information might be extrapolated to other costumers. This assumption gains ground when one verifies that organizations specialized in areas whose business is based in development of projects (like instrumentation and opto-electronics) identify market learning potential. This speculation is reinforced by the evidence that 7 out of the 15 organizations with budget higher than 100,000 Euros (which might correspond to development projects) declared positive benefits in terms of market learning. By the other hand, question 2 of annex 4 indicates that, statistically speaking, orders' size does not influence market learning scoring.

. Establishment of a long term relation with ESO:

Did contracts with ESO foster a long term relation with ESO? One supposes they did, taking into account the results of this question, showed in the figure below:

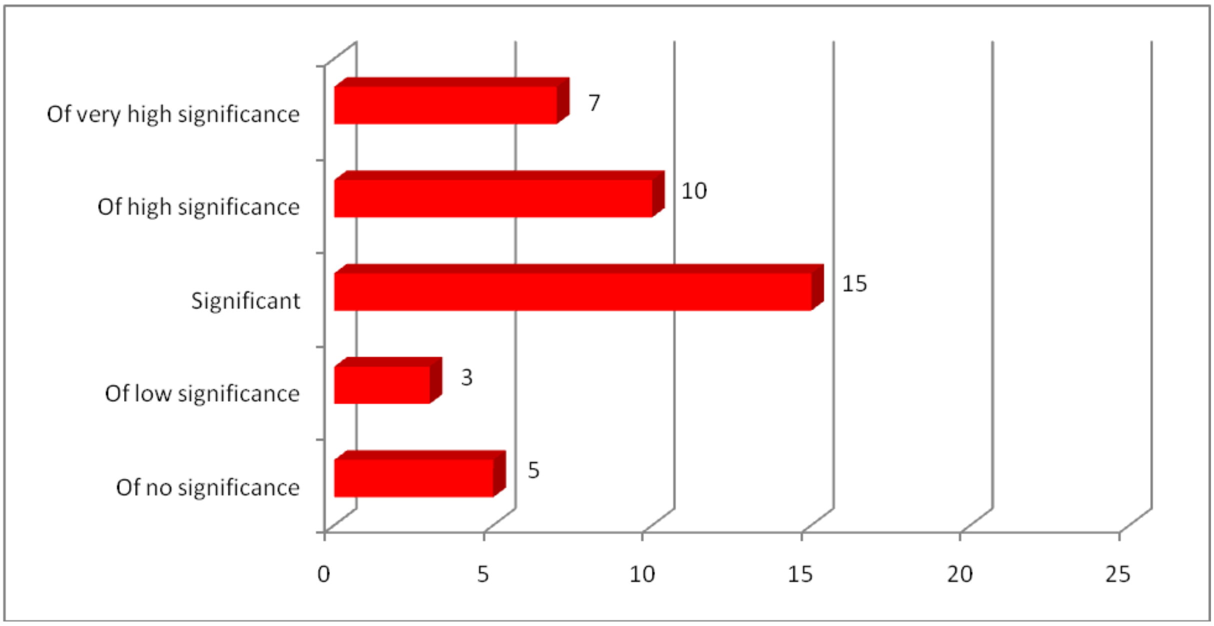


Figure 24: Frequencies of answers regarding the question about organization's relation with ESO

Only 8 organizations out of the 40 respondents considered that this benefit is not relevant. Of this group, 7 organizations are companies. One is a R&D centre dedicated to astronomy. One did not find a significant pattern in the group of respondents that did not valued this benefit. One scanned it taking into account the size of companies - there are 4 SME and 3 big companies -, the size of the budget - one found 4 organizations with budget inferior to 100,000 Euros, 3 organizations with budget between 100,000 Euros and 1,000,000 Euros, and one organization with budget superior to 1,000,000 Euros -, or the technical specialization. It is curious to verify that 4 out of these 7 companies declared active astronomy contracts or astronomy revenue in 2009. In addition, a fifth company possesses workers allocated to astronomy projects. Perhaps these companies are developing business with alternative astronomy clients. Still, about this group of respondents, one company informed at the time of the survey that they developed only one single contract with ESO.

The average scoring of this benefit is 3.275 with a standard deviation of 1.219. The standard error of the sample average is fixed at 0.193 meaning that, for this question, the average scoring of different samples of 40 ESO's suppliers within the VLT project does not vary more than ± 0.193 in relation with 3.275. One may say that the average scoring of this benefit will always be superior to 3 independently of the samples of 40 organizations taken out of the population of ESO suppliers for the VLT. This may imply that ESO is a costumer which tends to fidelization. That is, if a supplier wins a first contract with ESO and the results correspond to ESO's expectations, there is a reasonable probability that this supplier will win new contracts concerning the same tasks/objectives. This supposition complements what was evidenced in section 4.3.4.1: organizations are still doing business with ESO after VLT project.

The results of this question might also reflect the nature of the contracts with ESO. Development contracts are spread out in time fostering proximity between partners. Analysing the answers of organizations with budgets between 100,000 Euros and 1,000,000 Euros one sees that 3 organizations consider this benefit significant, 3 organizations value it as high significant and one organization gives very high importance to this outcome. With regard to organizations with budgets higher than 1,000,000 Euros, one checks the following scores: 1 significant, 2 high significances and one very high significance. One concludes that, although not statistically significant (question 2 of annex 4), organizations with bigger budgets attributed upper scores to this benefit. At last, one underlines that 5 out of 7 organizations which gave very high significance to this benefit are R&D organizations. This fact is confirmed by the statistical analysis taken under question 1 of annex 4. This exercise detects statistical evidence that, in this benefit, scores from R&D organizations are higher than those of companies. This evidence indicates that projects like VLT tend to promote the reinforcement of scientific networks.

. Marketing / image benefits (for example, association with high tech or big science projects):

This question tries to capture whether supplier organizations view ESO as a marketing reference, whether they feel that their relation with ESO increases their credibility as a supplier, and whether they recognize a positive effect of their relation with ESO in their reputation as technology organizations. In average, the majority of organizations answered that they recognize significant image benefits derived from their relation with ESO: the average scoring is 3. The standard deviation is 1.265. The standard error is 0.198. Results are shown below:

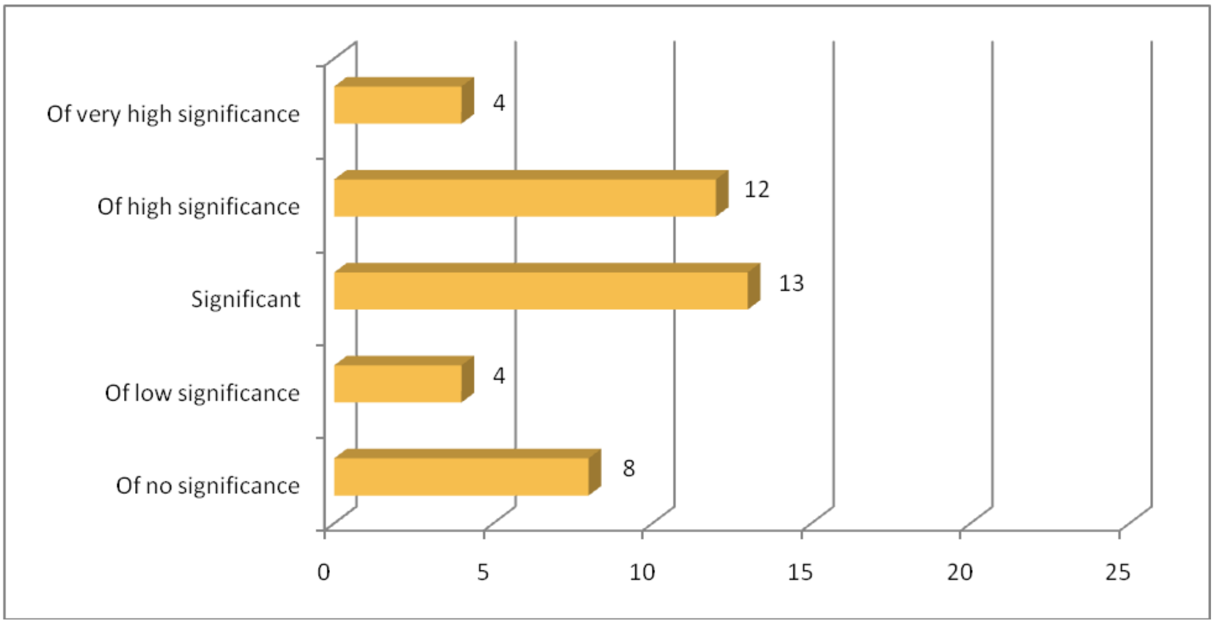


Figure 25: Frequencies of answers regarding the question about image benefits

Looking to results taking in account the type of organizations one concludes that 70% of R&D centres (7 out of 10) believe that their relation with ESO brought image benefits. 2 R&D centres attributed very high significance to this benefit. On the other hand, 3 R&D centres attributed high importance to image benefits. On the companies' side, one concludes that 71% of respondents (22 out of 31) answered that their relation with ESO originated image benefits. 30% of respondent companies (9 out of 31) consider that image benefits have high significance while 2 companies think that image benefits have very high significance.

Characterizing organizations which did not value image benefits, one observes that there are 2 organizations that work in electronic engineering (making half of organizations specialized in that field) and 3 organizations which develop activity in Astronomy (making half or centres specialized in that area). With regard to the latter respondents, one guesses that they think that their image is already associated to astronomy, technology and science, supposing that their partnerships with ESO do not add value in terms of image.

Image benefits might be a particularly relevant aspect for SME or young companies because these tend to suffer from a "credibility gap". One finds that 64% of companies classified as SME (that is, 7 out of 11) considered image benefits at least significant. 3 SME attributed high relevance to this marketing benefit. If one views data from the R&D organizations standpoint, one verifies that 5 out of 6 small or medium R&D centres considered that this outcome is at least significant. Note that this feeling is shared by big companies since all gave importance to this outcome: 2 considered it as relevant, other 2 classified it as high relevant and one gave a very high significance to this outcome.

After the analysis of this question one keeps in mind that there is evidence that ESO's suppliers identify potential to use their relation with ESO as a reference in order to increase their credibility in the marketplace.

(3) R&D and technological benefits:

. Transfer of technology from ESO:

When one speaks of transfer of technology from ESO one refers to the integration or exploration by suppliers of instrumentation, patents, techniques or methods developed in ESO. As observed in the figure below, transfer of technology from ESO to suppliers rarely occurred within the VLT project:

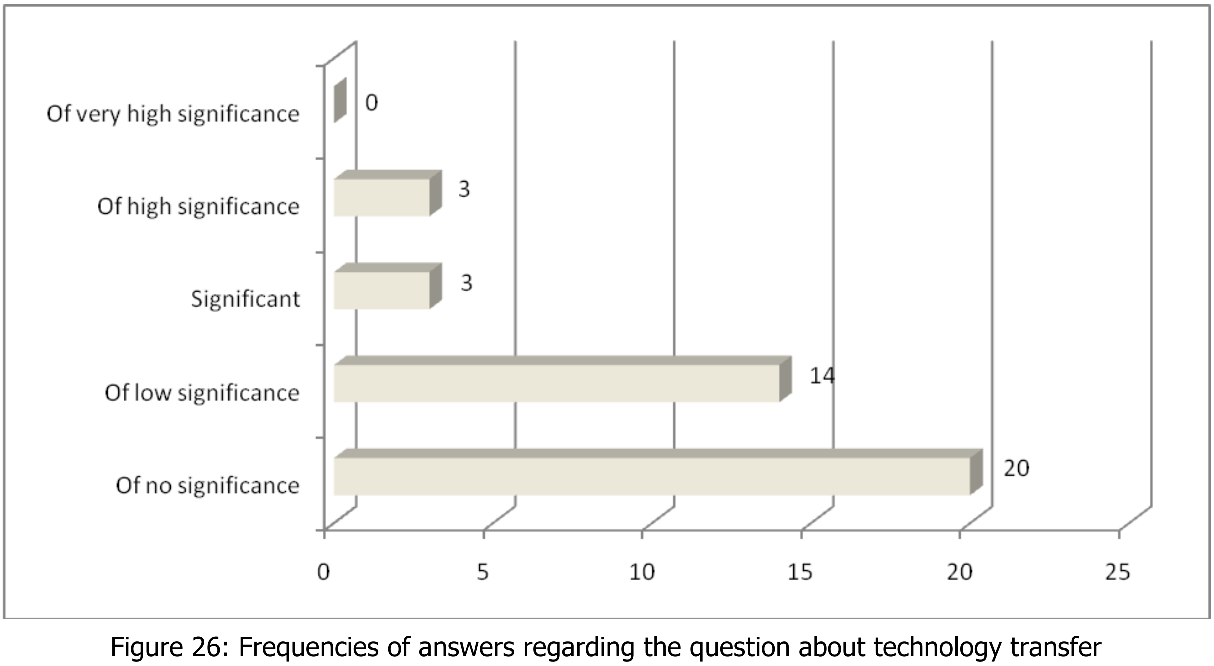


Figure 26: Frequencies of answers regarding the question about technology transfer

Only 6 out of 40 respondents indicated medium to strong significance of transfer of technology leading to an average scoring of 1.725 with a standard deviation of 0.905. The standard error of the mean is 0.143.

Symptomatic is the revelation that 5 out of the 6 organizations which identified technology transfer are R&D organizations. That means that 50% of R&D organizations observe technology transfer between ESO and them. The obvious conclusion is that knowledge flows in a bidirectional way when one is facing scientific relations. This fact might also have origin in the close relations that scientific organizations have between each other, materialized in scientific networks. Regarding the 6 astronomy organizations, 4 recognized technology transfer indicating that they view ESO as a source of knowledge.

. R&D learning:

R&D learning is connected to technology transfer. The difference is that in this case, transferred knowledge can be described as immaterial or tacit, such as ideas, skills or not codified methods. This knowledge is transferred through an informal way, independently of the establishment of formal agreements. Next, one may check the output for this question:

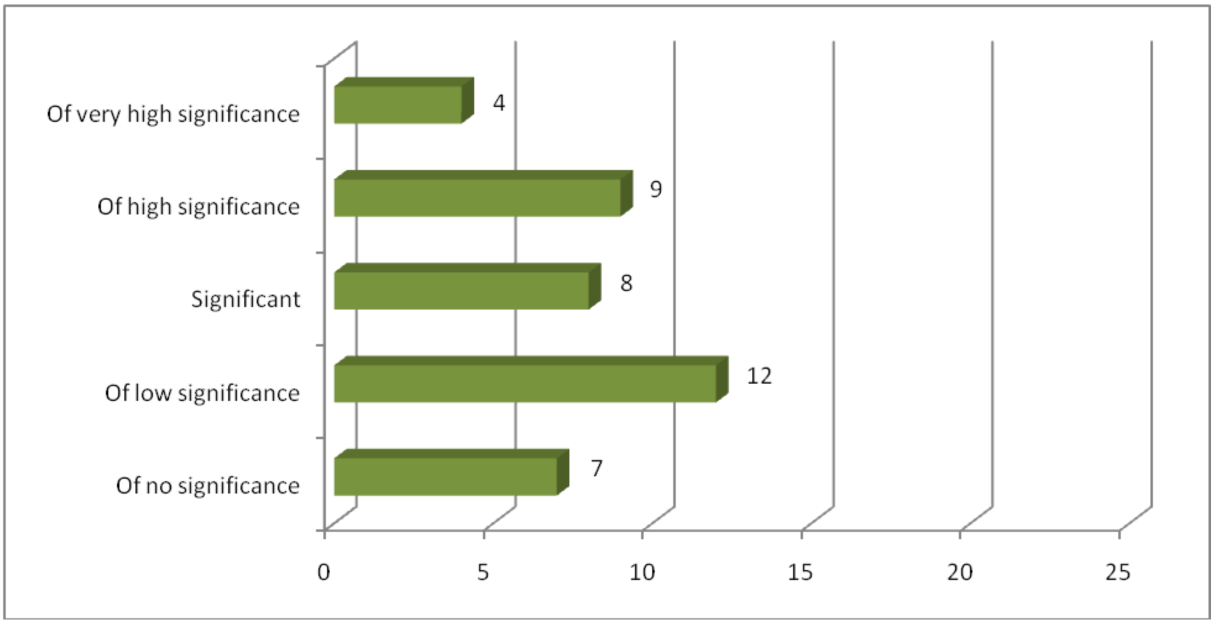


Figure 27: Frequencies of answers regarding the question about R&D learning

From the figure one can observe that R&D learning outcomes of collaborations with ESO were noticeable, with 21 of the 40 respondents (52.5%) indicating medium to strong R&D learning, while the remaining organizations indicated no or weak R&D learning. In consequence, the mean scoring is 2.775 with a standard deviation of 1.271. The standard error of the mean is fixed at 0.201.

R&D learning benefits do not appear uniformly distributed in the respondent sample: while some organizations are able to derive significant or very significant R&D learning from their relation with ESO, other organizations appear less able to realize such benefits. Let's check the sample by type of organizations to see if one unveils patterns.

R&D organizations recognize strong synergies with ESO in terms of R&D learning: 90% of R&D centres answered favourably to this question. 40% of R&D centres attributed a very high significance to this outcome while 30% of institutions attributed a high significance to it. Companies were more cautious with relation to this benefit: 40% of respondents give significance to this outcome, half of which attribute a high value to it. As seen in the last benefit, it seems that R&D organizations are able to exploit with more effectiveness R&D synergies with ESO, maybe because their aim, scientific exploitation, and object of study are close. As stated in question 1 of annex 4 this difference in R&D learning scoring between R&D organizations and companies is statistically significant.

Analysing organizations that identified medium to strong R&D learning by specialization one finds that astronomy, optics and instrumentation are the areas of knowledge where organizations find more potential to learn with ESO. All organizations that work in optics recognized R&D learning while 5 out of 6 organizations that work in Astronomy identified learning opportunities. By its turn, in instrumentation, 4 out of 6 organizations found R&D learning.

Taking into consideration companies' sizes one highlights that 45.5 % of SME (5 out of 11) indicated medium to strong R&D learning while 80% of big companies (4 out of 5) declared the same result. One guesses that R&D learning is more about the type of project the supplier develops rather the size of the organization.

The relation's technological intensity might be other potential determinant of R&D learning. Taking the size of the budget as a proxy of technological intensity of the project one sees that 60% of organizations (3 out of 5) with budget above 1,000,000 Euros noticed medium to strong R&D learning. The same happened to 55.(5)% (5 out of 9) of respondents with budget between 100,000 Euros and 1,000,000 Euros. On the other hand, 42.3% of organizations with budgets up to 100,000 Euros gave analogue answer. These figures, although not statistically significant (please, see question 2 of annex 4), indicate that higher scorings for this outcome are relatively biased to organizations with higher budgets. Alternatively, if one checks organizations that declared having R&D intensity, being the proxies the number of workers allocated to R&D and R&D expenses as percentage of revenue, one verifies that 64.3 % of R&D intensive (18 in 28) organizations indicated medium to strong R&D learning, of which 8 attributed high importance to this outcome while 4 attributed very high importance to it. This result is confirmed by statistical tests in question 4 of annex 4 which detect differences (p=0.002) between R&D intensive organizations and non R&D intensive organizations in the scoring of this benefit. Taking off R&D organizations (naturally R&D intensive) the percentage of medium to strong valuation goes down to 47%.

. Access to scientific or technological networks:

Once again, when referring to networks, respondents did not identify much impact caused by their relation with ESO. One may check the results in the figure bellow:

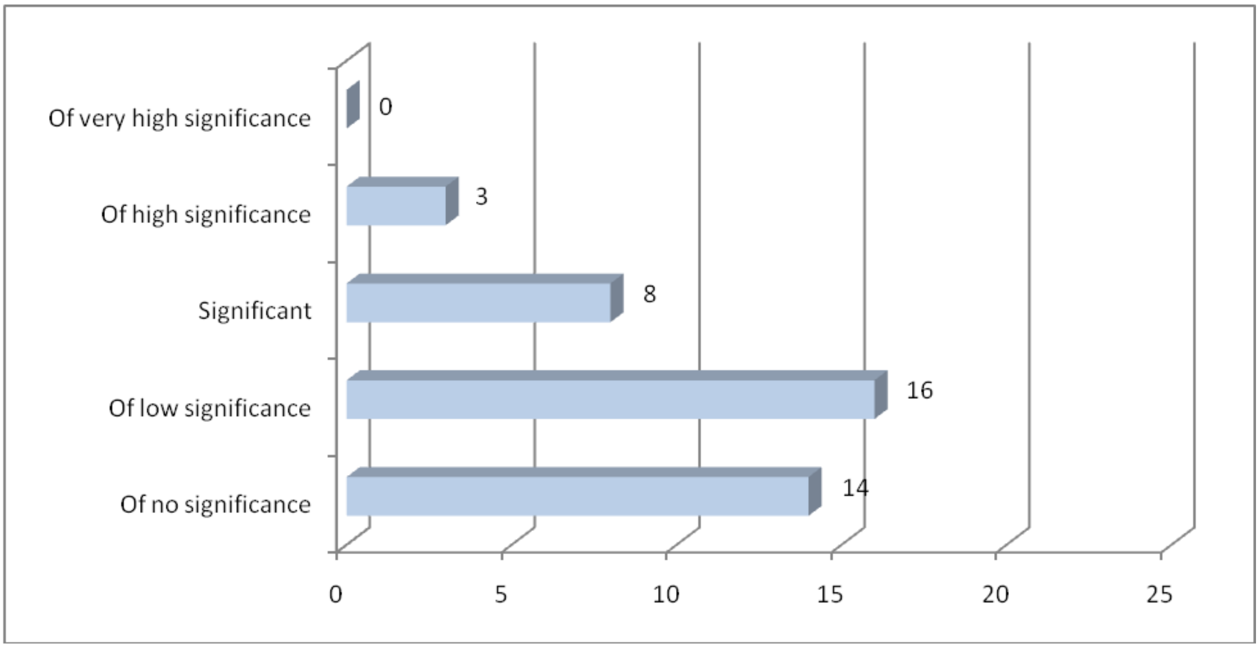


Figure 28: Frequencies of answers regarding the question about scientific networks

Only 11 out of 41 respondents (27%) answered that their relation with ESO gave them access to scientific or technological networks. The average scoring is 2.488 with a standard deviation of 1.165. The standard error is 0.182.

Dividing the sample of respondents by type of organizations, one finds that 60% of R&D institutions did not identify advantages brought by ESO in terms scientific network access, maybe because they, as scientific organizations, already belong to these networks. With regard to companies, only 23% (7 out of 31) gained increased access to scientific or technological networks due to ESO.

Characterizing organizations that identified access opportunities to scientific networks, one sees that 2 out of the 3 organizations that think that ESO gives high access opportunity to scientific networks are companies working in areas not directly related with Astronomy: mechanical engineering and electronics. Maybe the contracts they developed with ESO were the motive to liaison with more R&D institutions via ESO. The third organization belonging to this group is an Astronomy R&D organization. One underlines that half of the astronomy organizations views ESO as a gateway to scientific networks. Maybe they see it not as an entrance door but as an opportunity to reinforce bounds within these networks. Other result is that half of the electronics firms value this impact. In this case, since electronics is not specific to Astronomy, one tends to think that the contract with ESO worked as a door to scientific networks. In the end, as said before, maybe organizations do not recognize this benefit because they already belong to scientific and industry networks. An evidence is that most of organizations form consortia to participate in projects with ESO.

. Sharing of R&D or innovation risks:

R&D implies risk due to uncertainty of its results. Collaboration between an organization and a big science centre like ESO originated by a supply contract might decrease the risks of a certain precedent related line of R&D due, for instance, to additional funding, to sharing of costs, to new complementary or multidisciplinary human and technological resources to tackle R&D challenges, to gaining of forefront knowledge of R&D trends and emergent technologies or to access to state-of-the-art equipment and facilities (CBI, 2001). The next figure captures suppliers' perception regarding this possible outcome:

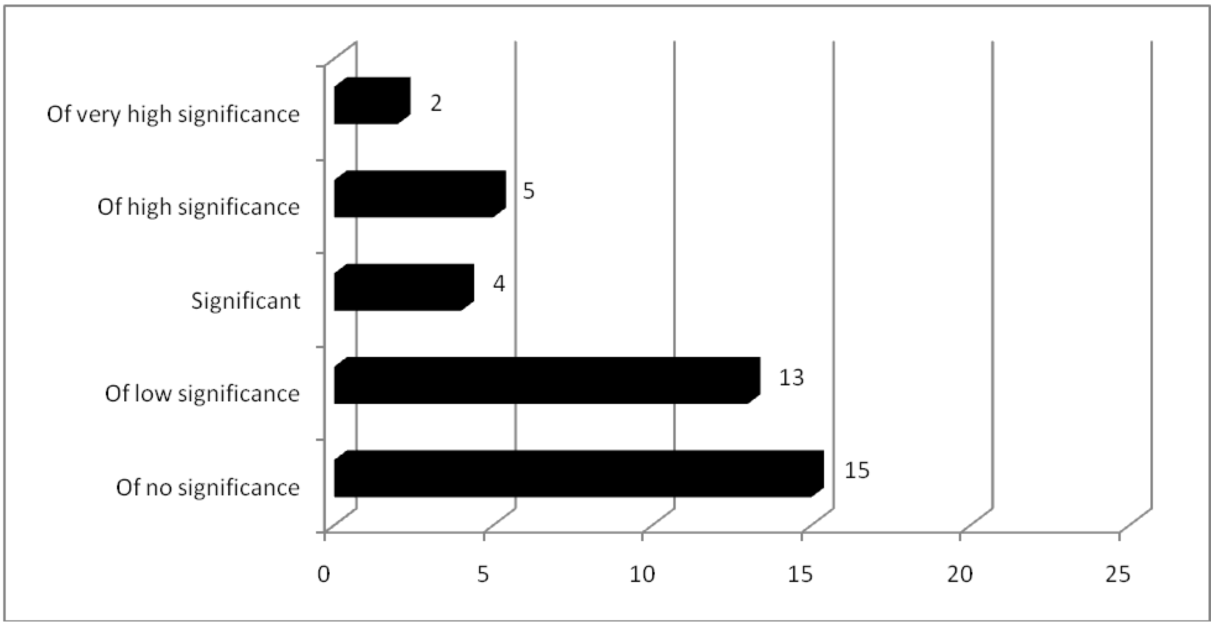


Figure 29: Frequencies of answers regarding the question about R&D or innovation risks

The majority of respondents (28 out of 39 respondents) considered that contracts with ESO did not originate the sharing of R&D risks between partners. This is translated in the average scoring for this benefit calculated in 2.128 with a standard deviation of 1.218. The standard error of the mean is 0.195. One underlines that 64% of organizations (7 out of 11 organizations) that recognized this outcome are R&D centres. This means that 7 out 10 R&D organizations identified this benefit. The prevalence of R&D organizations among positive respondents may have its seed in the fact that they share scientific objectives and work in a close connection with ESO. Companies might work more independently. The truth is that R&D centre's scores in this question are higher than those of companies. This difference is statistically significant (please see question 1 of annex 4). Only 4 firms valued this benefit as significant. All of them have budgets higher than 100,000 Euros (one of them has budget higher than 1,000,000 Euros) and are R&D intensive organizations. With regard to this last classification, one notices that all positive respondents are R&D intensive organizations representing 39.3% (11 out of 28) of R&D intensive respondents.

One should notice that although often implying changes in direction of projects and unpredicted costs, uncertainty might not be an obstacle to learning and innovation. By the contrary, learning is often catalysed by the need to deal with unexpected eventualities (Autio et al, 2003).

. Development of new knowledge:

In the survey, this question indicates technology and publications as illustrations of new knowledge derived from ESO contracts. This new knowledge may origin innovation on the industry side. On the R&D institutions side, this new knowledge besides scientific achievement may result in technology transfer to industry (and thus innovation, if commercially exploited) or push frontiers of science even further. The stats for this question are found below:

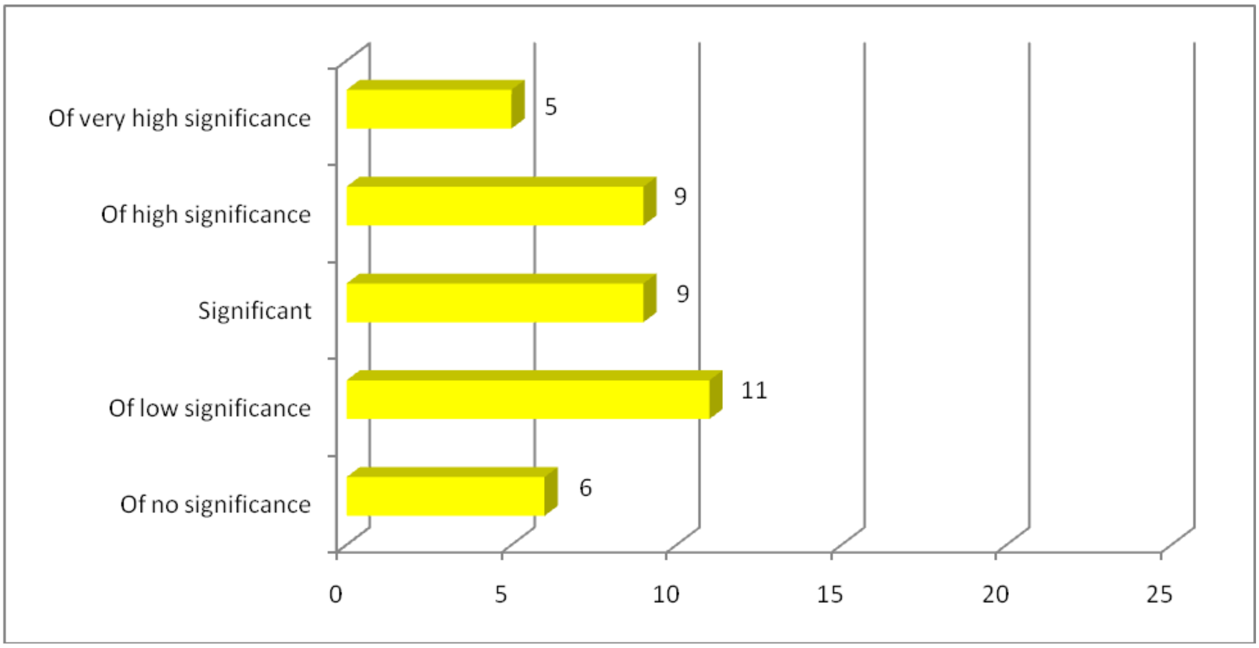


Figure 30: Frequencies of answers to the question associated to development of new knowledge

This question was answered by 40 organizations. Even though the average of scores is fixed in 2.9 (below the level of 3), 58% of respondents (23 out of 40) considered this benefit at least significant, being a sign that these suppliers were able to create new knowledge in consequence of their projects with ESO. The σ of ± 1.277 indicates a significant dispersion of observations. The σM is equal to ± 0.202. The breakdown of respondents by type of organizations will allow knowing which organizations were able to create new knowledge and what kind of knowledge they refer to. One concludes that 50% of respondent companies (15 out of 30) indicated that their contracts with ESO generated new knowledge. A surprising evidence is that 10 of these 15 companies have budgets below 100,000 Euros. One should remember that there are 19 companies with budgets less than 100,000 Euros. Assuming that the degree of complexity is associated to the budget, one expected that positive responses would tend to come from companies with bigger budgets. Reinforcing this unexpected evidence, statistical tests did not detect relevance of this factor in respondents' evaluation of this benefit (please see question 2 of annex 4).

In the group of companies with budgets between 100,000 Euros and 1,000,000 Euros, 3 out of 8 identified knowledge creation while from the group of companies with budget higher than 1,000,000 Euros, 2 out of 3 respondents indicated this positive outcome. Less surprising is that 11 respondent companies are R&D intensity, which makes 61.1% of all companies (18) that are classified as R&D intensive. This evidence links creation of new knowledge to R&D, statistically confirmed by the test of question 4 of annex 4.

Analyzing the size of companies that responded favourably to the question, one underscores that 4 out of 5 are big organizations while 5 out of 11 are SME. The relative dominance of big companies in this group of respondents could translate the additional means (organization, tools, human resources) big companies have to facilitate knowledge generation. Note that question 5 of annex 4 does not confirm statistically relevant scoring differences between big companies and SME.

R&D institutions, by their turn, are almost unanimous in recognizing the creation of new knowledge in the framework of ESO's contracts: this question received favourable answers from 80% of respondent R&D organizations (8 out of 10). Perhaps these results are influenced by the vocation of the majority of respondent R&D institutions: investigate fundamental matters and producing knowledge. This benefit was not identified by one applied research organization and one fundamental research organization.

When looking to the specialization of respondents one concludes that the areas that recognize more advantages in collaboration are optics (100% of respondents gave favourable answers), opto-electronics (4 out of 5 positive answers), astronomy with 5 out of 6 positive answers and instrumentation with 3 out of 5 positive answers.

Once again, like in the question which inquiries about new product/service development, one is not certain whether respondents considered their deliverables to ESO as new knowledge or they were thinking in new knowledge beyond their contracts with ESO. Either way the results for this question reveal the potential of astronomy projects in working as drivers of knowledge generation at the same time they develop their mission of doing fundamental science.

. Application of new patents, copyrights or other intellectual property rights:

This question is trickier to scrutinize because application for IP rights depends not only of the generation of protectable R&D results (for example, R&D results to be patentable have to follow 3 main requisites: novelty, involve an inventive step, be susceptible of industrial application) but also of the IP policy of the organization. Although the recent trend is to apply for patents, some organizations, mostly companies, prefer alternative forms of IP protection such as industrial secret. So, the following results should not be viewed only through the light of VLT projects' capacity (or not) of generating IP rights:

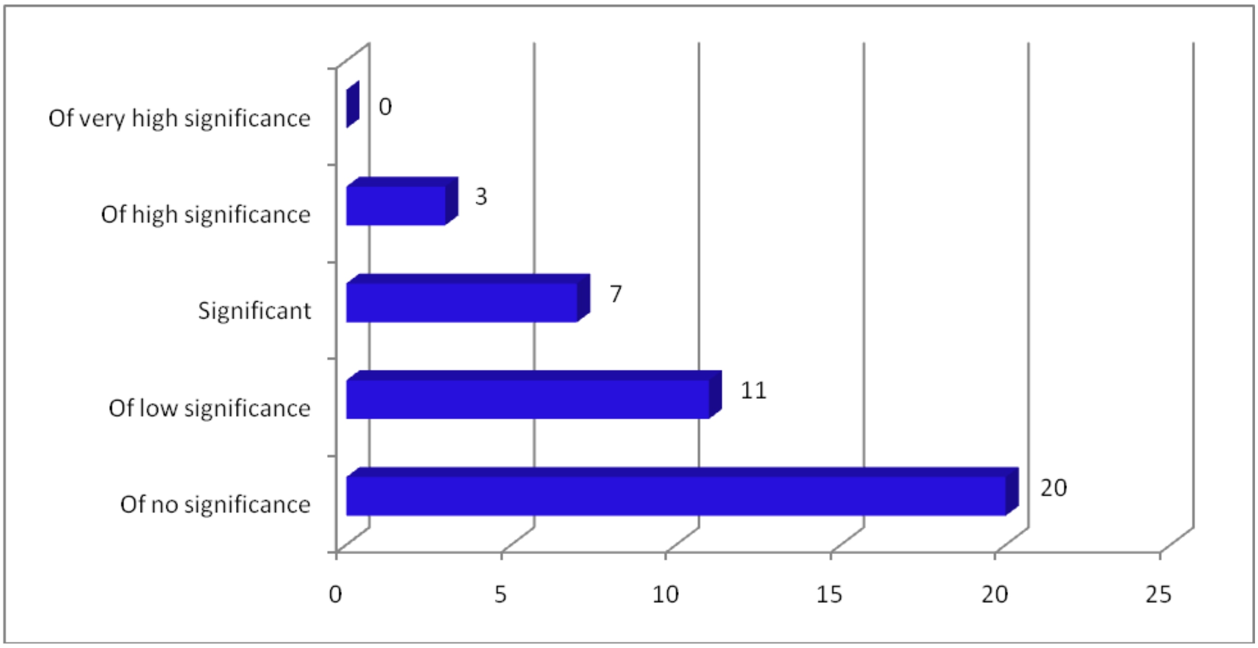


Figure 31: Frequencies of answers to the question associated with IP rights

Results put in evidence that the majority of suppliers did not apply for IP rights' protection in consequence of their collaboration with ESO: only 10 out of 41 respondents chose that path. These results are translated in an average scoring of 1.829 with a standard deviation of 0.972. The standard error of the mean is 0.152.

The group of positive respondents is constituted by 4 R&D organizations and 6 companies. Two companies stated that IP protection was highly significant as a result of the collaboration with ESO.

(4) Organizational benefits:

. Improved technical skills / know how in collaborators:

ESO is a high tech organization. As such, its procurement requests probably bring considerable technical challenges to its suppliers. These challenges might work as drivers for improvement of skills and know how in suppliers' workers. Results for this question confirm this conjecture, as one may observe in the following figure:

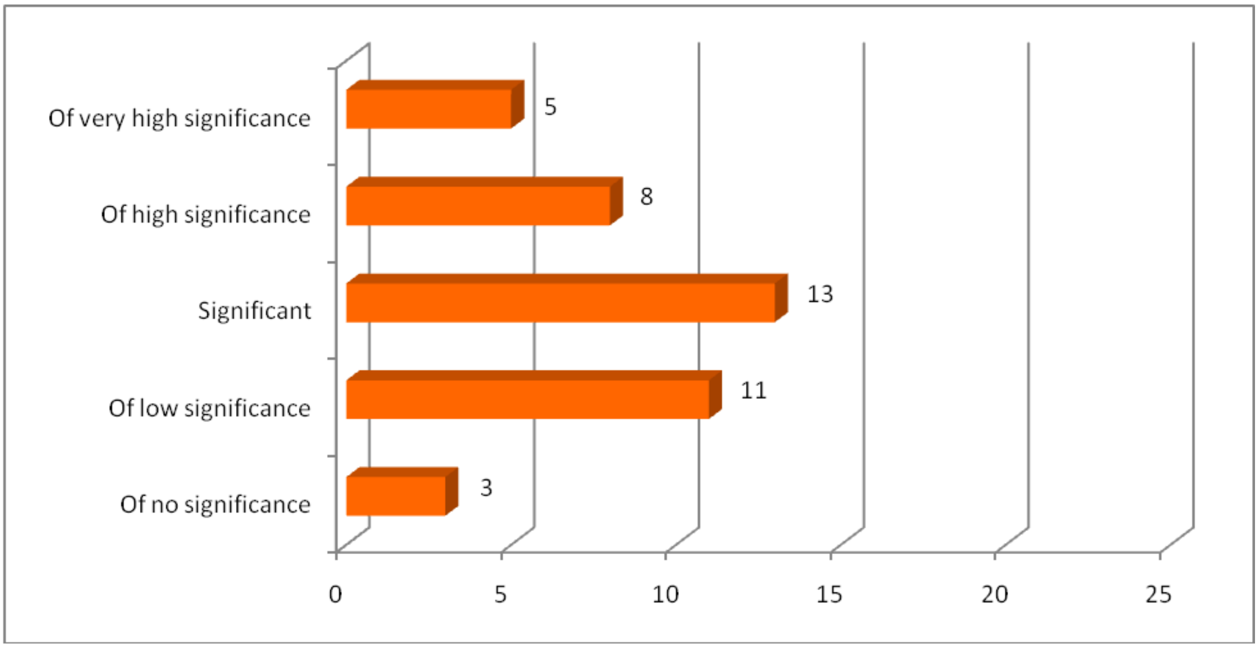


Figure 32: Distribution of frequencies regarding improved technical skills / know how in collaborators

In all, 65% of respondents (23 out of 40 respondents) indicated moderate to very strong improvement of skills/know how as consequence of their collaboration with ESO, which results in an average scoring of 3.025, with a standard deviation of 1.143. The standard error of the mean is 0.181.

One highlights that 90% of R&D organizations (9 out of 10 respondents) identified the benefit whereas 57% of companies (17 out of 30 respondents) recognized this outcome. Notice that all 3 applied R&D organizations stated this benefit, of which 2 belong to the group of 4 R&D organizations that said that improved skills have very high significance. This may signify that training or learning does not resume to be fostered by transference of ESO's produced scientific knowledge (which supposedly occur with more frequency in interactions between fundamental R&D organizations) but also by technological challenges. With regard to companies, 5 out of 11 organizations classified as SME valued this outcome whereas all 5 organizations classified as big companies identified it. Furthermore, tests made in question 5 of annex 4 proved statistically significant differences between scores of SME and those of big companies. Average scores in big companies are higher than those in SME.

Taking the size of the budget as a proxy of technological intensity or complexity of the project one sees that 60% of organizations (3 out of 5) with budget above 1,000,000 Euros noticed medium to strong improvement of know-how. The same happened to 44.(4)% (4 out of 9) of respondents with budget between 100,000 Euros and 1,000,000 Euros. On the other hand, 73% of organizations with budgets up to 100,000 Euros gave analogue answer. So it seems that organizations with smaller budget are relatively more acquainted with this outcome. One possible rationalization for this unexpected result is that companies were thinking in the continuum of collaborations with ESO and not only in this discrete, punctual contract within the VLT. A pertinent information is that statistical tests did not find evidence of budget's influence on respondents' scores so one should interpret this statistic with parsimony.

There are specializations where almost all members pointed out this benefit. One refers to optics, 5 out of 5 respondents, instrumentation, 5 out of 6 respondents, astronomy, 5 out of 6 respondents and electronics, 4 out of 6 respondents. One may argue that these are the specializations where technical learning or training derived from ESO's contracts has more potential.

. Improved project management skills (for example, contract control):

Deadlines, requisites and the technical complexity of big science projects demand project management capabilities. Let's verify whether ESO's suppliers realized that their project management skills became strengthened during the collaboration.

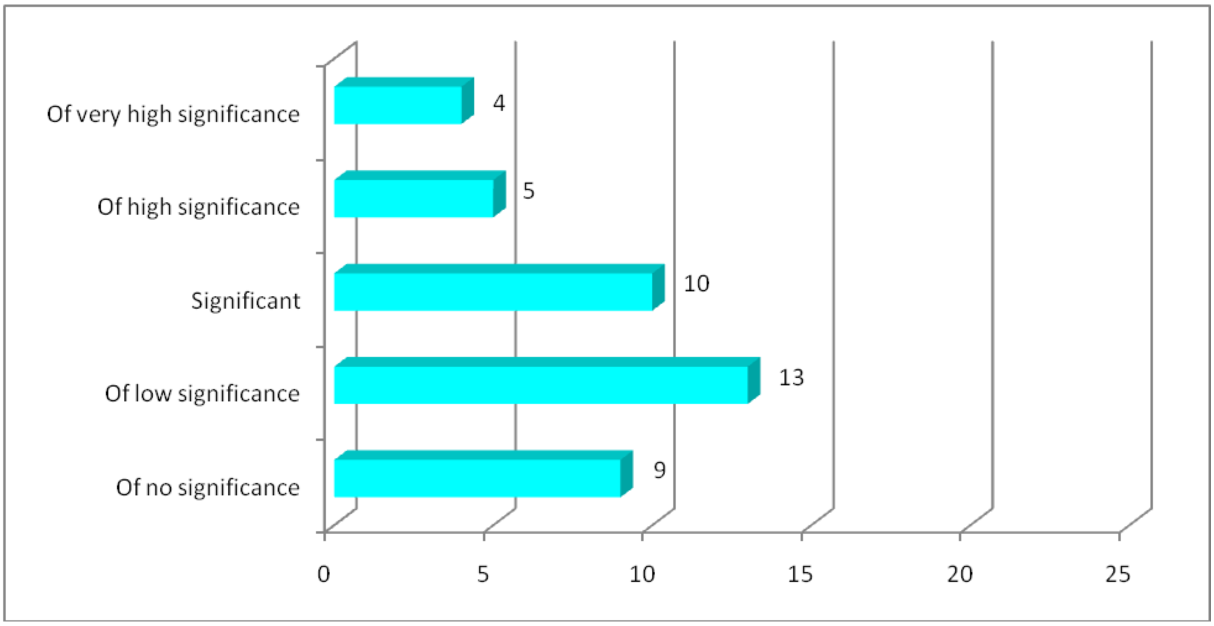

Figure 33: Distribution of frequencies regarding improved project management skills

Altogether 46.3 % of respondents (19 out of 41) indicated moderate, strong or very strong improvement of project management skills. Of this group of respondents, 6 are R&D institutions and 13 are companies.

Concerning companies, 5 SME (out of 11) recognized improvement of project management skills. 4 big firms (out of 5) did it too. A possible factor for project management learning is the complexity of the project. Scrutinizing respondents through the optic of budget size, one unveils that 2 out of 5 organizations with budget above 1,000,000 Euros noticed medium to strong improvement in project management skills. The same happened to 2 out of 10 respondents with budget between 100,000 Euros and 1,000,000 Euros. If one complements these stats with the lack of statistically significance of scoring differences between bigger orders and smaller orders (annex 4), one concludes that there is not enough data to prove a direct association between the size of the budget and benefits related with project management capabilities.

. Improved processes or manufacturing methods:

Next figure shows suppliers' perception about the improvement in their manufacturing capability because of the VLT project:

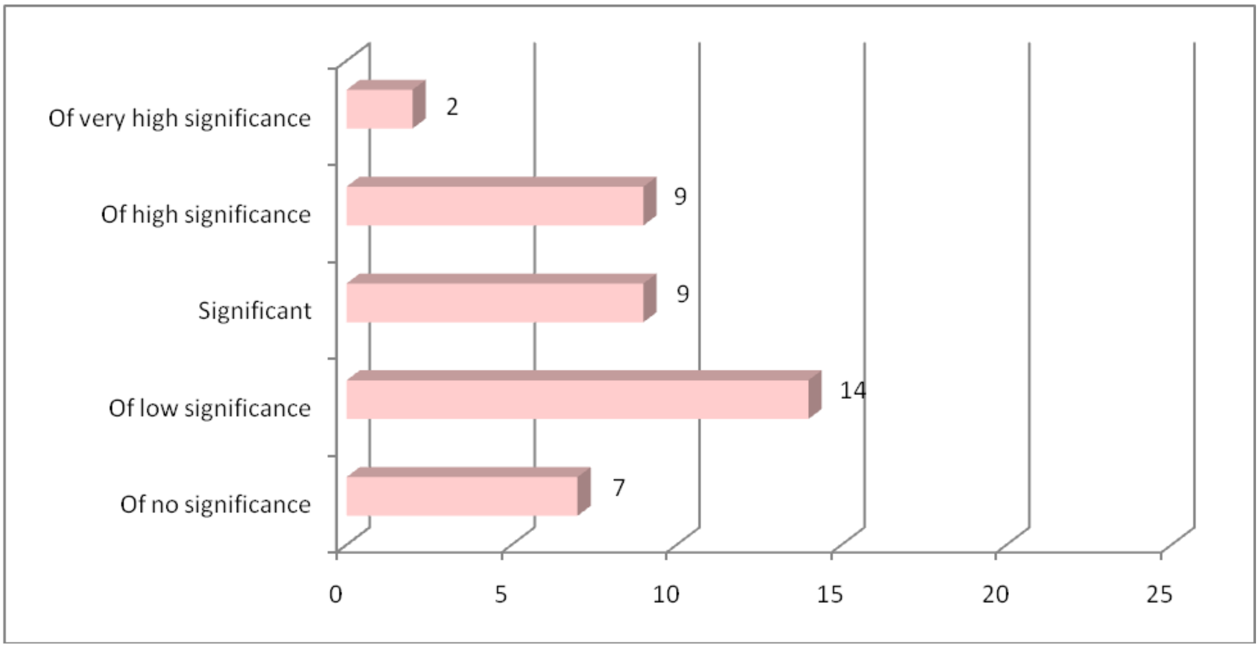


Figure 34: Distribution of frequencies regarding improved process or manufacturing methods

These capability benefits have a fair impact, as 48.8% of respondents (20 out of 41 respondents) indicate moderate or strong agreement with this statement. These stats are translated in an average scoring of 2.634 with a standard deviation of 1.157 and a standard error of the mean of 0.181.

Symptomatically, favourable responses are relatively dominated by R&D organizations. Positive answers from R&D organizations make 40% of positive answers and represent 80% of responses from R&D institutions. If one digs the projects in which R&D organizations collaborated, one understands the prevalence of positive answers in this issue (supposedly more related with industrial activities). All 6 R&D organizations that attributed a high or very high importance to this benefit collaborated in consortia (together with companies) to deliver instrumentation to VLT. One refers to projects with the aim of developing equipment for adaptive optics, spectrographs with a variety of scientific objectives or laser equipment for star tracking or guidance. As one sees, these projects require the organization and implementation of production plans. These projects may allow a gain of practical experience to institutions more used to fundamental work.

With regard to companies, 38.7% of respondents (12 out of 31) identified this positive outcome. One highlights that 2 out of 4 companies with budgets higher than 1,000,000 Euros, gave high importance to this benefit. This may be due to the fact that their projects, corresponding to the second and third biggest budgets of respondents (one close to 5 million Euros and other around 6.5 million Euros), brought to companies significant challenges in terms of production.

. Improved organizational practices:

Another possible organizational outcome from projects with ESO is related with the development of organizational capabilities. By organizational capabilities, one refers to organizational routines and related competencies that enable the organization to perform various tasks, such as production tasks, procurement tasks, logistical tasks, R&D tasks, or marketing tasks. The results for this question are shown below:

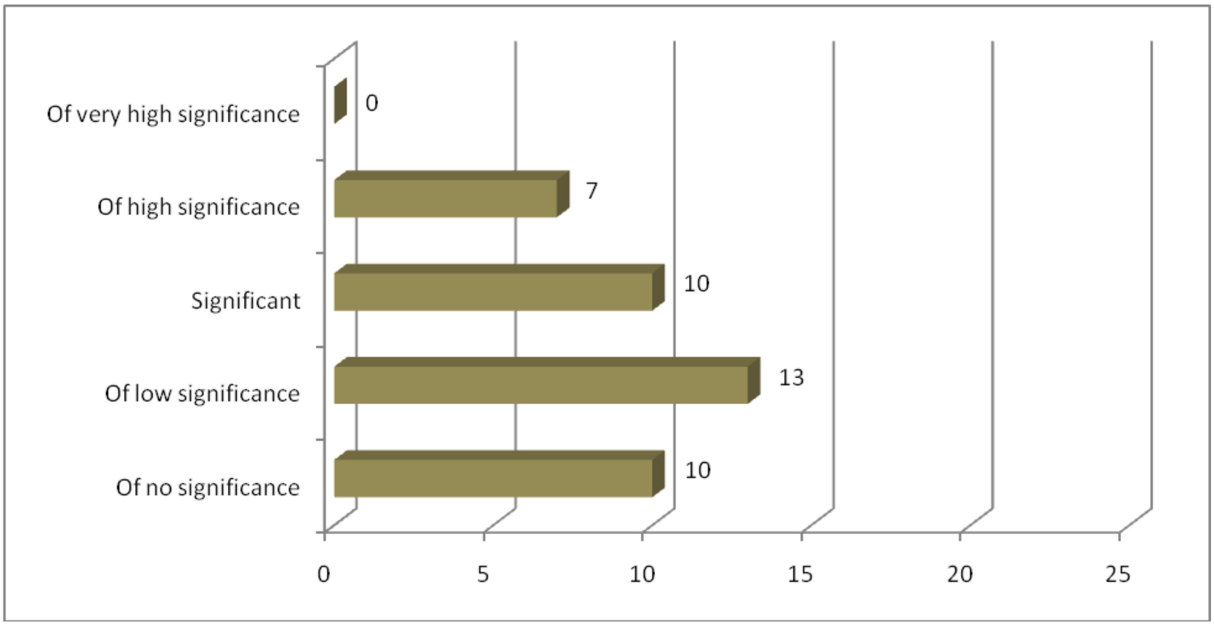


Figure 35: Distribution of frequencies regarding improved process or manufacturing methods

This impact was not recognized by 57.5% of respondents (23 out of 40 respondents) which is converted in an average scoring of 2.35 with a standard deviation of 1.051. The standard error is 0.166.

Half of respondent R&D organizations classified this benefit as an effect of their contract with ESO, of which 4 institutions valued it as a high significant impact. These 4 organizations worked in close contact with other organizations (namely companies) in the framework of consortia made in order to deliver instrumentation and high tech equipment to ESO.

Paying attention to companies, one finds that among positive respondents, 2 organizations have budgets higher than 1 million Euros, 3 firms have budgets between 100 thousand and 1 million Euros and 7 companies have budgets bellow 100 thousand Euros. Pointing out to the latter companies and making a brief web search regarding their projects in Astronomy, one finds that they have been working in consortia with other institutions (companies and R&D organizations). This may explain their answer despite their low budget in the VLT. The underlying assumption is that working in consortia favours exchange of organizational best practices.

. Improved compliance / quality assurance:

Another likely area of organizational capability development relates to the improvement of suppliers' compliance systems. The assumption is that big science's demands as highly sophisticated customer push suppliers to upgrade their quality control capabilities. Big science usually places very stringent quality and schedule demands on its suppliers. As suppliers are forced to meet those demands, they end up improving their related capabilities (Autio et al, 2003). Results are laid out in next figure:

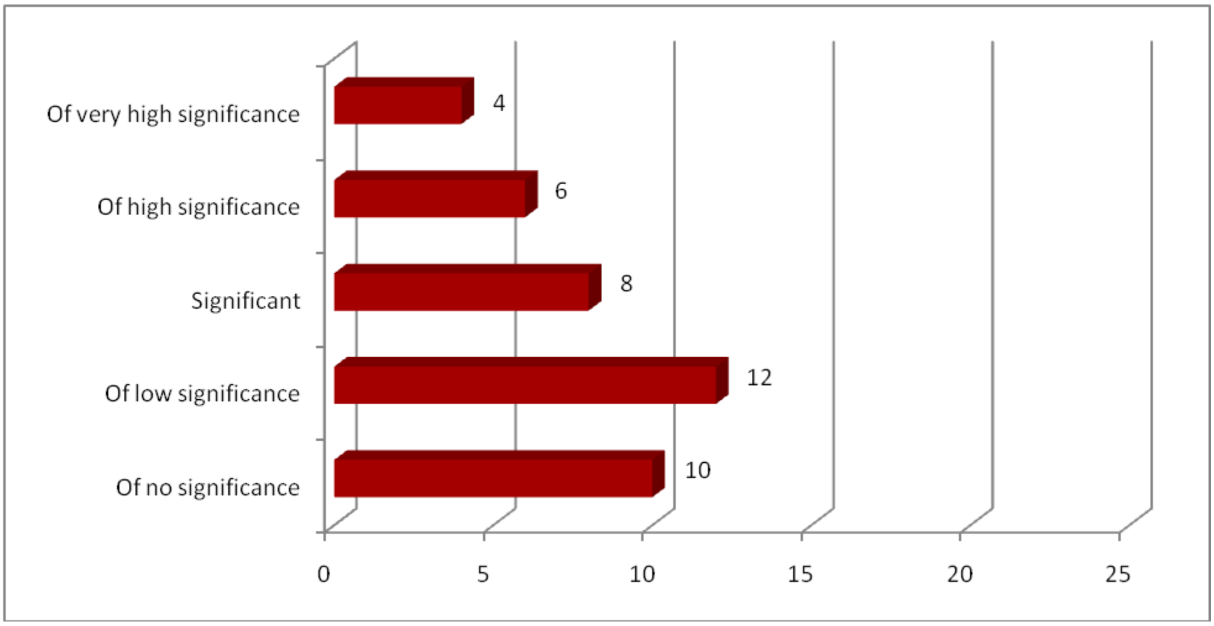


Figure 36: Distribution of frequencies regarding improved compliance

In all, 45% of respondents (18 out of 40) indicated moderate or strong agreement with the hypothesis of their quality system improve as an effect of their partnerships with ESO. In average, the significance of this benefit was scored at 2.55 with a standard deviation of 1.30. The standard error of the mean is 0.206. Separating respondents by type of organization, one finds that 60% of R&D institutions recognized that their projects with ESO improved their quality systems. The percentage of favorable responses decreases to 40% among companies. It happens that companies, most of the times, especially in high tech sectors, take the initiative of implementing and certifying quality systems. Nowadays, implementing a certified quality system is viewed as compulsory in order to negotiate with big costumers or to apply for public tenders.

Intriguingly, SME, organizations whose supposedly less developed quality systems have more potential to be improved due to the contact with strict quality control requirements, did not value this effect: only 3 out of 11 respondents assumed it as significant. By their turn, 4 out of 5 classified big companies recognized this benefit, of which, two considered that it has strong impact and one said that it has very strong impact. Qualitative data is needed to understand these results.

. Increased collaborator's motivation:

One thinks that this is a subjective outcome but important because it influences productivity, the quality of the work and of course, the well being of workers. A proxy of workers' motivation may be the dedication (in terms of hours of work, solutions suggested, enthusiasm showed in meetings, goodwill to execute tasks) they employ in certain project.

By the results shown bellow, one is lead to conclude that workers of respondents like to work with ESO:

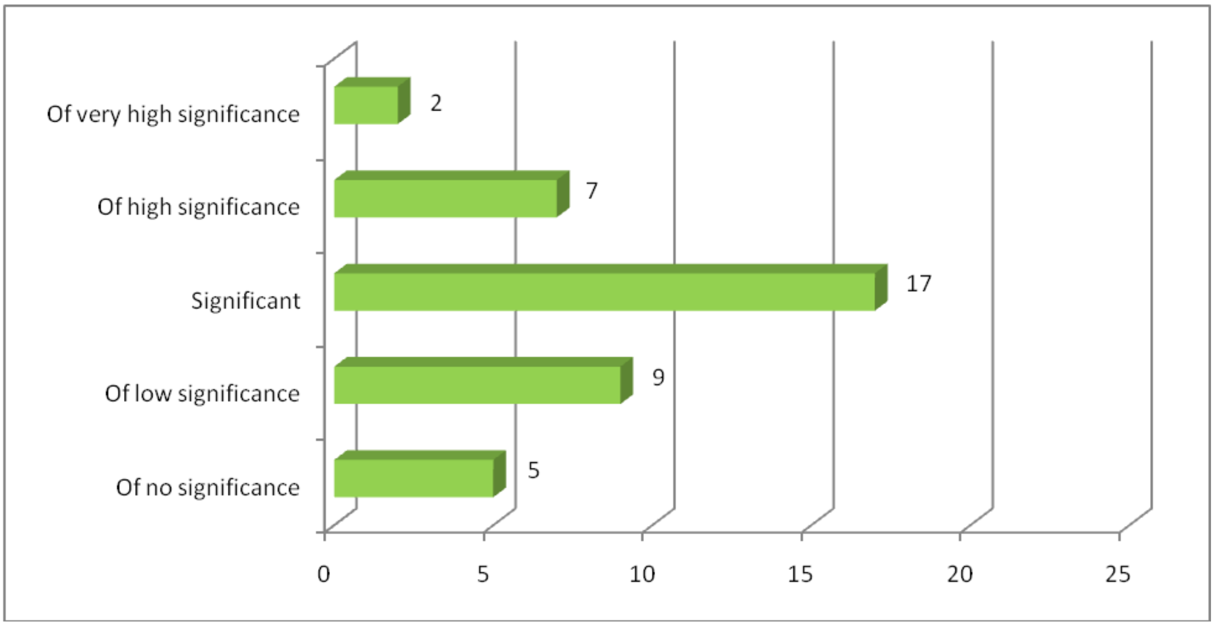


Figure 37: Distribution of frequencies regarding improved workers' motivation

Remarkably, 65% of respondents (26 out of 40) declared that their collaborators feel motivated in working with ESO. One guesses that the main drivers for workers' motivation are: to contribute for the increase of human knowledge about the Universe; financial rewards; to work in international projects with multicultural and multidisciplinary teams; and the technical or scientific puzzles that ESO projects imply. With regard to this last factor, one highlights that specializations where the conscience of this benefit is unanimous are optics – 5 out of 5 respondents gave a favourable answer – and software – 3 out of 3 respondents gave a positive answer. One also underlines astronomy and opto-electronics fields, with respectively 83% (5 out of 6) and 60% (3 out of 5) respondents valuing this benefit.

When respondents were asked to disclose additional benefits, not predicted by the survey, one organization specialized in applied R&D in optics shared that they benefited with increased collaboration in international networks. In addition, one company specialized in opto-electronics stated that the results coming from the system developed for ESO improved their performance data. One interprets that the key performance indicators of this company improved with the collaboration with ESO. Other company in opto-electronics saw its work with ESO as an opportunity to increase its knowledge about its own products. This statement confirms what was said in chapter 2.2.4.2 regarding big science projects as product test opportunities.

The survey tried to get suppliers' feedback about the impact of these benefits in their business or activities outside Astronomy. Results for this question are shown below:

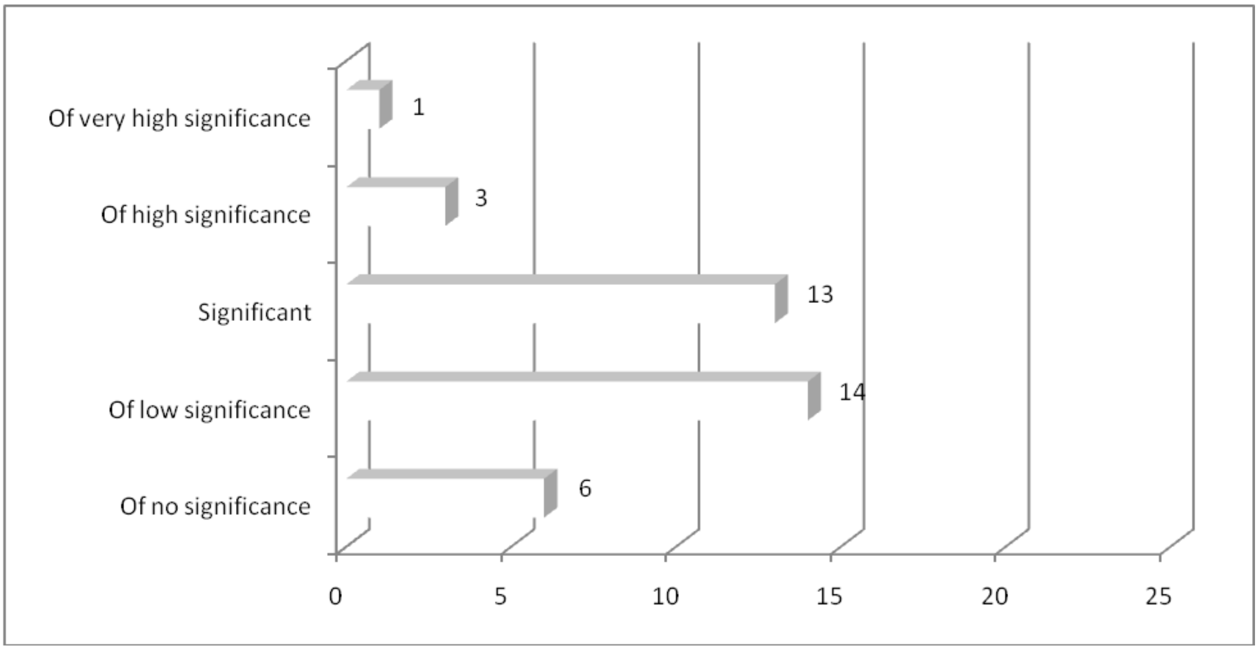


Figure 38: Distribution of frequencies regarding impact of benefits outside of Astronomy activities

Statistics show low to moderate impact of Astronomy benefits in other areas of business / activities since 46% of respondents (17 out of 37 valid respondents) stated that this outcome is at least significant. "Valid answers" means answers which scored this impact. Note that 2 companies and one R&D institution answered that they could not give an answer about this impact. The average scoring of this outcome is situated at 2.432 with a standard deviation of 0.959. The standard error of the mean is 0.158.

One highlights that there is a group of organizations whose core activity is Astronomy. Analysing the 6 organizations that belong to this group, one notes that half of respondents stated that the present outcome is significant. This apparently contradictory result should be depicted with further qualitative data.

If one looks to organizations on the opposite side of the spectrum, that is, organizations with little activity in astronomy (for instance, organizations whose Astronomy revenue is less than 10% in 2009), one finds that 60% of organizations (9 out of 15 respondents) recognize that Astronomy benefits had impact beyond these projects. The corollary of this result could be that Astronomy benefits had structural effects in these organizations. Once again, this guess should be validated with further investigation.

Screening the group of organizations that recognized impacts of Astronomy benefits in other businesses/activities, one finds that it is composed by 6 R&D organizations (making 60% of respondent R&D institutions) and 11 companies (making 37% of respondent companies).

#### 4.3.4.2.2 Efforts

A complementary way of inferring the impact of collaborations with ESO is to check whether suppliers made a significant effort to deliver the service or the product to ESO in the framework of the VLT project. Following, one shows the perception respondents have about each of the efforts named in the survey:

. Investment in new process equipment:

Results put in evidence that the majority of organizations did not need to invest in new production equipment in order to honour the contractual commitment with ESO. Looking with more detail, one finds that the average scoring for this effort is 2.297 with a standard deviation of 1.051. The standard error of the mean is 0.173. Next figure resumes stats of this question:

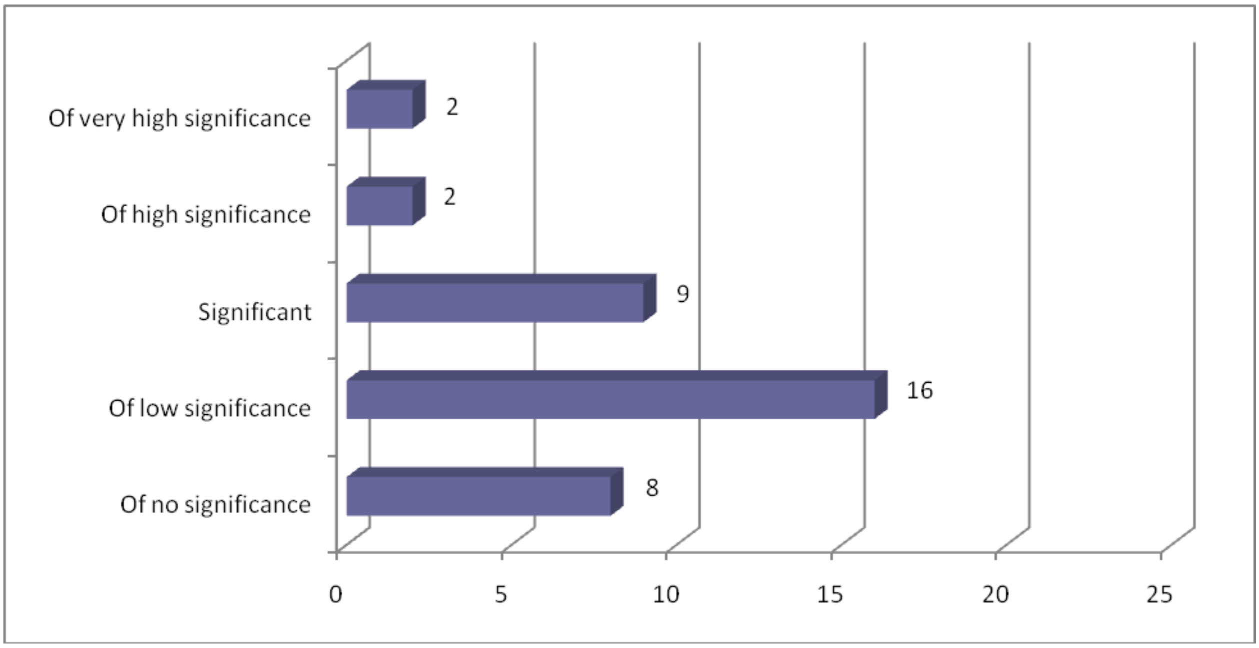


Figure 39: Distribution of frequencies regarding investment in new process equipment

As viewed, only 35% of respondents (13 out of 37 respondents) had the need to invest in new production equipment in the framework of their contract with ESO. Revamp or size variation of production lines is usually related with the objective of delivering new products or with production volume modifications. The proxy one chose to test the influence of these factors in process equipment acquisition was suppliers' budget size. The assumption is that smaller budgets do not imply significant alterations of production processes whereas bigger budgets have impact in internal production organization. The evidence tends to refute this hypothesis since none of organizations with budgets higher than 1 million Euros noticed this effort as relevant. Summing up, 5 out of 9 organizations with budgets between 100 thousand Euros and 1 million Euros did not recognize this effort. In addition, tests in question 2 of chapter 4 did not detect statistically relevant differences in function of budget among respondents' scores. Taking into account respondents, it seems that investment in new process equipment is not solely dependent of the contract's budget size.

An interesting outcome is that 70% (7 out of 10) of R&D organizations pointed to the relevance of this effort. 5 out of 7 R&D organizations which gave favourable answers develop fundamental research in Astronomy. Is this result related with the fact that within VLT these organizations were asked to collaborate in more practical, industrial like projects such as instrumentation development?

. Investment in new testing equipment:

Test equipment is usually needed in tailor made product delivery, product development projects or when precision of products (for example, measurement equipment) is crucial. Answers regarding this effort are shown below:

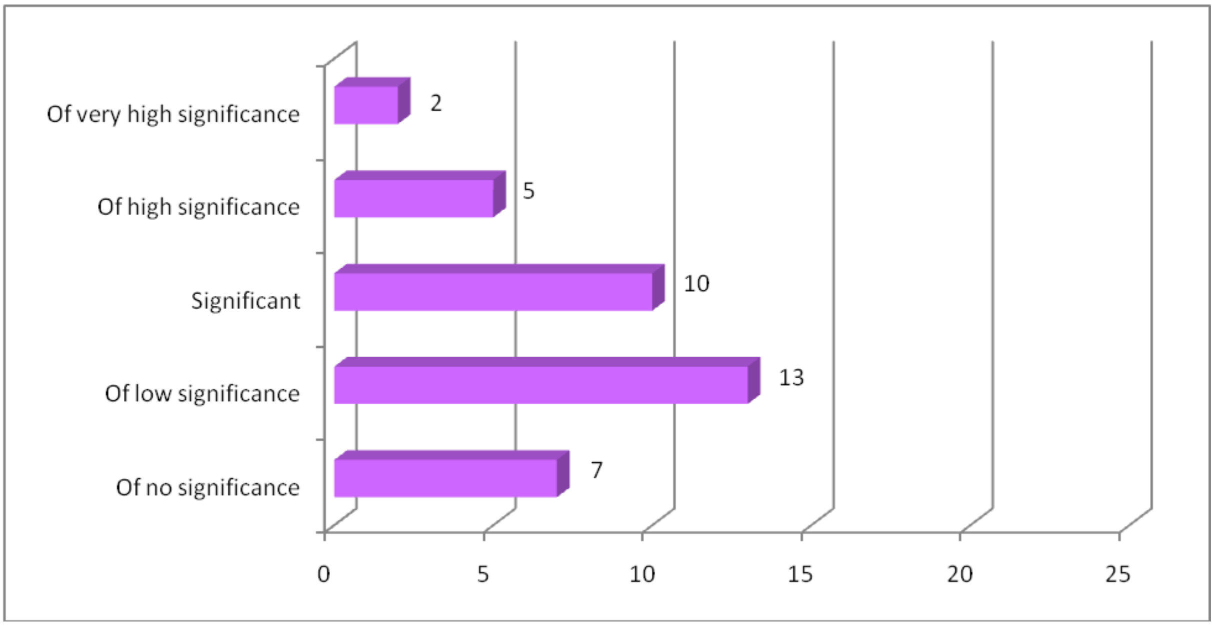


Figure 40: Distribution of frequencies regarding investment in new test equipment

One concludes that 17 out 37 respondents declared moderate to very strong acquisition of test equipment. This represents 46% of respondents. The average score of this question is 2.514 with a standard deviation of 1.121. The standard error is 0.184.

After this result one may take the chance of stating that in at least 46% of the studied cases the collaboration with ESO required something more than the "business as usual" suppliers' production.

Taking the budget size as a proxy of project complexity, one finds that 2 out of 5 organizations with budget higher than 1 million Euros invested in new test equipment, together with 5 out of 9 organizations with budget between 100 thousand Euros and 1 million Euros.

Once again, R&D institutions explain more than half of favourable answers. More precisely, 9 out of 10 respondents declared this investment, making 53% of positive responses. One brings to light that 5 R&D institutions recognized that investment in test equipment had high significance and one identified very high importance.

. Training of collaborators:

Training might be one of the investments organizations do in order to work in high tech markets. Mostly when an organization has a general vocation and wants to develop projects that involve specific objectives or technologies, such as big science (like Astronomy endeavours). Figure number 41 shows the frequencies of answers for this question:

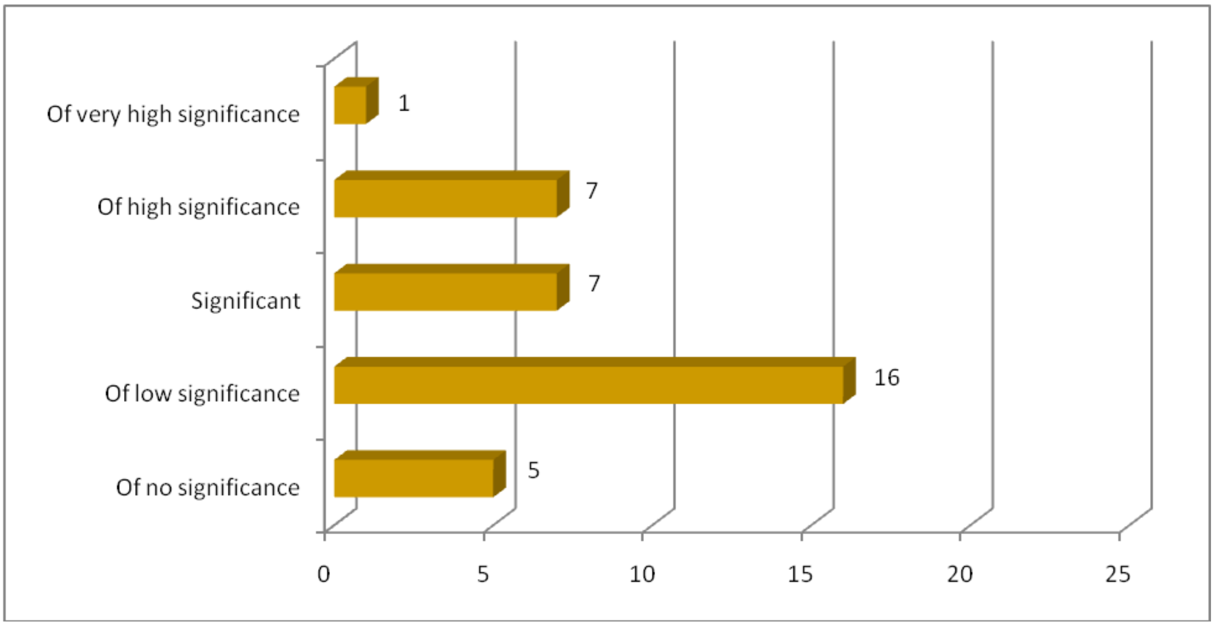


Figure 41: Distribution of frequencies regarding training of workers

The mean score of the 36 answers is 2.528 with a standard deviation of 1.055. The standard error is 0.176. Statistics reflect that 41.6% of respondents significantly invested in training (15 out of 36).

This effort confirms the prevalence of R&D institutions among favourable respondents: 90% of R&D institutions (9 out of 10 R&D institutions) invested in training in order to cope with VLT projects requirements.

It is curious to know that of the 15 organizations which invested in training 13 concluded that their workers won know how or perfected technical skills with ESO project. Is there a direct relation between the present effort and the referred benefit? At least, there is a linear association between this effort and the referred benefit since question 8 of annex 4 indicates a strong, high statistical correlation between them ($r=0.551$, $p<0.001$). One should investigate further, for instance, the type and objectives of the training programs workers received. What one knows is that of the 26 organizations which identified improved technical skills in consequence of their collaboration with ESO, 11 stated that did not make training investments. Is perhaps a sign that skills were acquired through "learning by doing".

In terms of specialization of respondents, is worth to register that 5 out of 6 organizations specialized in Astronomy made significant investments in training.

. Visits to ESO (or other costumers):

Normally, collaborations that imply product development, medium or long projects and multi-organizational teams imply frequent meetings between partners. This indicator can be used as a proxy of the type of relations one is dealing with: transaction of "off the shelf" products or development of tailor made products. Despite this last assumption, one should note that when the previewed volume of transactions is considerable it is common practice organizations schedule commercial, face to face meetings in order to allow people to get acquainted with each other. This happens even when one is dealing with standardized supplying. Results for this question can be observed hereby:

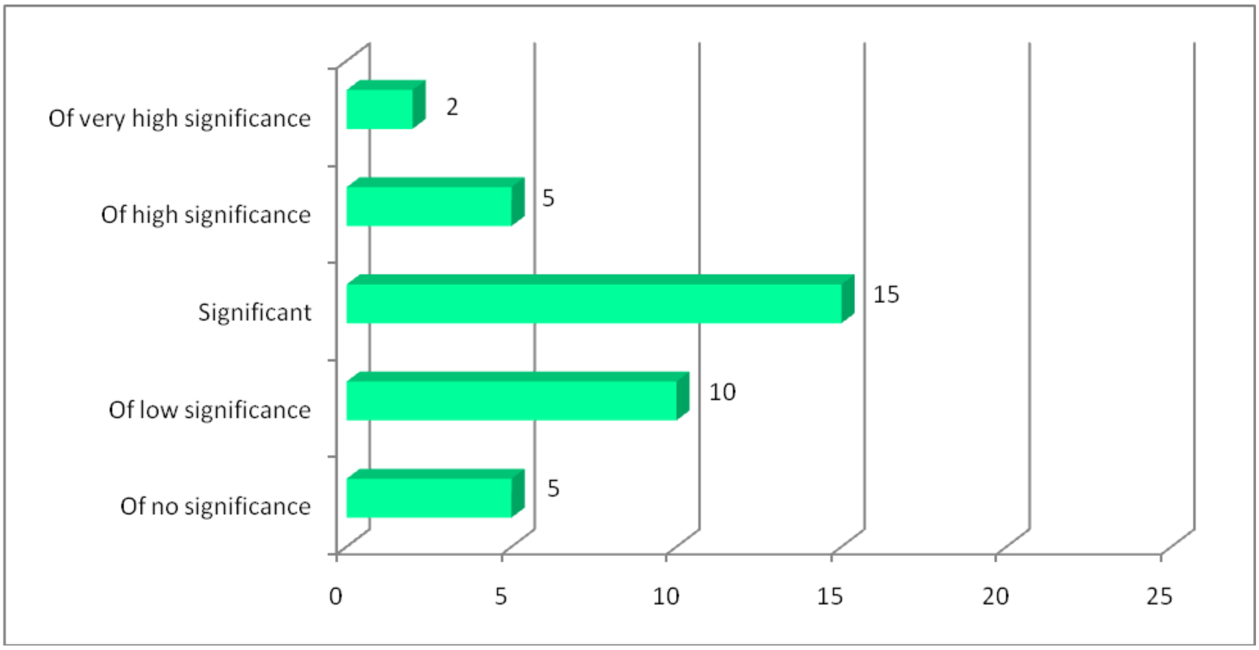


Figure 42: Distribution of frequencies regarding visits to ESO

Results confirm that visits to costumers are common practice among suppliers: 60% of suppliers (22 out of 37 respondents) consider that this action is relevant in the case of their relation with ESO.

With respect to the hypothesis of using this indicator as a proxy of the complexity of contracts, one finds that 3 out 5 organizations with budget higher than 1 million Euros visited ESO. The same is confirmed by 6 out of 9 organizations with budget between 100 thousand and 1 million Euros. Even though differences between scorings given by respondents with big budgets and small budgets are not statistically significant (please, consult question 2 of annex 4) one believes that there is a reasonable margin to make the case of using this effort as an indicator of the type of collaboration between a supplier and a big science organization. Despite that, remains the doubt whether respondents consider visits to ESO a relevant effort or is internalized as a usual procedure in the commercial or production process.

In the end, one is tempted to consider that visits to costumers tend to be a commercial good practice from suppliers' perspective, independently of the costumers they are dealing with.

. Hiring new people:

When organizations predict substantial increase of demand or they want to expand their products/services to new markets or to diversify their portfolio of products or services, they tend to hire new workers. Contracts with big science can be the cause for one (or all) of the referred scenarios. One invites to check results for the present question:

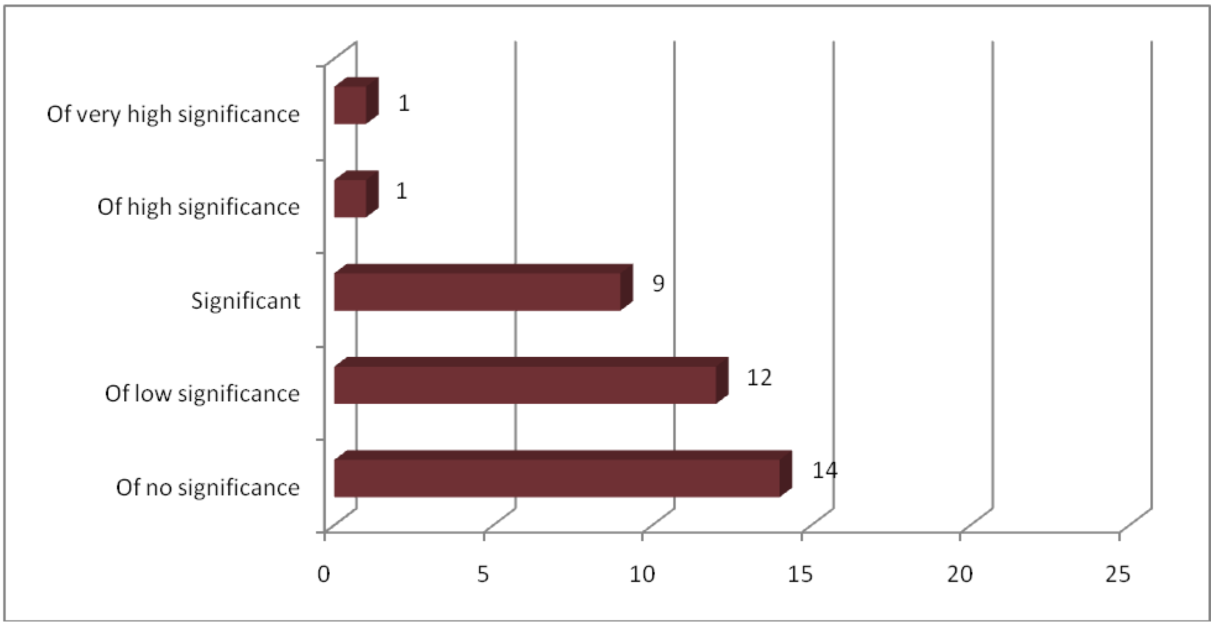


Figure 43: Frequencies of answers for the question regarding the recruitment of new people

Results are clear about the low impact of ESO contracts in suppliers' recruitment activities. The average scoring for this question is 2, with a standard deviation of 1. This measure reflects the fact that only 29.7 % of respondents (11 out of 37 respondents) recruited new workers in consequence of ESO's contract. The standard error of the mean is 0.164.

One is reaching to a pattern in questions related with efforts caused by ESO contracts: the majority of R&D institutions recognize this type of impact. In this case, 70% of R&D centres (7 out of 10 respondents) hired new workers against only 4 companies which made new labour contracts. One firm had a budget higher than 1 million Euros and other had a budget between 100 thousand and 1 million Euros. The other two had contracts valuing less than 100 thousand Euros. Additionally, one finds that, in 2009, 3 firms employed less than 40 workers each and that other firm had less than 150 workers. A possibility to be verified is that the elasticity recruitment of a firm behaves inversely to the number of workers in the organization. As an example, taking survey data as a reference, one divided respondents by 4 categories taking into consideration the declared number workers: less than 10 workers, between 11 and 50 workers, between 51 workers and 250 workers, more than 251 workers. A parametric ANOVA – Analysis of variance and, a non parametric, independent-samples Kruskal Wallis test were performed for this type of effort against these 4 categories. Both tests did not detect statistical significant scoring differences between categories.

. Implementation of new procedures:

Requisites, norms, rules or standards inherent to scientific projects like the VLT can be a force that leads suppliers to change their organizational procedures. This impact was included in the survey. Answers are resumed bellow:

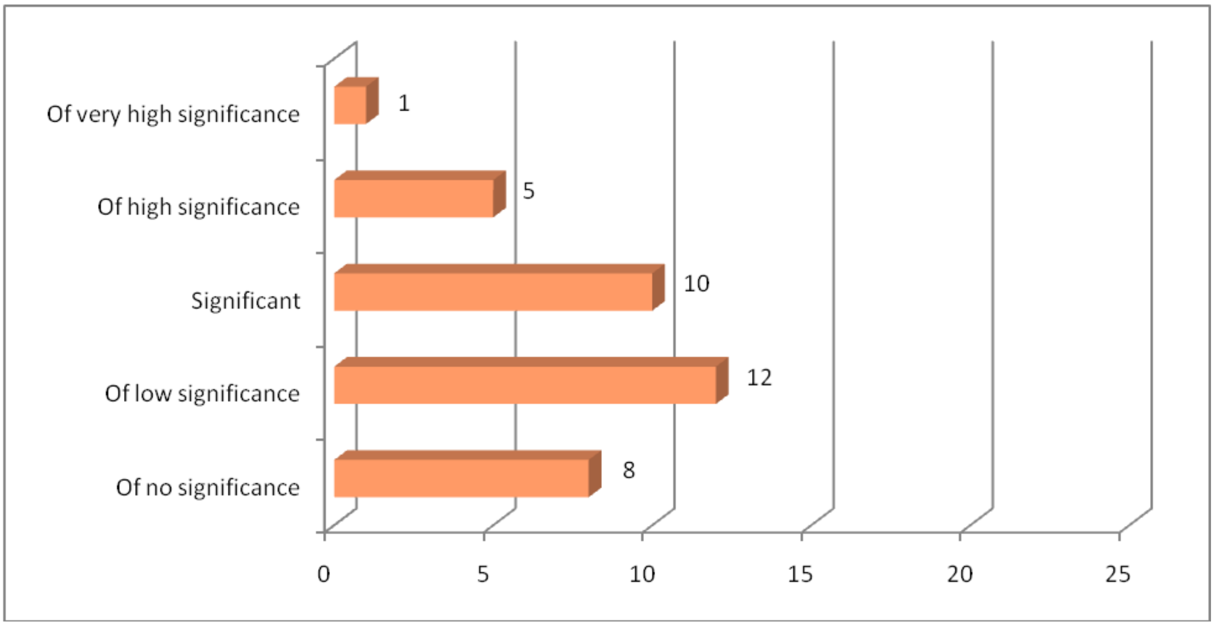


Figure 44: Frequencies of answers for the question regarding the implementation of new procedures

The average score given by organizations to this impact is 2.417 with a standard deviation of 1.079. 16 out 36 respondents felt moderate to very strong impact in terms of new procedures adoption. It means that 44.(4) % of respondents recognized this impact. The standard error of the mean is 0.18.

One finds that 8 out of 10 respondent R&D institutions made this effort as a response to ESO's commitment, representing half of organizations which gave a favourable answer in the present question. With regard to companies, one knows that 4 are SME, making 40% of classified SME whereas one is a big company, making 25% of classified big firms. Two companies work in mechanical engineering, representing half of organizations dedicated to this business.

One may test whether there is a relation between the implementation of new procedures and the improvement of quality systems. One verifies that 11 out of 16 organizations that implemented new procedures got their quality systems improved whereas 5 organizations declared improvement of their quality despite not having made efforts in terms of procedures. Two organizations that recognized quality assurance progresses did not answer to the present question. Correlation analysis found a strong, high significant linear association between this effort and the improvement of quality systems by respondents ($r=0.605$, $p < 0.001$). One may check results of correlation analysis in question 8 of annex 4.

. Bibliographical research:

Bibliographical research is possibly done if one is dealing with challenges in unknown areas or one wants to know the state of art of certain technology. Bibliographical research is usually connected with R&D tasks. By the results shown bellow, this effort is not considered relevant for the majority of the 35 respondents:

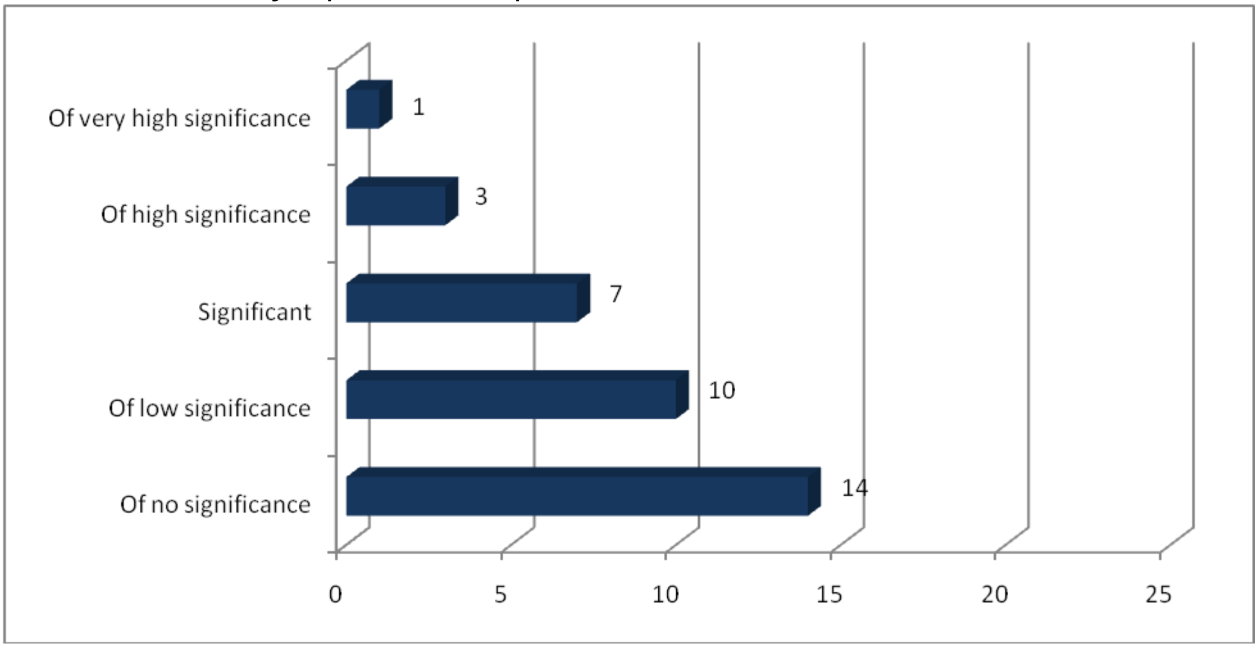


Figure 45: Frequencies of answers for the question regarding bibliographical research

The average scoring of the present question is 2.057 with a standard deviation of 1.11. The standard error is 0.188.

The majority of favourable respondents come from the R&D side: 7 out of 10 R&D organizations made considerable efforts in bibliographical research. Only 4 companies declared this effort. With regard to R&D institutions, one assumes that the declared bibliographical research is not part of R&D institutions' regular bibliographical research activity. That is, it is linked to the existence of contracts with ESO. In parallel, one presumes that companies would not interpret bibliographical research as a regular step in the production process. Hence, they would value it as an extra effort or investment.

. Market research:

Results show that organizations did not have to make relevant efforts in terms of market research in order to comply with ESO's contracts. One may analyse the findings in next figure:

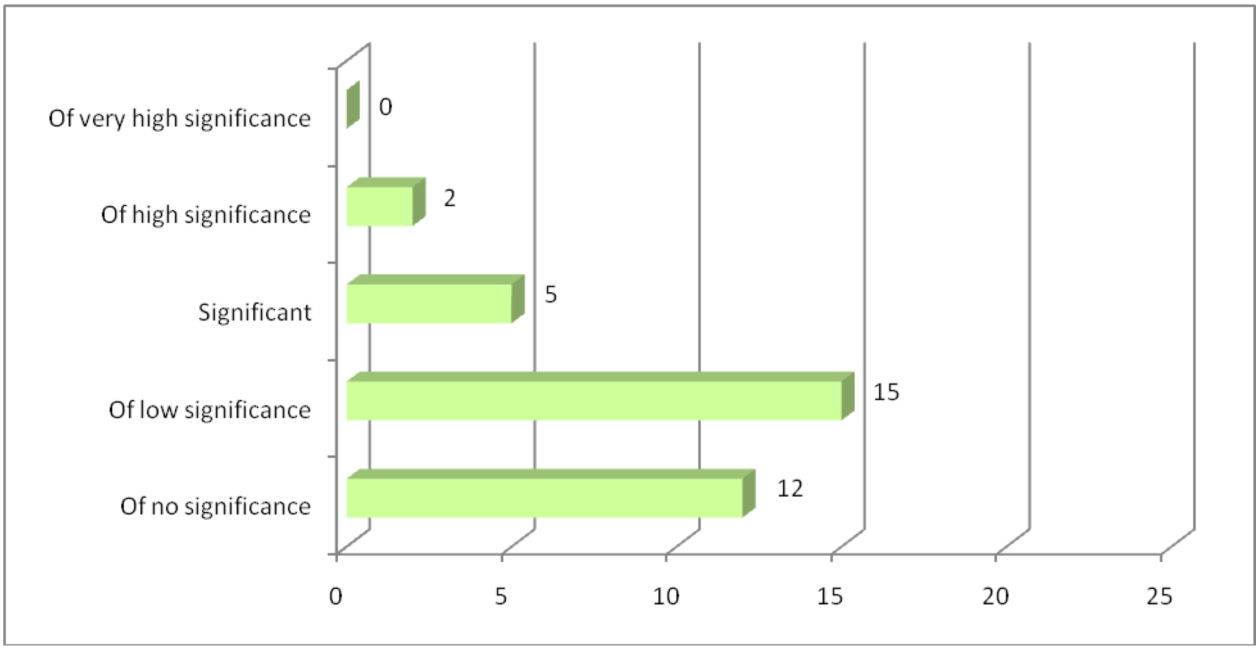


Figure 46: Frequencies of answers for the question regarding market research

Only 7 out of 34 respondents claimed having developed market research in the framework of VLT project. This corresponds to 20.5% of respondents. The average score for this question is 1.912, with a standard deviation of 0.866. The standard error of the mean is 0.148.

Four R&D institutions declared market research efforts. 3 companies declared this effort too. This isolated industrial group is composed by one big company with a budget around 4.6 million Euros, a micro enterprise with a budget around 250 thousand Euros and a big company with a budget less than 100 thousand Euros.

Regarding possible outcomes derived from this effort, one underlines that 5 out of the 7 organizations which researched the market declared that market learning is being a relevant output of their collaboration with ESO. One organization did not answer to the question about market learning. Still analysing the group of 7 respondents, one finds that 4 of them registered an increase of new costumers in consequence of VLT contract whereas 5 of them registered an increase of similar costumers. Correlation analysis found strong, significant positive linear associations between this effort and marketing benefits, namely, by descend order of statistical importance, access to industry networks ($r=0.501$, $p=0.003$), market learning ($r=0.490$, $p=0.004$) and increase of similar clients ($r=0.445$, $p=0.009$). One may check results of correlation analysis in question 8 of annex 4.

. R&D:

This effort is the most recognized by respondents, indicating the scientific and technical challenges that ESO's projects involve. Results are shown below:

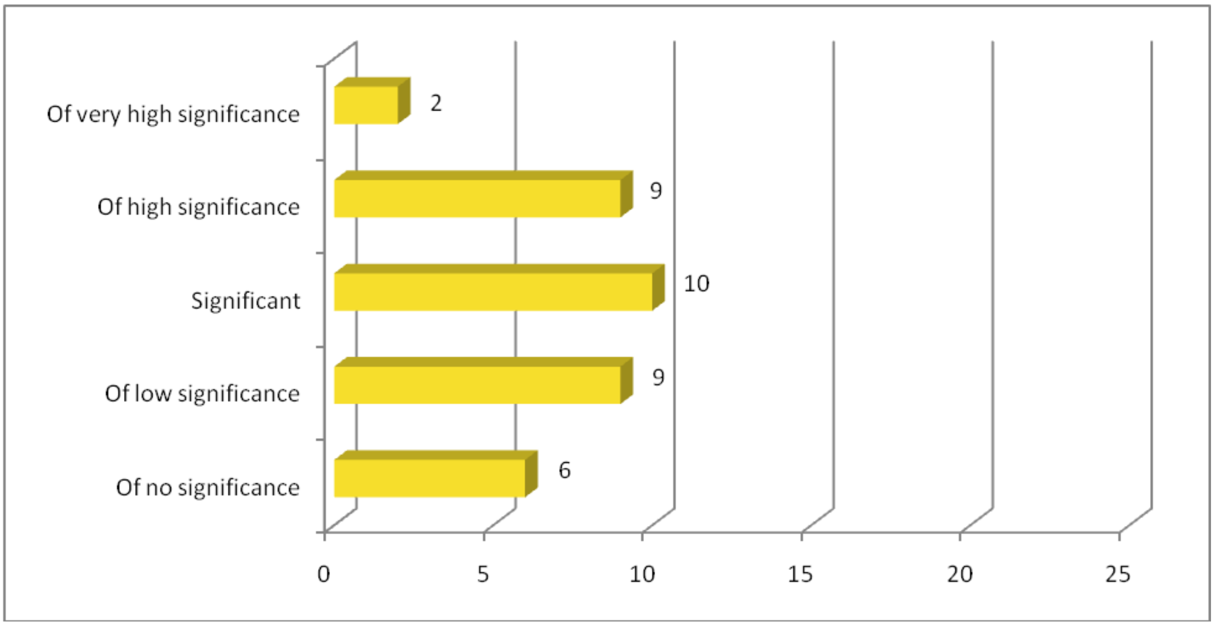


Figure 47: Frequencies of answers for the question regarding R&D efforts

58.(3)% of respondents (21 out of 36 respondents) declared R&D as a relevant effort within VLT project. This evidence is translated in an average scoring of 2.778 with a standard deviation of 1.174. The standard error is 0.196.

Breaking down respondents by type of organization, one concludes that 90% of R&D institutions (9 out 10 respondents) made R&D during the VLT project. One highlights that 70% of respondents gave high to very high importance to this effort. Companies, by their turn, were more divided in their answers: 46.1% of respondent companies (12 out of 26) declared this effort, of which 4 gave it high importance. Looking for companies' size, one finds that 3 out of 4 big companies made R&D. The same was declared by 5 out of 10 respondent SME. Note that 11 out of 17 R&D intensive firms valued this impact which indicates a reasonable connection between R&D intensity and the tasks performed during the VLT project. As seen in question 4 of annex 4, statistical tests confirm R&D intensity as a factor of higher scores in R&D effort ($p=0.01$).

Pointing out to contracts budget as a proxy of project complexity, one finds that 3 out of 5 organizations with budget higher than 1 million Euros identified the present effort. On the other hand, 4 out of 8 respondent organizations with budget between 100 thousand Euros and 1 million Euros made R&D efforts during the VLT. Specializations where R&D efforts were more generalized were optics (5 in 5 possible respondents), astronomy (5 in 6 possible respondents), instrumentation (4 in 6 possible respondents) and opto-elecronics (3 in 5 possible respondents). Note that neither budget nor specialization were considered statistically important for R&D efforts scorings. These findings may be consulted in question 2 and question 3 of annex 4.

One believes that it is useful to know that 19 out of 21 organizations that made R&D efforts recognized the increase of knowledge as a significant benefit of their collaboration with ESO. Two organizations that identified this benefit did not consider R&D efforts relevant. Other 2, did not answer to the present question. Correlation analysis found a strong, high significant positive linear association between R&D efforts and increase of knowledge by respondents ($r=0.766$, $p < 0.001$). One may check results of correlation analysis in question 8 of annex 4.

Looking into more material outcomes in the group of organizations which responded favourably to this question, one finds that 15 developed new products or services. One did not answer to the question in mind. Inversely, only one organization that developed new products or services did not value R&D efforts. Three organizations did not answer to the present question. Again, correlation analysis found a strong, high significant positive linear association between R&D efforts and development of new products and services ($r=0.694$, $p < 0.001$).

At last, one infers that the majority of organizations which made R&D faced it as a learning opportunity (maybe with other partners) since 17 out of the 21 targeted organizations declared having learnt in terms of R&D. Only two organizations which gave importance to this benefit declared low significant R&D efforts. Other two did not answer to the present question. The correlation coefficient between R&D efforts and R&D learning is 0.82 ($p<0.001$).

As a final remark regarding efforts made by suppliers, one lets the testimony of a company which declared that, besides the named efforts, their collaboration with ESO brought them experience in processing exotic materials.

#### 4.3.4.2.3 Results

One wraps up the evaluation of impacts with a series of "holistic" questions about the influence of the collaboration with ESO in the organization's wealth. Here, participants are invited to imagine organizations' results in case there was no collaboration with ESO.

Inquiring organizations in the negative form is a way of controlling responses. One disadvantage is that increases the risk of respondents misunderstand the question. One believes that it was what happened with two R&D organizations. During the validation of answers one noticed that answers to the present question were not coherent with the valuations given in questions about benefits and efforts. While they always gave moderate to high significance to benefits and efforts coming from their collaboration with ESO, here they stated that they would be better without the partnership with ESO. In these two cases, one took the freedom to homogenise present question's answers with the tone registered in their statements about benefits and efforts.

One finds hereby the summary of results for this group of questions:

. Growth in revenue:

Figure 48 reports respondents' assessments of what their sales would have been, had collaboration with ESO project not taken place:

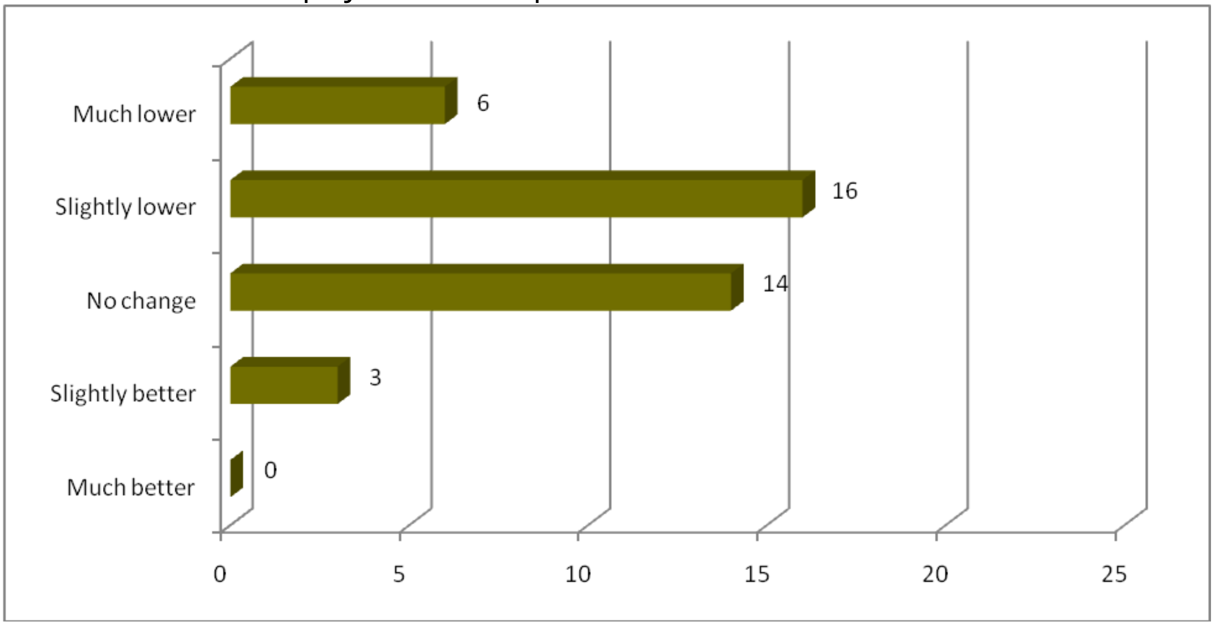


Figure 48: Frequencies of answers for the question regarding revenue growth

The majority (56.4%) of respondents (22 out of 39 respondents) indicated that, without VLT project their sales would have been slightly or much lower. On the other hand, only 7.7% of respondents (3 out of 39 respondents) indicated that the VLT project carried a significant sales opportunity cost, meaning that for this 7.7% of respondents, the project tied up so much of the organizations' resources that this stopped their ability to do business elsewhere.

Overall, one concludes that the impact of VLT project on organizations' sales is positive: the average score of this result is 3.64. Remember that the score 3 means that the organization would remain the same independently of collaborating with ESO, that is, it is the reference to whom wants to declare that VLT project is neutral. Scores lower than 3 translate negative impacts derived from ESO's project while scores higher than 3 imply positive impacts. The standard deviation is 0.843 and the standard error of the mean is fixed at 0.135.

One underlines that 70% of R&D institutions (7 out of 10 respondents) recognize a positive impact of ESO, joined by 51.7% of companies (15 out of 29 respondents). Other evidence worth of note is that 4 out of 5 respondents with budget higher than 1 million Euros as well as 6 out of 9 respondents with budget between 100 thousand Euros and 1 million Euros identify a positive impact of VLT project in terms of revenue. This is a natural conclusion taking into consideration the amount of revenues their contracts generated.

Considering the specializations of organizations, one concludes that in Optics (4 in 5 respondents) Astronomy (4 in 6 respondents), Instrumentation (4 in 6 respondents) and Opto-electronics (3 in 5 respondents) the perception that ESO brought positive impacts in terms of revenue is almost unanimous. One also finds that specializations whose revenues are more dependent on ESO contracts are Astronomy and Instrumentation with 2 organizations each stating that their revenue would have been much lower if they did not work with ESO.

. Growth in the number of collaborators:

About the increase in the number of workers, the majority of the 39 respondents, 56.4%, recognized no impact coming from VLT project. A second group of respondents, constituted by 16 organizations, identified a positive impact originated by ESO's project. These facts are reflected in the average scoring of this question, fixed in 3.436. The standard deviation is 0.641 and the standard error is 0.103. Results are summarized below:

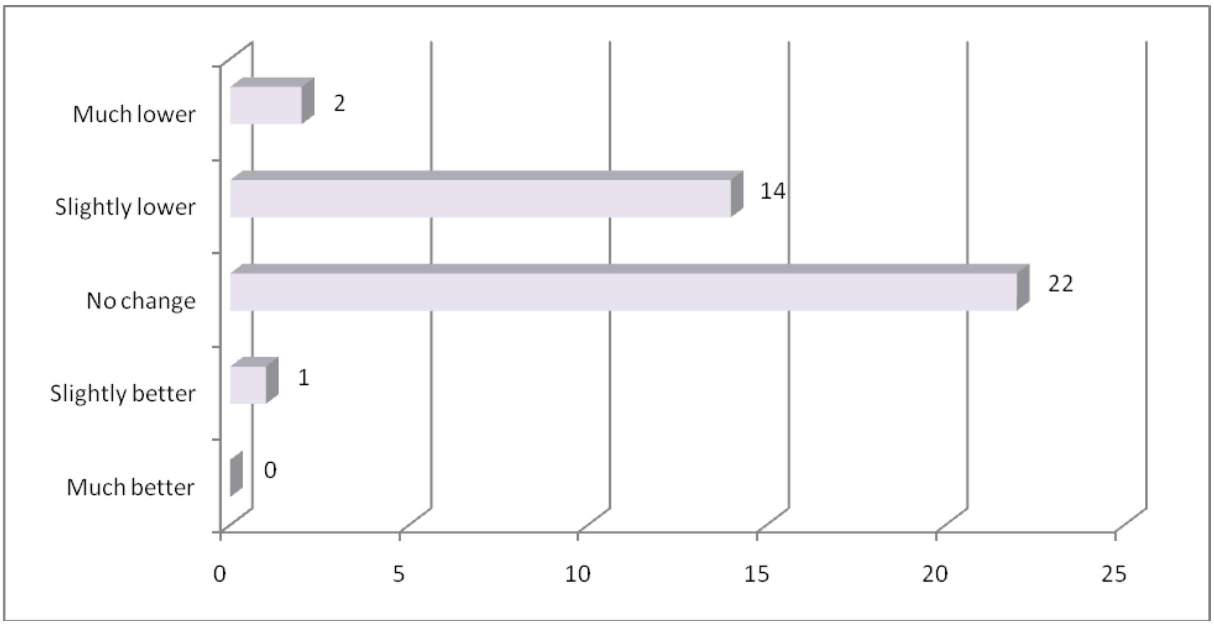


Figure 49: Frequencies of answers for the question regarding number of collaborators variation

Looking deeper to the group of 16 organizations which identified positive impacts coming from ESO, one finds that it is constituted by 8 R&D institutions (80% of R&D institutions) and 8 companies. With respect to these 8 companies, 3 have budgets higher than 1 million Euros, one has a budget between 100 thousand Euros and 1 million Euros and the last four have budgets lower than 1 million Euros. Remembering the 11 organizations which hired workers for the VLT project, 9 would see a decrease in the number of workers if they did not collaborate with ESO. Of this group one organization did not answer to the present question. Correlation analysis found a significant positive linear association between hiring efforts and the result one is analyzing ($r=0.556$, $p < 0.001$).

The discrepancy between the number of organizations that hired new people (11) and the number of organizations which recognized influence of ESO in their human resources trends (16) may be a sign that human resources trends depend less of the realization of a specific project and more of medium and long term relations with costumers (in this case, a big science costumer).

. Technological / R&D excellence:

A supporter of big science, namely Astronomy projects, would certainly use the results of this question as an argument for investing in this type of infra structures. The motive is that 64.8% of respondents (24 out of 37 respondents) said that their R&D excellence would be lower, had collaboration with ESO project not taken place. Next, one may observe the summary of results:

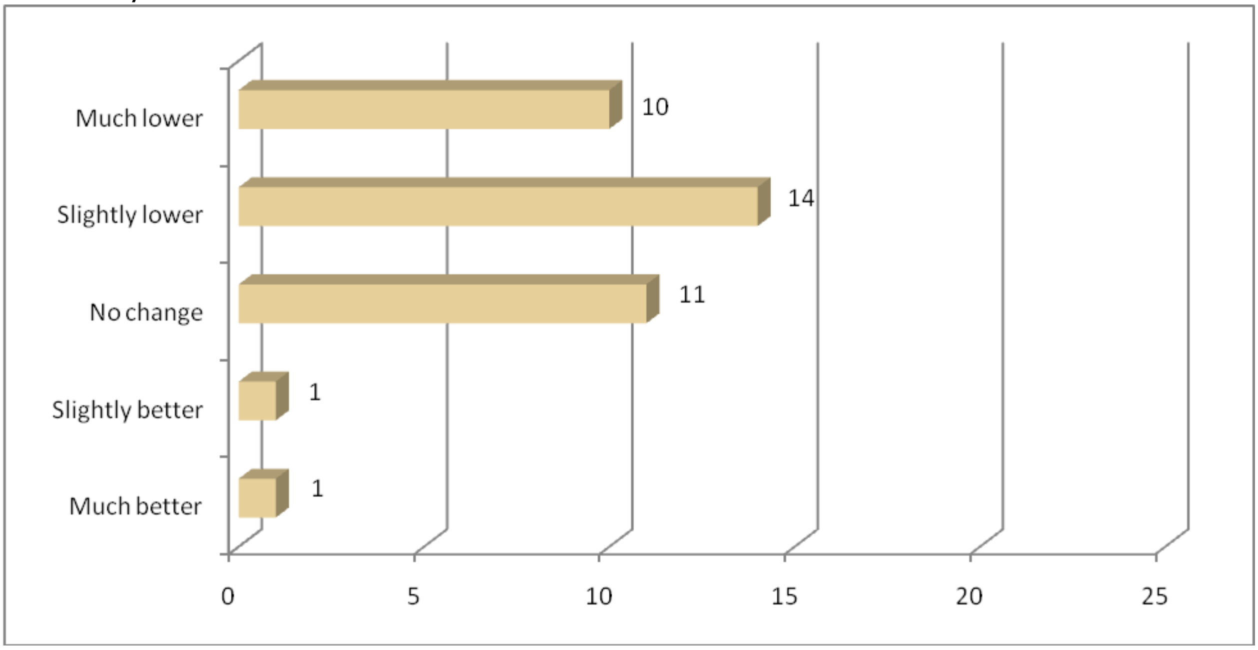


Figure 50: Frequencies of answers for the question regarding R&D / technological excellence

So, one calculates an average scoring of 3.838 with a standard deviation of 0.958. The standard error is 0.157. One underlines that 10 respondents said that they their R&D excellence would be much lower if they did not worked with ESO. Four respondents are companies and 6 are R&D organizations.

One depicts the 24 respondents which identified a positive impact in 8 R&D organizations (80% of total R&D organizations) and 16 companies (59.2% of respondent companies). Looking to the size of companies, one notes that half of classified SME and big firms, respectively 5 out of 10 respondent SME and 2 out of 4 big companies, are better with ESO, in terms of R&D excellence. This impact is particularly important in companies that rely their competitiveness in R&D: 10 out of 17 respondent R&D intensive firms recognize this impact.

As seen in the question concerning R&D efforts, project complexity may call for R&D. Using budget size as a proxy for project complexity one confirms that 3 out of 4 respondent companies with budgets higher than 1 million Euros as well as 4 out of 6 respondents with budgets between 100 thousand and 1 million Euros agree that ESO has a positive impact in their R&D performance. Note that budget size was not considered statistically important for R&D excellence scorings. These findings may be consulted in question 2 and question 3 of annex 4.

One also calls attention to alternative, more direct, ways of trying to know whether a project is complex and R&D intensive. For instance, in 2003 study about technological learning through CERN's procurement activity, its authors measured project's technological intensity with various questions probing the nature of the project: whether it was considered a fairly standard delivery, whether there were significant development tasks associated with the project, and whether the respondent thought that the project represented the world state-of-the-art in its area (Autio et al, 2003).

. Innovation / Competitiveness (Product, Process, Organization, Marketing):

Answers regarding this possible result are in line with precedent questions. One may verify the findings below:

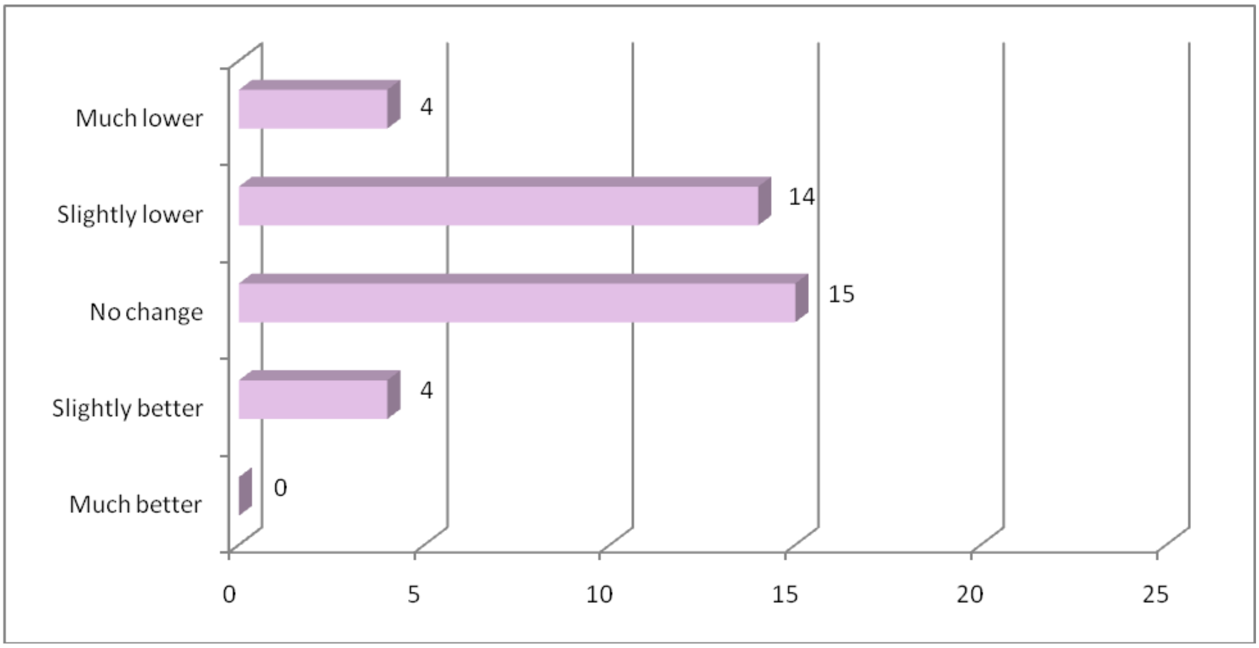


Figure 51: Frequencies of answers for the question regarding innovation / competitiveness

18 out of 37 respondents think that they are better in terms of innovation after collaborating in Astronomy projects. This figure represents 48.6% of respondents. Calculations show that the average scoring of this result is 3.486 with a standard deviation of 0.837. The standard error is 0.138.

Since this question is mostly directed to companies, entities whose mission is exploit commercially new knowledge, one will concentrate the analysis in this group of respondents. Eleven companies out of 27 respondent companies consider that their relation with ESO has positive impact in terms of competitiveness. This represents 40.7% of the group. The typical profile of this group is a high tech SME whose budget in the VLT is lower than 100 thousand Euros.

. Net value of your Organization:

Results for this last question confirm the positive perception organizations have with regard to their collaboration with ESO. Statistics are summarized below:

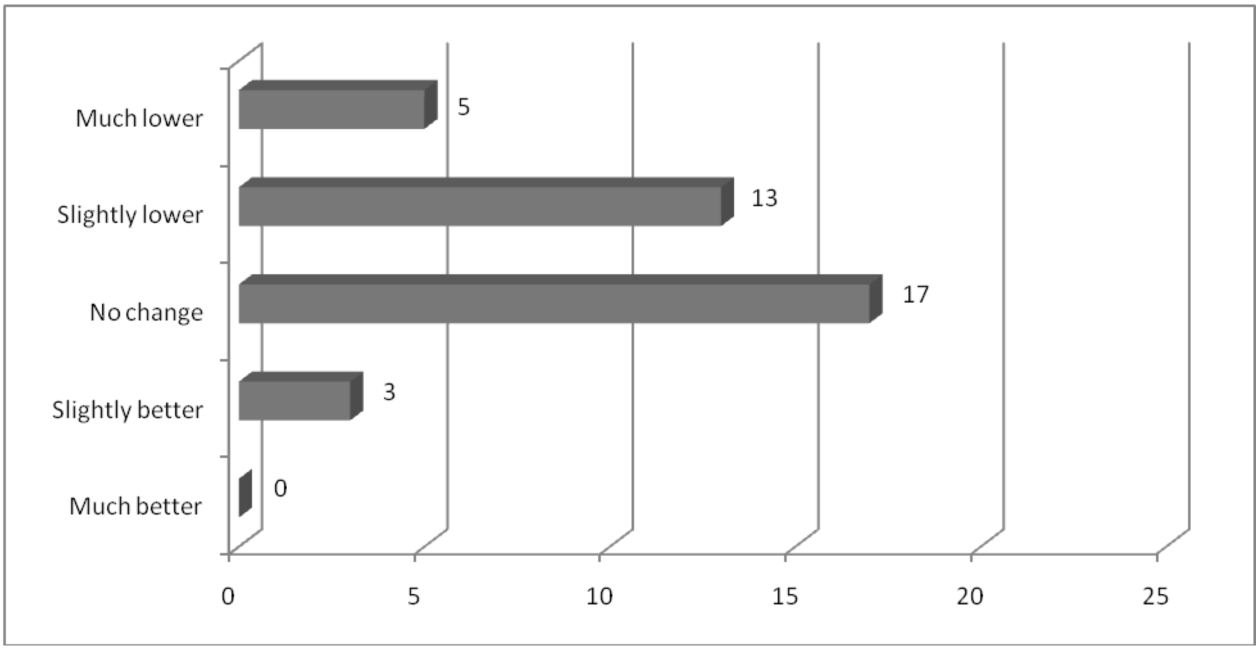


Figure 52: Frequencies of answers for the question regarding net value of ESO's suppliers

The average scoring for this result is 3.526 with a standard deviation of 0.830. This means that results are closer to the positive side of impacts. The standard error of the mean is 0.135. Resuming, one underlines that 18 out of 38 respondents consider that the net value of their organization would be lower if they did not cooperate with ESO. The ultimate objective of an organization, chiefly for companies, is to increase their net value. So this result deserves to be kept in mind. Focusing in companies, one finds that 11 out of 28 respondents (39.3%) are seeing their net value improving due to their collaboration with ESO. The typical profile of the group of companies that find value in their collaboration with ESO is a high tech SME whose budget in the VLT is higher than 100 thousand Euros.

One interesting analysis is to check trade-offs of organizations' partnerships with ESO. Because VLT project ties up the suppliers' resources, which otherwise could have been allocated to alternative uses, an opportunity cost may be associated with it. By the figure, the opportunity cost is not alarming, since only 7.89 % of organizations (3 out of 38 respondents) indicated that an alternative use of their resources would have resulted in greater net value.

### 4.3.4.2.4 Key findings

The objective of this sub chapter is to summarize the findings of the survey. One starts for taking some conclusions based on the organizational information given by respondents.

First of all, the majority of respondents are intensive in R&D which can give a clue that one is dealing with high tech activities. Remember that one presumes that R&D intensity is function of the number of workers dedicated to R&D and of the weight of R&D expenses in organizations' revenue.

Thinking in Astronomy as spin off generator, taking only into account data from the survey, one might be lead to the conclusion that this Science has a small impact in terms of company creation. Similarly, survey shows that organizations do not recognize advantages in hiring people coming from Astronomy since the big portion of respondents reported that they do not have workers with that background. Remember that the referred conclusions are related with the second and third hypothesis set in sub chapter 3.1, which state that there might be technologies, company spin offs and person embodied benefits coming from Astronomy. Publicly available examples of technology spin offs from Astronomy, shared in annex 1, also give clues about the second proposition. Also, in sub chapter 2.2.4.2 one may find citations of secondary information coming from studies which contribute for the discussion of the third hypothesis.

Other relevant finding is that, taking into account the revenue associated to Astronomy and the number of active contracts in 2009, the survey puts in evidence that approximately half of the companies had a business connection with Astronomy projects in 2009.

Advancing to the analysis of the perception respondents have with regard to the impact of Astronomy projects in their organization, one reports below the quantitative evidence of the four groups of benefits - performance outcomes, marketing benefits, technological benefits and organizational benefits – resulting from ESO's contracts:

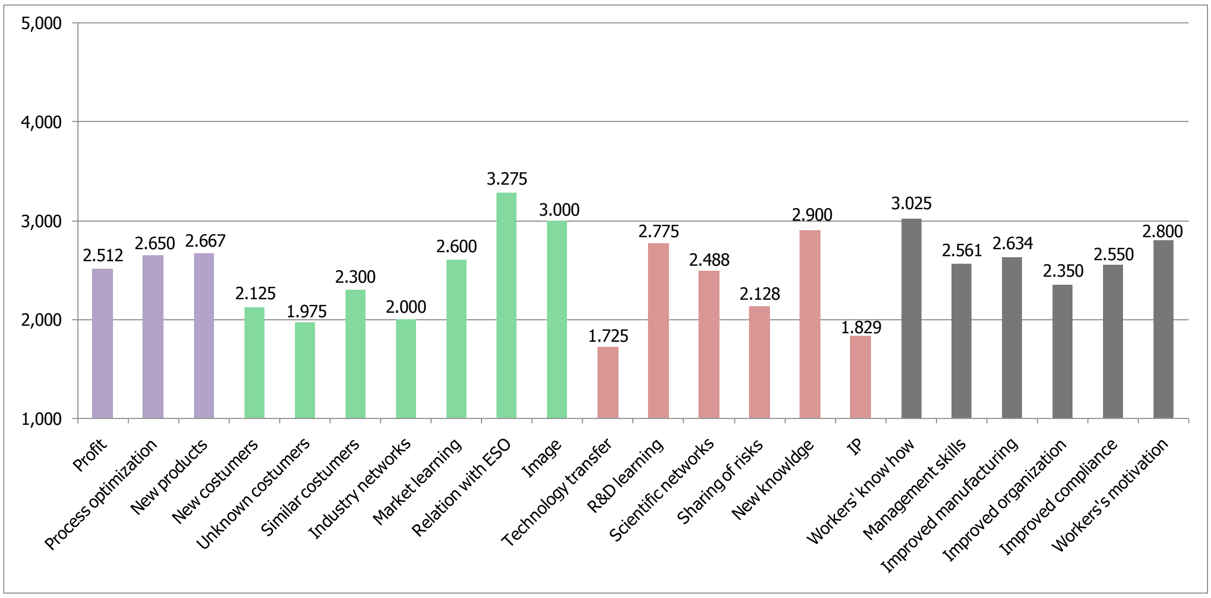


Figure 53: Average scoring of benefits

Organizational benefits are the ones with highest impact, with an average fixed at 2.653. This might indicate that Astronomy projects have structural effects in organizations. Structural effects are typically associated to sophisticated, lead-user customers, like big science. This evidence is in certain way confirmed by the factor analysis done as an answer to question 9 of annex 4 since the highest loading benefits in the first extracted factor are associated with organizational benefits.

Analysing benefits individually, one observes that the highest benefits are the establishment of a long term relation with ESO, improvement of workers know how, image benefits and the generation of new knowledge.

The presence of two marketing benefits in the group of highest scores suggests that organizations are able to take advantage of collaborations with ESO as a proof of their technological capabilities. This image impact is even clearer when one refers to future contracts with ESO (as shown in the score of the benefit "establishment of a long term relation with ESO"). Thus, marketing benefits are invariably connected to technological benefits perceived by the market.

Comparing present findings with those of the studies about CERN impacts, one highlights that, equally, highest impacts are split between technical and commercial areas. In the study about "R&D collaborations between CERN and industrial companies" it is observed that the highest benefits are R&D benefits, improved motivation, marketing and increase of other customers (Hähnle, 1997). While in the survey made for the study "Contract benefits and competence-based supplier strategies - CERN as a case example" it is observed that the highest benefits are marketing, improved motivation, improved quality, R&D benefits and improved technical skills (Nordberg, 1994).

Regarding benefits, one last word for the results that sign low to moderate impact of Astronomy benefits in areas of business / activities outside the ones related with Astronomy: 46% of respondents stated that benefits outside Astronomy are at least significant. Is this a pointer that business units inside an organization are hermetic or that astronomy benefits are business unit specific?

Now, going ahead with the conclusions about efforts taken by organization in order to comply with ESO's projects, one views by the figure below that the most relevant effort is R&D:

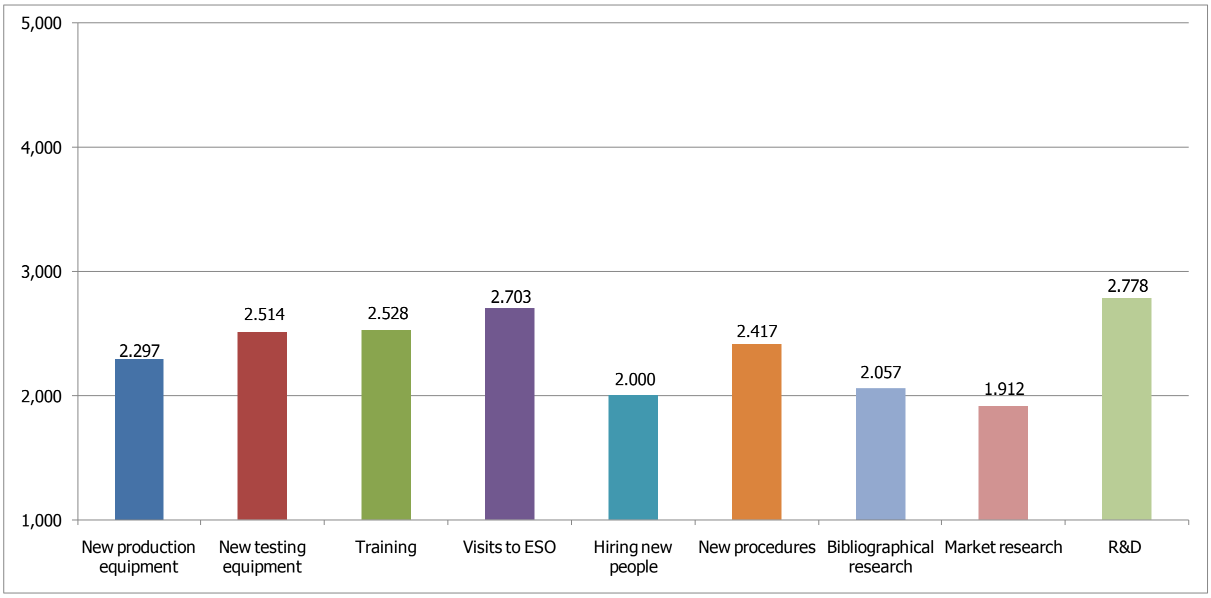


Figure 54: Average scoring of efforts

One verifies a high correlation between R&d efforts and the perceived improvement of workers know-how ($r=0.787$, $p<0.01$) and the perceived generation of new knowledge ($r=0.766$, $p<0.001$). One of the factors of this relationship might be learning opportunities generated by R&D executed in the framework of Astronomy projects.

A valuable exercise could be to understand the drivers for learning. Precedent studies explored these factors reaching the conclusion that learning outcomes may be influenced by governance aspects of the contractual relation, for example, by the frequency and extent with which Big Science organizations and their suppliers interact, by how much trust and social capital can be built into the relationship, and by what kinds of resources each side brings into the relationship (Autio et al, 2003).

With regard to results, the next figure resumes the stats:

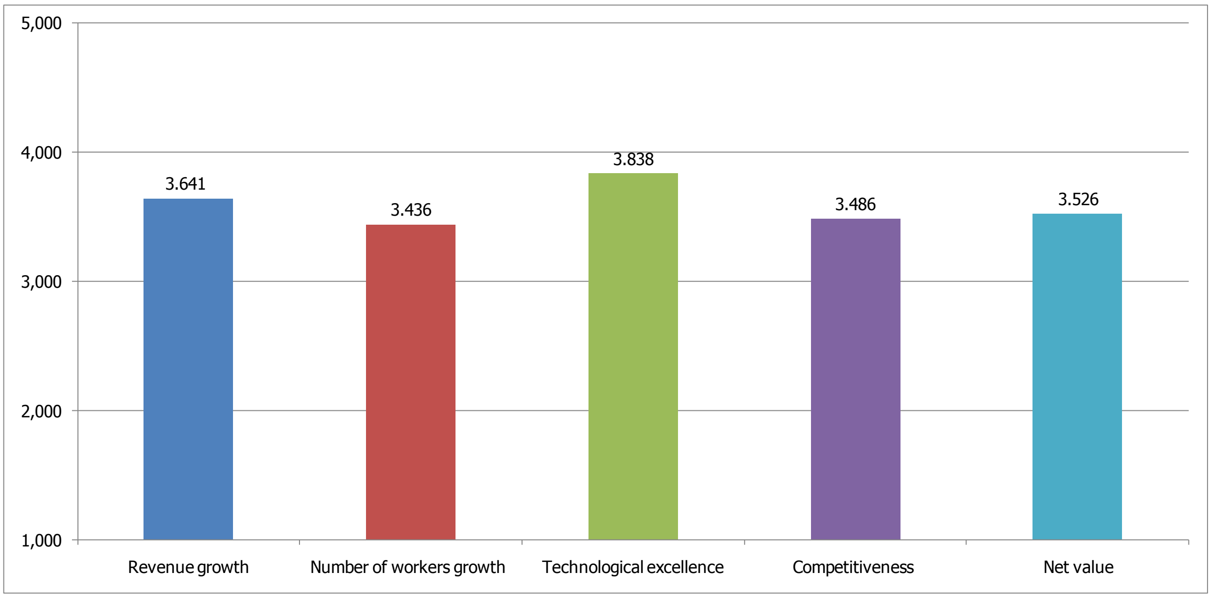


Figure 55: Average scoring of results

One notices that collaboration in Astronomy projects originated moderate positive impacts in all analysed variables. Findings about results of collaboration in Astronomy projects point to the same direction of benefits and efforts, thereby suggesting good validity of the measures used. A way of checking consistency between benefits, efforts and results is to consult correlation tables in question 8 of annex 4.

One highlights technology excellence as the main impact perceived by respondents. Faraway of underestimating the relevance of this conclusion, one should note that results regarding technological excellence have a self-evaluation side, which may increase the probability of overestimations of this outcome by respondents.

At this point, one takes the opportunity to refer some pitfalls that could endanger the robustness of this survey.

First of all, although one believes that the requisites for a valid survey were met, as seen in sub chapter 4.3.3, one thinks that both the number of respondents and the surveyed population are small if compared with similar studies. For instance, the supplier company survey made by Autio et al in their study on the technology transfer and technological learning through CERN's procurement activity had responses of 154 companies (out of 629 companies).

Secondly, together with the already mentioned risk of respondents misunderstand some survey's questions there is a chance that respondents, due to their condition of ESO's suppliers, overestimate ESO's impacts to favour future business with this costumer. One believes that this risk was minimized by the introduction of a confidentially clause in the survey and by the clarification in the communication with suppliers that this study is independent of ESO. Other possible factor of biased results was the scale chosen for answers: questions include 3 chances for "significant" answers against 2 chances for "no significant" scores. This may lead to biases towards positive scorings.

In addition, one thinks that could be valuable to introduce a question about the influence of the collaboration with ESO in the internationalization of organizations. That introduction would allow testing the assumption that big science projects foster links outside the country of origin of suppliers.

Other improvement that might be introduced would be transforming the first performance outcome in two benefits. Financial income is different of profit. While financial income is related with revenues, profits take also into account the cost of generating these revenues. So they measure different effects. Separating them in two questions would allow to measure whether astronomy projects generate relevant revenues to organizations as well as to know whether the participation in astronomy projects is profitable.

In the end, the survey shows that organizations perceive modest economic impacts coming from their collaboration in the VLT project. Notwithstanding, one believes that the survey findings do not exclude the first hypothesis of this work, that is Astronomy has a positive impact in the Economy through its procurement activity, namely by the means of the secondary economic effects of Astronomy projects.

The fifty-fifty findings of the survey are in line with results of the other known case study focused in astronomy: "Spin off from basic science – the case of radioastronomy" by Ben Martin and John Irvine. From the interviews authors made to companies they found punctual economic benefits coming from supplies to radioastronomy (Martin et al, 1981).

Although one expected more incisive results regarding the impact of VLT project, one should not forget the importance of this kind of projects as drivers of market demand to high tech organizations. Astronomy projects grant stable and relevant demand to high tech organizations (demand pull). As a consequence, astronomy suppliers generate cash flows, benefiting of opportunities for consolidating their technological competencies. Survey shows that suppliers' sales increased due to their collaboration within VLT project at the same time that suppliers recognized the establishment of a long term relation with ESO. Note that in 2009 approximately half of the companies were engaged in astronomy projects.

Astronomy, optics, opto-electronics and instrumentation were industries that perceived a strong impact. It is a pity that one was not able to receive the feedback from suppliers coming from opto-mechanics. One suspects that organizations belonging to this industry would also recognize positive impacts derived from Astronomy. In compensation, one of the cases elected as examples of astronomy spin offs (annex 1) concerns an opto-mechanics company.

It is also evident that the majority of R&D organizations systematically declared impacts coming from VLT project. This means that if the analysis was made focusing only in the company side, declared overall impacts would be lower.

With respect to the group of companies, it is worth to add that two companies, one from opto-electronics industry and other specialized in textile instruments, whose answers systematically show low or no impact coming from ESO project, declared that they only developed one contract for ESO.

Still, about qualitative data, one includes the contribution of a Chilean company specialized in mechanical engineering that declared low impact coming from Astronomy projects: *"He respondido a vuestro cuestionario en línea, normalmente los productos que vendemos a ESO son Off the shelf así que no representan una gran fuente de innovación de nuestra actual cartera de productos y el impacto financiero es muy limitado por cuanto su uso en vuestra organización es muy limitado."* One verifies that this company supplies standardized products to ESO, meaning lower chance of impacts in terms of innovation.

Other electronics company justified the absence of answers about efforts and results as follows: *"It is right that components of our company are used in the VLT but I have problems answering your questions. Normal automation drive and energy components which are used also in the industry are used in the VLT. We have no special astronomy area which* *especially develops components for ESO. Therefore unfortunately, I cannot answer all of your questions."* Just for the record, in questions about benefits, this company declared significant impacts coming from ESO.

One also discloses the statement of a company specialized in instrumentation which declared difficulty in distinguishing between astronomy and space costumers: *"I have some difficulty in the interpretation of Astronomy projects: we as a space company, provide solar arrays, launcher-contributions, control systems also for astronomy satellites, but we normally have nothing to do with the astronomy itself."* In general, this company declared positive impacts coming from Astronomy.

Two organizations, although not responding to the survey, gave qualitative contributions which reinforce the idea of significant impacts coming from ESO projects.

The first organization, a R&D institution specialized in Astronomy declared the following: *"We are a pure research institute, and our relation with ESO is purely scientific, without any commercial interest and cash-transfer. Even though we work together with ESO on major instrument developments, these collaborations are executed as scientific collaborations, not on a contractual / business basis. ESO is certainly the most important and most valuable partner for the ground based astronomy of our infrared & submillimeter division. Over the last 15 years we have been leading as PI or Co-PI institute the development of several instruments for ESO telescopes, including the SINFONI spectrometer, the PARSEC laser for the LGSF, the CONICA AO camera, and we are currently leading the development / studies of the 2nd generation VLTI GRAVITY instrument and the E-ELT MICADO instrument. The typical development cost of each instrument is up to several million Euros, but as said before, these instruments are developed in a collaborative effort with ESO, not on a business basis. A major fraction of the publications and citations of our infrared and submm Group is based on these instruments, as well as our worldwide recognized lead in the associated astronomical research."*

With regard to the second organization, a company specialized in instrumentation, one quotes the following: *"I can state that we greatly value our relationship with ESO. ESO is a highly valued customer and we consider our relationship with ESO to be a partnership for furthering astronomical science. As you know, ESO is the largest ground-based astronomy organization in the world and thus we greatly appreciate every opportunity to provide high performance imaging sensors to ESO. ESO also provides valuable feedback to us on the quality of our imaging sensors, since ESO's scientists and engineers can put more time into testing individual imaging sensors and exercising the sensors to the limit of their performance. ESO staff has made breakthroughs in the understanding of high performance imaging sensors, and feedback from ESO has enabled our company to develop improved sensor technology."*

## 5. CONCLUSION

Wrapping up this study, one may affirm that there is reasonable evidence that Astronomy generates economic benefits. Resuming the hypotheses that were stated in this work:

(1) Astronomy projects have a positive impact in the Economy through its procurement activity, namely by the means of the so called secondary economic effects.

The empirical evidence was produced through a survey made to organizations which supplied ESO in the framework of the VLT project. With regard to the findings of the survey, one highlights that suppliers declared that their participation in VLT project originated the improvement of workers know how, image benefits and the generation of new knowledge. Respondents also give importance to the R&D efforts that they made in order to answer to ESO's demands. Organizations informed that as a result of their partnership with ESO they improved their R&D and technological excellence.

Although one expected more incisive results regarding the impact of VLT project, one should not forget the importance of astronomy projects as generators of relevant demand to high tech organizations (demand pull). As a consequence, astronomy suppliers see an incoming of stable cash flows, benefiting of opportunities for consolidating their technological competencies. The survey shows that suppliers' sales increased due to their collaboration within VLT project at the same time that suppliers recognized the establishment of a long term relation with ESO. Note that in 2009 approximately half of the companies which collaborated in the VLT project were still engaged in astronomy projects.

(2) Astronomy produces economic benefits in the form of technologies transferred into industry and spin off companies emerged from this science.

Examples of commercial application of knowledge produced in Astronomy are unveiled. Examples come from different areas of work in Astronomy, specifically, adaptive optics, x-ray astronomy and opto-mechanics.

(3) Astronomy generates person embodied economic benefits.

Focusing on human resources graduated and post graduated in Astronomy one refers that two studies made in Great Britain, in two different periods of time, concluded that industry identifies benefits in employing high skilled human resources coming from Astronomy.

Recognizing the advantages of training human resources in Astronomy projects, the Portuguese Government signed a protocol with ESO in 15th May 2001 with the aim of organizing an internship program for young Portuguese engineers and scientists in ESO. The spirit of the protocol was that the training of human resources in high technological environments will foster the competitiveness of Portuguese companies when these human resources return to Portugal.

From 2002 until January 2010, 11 internships occurred in ESO in the framework of this program (ADI, 2010). 60% of the trainees come from electronics and computer engineering and 20% come from aeronautics and aerospace engineering. After a survey of ADI one knows that 17% of the former trainees are collaborating in Portuguese Academy. By their turn, 33% of the former trainees work in Portuguese industry against 17% of the formers trainees who work in International industry. 33% of the former trainees are in an undefined situation (ADI, 2010).

Also, recognizing big science projects as drivers of business, Portugal created an industrial liaison office, based in FCT – Portuguese Foundation for Science and Technology, whose objective is to increase Portuguese industrial benefits (materialized in contracts), besides the scientific and training benefits, coming from the country's membership of CERN, ESA, ESO and ESRF. The idea is to receive industrial benefits at least proportional to Portuguese contribution to CERN, ESA and ESO and ESRF's budget.

In the particular case of Astronomy, Portugal has a share of sensibly 1%-1.5%[13] in ESO's annual budget, which means an average annual contribution of 1.5 Million Euros. Since the accession of Portugal to ESO, in 2001, Portuguese companies have exported goods and services valuing 2.5 million Euros to ALMA and E-ELT projects (ADI, 2010). From 2000 to the end of 2009 the accumulated industrial return from ESO was less than 0.5[14]. In 2009 Portugal achieved an industrial return of 2.94, the biggest among ESO's member states. Portuguese industry will have the challenge of adapting itself to ESO's requisites and technological objectives in order to maintain 2009's good performance. Presently, 30 Portuguese companies are registered as ESO's suppliers. 30% of them have already been selected to supply ESO[15]. Supplies were in the fields of software, quality control, energy (energy provision systems) and mechanical engineering.

One of the drivers of companies' motivation to invest in big science projects is their perception about the medium and long term benefits of this kind of collaborations. One hopes the findings of the present work help companies to recognize some of these benefits. This work also gives support to public policy directed to the promotion of industry participation in astronomy projects.

Despite economic benefits of Astronomy are the focus of this study one should not forget the contributions of this science for the development of other sciences. For example, the whole concept of gravity, the study of the gravitational force and Newton's Laws derive from the accurate measurement of the position and motion of the planets. Another example is the study of stellar spectra, which has led to the development of atomic physics (Branduardi-Raymont, 1995).

Other aspect that should be underlined is the potential of Astronomy in education. Astronomy is an integrating science, field of application of other sciences like mathematics, physics or chemistry. Its practical side, the observation of nature, may be a fertile context for experience and discovery by students, thus for active learning (Vicino, 1990). Because Astronomy stimulates new dreams and people's imagination, it has the power of attracting new generations for sciences and engineering, helping the formation of scientific-minded people. That's why it is not surprising to observe an increase of Astronomy subjects in curricula of secondary level education (Calado, 2009).

Remembering the basics of the Economics of Astronomy, one calls attention for the existence of circular causalities between inputs and outputs of Astronomy. That is, there are outputs that work as inputs and vice-versa. As illustration, knowledge developed in Astronomy contexts will foster the development of technologies that allow this science to excel in its challenges. Sciences like Physics that see their principles tested within Astronomy will feed the theoretical basis as well as the tools (for example, instrumentation) needed to answer to Astronomy questions. One mentions also the case of spin off companies from Astronomy that end being suppliers of Astronomy projects.

In the end, this work enlightened the conviction that Astronomy might be a driver of short term, quantifiable benefits for our Society. Not to speak of the medium and long term, immensurable, benefits that Astronomy generates due to knowledge creation. Benefits that are far beyond and at the same time inspire our imagination.

[13] Source: Industrial Liaison Office of FCT - Foundation for Science and Technology
[14] Source: Industrial Liaison Office of FCT - Foundation for Science and Technology
[15] Source: Industrial Liaison Office of FCT - Foundation for Science and Technology

Quoting the book "Astronomy and Astrophysics in the new millennium" (BPA, 2001), perhaps the most persuasive, but least quantifiable, justification for investment of public resources in Astronomy challenges lie in the importance Humankind *has always attached to exploring new frontiers, and in the deep human desire to understand how we came to be, the kind of universe we live in, whether we are alone, and what our ultimate fate will be. Exploring frontiers of unimaginable mystery and beauty, Astronomy speaks compellingly to these fundamental questions.*

Figure 56: Icarus (Icare), from "Jazz", Henri Matisse, 1947

## 6. REFERENCES


**A**

Agência da Inovação, SA (ADI) (2010): "Agência da inovação – resultados – Estágios tecnológicos no CERN, ESA e ESO". Fundação para a Ciência e Tecnologia. Ministério da Ciência, Tecnologia e Ensino Superior. Portugal

Autio, Erkko; Bianchi-Streit, Marinela; Hameri, Ari-Pekka (2003): "Technology transfer and technological learning through CERN's procurement activity". CERN's Scientific Information Service. Geneva.

Autio, Erkko; Hameri, Ari-Pekka; Vuola, Olli (2004): "A framework of industrial knowledge spillovers in big-science centers". Research Policy, number 33, pages 107–126.

**B**

Branduardi-Raymont, G. (1995): interview given to Physics Education review. Interview conducted by Jo Quinton-Tulloch. Physics Education review, volume 30, number 6.

Barbalat, O. (1989): "Technology and industrial spin-off from particle accelerators". Turner, S, editor. CERN Accelerator School - 3rd general accelerator course, Salamanca. Pages 194-218.

Bezdek, R., H.; Wendling, R., M. (1992): "Sharing out NASA's Spoils. Nature, volume 355. Pages 105-106.

BETA (1980): "The economic effects of ESA contracts. Strasbourg, Université Louis Pasteur, Bureau D'Economie Théorique et Appliquée.

BETA (1988): "Study of the economic effects of European space expenditure – Results, Volume I". Strasbourg, Université Louis Pasteur, Bureau D'Economie Théorique et Appliquée.

Bianchi-Streit, Marinela; Blackburne, N.; Budde, R.; Reitz, H.; Sagnell, B.; Schmied, H.; Schorr, B. (1984): "Economic utility resulting from CERN contracts (second study)". CERN Scientific Information Service, Geneva.

Board on Physics and Astronomy – Space Studies Board (BPA) (2001): "Astronomy and Astrophysics in the New Millennium". National Research Council. National Academy Press, Washington, D.C. ISBN-13: 978-0-309-07312-7

**C**

Calado, M. J. (2009): "Mars at school". Thesis for the Master in curricular development by Astronomy. Faculty of Sciences of University of Porto.

Callon, Michael (1994): "Is science a public good?" Science, Technology and Human Values. Number 19, pages 345–424.

Carr, Geoffrey (2002): "The myth-makers". The Economist, January, pages 47–49.

Chapman, R., L.; Lohman, L., C.; Chapman, M., J. (1989): "An exploration of benefits from NASA Spinoff". NASA Contract 88-01 with NERAC Inc. Littleton Co, Chapman research group Inc.

Committee for economic development (CED) – Research and Policy Committee (1998): "America's basic research: prosperity through discovery - a policy statement". ISBN 0-87186-130-5.

Confederation of British Industry Publications (CBI) (2001) - "Partnerships for research & innovation between industry & universities – a guide to better practice", CBI Report.

**D**

DTZ Pieda Consulting (2003): "A study of the career paths of Particle Physics and Astronomy Research Council (PPARC) PhD Students". Reference 02/092957.

**E**

European Commission (EC) (1997): Second European report on Science & Technology indicators. European Commission DG XII, Brussels.

European Commission (2008): "Guide to cost-benefit analysis of investment projects". Directorate General Regional Policy, Brussels.

Evans, M., K. (1975): "Economic impact of NASA R&D spending". Bala-Cynwyd, Chase Econometric Associates.

**F**

Federal Aviation Administration Office of Commercial Space Transportation (FAA) (2008): "The Economic Impact of Commercial Space Transportation on the U.S. Economy".

Feldman, M.; Florida, R. (1994): "The geographic sources of innovation: technological infrastructure and product innovation in the United States". Annals of the Association of American Geographers, number 84 (2), pages 210-229.

Ferreira, Máximo; Almeida, Guilherme de (1997): "Introdução à Astronomia e às Observações Astronómicas", Quarta edição. Plátano Edições Técnicas, Lisboa. ISBN-972-707-079-5.

**G**

Greenway, A.; Burnett, J. (2004): "Technology tracking - industrial and medical applications of adaptive optics". Institute of physics publishing and QinetiQ.

Gulbrandsen, Markus (2009): "The role of basic research in innovation". Confluence: Interdisciplinary communications 2007/2008, pages 55-58. ISBN-978-82-996367-6-6.

**H**

Hähnle, Michael (1997): "R&D Collaborations between CERN and Industrial Companies - Organisational and Spatial Aspects". Vienna University of Economics and Business Administration, Vienna.

**I**

Imrie, D C. (1986): "Technological spin-off from particle physics". Physics and Technology. Volume 17, pages 56-61.

International Year of Astronomy (2009): Slide show presentation about Astronomy. Available at http: //www.astronomy2009.org/.

**K**

Katz, J. S. (1994): "Geographical proximity and scientific collaboration". Scientometrics, number 31 (1), pages 31–43.

Kline, Stephen; Rosenberg, Nathan (1986): "An overview of innovation (the positive sum strategy)". National Academy Press, Washington D.C., pages 275-305.

**L**

Lederman, Leon M. (1984): "The Value of Fundamental Science". Scientific American. Volume 251 (5). November. pages 34-41.

**M**

Martin, Ben (2007): Lecture "Assessing the impact of basic research on society and the economy". FWF-ESF International Conference on "Science impact: rethinking the impact of basic research on society and the economy", Vienna.

Martin, Ben; Irvine, John (1981): "Spin off from basic science – the case of radioastronomy". Physics in Technology, number 12, 204–212.

Mathech Inc. (1977): "A Cost benefit analysis of selected technology utilization office programs". Washington D.C., NASA.

Mathematica Inc. (1976): "Quantifying the benefits to the national Economy from secondary application of NASA technology". Washington D.C., NASA.

**N**

Nadiri, M. Ishaq (1993): "Innovations and Technological Spillovers", Economic Research Reports, CV Starr Center for Applied Economics, New York University, NBER WP 4423, CVS RR 93-31.

Nelson, Richard (1959): "The Simple Economics of Basic Scientific Research". Journal of Political Economy, June, pages 297-306.

Nelson, Richard (1962): "The Link between Science and Invention: the Case of the Transistor". The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pages 549-583.

Nelson, Richard (2003): "On the uneven evolution of human know-how". Research Policy, number 32, pages 909-922.

Neves, João César das (1993): "Introdução à Economia", Segunda edição. Editorial Verbo, Lisboa.

Nightingale, Paul (1997): "Knowledge in the process of technological innovation: a study of the UK pharmaceutical, electronic and aerospace industries". Doctoral dissertation, SPRU, University of Sussex, Brighton.

Nordberg, Markus (1994): "Contract Benefits and Competence-based Supplier Strategies - CERN as a Case Example". Helsinki University of Technology, Institute of Industrial Management, Espoo.

**O**

Organization for Economic Co-Operation and Development (OECD) (1997): "OECD Global Forum on Space Economics - descriptive overview".

OECD and Eurostat (2005): "Oslo Manual – guidelines for collecting and interpreting innovation data". Third edition.

**P**

Pallant, Julie (2005). "SPSS Survival Manual". Allen & Unwin. ISBN 1 74114 478 7.

Pavitt, Keith (1991). "What makes basic research economicly useful?" Research Policy, number 20, pages 109–119.

Pavitt, Keith (1998): "The social shaping of the national science base". Research Policy, number 27, pages 793–805.

Pavitt, Keith (2001): "Public policies to support basic research: what can the rest of the world learn from US theory and practice? (and what they should not learn)". Industrial and Corporate change, volume 10, issue 3, pages 761-779.

Pinho, Paulo; Vilares, Manuel; Morgado, António; Silva, Cecília; Lopes, Emídio; Sá, Frederico; Torres, Miguel (2008): "Avaliação do impacto global da 1ª fase do projecto do Metro do Porto".

**R**

Rosenberg, Nathan (1990): "Why do firms do basic research (with their own money)?" Research Policy, number 19, pages 165–174.

**S**

Salter, Ammon; Martin, Ben (2001): "The economic benefits of publicly funded basic research - a critical review". Research Policy, number 30, pages 509-532.

Saxenian, A. (1994): "Regional Advantage - industrial adaptation in Silicon Valley and route 128." Harvard University Press, Cambridge.

Schmied, H. (1975): "A study of economic utility resulting from CERN contracts". CERN 75-5 DG, Geneva.

Schmied, H. (1977): "A Study of economic utility resulting from CERN contracts". IEEE - transactions of engineering management, EM-24(4), pages 125-138.

Schmied, H. (1987): "About the quantification of the economic impact of public investments into scientific research." International Journal of Technology Management, 2 (5–6), pages 711–729.

**T**

Teece, David (1988): "Technological Change and the Nature of the Firm". Technical Change and Economic Theory. Pinter Publishers, London, Pages 256-281.

**U**

University of California (UC) (2003): "California's Future: it starts here. UC's contributions to economic growth, health, and culture. An impact study for the University of California".

University of California, Berkeley (UCB) (2007): "The Economic Impact & Social Benefits of the University of California, Berkeley in 2005/2006".

**V**

Varian, Hal R. (1992): "Microeconomic analysis", Third Edition, W. W. Norton and Company, ISBN: 0-393-95735-7.

Vicino, Gonzalo (1990): "The teaching of Astronomy and social and economic development". The Teaching of astronomy, proceedings of IAU Colloquia 105. Cambridge University Press, 1990, pages 403-405.

Vuola, Olli; Hameric, Ari-Pekka (2006): "Mutually benefiting joint innovation process between industry and big-science". Technovation, number 26, pages 3–12.

## ANNEX 1 - Examples of astronomy spin offs

Astronomy, although in tune with the skies, has been a source of numerous benefits to Earth society. Just for illustration, one notes that Astronomy findings are inspiring nuclear fusion projects, which try to replicate stars' way of producing energy[16].

Astronomy has given less ethereal contributions to Earth ecosystem, namely through technological contributions. These contributions derive from the need to measure precise positions, luminosities, and structural details in faint and distant cosmic sources; to measure time with exquisite precision; or to analyze large statistical samples of objects spanning a wide range of physical, chemical, and evolutionary conditions (BPA, 2001). As a response for these challenges, Astronomy organizations like ESO foster R&D activities that involve, for instance, sophisticated optomechanical and optoelectronic systems which involve extremely high-precision control and steering of heavy equipment. Other activities involve hardware and software for complex telescopes and instruments, mathematically advanced image analysis, optimal handling, archiving and retrieval of extremely large amounts of data[17]. All these activities have a common ground: they push technological and scientific frontiers. Occasionally, opportunities are identified for transferring R&D results into industry or commercial applications.

Taking the book "Astronomy and Astrophysics in the new millennium" as a reference one quotes that one of the major technological contributions by Astronomy *has been the development or improvement of devices that convert light and other forms of radiation into images. Historically, Astronomy has pushed the development of photographic film to greater sensitivities and resolution. However, film has now been largely replaced by electronic sensors, detectors, and amplifiers—devices that enable accurate digitized measurements of brightness over a wide range of wavelengths* (BPA, 2001). The book names several Astronomy contributions to signal detection in several frequency bands of the spectrum: from high-frequency x-ray band to ultraviolet, optical, infrared, and radio.

Picking x-ray band, one may testify new uses of x-ray charge-coupled devices [charge-coupled devices (CCD) are high resolution detectors of light] in video cameras, to provide electronic images at very high resolution, or in dentistry. *Dentists use a piece of equipment, a bit thicker than a pen, with a CCD at one end. They use it to point at particular places in the mouth and instantaneously deliver the image on a display screen* (Branduardi-Raymont, 1995). X-ray CCD replaced dental x-ray film, a change that reduced exposure to x-rays.

With regard to radio waves, one underlines that not only radio and television, but also satellite communications have been accomplished through this wavelength. Radio astronomers have provided the impetus to technical advances that have improved the stability, widened the bandwidth, and reduced the noise and interference of radio communications: low-noise maser, parametric, and other transistor amplifiers that have had wide application in the communications industry (BPA, 2001).

Together with signal detection, other field of relevant intervention of Astronomy is the development of precise instrumentation that separate and analyze the different frequencies present in a beam of radiation. These instruments are called spectrometers. These developments have been highly beneficial to the industrial, defense, environmental and medical sectors of the Economy (BPA, 2001). For instance, infra red spectrometers remotely analyze the composition of the atmosphere. Space and ground-based radio spectrometers remotely monitor temperature, winds, humidity, and chemical composition in the atmosphere with applications to weather prediction, global warming, and pollution monitoring. The

[16] For further reading about nuclear fusion, please visit http://www.iter.org/sci/whatisfusion

[17] Source: ESO's webpage

depletion of ozone has been monitored with astronomical radio telescopes equipped with radio spectrometers. Space radio spectrometers also have the capacity of sensing ground-level quantities such as soil moisture, vegetation cover, ocean height, oil spills, snow cover, and iceberg hazards. Essential components of all these spectrometers have been invented or perfected by the astronomical community (BPA, 2001).

Another field of influence is information and communication technologies. The enormous quantities of data streaming from modern astronomical sensors and large sky surveys, and the large computational speeds required for both simulations and database searches put serious challenges to computer sciences. Astronomy has been a major driver of supercomputer architecture and computational science (BPA, 2001). The needs of Astronomy are helping the development of new computational methods (like GRID computing) and innovative hardware and software.

The general examples referred above give a flavour of Astronomy's economic impact. At this point, one finds valuable to expose 3 concrete cases of Astronomy spin offs that were found during the research made in the framework of the present work.

### Adaptive optics into earth

Earth's atmosphere turbulence causes distortions in radiation emitted by celestial objects, bringing difficulties to ground based telescopes. Astronomers have turned to a method called adaptive optics. Sophisticated, deformable mirrors controlled by computers correct in real-time that distortion making the images obtained almost as sharp as those taken in space.

Nowadays, adaptive optics systems are entering in the industry of optical engineering. For example, wavefront sensing techniques are being exploited in modern medicine in connection with refractive laser surgery in order to correct higher-order aberrations in the eye. Adaptive optics techniques are being refined to produce ophthalmic instruments that can image the retina of an eye and measure an individual's eye aberrations with detail. The potential exists for low-cost diagnosis of eye disease, as well as for specification of parameters for either contact lenses that will provide "supernormal vision" and corrective eye surgery (BPA, 2001).

Expanded opportunities for adaptive optics were brainstormed in the 2004 report "Industrial and medical applications of adaptive optics": the commercial sector is starting to explore the potential of adaptive optics in a range of applications. Patent activity in adaptive optics has more than doubled between 2001 and 2003, an indication of increasing commercial interest (Greenway et al, 2004). It seems that a growing portion of development has been aimed at different markets such as ophthalmology, laser-based telecom, optical metrology and confocal microscopy.

One example of adaptive optics spin off is the foundation in 2000 of a company by a group of scientists from the University of Hawaii's center for adaptive optics. The aim of the company is to exploit commercial opportunities of adaptive optics technology, namely in biometrics, defense laser communications and commercial laser communications. The company employed in 2009 around 75 full-time staff, the vast majority of whom were in R&D and engineering[18].

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[18] Source: www.optics.org

## X-ray technology applications

X-ray astronomy develops imaging systems for the study of stars and galaxies recurring to the detection, processing and analysis of the X-rays that the cosmic objects emit. Based in these technologies NASA's Goddard space flight centre produced a small, portable, low-radiation X-ray instrument, known as the Low Intensity X-ray Imaging Scope (Lixiscope), for diagnostic use in the field, such as at accident sites or at sporting events. This X-ray microscope is suited to image small objects with fine detail, with applications in energy research and biomedical research. After development, NASA licensed the technology to several companies. Presently, it is being used in neonatology, out-patient surgery, diagnosis of sports injuries, and developing countries' clinics. The Lixiscope is NASA's second largest source of royalties (BPA, 2001).


Figure 57: Example of a product based in the Lixiscope

The latest application of the Lixiscope technology is the Inner View Realtime X-Ray Imaging System. Inner View allows low cost and safety for industrial X-ray applications such as airport and building security (inspection of luggage, containers, boxes, etc), non destructive testing, quality control inspection and production inspection[19].

[19] Source: http://www.nsbri.org/HumanPhysSpace/appendix/appendixb.html

**Optomechanics spin off**

The present case is a company specialized in Optomechanics. It was founded in 1983 as a result of the merging of technical complementarities between a company whose business was high precision mechanics (for example, development of iron and steel structures) and an Astrophysics Institute, experienced in optical systems.

The main offers of the company are the development of equipment to test satellites on the ground; of on board equipment; and of equipment for professional astronomy, for example, telescopes, components and auxiliary instruments. Naturally, its major costumers come from space industry and professional Astronomy. Due to the complexity of the projects in which they collaborate, they have reinforced their know-how in high accuracy optomechanical engineering and their skills in project management. Nowadays, the company is a vertical integrator, that is, it is capable of delivering turnkey projects.

This company was responsible for the design, procurement, manufacturing, assembling, testing and packing of the four mobile auxiliary telescope systems for the VLT Project. In 2010 this company was awarded the contract for the construction of the new Javalambre Astronomical Observatory, in Spain. They will supply two telescopes. The largest one will have a field of observation of 3° and include a primary mirror of 2.5 meters diameter. It will weigh 40 tons, for a height of 6.5 meters and an outer diameter of 5 meters. The smaller telescope will have a primary mirror of 80 cm diameter. The contract attributed to the company amounts 10 million Euros, value equivalent to one year of workload for the entire company. Presently, the company is constituted by 75 people.

**ANNEX 2 - Survey in English to ESO's suppliers**

1. ORGANIZATIONAL DATA:

1.1 Name of the Organization

1.2 Name of your Business unit (if your organization is divided in business units)

1.3 Main activities of your Organization or Business unit

1.4 Is your Organization or Business unit a spin-off of a University or of a Research & Development centre/institute?[20]

1.5 If so, what is the main scientific or technological field of the University/centre/institute?

2.1 Number of collaborators of your Organization or Business unit (2009)

2.2 Number of collaborators working in projects related with Astronomy

2.3 Number of collaborators with background or professional experience in Astronomy projects

2.4 Number of collaborators working in R&D activities

3.1 Revenue of your Organization or your Business unit (2009)[21]

3.2 Revenue originated by contracts or transactions related with projects in Astronomy[22]

3.3 Number of active contracts related with projects in Astronomy

3.4 EBITDA of your organization (2009) EBITDA = Earnings before interests, taxes, depreciations and amortizations

3.5 EBITDA related with projects in Astronomy

3.6 R&D expenses (2009)

3.7 R&D expenses related with projects in Astronomy or percentage of R&D expenses in Astronomy projects in the total of R&D expenses of the Organization

2. IMPACT IN YOUR ORGANIZATION:

1.1 Considering the contracts or transactions derived of projects related with Astronomy (for instance, the contracts developed in the framework of ESO's VLT project) please, indicate the extent to which each of the following benefit was or is being relevant to your Organization or Business Unit:

Options: 1 – 5 or cannot say; 1: of no significance, 3: significant, 5: of very high significance

1. Financial income / profit generated by the contracts
2. Increased number of contracts with new costumers

[20] In this survey "spin-off" means an Organization founded on the findings of a member or by members of a research group at an already existing Organization. R&D means research and development.

[21] Revenue means sales, turnover. Please indicate the currency (for instance, EUR, USD or CLP) after the amount.

[22] Please indicate the currency (for instance, EUR, USD or CLP) after the amount. In case this information is hard to get, you may answer this question with an approximate percentage of the revenue coming from Astronomy in the total revenue of the Organization.

3. Increased number of contracts with previously unknown costumers
4. Increased number of contracts with similar costumers (Astronomy or Big Science)
5. Establishment of a long term relation with ESO
6. Optimization of process or manufacturing/production capacity
7. Marketing / image benefits (for example, association with high tech or Big Science projects)
8. Market learning (about customers, their needs, market trends)
9. Transfer of technology from ESO (for example, instrumentation, patents, techniques / methods)
10. R&D learning (new ideas, knowledge, skills, methods)
11. Access to industry networks
12. Access to scientific or technological networks
13. Sharing of R&D or innovation risks
14. Improved technical skills / know how in your Organization's collaborators
15. Improved project management skills (for example, contract control)
16. Improved processes or manufacturing methods
17. Improved organizational practices (for instance in production, marketing, procurement, R&D)
18. Improved compliance / quality assurance
19. Development of new products / services
20. Development of new knowledge (for example, technology, publications)
21. Application of new patents, copyrights or other intellectual property rights
22. Increased collaborator's motivation

1.2 Others. May you name them?

1.3 Please indicate the extent to which the cited benefits are contributing for the development of contracts in projects not related with Astronomy

Options: 1 – 5 or cannot say; 1: of no significance, 3: significant, 5: of very high significance

2.1 Please indicate the extent of the efforts that were or are being taken by your Organization or your Business unit in order to comply with contracts/transactions derived of projects related with Astronomy (for instance, the contracts developed in the framework of ESO's VLT project)

Options: 1 – 5 or cannot say; 1: of no significance, 3: significant, 5: of very high significance

1. Investment in new process equipment
2. Investment in new testing equipment
3. Training of collaborators
4. Visits to ESO (or other costumers)
5. Hiring new people

6. Implementation of new procedures
7. Bibliographical research
8. Market research
9. R&D

2.2 Others. May you name them?

3. Considering the results of your Organization / Business unit after the completion of your Organization's contracts related with projects in Astronomy (for instance, the contracts with ESO in the framework of VLT project) what do you imagine they would have been if you had not worked with these costumers (for example, ESO)?

Options: 1 – 5 or cannot say; 1: much better, 2: slightly better, 3: no change, 4: slightly lower, 5: much lower

1. Growth in revenue (sales)
2. Growth in number of collaborators
3. Technological / R&D excellence
4. Innovation / Competitiveness (Product, Process, Organization, Marketing)
5. Net value of your Organization

## ANNEX 3 - Survey in Spanish to ESO suppliers

Estudio sobre el impacto en las Empresas de hacer negocios con el ESO - European Southern Observatory

OBJETIVO: El estudio se centra en la colaboración entre ESO y Empresas. El objetivo de esta encuesta es conocer el impacto la colaboración com ESO tiene en su organización.

CONFIDENCIALIDAD: Todas las respuestas serán estrictamente confidenciales. Los resultados serán utilizados sólo con fines de investigación y se presentarán en formato agregado solamente. No se hará referencia individual a las organizaciones.

ESTRUCTURA: La encuesta se divide en dos capítulos: "Información de la Organización" e "Impacto en la Organización". La encuesta consta de 3 páginas. La primera página és dedicada al primer capítulo y la páginas siguientes son para el segundo capítulo.

INSTRUCCIONES: Con el fin de pasar a la siguiente página, usted debe pulsar el botón "Continuar". Para enviar la encuesta debe pulsar el botón "Enviar" en la tercera página. Si quiere volver atrás en una página, debe pulsar el botón "Anterior".

1. INFORMACIÓN DE LA ORGANIZATION

1.1 Nombre de la organización:

1.2 Nombre de su unidad de negocio (Si su organización se divide en unidades de negocio):

1.3 Actividades principales de su unidad de negocio o de la organización:

1.4 Es su unidad de negocio o organización una "Spin off" de una universidad o de un centro de Investigación y Desarrollo?

"Spin-off" traduce una organización fundada en los resultados de un miembro o miembros de un grupo de investigación en una organización ya existente. R&D (Research and Development) significa Investigación y Desarrollo.

1.5 Si es una "Spin off" cuál es el campo científico o tecnológico principal de la universidad o del centro de Investigación y Desarrollo?

2.1 Número de colaboradores de su unidad de negocio o de la organización (2009):

2.2 Número de colaboradores que trabajan en proyectos relacionados con Astronomía (2009):

2.3 Número de colaboradores con graduación o post graduación en Astronomía o con experiencia profesional en Organizaciones de Astronomía (2009):

2.4 Número de colaboradores que trabajan en actividades de Investigación y Desarrollo (2009):

3.1 Volumen de negocio de su organización o de su unidad de negocio (2009):

Volumen de negocio significa ventas. Por favor, indique la moneda (por ejemplo, EUR, USD o CLP) después de la cantidad.

3.2 Volumen de negocio originado por los contratos o transacciones relacionados con proyectos en Astronomía (2009):

Por favor, indique la moneda (por ejemplo, EUR, USD o CLP) después de la cantidad. En caso de que esta información es difícil de conseguir, es posible responder a esta pregunta con un porcentaje aproximado de lo Volumen de negocio procedente de la Astronomía en el total de Volumen de negocio de la Organización.

3.3 Número de contratos activos relacionados con proyectos en Astronomía (2009):

Por favor, escriba "no aplica" si esta cuestión no se aplica al tipo de negocio de su Organización.

3.4 EBITDA de la Organización (2009):

EBITDA = Resultado (Ganancias menos Perdidas) antes de intereses, de impuestos, de depreciaciones y de amortizaciones. Por favor, indique la moneda (por ejemplo, EUR, USD o CLP) después de la cantidad.

3.5 EBITDA originado por proyectos en Astronomía(2009):

Por favor, indique la moneda (por ejemplo, EUR, USD o CLP) después de la cantidad. En caso de que esta información es difícil de conseguir, es posible responder a esta pregunta con un porcentaje aproximado de EBITDA procedente de proyectos en Astronomía en el total de EBITDA de la Organización.

3.6 Inversión en Investigación y Desarrollo (2009):

Por favor, indique la moneda (por ejemplo, EUR, USD o CLP) después de la cantidad.

3.7 Inversión en Investigación y Desarrollo relacionada con proyectos en Astronomía(2009):

Por favor, indique la moneda (por ejemplo, EUR, USD o CLP) después de la cantidad. En caso de que esta información es difícil de conseguir, es posible responder a esta pregunta con un porcentaje aproximado de Inversión en Investigación y Desarrollo relacionada com proyectos en Astronomía en el total de Inversión en Investigación y Desarrollo de la Organización.

2. IMPACTO EN LA ORGANIZATION

1.1 Teniendo en cuenta los contratos o transacciones comerciales derivadas de proyectos relacionados con la Astronomía, por favor, indique el grado en que cada uno de los benefícios siguientes fue o está siendo relevante para su organización o unidad de negocio:

En lo que respecta a los contratos o transacciones, usted puede considerar, por ejemplo, los contratos o transacciones que su organización desarrollou en el marco del proyecto VLT de ESO. Si no hay información para evaluar la pertinencia de ciertos beneficios, por favor no escriba en la fila que corresponde a ese beneficio.

Opciones: 1 - de ninguna significancia, 2 – de poca significancia 3 - significativo, 4: de significancia alta, 5 – de significancia muy alta

1. Volumen de negocio o Resultado financiero generado por los contratos o transacciones

2. Número creciente de contratos o transacciones con nuevos clientes

3. Número creciente de contratos o transacciones con clientes previamente desconocidos

4. Número creciente de contratos o transacciones con los clientes similares (Astronomía o grande ciencia)

5. Establecimiento de una relación a largo plazo con ESO

6. Optimización del proceso o de la capacidad de fabricación/producción/servicio

7. Beneficios de marketing / imagen (por ejemplo, asociación con ciencia de alta tecnología o proyectos de grande ciencia)

8. Aprendizaje de mercado (sobre clientes, sus necesidades, las tendencias del mercado)

9. Transferencia de tecnología de ESO (por ejemplo, instrumentación, patentes, técnicas/métodos)

10. Aprendizaje con respecto a Investigación y Desarrollo (nuevos ideas, conocimiento, habilidades, técnicas, métodos)

11. Acceso a redes de la industria

12. Acceso a redes científicas o tecnológicas

13. Compartir los riesgos de Investigación y Desarrollo o de innovación

14. Mejoría de las competencias técnicas / saber hacer de los colaboradores de su organización

15. Mejoría de las competencias en gerencia de proyecto (por ejemplo, control de contratos)

16. Procesos o métodos de fabricación mejorados

17. Prácticas de organización mejoradas (por ejemplo en la producción, comercialización / marketing, compras, Investigación y Desarrollo)

18. Mejoría de la garantía de conformidad / calidad de producción o serviço

19. Desarrollo y oferta de nuevos productos / servicios

20. Desarrollo de nuevo conocimiento (por ejemplo, tecnología, publicaciones)

21. Sumisión de nuevos pedidos de patentes, copyright o otros derechos de propiedad intelectual

22. Aumento de la motivación de los colaboradores

1.2 Recuerda otros beneficios? Puede usted nombrarlos?

1.3 Indique por favor el grado de contribución de los beneficios citados (en 1.1 e en 1.2) para el desarrollo de contratos e transacciones en proyectos no relacionados con Astronomía:

Opciones: 1 - de ninguna significancia, 2 – de poca significancia 3 - significativo, 4: de significancia alta, 5 – de significancia muy alta, 6 – no lo sé

2.1 Por favor, indique el grado de los esfuerzos que eran o están siendo tomados por su organización o su unidad de negocio en orden para conformarse con los contratos o las transacciones derivados de los proyectos relacionados con astronomía:

En lo que respecta a los contratos o transacciones, usted puede considerar, por ejemplo, los contratos o transacciones que su organización desarrollou en el marco del proyecto VLT de ESO. Si no hay información para evaluar la pertinencia de ciertos beneficios, por favor no escriba en la fila que corresponde a ese beneficio.

Opciones: 1 - de ninguna significancia, 2 – de poca significancia 3 - significativo, 4 - de significancia alta, 5 – de significancia muy alta.

1. Inversión en nuevo equipo / máquinas / instrumentos de producción
2. Inversión en nuevo equipo / máquinas de prueba / teste
3. Entrenamiento / Formación de colaboradores
4. Visitas a ESO (o a otros clientes)
5. Contratación de nuevos colaboradores
6. Puesta en práctica de nuevos procedimientos
7. Investigación bibliográfica
8. Estudio de mercados
9. Investigación y Desarrollo

2.2 Recuerda otros esfuerzos? Puede usted nombrarlos?

3. Teniendo en vista los resultados de su unidad de negocio o de la organización en consecuencia de los contratos o transacciones comerciales de su organización con proyectos en Astronomía, qué usted los imaginaria que serian si vuestra Organización no había trabajado con estos clientes (por ejemplo, ESO)?

En lo que respecta a los contratos o transacciones, usted puede considerar, por ejemplo, los contratos o transacciones que su organización desarrollou en el marco del proyecto VLT de ESO. Si no hay información para evaluar la pertinencia de ciertos beneficios, por favor no escriba en la fila que corresponde a ese beneficio.

Opciones: 1 – mucho mejor, 2 - mejor, 3 - ningún cambio, 4 – más bajo, 5 - mucho más bajo

1. Crecimiento en el Volumen de negocio (ventas)
2. Crecimiento en número de colaboradores
3. Excelencia tecnológica e del Investigación y Desarrollo
4. Innovación/competitividad (producto, proceso, organización, comercialización)
5. Valor de su Organización

## ANNEX 4 – Complementary statistical analysis

The present annex presents the main assumptions, steps and outputs of the complimentary statistical analysis of survey's results.

Statistical calculations were developed with the aid of IBM SPSS - Statistical Package for the Social Sciences, version 19. One recommends the book "SPSS Survival Manual" (Pallant, 2005) as a valuable help to understand the mechanics of SPSS.

The objective of this complimentary statistical analysis is to enrich the conclusions of the survey as well as to test hypotheses about impacts. These hypotheses were set during the interpretation of descriptive statistics of the survey.

The majority of statistical techniques require continuous variables. Although the variables under study - benefits, efforts, results – follow a discrete, 5-point Likert scale, they are treated as continuous, similarly to previous works like the one of Markus Nordberg, on contract benefits and competence-based supplier strategies (Nordberg, 1994).

Other major assumption of statistical techniques is that variables under study follow a normal distribution. That is not the case of the variables benefits, efforts and results. Even after transformation, if one takes into account the test of normality Kolmogorov-Smirnov, none of the transformed variables is close to a normal distribution. That is, in all transformed variables, the hypothesis of a normal distribution remains rejected ($p < 0.05$). One of the reasons for this fact is the dimension of the sample. One notes that the number of answers of the survey (number of observations) is 41, too small to apply the central limit theorem. Still, one went on with the statistical analysis. Even if it misses the desirable scientific robustness level, the statistical analysis will be useful to indicate trends. Whenever possible the analysis is carried out through non parametric techniques. Non parametric tests don't require strict assumptions, for instance, normal distribution, but they are less powerful in detecting differences and relationships even when they actually exist (Pallant, 2005).

Recalling survey's frequencies, disclosed in chapter 4.3.4.2, one will test and try to clarify the following doubts:

1) Is there a statistically significant difference in impact scoring between companies and R&D organizations?

A t-test for equality of the means was executed. An additional assumption in t-tests is that the groups to be compared have similar variances. In this case, for a particular impact, the variance of companies' scores must me close to the variance of R&D organizations' scores. A Levene's test for equality of variances is also executed. Note that the sample of respondents is constituted by 31 companies and 10 R&D organizations. This disparity in group size might hurt the equal variance assumption.

In parallel with the t-test, an independent-samples Mann-Whitney U test was performed. This non-parametric test verifies the null hypothesis that the distribution of certain impact is the same in companies and in R&D organizations. If Sig. < 0.05 the null hypothesis is rejected thus there is a statistically significant difference between companies and R&D organizations' scoring medians regarding that impact.

Hereby one may consult the variables where a significant difference of the means and of the medians (Mann-Whitney U test) was verified:

Benefits

| | | Levene's test | T-test | |
|---|---|---|---|---|
| | | Sig. | Sig. (2-tailed) | Mean difference |
| LogBoptimization* | equal variances assumed | 0.862 | 0.043 | -0.185 |
| | equal variances not assumed | | 0.049 | |
| RsqBrelationESO* | equal variances assumed | 0.164 | 0.012 | 0.339 |
| | equal variances not assumed | | 0.042 | |
| SqBTTESO* | equal variances assumed | 0.443 | 0.0 | -0.414 |
| | equal variances not assumed | | 0.002 | |
| SqBRDlearning* | equal variances assumed | 0.242 | 0.0 | -0.484 |
| | equal variances not assumed | | 0.0 | |
| SqBscientifnetworks* | equal variances assumed | 0.478 | 0.0 | -0.472 |
| | equal variances not assumed | | 0.003 | |
| BshareRisk* | equal variances assumed | 0.059 | 0.0 | -1.576 |
| | equal variances not assumed | | 0.005 | |
| BnewKnowledge* | equal variances assumed | 0.381 | 0.02 | -1.067 |
| | equal variances not assumed | | 0.05 | |
| BknowHow* | equal variances assumed | 0.675 | 0.04 | -1.167 |
| | equal variances not assumed | | 0.01 | |
| SqBprojManagement | equal variances assumed | 0.271 | 0.044 | -0.285 |
| | equal variances not assumed | | 0.084 | |
| SqBprocesses* | equal variances assumed | 0.982 | 0.021 | -0.304 |
| | equal variances not assumed | | 0.035 | |

* Mann-Whitney U test: reject the null hypothesis at the 0.05 level.

Efforts

| | | Levene's test | T-test | |
|---|---|---|---|---|
| | | Sig. | Sig. (2-tailed) | Mean difference |
| SqEequip* | equal variances assumed | 0.762 | 0.003 | -0.359 |
| | equal variances not assumed | | 0.003 | |
| SqEtest* | equal variances assumed | 0.62 | 0 | -0.465 |
| | equal variances not assumed | | 0 | |
| SqEtraining* | equal variances assumed | 0.713 | 0 | -0.413 |
| | equal variances not assumed | | 0.001 | |
| LogEhiring* | equal variances assumed | 0.002 | 0 | -0.288 |
| | equal variances not assumed | | 0 | |
| SqEnewProcesses* | equal variances assumed | 0.563 | 0.002 | -0.394 |
| | equal variances not assumed | | 0.001 | |
| SqEbibliogResearch* | equal variances assumed | 0.789 | 0.001 | -0.439 |
| | equal variances not assumed | | 0.004 | |
| SqEmktResearch* | equal variances assumed | 0.774 | 0.028 | -0.258 |
| | equal variances not assumed | | 0.038 | |
| Erd* | equal variances assumed | 0.319 | 0.001 | -1.415 |
| | equal variances not assumed | | 0.001 | |

* Mann-Whitney U test: reject the null hypothesis at the 0.05 level.

Results

| | | Levene's test | T-test | |
|---|---|---|---|---|
| | | Sig. | Sig. (2-tailed) | Mean difference |
| Rworkers* | equal variances assumed | 0.428 | 0.006 | -0.624 |
| | equal variances not assumed | | 0.009 | |
| Rnetvalue | equal variances assumed | 0.169 | 0.033 | -0.643 |
| | equal variances not assumed | | 0.098 | |

* Mann-Whitney U test: reject the null hypothesis at the 0.05 level.

The scoring means of R&D organizations are bigger than those of companies in all impact variables, except in the market learning benefit. Above, one may consult the list of impacts where the differences of the means are statistically significant.

2) Is there a statistically significant relation between order amount and impact scoring?

Recalling table 9, located in chapter 4.3.3 of this work, one distributed respondents by three categories of orders: orders up to 99,999 Euros, orders between 100 K Euros and 1 M Euros, and orders amounting more than 1 M Euros. The next step was to execute a one way ANOVA – Analysis of Variance with the transformed variables (benefits, efforts, results).

One concluded that the only statistically significant difference between variances of different categories of orders, at the $p < 0.05$ level, occurred in the benefit "increased number of contracts with unknown costumers" ($p= 0.009$). With regard to this benefit post-hoc comparisons using the Tukey HSD test indicated that the mean score for the group of organizations with budget lower than 100 K Euros (Mean=2.28, Standard Deviation=0.891) was significantly different from the group of organizations with budget between 100 K Euros and 1 M Euros (M=1.50, SD=0.527).

The alternative non parametric test is the independent-samples Kruskal-Wallis test which verifies the null hypothesis that the distribution of the impact variable is the same across categories of orders. Once again only in the benefit "increased number of contracts with unknown costumers" the null hypothesis was rejected. Even this non parametric test may fail if the distributions of each category of orders are not identical. This may be the case of the present categorization since the sizes of groups are different: the group of orders less than 100 K Euros is constituted by 26 observations whereas the group of orders between 100 K and 1 M is made of 10 observations. By its turn, the group of orders larger than 1 M Euros has 5 elements.

So, one went through other way of checking whether order amount and impact scoring are related. Specifically, treating respondent's budget as a continuous variable, a correlation analysis between this variable and between all the different impacts (benefits, efforts, results) was run. The correlation gives some idea to what extent two variables can be considered to be linearly dependent of each other. Note that one considers that linear relationship analysis is sufficient for the purposes of this study.

Since budget variable does not follow a normal distribution a Spearman rank order correlation was taken. Note that the correlation coefficient ($r$) varies between -1 and +1. If $r$ is 0, no correlation exists between the studied variables. If $r$ is +1, a perfect positive linear relationship exists between the variables. If $r$ is -1, the relationship is negative.

Spearman rank order correlation test signaled only one statistically significant correlation. One refers to the positive correlation between orders' value and the benefit "optimization of production" ($r = 0.33$; $p=0.037$) with high/low levels of budget associated with high/low levels of relevance of the benefit "optimization of production".

In the end, one underlines the lack of statistically significant linear association between orders' budgets (commonly used as proxies of the complexity of a business contract) and impacts scoring. Remains the doubt whether this hypothetical association is non linear, whether does not exist or whether the association was not captured by statistical tests due to survey pitfalls, such as small number of observations or short scoring scale.

3) Is there a difference in impact scoring between different specializations?

One based this test on the categorization present in table 10 of chapter 4.3.3. The next step was to execute a one way ANOVA – Analysis of Variance with the transformed variables (benefits, efforts, results) applying the specialization of organizations as a categorical independent variable.

Categories "Textile structures" and "Transports & logistics" have only one observation each. Given the impossibility of SPSS run post-hoc tests when one category has fewer than two cases for analysis, one defined an alternative categorical variable where these two categories were gathered in only one category called "outsiders". This iteration did not detect any statistically significant difference of variance among variables.

Once again a number of variables were excluded of the analysis because at least one category had fewer than two observations for these variables. One refers to the following benefits: R&D learning, Sharing of R&D risk, know-how gains. Also, R&D efforts and the result R&D excellence were excluded. One chose to create other categorical variable which excluded the less represented category "outsiders" in order to analyze the variance of these variables. The new categorical variable was dubbed as "short".

One concluded that the only statistically significant difference between variances of different specializations, at the $p < 0.05$ level, occurred in the R&D effort ($p= 0.032$). With regard to this benefit post-hoc comparisons using the Tukey HSD test indicated that the mean score for the group of astronomy organizations (Mean=3.83, Standard Deviation=1.169) was significantly different from the group of mechanical engineer organizations (M=1.50, SD=0.577).

The non parametric independent-samples Kruskal-Wallis test was executed using the original categorical independent variable, the "outsiders" variable and the "short" variable. All three tests detected different distributions across specializations in the "integration in scientific networks" benefit. The Kruskal-Wallis test using the "outsiders" variable detected also different distributions across specializations in the "equipment" effort.

Resuming, small statistical evidence is detected with regard to differences between means or medians of different specializations. This may be due, for example, to the scarceness of observations within the different specializations.

4) Is there a difference in impact scoring between R&D intensive organizations and non R&D intensive organizations?

A t-test for equality of the means of original impact variables was executed. A Levene's test for equality of variances was also executed. Note that the sample of respondents is constituted by 28 R&D intensive organizations and 7 non R&D intensive organizations. This disparity in group size might hurt the equal variance assumption.

In parallel with the t-test, an independent-samples Mann-Whitney U test was performed. This non-parametric test verifies the null hypothesis that the distribution of certain impact is the same in R&D intensive and non R&D intensive organizations.

Similar t-tests and Mann-Whitney tests were performed using transformed impact variables.

Hereby one may consult the variables where a significant difference of the means (T-test) and of the medians (Mann-Whitney U test) was verified:

Benefits

| | | Levene's test | T-test | |
|---|---|---|---|---|
| | | Sig. | Sig. (2-tailed) | Mean difference |
| BR&Dlearning* | equal variances assumed | 0.184 | 0.002 | 1.607 |
| | equal variances not assumed | | 0.001 | |
| BscientifNetworks | equal variances assumed | 0.016 | 0.131 | 0.75 |
| | equal variances not assumed | | 0.029 | |
| BshareRisk | equal variances assumed | 0.023 | 0.051 | 1.095 |
| | equal variances not assumed | | 0.003 | |
| BnewKnowledge* | equal variances assumed | 0.485 | 0.033 | 1.179 |
| | equal variances not assumed | | 0.04 | |
| BnewIP* | equal variances assumed | 0.02 | 0.025 | 0.929 |
| | equal variances not assumed | | 0.001 | |
| BKnowHow | equal variances assumed | 0.048 | 0.063 | 0.893 |
| | equal variances not assumed | | 0.007 | |
| Bprocesses* | equal variances assumed | 0.027 | 0.04 | 1.036 |
| | equal variances not assumed | | 0.009 | |
| LogBnewProdServices | equal variances assumed | 0.798 | 0.049 | 0.211 |
| | equal variances not assumed | | 0.095 | |
| SqBR&Dlearning | equal variances assumed | 0.731 | 0.001 | 0.526 |
| | equal variances not assumed | | 0.002 | |
| SqBprocesses* | equal variances assumed | 0.092 | 0.047 | 0.318 |
| | equal variances not assumed | | 0.022 | |

* Mann-Whitney U test: reject the null hypothesis at the 0.05 level.

Efforts

| | | Levene's test | T-test | |
|---|---|---|---|---|
| | | Sig. | Sig. (2-tailed) | Mean difference |
| ER&D* | equal variances assumed | 0.197 | 0.01 | 1.648 |
| | equal variances not assumed | | 0.0 | |

* Mann-Whitney U test: reject the null hypothesis at the 0.05 level.

The scoring means of R&D intensive organizations are bigger than those of non R&D intensive organizations in all impact variables, except in the benefits "increase of unknown clients" and "access to industry networks". Also, the mean scores in the "net value" result are the same, more precisely 3.5. One may check in the previous charts impacts where the differences of the means are statistically significant. One underlines that 5 out of 6 R&D and technology related benefits are present in the chart, together with the R&D effort. One interpretation for this fact is that R&D intensive organizations are more conscious or mindful of Astronomy projects impacts in their R&D strategy and activities.

5) Is there a difference in impact scoring between SME – small and medium enterprises and big companies?

Before going ahead with a t-test for equality of the means of transformed impact variables, a new categorical independent variable was created. This new variable distinguishes SME and big companies. One concludes that the sample of respondents is constituted by 11 SME and 5 big companies. The small dimension of groups as well as the disparity in group size might hurt this exercise. In parallel with the t-test, an independent-samples Mann-Whitney U test was performed.

One may check in the following chart the impacts in which differences of the means are statistically significant:

Benefits

| | | Levene's test | T-test | |
|---|---|---|---|---|
| | | Sig. | Sig. (2-tailed) | Mean difference |
| BnewIP | equal variances assumed | 0.196 | 0.024 | -1.145 |
| | equal variances not assumed | | 0.088 | |
| BknowHow* | equal variances assumed | 0.582 | 0.023 | -1.255 |
| | equal variances not assumed | | 0.026 | |
| SqBprocesses* | equal variances assumed | 0.913 | 0.05 | -0.470 |
| | equal variances not assumed | | 0.01 | |

* Mann-Whitney U test: reject the null hypothesis at the 0.05 level.

One highlights the fact that the scoring means of big companies are systematically bigger than those of SME. The exceptions are: benefits in projects outside astronomy; new process implementation and bibliographical research, on the efforts side; innovation and net value on the results perspective. As not seen in the chart, these last impacts are not statistically significant.

6) Does the weight of Astronomy in human resources, revenues and R&D influence impact scoring?

In the first part of the survey, organizations gave information about the number of workers who collaborate in astronomy projects, revenues coming from Astronomy and weight of Astronomy in R&D expenditures. 3 different variables were created taking into account the percentage of workers' dedication to Astronomy, percentage of Astronomy revenues in total revenues and weight of Astronomy in R&D expenditures. After transformation one realizes that these variables follow a distribution close the normal distribution. Despite that, one decided to go on with a Spearman rank order correlation between original impact variables and transformed and non transformed Astronomy workers, Astronomy revenue and Astronomy R&D expenditures since impact variables do not follow a normal distribution. One did not use transformed impact variables since results do not change significantly when one adopts them. The following tables show the calculated correlations between variables under study:

| | | SqWorkersA | LogRevenuesA | RevenuesA | R&DA |
|---|---|---|---|---|---|
| SqWorkersA | Correlation Coefficient | | | | |
| | Sig. (2-tailed) | | | | |
| LogRevenuesA | Correlation Coefficient | ,721** | | | |
| | Sig. (2-tailed) | ,000 | | | |
| RevenuesA | Correlation Coefficient | ,749** | | | |
| | Sig. (2-tailed) | ,000 | | | |
| R&DA | Correlation Coefficient | ,475* | ,633** | ,633** | |
| | Sig. (2-tailed) | ,047 | ,005 | ,005 | |
| Bprofit | Correlation Coefficient | ,252 | ,168 | ,105 | ,392 |
| | Sig. (2-tailed) | ,163 | ,432 | ,617 | ,097 |
| Boptimization | Correlation Coefficient | ,233 | ,241 | ,203 | ,532* |
| | Sig. (2-tailed) | ,200 | ,256 | ,330 | ,019 |
| Bnewps | Correlation Coefficient | ,235 | ,251 | ,160 | ,454 |
| | Sig. (2-tailed) | ,212 | ,260 | ,466 | ,058 |
| Bnewclients | Correlation Coefficient | ,210 | ,072 | -,009 | ,143 |
| | Sig. (2-tailed) | ,256 | ,738 | ,964 | ,559 |
| Bunkclients | Correlation Coefficient | -,130 | -,060 | -,127 | ,121 |
| | Sig. (2-tailed) | ,485 | ,780 | ,545 | ,622 |
| Bsimclients | Correlation Coefficient | ,181 | -,096 | -,126 | ,187 |
| | Sig. (2-tailed) | ,330 | ,655 | ,548 | ,445 |
| Bindnetworks | Correlation Coefficient | ,151 | ,194 | ,057 | ,240 |
| | Sig. (2-tailed) | ,410 | ,364 | ,786 | ,322 |
| Bmarketlearn | Correlation Coefficient | ,210 | -,031 | -,067 | -,039 |
| | Sig. (2-tailed) | ,256 | ,888 | ,755 | ,878 |
| BrelationESO | Correlation Coefficient | ,487** | ,447* | ,452* | ,373 |
| | Sig. (2-tailed) | ,005 | ,029 | ,023 | ,116 |
| Bimage | Correlation Coefficient | ,407* | ,150 | ,093 | ,303 |
| | Sig. (2-tailed) | ,021 | ,485 | ,657 | ,208 |
| BttESO | Correlation Coefficient | ,405* | ,517* | ,342 | ,477* |
| | Sig. (2-tailed) | ,024 | ,012 | ,101 | ,039 |
| Brdlearn | Correlation Coefficient | ,398* | ,286 | ,287 | ,595** |
| | Sig. (2-tailed) | ,027 | ,175 | ,164 | ,007 |
| Bscinetworks | Correlation Coefficient | ,540** | ,382 | ,406* | ,563* |
| | Sig. (2-tailed) | ,001 | ,065 | ,044 | ,012 |
| Bsharerisk | Correlation Coefficient | ,496** | ,442* | ,500* | ,636** |
| | Sig. (2-tailed) | ,005 | ,035 | ,013 | ,003 |
| Bnewknow | Correlation Coefficient | ,424* | ,394 | ,331 | ,659** |
| | Sig. (2-tailed) | ,015 | ,057 | ,106 | ,002 |
| BnewIP | Correlation Coefficient | ,452** | ,473* | ,510** | ,525* |
| | Sig. (2-tailed) | ,009 | ,020 | ,009 | ,021 |
| BknowHow | Correlation Coefficient | ,576** | ,385 | ,386 | ,430 |
| | Sig. (2-tailed) | ,001 | ,063 | ,057 | ,066 |
| Bprojmanag | Correlation Coefficient | ,585** | ,423* | ,378 | ,387 |
| | Sig. (2-tailed) | ,000 | ,039 | ,063 | ,102 |
| Bprocesses | Correlation Coefficient | ,462** | ,456* | ,400* | ,663** |
| | Sig. (2-tailed) | ,008 | ,025 | ,048 | ,002 |
| Borganiz | Correlation Coefficient | ,389* | ,362 | ,290 | ,387 |
| | Sig. (2-tailed) | ,031 | ,089 | ,169 | ,113 |
| Bquality | Correlation Coefficient | ,403* | ,398 | ,297 | ,394 |
| | Sig. (2-tailed) | ,022 | ,054 | ,150 | ,095 |
| Bmotivation | Correlation Coefficient | ,433* | ,258 | ,234 | ,455 |
| | Sig. (2-tailed) | ,013 | ,224 | ,261 | ,050 |
| BoutA | Correlation Coefficient | ,168 | ,071 | ,035 | ,357 |
| | Sig. (2-tailed) | ,365 | ,749 | ,871 | ,145 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

| | | SqWorkersA | LogRevenuesA | RevenuesA | R&DA |
|---|---|---|---|---|---|
| Eequip | Correlation Coefficient | ,593** | ,534** | ,434* | ,504* |
| | Sig. (2-tailed) | ,000 | ,007 | ,030 | ,028 |
| Etest | Correlation Coefficient | ,600** | ,418* | ,431* | ,593** |
| | Sig. (2-tailed) | ,000 | ,042 | ,032 | ,007 |
| Etraining | Correlation Coefficient | ,485** | ,528** | ,444* | ,773** |
| | Sig. (2-tailed) | ,007 | ,008 | ,026 | ,000 |
| EvisitESO | Correlation Coefficient | ,565** | ,387 | ,428* | ,365 |
| | Sig. (2-tailed) | ,001 | ,062 | ,033 | ,125 |
| Ehiring | Correlation Coefficient | ,522** | ,652** | ,618** | ,769** |
| | Sig. (2-tailed) | ,003 | ,001 | ,001 | ,000 |
| Enewproc | Correlation Coefficient | ,547** | ,301 | ,238 | ,389 |
| | Sig. (2-tailed) | ,002 | ,153 | ,253 | ,100 |
| Ebibresearch | Correlation Coefficient | ,386* | ,538** | ,519** | ,453 |
| | Sig. (2-tailed) | ,039 | ,008 | ,009 | ,059 |
| Emktresearch | Correlation Coefficient | ,621** | ,281 | ,357 | ,382 |
| | Sig. (2-tailed) | ,000 | ,205 | ,095 | ,118 |
| Erd | Correlation Coefficient | ,604** | ,371 | ,435* | ,639** |
| | Sig. (2-tailed) | ,000 | ,075 | ,030 | ,003 |
| Rrevenue | Correlation Coefficient | ,403* | ,294 | ,253 | ,268 |
| | Sig. (2-tailed) | ,024 | ,174 | ,234 | ,267 |
| Rworkers | Correlation Coefficient | ,435* | ,552** | ,436* | ,522* |
| | Sig. (2-tailed) | ,014 | ,006 | ,033 | ,022 |
| Rrdexcellence | Correlation Coefficient | ,508** | ,463* | ,335 | ,465* |
| | Sig. (2-tailed) | ,004 | ,026 | ,109 | ,045 |
| Rinnovation | Correlation Coefficient | ,428* | ,330 | ,255 | ,568* |
| | Sig. (2-tailed) | ,018 | ,134 | ,240 | ,014 |
| Rnetvalue | Correlation Coefficient | ,511** | ,524* | ,441* | ,565* |
| | Sig. (2-tailed) | ,004 | ,012 | ,035 | ,015 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

One notices that all strong and significant correlations, highlighted in black rectangles and white lettering, are positive correlations. That is, organizations with high/low percentages of workers dedicated to astronomy, of revenues coming from astronomy or of astronomy R&D declared high/low levels of relevance in the pointed impacts. Tables 14, 15 and 19 of chapter 4.3.4.1 should be consulted in order to recall the distribution of respondents in these 3 variables.

7) Is there a memory effect in impact scoring?

A time variable was defined in order to check whether the order's year influences impact scoring. For each respondent one registered the year when ESO's order was sent. Categories ranged from 2001 to 2009. Respondents whose orders were spread throughout the period of construction of VLT were excluded. The accounting of years' orders resulted in 21 valid observations. The next step was to execute a one way ANOVA – Analysis of Variance of benefits, efforts and results applying the year as a categorical independent variable. This analysis did not find statistically significant differences between categories. The non parametric, independent samples Kruskal-Wallis test did not detect significant differences too. Once more, one suspects that the scarceness of observations for each category harmed this analysis.

8) Are benefits related between each other and between efforts and results? And about the relationships among efforts and between efforts and results? And about the relationships amongst results?

The path chosen to investigate this question was to check the Spearman rank order correlation between benefits, efforts and results. Following tables show the correlations found between these variables. Note that all strong (r > 0.5) and highly significant correlations (p < 0.01) are highlighted with black rectangles and white lettering. Red lines make the border between different types of benefits:

Benefits vs Benefits

| | | Bprofit | Boptimization | Bnewps | Bnewclients | Bunkclients | Bsimclients | Bindnetworks | Bmarketlearn | BrelationESO | Bimage |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Boptimization | r | ,359* | | | | | | | | | |
| | Sig. (2-tailed) | ,023 | | | | | | | | | |
| Bnewps | r | ,325* | ,476** | | | | | | | | |
| | Sig. (2-tailed) | ,043 | ,002 | | | | | | | | |
| Bnewclients | r | ,732** | ,273 | ,405* | | | | | | | |
| | Sig. (2-tailed) | ,000 | ,092 | ,012 | | | | | | | |
| Bunkclients | r | ,469** | ,254 | ,245 | ,725** | | | | | | |
| | Sig. (2-tailed) | ,002 | ,119 | ,138 | ,000 | | | | | | |
| Bsimclients | r | ,646** | ,172 | ,366* | ,724** | ,658** | | | | | |
| | Sig. (2-tailed) | ,000 | ,296 | ,024 | ,000 | ,000 | | | | | |
| Bindnetworks | r | ,332* | ,310 | ,416** | ,342* | ,232 | ,342* | | | | |
| | Sig. (2-tailed) | ,034 | ,052 | ,008 | ,031 | ,150 | ,031 | | | | |
| Bmarketlearn | r | ,232 | ,123 | ,550** | ,428** | ,392* | ,421** | ,321* | | | |
| | Sig. (2-tailed) | ,149 | ,457 | ,000 | ,007 | ,013 | ,008 | ,043 | | | |
| BrelationESO | r | ,478** | ,534** | ,447** | ,491** | ,367* | ,394* | ,301 | ,271 | | |
| | Sig. (2-tailed) | ,002 | ,000 | ,005 | ,002 | ,022 | ,013 | ,059 | ,095 | | |
| Bimage | r | ,608** | ,474** | ,599** | ,576** | ,498** | ,643** | ,411** | ,652** | ,427** | |
| | Sig. (2-tailed) | ,000 | ,002 | ,000 | ,000 | ,001 | ,000 | ,008 | ,000 | ,006 | |
| BttESO | r | ,303 | ,262 | ,518** | ,392* | ,151 | ,309 | ,553** | ,267 | ,325* | ,436** |
| | Sig. (2-tailed) | ,057 | ,108 | ,001 | ,014 | ,359 | ,056 | ,000 | ,101 | ,043 | ,005 |
| Brdlearn | r | ,326* | ,374* | ,670** | ,393* | ,136 | ,385* | ,284 | ,289 | ,380* | ,419** |
| | Sig. (2-tailed) | ,040 | ,019 | ,000 | ,013 | ,409 | ,016 | ,076 | ,074 | ,017 | ,007 |
| Bscinetworks | r | ,269 | ,366* | ,568** | ,298 | ,167 | ,360* | ,564** | ,306 | ,400* | ,421** |
| | Sig. (2-tailed) | ,089 | ,020 | ,000 | ,062 | ,303 | ,022 | ,000 | ,055 | ,011 | ,006 |
| Bsharerisk | r | ,114 | ,387* | ,408* | ,241 | ,005 | ,344* | ,416** | ,267 | ,305 | ,326* |
| | Sig. (2-tailed) | ,488 | ,016 | ,012 | ,145 | ,978 | ,034 | ,009 | ,105 | ,063 | ,043 |
| Bnewknow | r | ,273 | ,548** | ,844** | ,340* | ,249 | ,316* | ,443** | ,433** | ,433** | ,602** |
| | Sig. (2-tailed) | ,088 | ,000 | ,000 | ,034 | ,127 | ,050 | ,004 | ,006 | ,006 | ,000 |
| BnewIP | r | ,355* | ,335* | ,508** | ,268 | ,236 | ,376* | ,461** | ,246 | ,362* | ,442** |
| | Sig. (2-tailed) | ,023 | ,034 | ,001 | ,095 | ,143 | ,017 | ,002 | ,126 | ,022 | ,004 |
| BknowHow | r | ,410** | ,559** | ,681** | ,495** | ,305 | ,411** | ,411** | ,376* | ,456** | ,654** |
| | Sig. (2-tailed) | ,009 | ,000 | ,000 | ,001 | ,059 | ,009 | ,009 | ,018 | ,004 | ,000 |
| Bprojmanag | r | ,298 | ,497** | ,471** | ,310 | ,167 | ,317* | ,588** | ,287 | ,263 | ,604** |
| | Sig. (2-tailed) | ,058 | ,001 | ,002 | ,051 | ,303 | ,046 | ,000 | ,073 | ,101 | ,000 |
| Bprocesses | r | ,335* | ,764** | ,682** | ,376* | ,309 | ,304 | ,347* | ,363* | ,421** | ,606** |
| | Sig. (2-tailed) | ,032 | ,000 | ,000 | ,017 | ,052 | ,056 | ,026 | ,021 | ,007 | ,000 |
| Borganiz | r | ,407** | ,437** | ,647** | ,435** | ,204 | ,399* | ,596** | ,380* | ,174 | ,591** |
| | Sig. (2-tailed) | ,009 | ,005 | ,000 | ,006 | ,213 | ,012 | ,000 | ,017 | ,289 | ,000 |
| Bquality | r | ,547** | ,539** | ,571** | ,555** | ,392* | ,474** | ,704** | ,388* | ,314 | ,666** |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | ,000 | ,014 | ,002 | ,000 | ,015 | ,052 | ,000 |
| Bmotivation | r | ,100 | ,493** | ,606** | ,264 | ,164 | ,189 | ,202 | ,166 | ,370* | ,373* |
| | Sig. (2-tailed) | ,540 | ,001 | ,000 | ,105 | ,317 | ,249 | ,210 | ,312 | ,019 | ,018 |
| BoutA | r | ,407* | ,473** | ,499** | ,545** | ,338* | ,485** | ,355* | ,190 | ,293 | ,524** |
| | Sig. (2-tailed) | ,012 | ,004 | ,002 | ,000 | ,041 | ,002 | ,031 | ,268 | ,083 | ,001 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

| | | BttESO | Brdlearn | Bscinetworks | Bsharerisk | Bnewknow | BnewIP | BknowHow | Bprojmanag | Bprocesses | Borganiz | Bquality | Bmotivation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brdlearn | r | ,583** | | | | | | | | | | | |
| | Sig. (2-tailed) | ,000 | | | | | | | | | | | |
| Bscinetworks | r | ,658** | ,636** | | | | | | | | | | |
| | Sig. (2-tailed) | ,000 | ,000 | | | | | | | | | | |
| Bsharerisk | r | ,538** | ,618** | ,721** | | | | | | | | | |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | | | | | | | | | |
| Bnewknow | r | ,651** | ,675** | ,662** | ,574** | | | | | | | | |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | ,000 | | | | | | | | |
| BnewIP | r | ,465** | ,490** | ,447** | ,371* | ,613** | | | | | | | |
| | Sig. (2-tailed) | ,003 | ,001 | ,003 | ,020 | ,000 | | | | | | | |
| BknowHow | r | ,595** | ,737** | ,615** | ,568** | ,735** | ,678** | | | | | | |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | ,000 | ,000 | ,000 | | | | | | |
| Bprojmanag | r | ,627** | ,442** | ,552** | ,560** | ,634** | ,658** | ,770** | | | | | |
| | Sig. (2-tailed) | ,000 | ,004 | ,000 | ,000 | ,000 | ,000 | ,000 | | | | | |
| Bprocesses | r | ,478** | ,568** | ,560** | ,503** | ,810** | ,568** | ,745** | ,727** | | | | |
| | Sig. (2-tailed) | ,002 | ,000 | ,000 | ,001 | ,000 | ,000 | ,000 | ,000 | | | | |
| Borganiz | r | ,582** | ,471** | ,563** | ,467** | ,560** | ,558** | ,677** | ,818** | ,725** | | | |
| | Sig. (2-tailed) | ,000 | ,002 | ,000 | ,003 | ,000 | ,000 | ,000 | ,000 | ,000 | | | |
| Bquality | r | ,567** | ,398* | ,553** | ,441** | ,615** | ,584** | ,633** | ,781** | ,713** | ,877** | | |
| | Sig. (2-tailed) | ,000 | ,012 | ,000 | ,006 | ,000 | ,000 | ,000 | ,000 | ,000 | ,000 | | |
| Bmotivation | r | ,541** | ,541** | ,474** | ,377* | ,619** | ,428** | ,653** | ,643** | ,692** | ,567** | ,378* | |
| | Sig. (2-tailed) | ,000 | ,000 | ,002 | ,020 | ,000 | ,006 | ,000 | ,000 | ,000 | ,000 | ,018 | |
| BoutA | r | ,526** | ,514** | ,546** | ,608** | ,531** | ,265 | ,570** | ,473** | ,523** | ,520** | ,538** | ,419* |
| | Sig. (2-tailed) | ,001 | ,001 | ,000 | ,000 | ,001 | ,113 | ,000 | ,003 | ,001 | ,001 | ,001 | ,011 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

It is easy to verify that all correlations between benefits are positive. It is noticeable that the biggest number of correlations of high statistical significance occurred, in average, in organizational benefits. That is, their scores are strongly associated with the scores of most of benefits, including benefits of the same type. On the other hand, the smallest number of correlations appeared to be associated in average with marketing related benefits.

A relevant observation is the high degree of inter-correlation between benefits. This indicates that the various benefits tend to occur together: a supplier which perceives one type of benefit from its participation in Astronomy projects, is likely to perceive other types of benefits from the same relationship.

The strong correlations between various benefits propel the will to know how strong the associations between benefits actually are as a group. That's the spirit of the next and last question (question number 9), to be explored later on.

Efforts vs Efforts

| | | Eequip | Etest | Etraining | EvisitESO | Ehiring | Enewproc | Ebibresearch | Emktresearch |
|---|---|---|---|---|---|---|---|---|---|
| Etest | r | ,755** | | | | | | | |
| | Sig. (2-tailed) | ,000 | | | | | | | |
| Etraining | r | ,631** | ,732** | | | | | | |
| | Sig. (2-tailed) | ,000 | ,000 | | | | | | |
| EvisitESO | r | ,351* | ,447** | ,492** | | | | | |
| | Sig. (2-tailed) | ,033 | ,006 | ,002 | | | | | |
| Ehiring | r | ,633** | ,656** | ,824** | ,542** | | | | |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | ,001 | | | | |
| Enewproc | r | ,577** | ,721** | ,667** | ,557** | ,645** | | | |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | ,000 | ,000 | | | |
| Ebibresearch | r | ,466** | ,575** | ,637** | ,523** | ,770** | ,592** | | |
| | Sig. (2-tailed) | ,005 | ,000 | ,000 | ,001 | ,000 | ,000 | | |
| Emktresearch | r | ,514** | ,527** | ,357* | ,558** | ,476** | ,371* | ,527** | |
| | Sig. (2-tailed) | ,002 | ,001 | ,038 | ,001 | ,004 | ,031 | ,001 | |
| Erd | r | ,440** | ,762** | ,606** | ,644** | ,642** | ,687** | ,626** | ,683** |
| | Sig. (2-tailed) | ,007 | ,000 | ,000 | ,000 | ,000 | ,000 | ,000 | ,000 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Like in benefits, one underlines the high degree of inter-correlation between efforts.

## Results vs Results

| | | Rrevenue | Rworkers | Rrdexcellence | Rinnovation |
|---|---|---|---|---|---|
| Rworkers | r | ,704** | | | |
| | Sig. (2-tailed) | ,000 | | | |
| Rrdexcellence | r | ,714** | ,782** | | |
| | Sig. (2-tailed) | ,000 | ,000 | | |
| Rinnovation | r | ,670** | ,720** | ,800** | |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | |
| Rnetvalue | r | ,708** | ,789** | ,811** | ,818** |
| | Sig. (2-tailed) | ,000 | ,000 | ,000 | ,000 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

All results are highly correlated between themselves.

## Efforts vs Benefits

| | | Eequip | Etest | Etraining | EvisitESO | Ehiring | Enewproc | Ebibresearch | Emktresearch | Erd |
|---|---|---|---|---|---|---|---|---|---|---|
| Bprofit | r | ,314 | ,408* | ,331* | ,272 | ,252 | ,481** | ,109 | ,189 | ,421* |
| | Sig. (2-tailed) | ,058 | ,012 | ,049 | ,103 | ,132 | ,003 | ,532 | ,283 | ,010 |
| Boptimization | r | ,325 | ,599** | ,564** | ,518** | ,523** | ,536** | ,405* | ,236 | ,545** |
| | Sig. (2-tailed) | ,053 | ,000 | ,000 | ,001 | ,001 | ,001 | ,017 | ,186 | ,001 |
| Bnewps | r | ,294 | ,476** | ,558** | ,523** | ,432** | ,414* | ,450** | ,527** | ,694** |
| | Sig. (2-tailed) | ,086 | ,004 | ,001 | ,001 | ,010 | ,015 | ,009 | ,002 | ,000 |
| Bnewclients | r | ,375* | ,313 | ,315 | ,297 | ,192 | ,521** | ,141 | ,321 | ,382* |
| | Sig. (2-tailed) | ,024 | ,063 | ,066 | ,079 | ,263 | ,001 | ,428 | ,069 | ,024 |
| Bunkclients | r | ,273 | ,191 | ,223 | ,087 | ,208 | ,299 | ,192 | ,187 | ,124 |
| | Sig. (2-tailed) | ,107 | ,265 | ,198 | ,616 | ,224 | ,081 | ,276 | ,297 | ,478 |
| Bsimclients | r | ,355* | ,326 | ,415* | ,282 | ,333* | ,418* | ,292 | ,445** | ,402* |
| | Sig. (2-tailed) | ,034 | ,053 | ,013 | ,096 | ,047 | ,013 | ,094 | ,009 | ,017 |
| Bindnetworks | r | ,332* | ,228 | ,317 | ,402* | ,409* | ,331* | ,371* | ,501** | ,354* |
| | Sig. (2-tailed) | ,044 | ,175 | ,060 | ,014 | ,012 | ,049 | ,028 | ,003 | ,034 |
| Bmarketlearn | r | ,243 | ,182 | ,041 | ,313 | ,018 | ,141 | ,038 | ,490** | ,340* |
| | Sig. (2-tailed) | ,154 | ,287 | ,817 | ,063 | ,917 | ,420 | ,832 | ,004 | ,046 |
| BrelationESO | r | ,459** | ,656** | ,672** | ,563** | ,501** | ,460** | ,454** | ,423* | ,563** |
| | Sig. (2-tailed) | ,004 | ,000 | ,000 | ,000 | ,002 | ,005 | ,006 | ,013 | ,000 |
| Bimage | r | ,391* | ,375* | ,347* | ,494** | ,355* | ,438** | ,198 | ,416* | ,514** |
| | Sig. (2-tailed) | ,017 | ,022 | ,038 | ,002 | ,031 | ,008 | ,253 | ,014 | ,001 |
| BttESO | r | ,499** | ,392* | ,589** | ,442** | ,608** | ,529** | ,440** | ,390* | ,503** |
| | Sig. (2-tailed) | ,002 | ,018 | ,000 | ,007 | ,000 | ,001 | ,009 | ,025 | ,002 |
| Brdlearn | r | ,241 | ,504** | ,494** | ,552** | ,493** | ,593** | ,616** | ,586** | ,820** |
| | Sig. (2-tailed) | ,157 | ,002 | ,003 | ,000 | ,002 | ,000 | ,000 | ,000 | ,000 |
| Bscinetworks | r | ,490** | ,608** | ,527** | ,521** | ,528** | ,508** | ,475** | ,697** | ,755** |
| | Sig. (2-tailed) | ,002 | ,000 | ,001 | ,001 | ,001 | ,002 | ,004 | ,000 | ,000 |
| Bsharerisk | r | ,392* | ,532** | ,460** | ,546** | ,551** | ,425* | ,433* | ,749** | ,758** |
| | Sig. (2-tailed) | ,020 | ,001 | ,006 | ,001 | ,001 | ,012 | ,012 | ,000 | ,000 |
| Bnewknow | r | ,392* | ,520** | ,560** | ,571** | ,570** | ,504** | ,488** | ,583** | ,766** |
| | Sig. (2-tailed) | ,018 | ,001 | ,000 | ,000 | ,000 | ,002 | ,003 | ,000 | ,000 |
| BnewIP | r | ,416* | ,521** | ,483** | ,449** | ,670** | ,502** | ,699** | ,618** | ,725** |
| | Sig. (2-tailed) | ,011 | ,001 | ,003 | ,005 | ,000 | ,002 | ,000 | ,000 | ,000 |
| BknowHow | r | ,492** | ,613** | ,551** | ,593** | ,593** | ,707** | ,560** | ,610** | ,787** |
| | Sig. (2-tailed) | ,002 | ,000 | ,001 | ,000 | ,000 | ,000 | ,001 | ,000 | ,000 |
| Bprojmanag | r | ,496** | ,469** | ,454** | ,467** | ,619** | ,615** | ,399* | ,467** | ,592** |
| | Sig. (2-tailed) | ,002 | ,003 | ,005 | ,004 | ,000 | ,000 | ,017 | ,005 | ,000 |
| Bprocesses | r | ,369* | ,611** | ,578** | ,508** | ,564** | ,650** | ,499** | ,445** | ,742** |
| | Sig. (2-tailed) | ,025 | ,000 | ,000 | ,001 | ,000 | ,000 | ,002 | ,008 | ,000 |
| Borganiz | r | ,333* | ,342* | ,446** | ,416* | ,514** | ,546** | ,356* | ,391* | ,544** |
| | Sig. (2-tailed) | ,047 | ,041 | ,007 | ,012 | ,001 | ,001 | ,039 | ,025 | ,001 |
| Bquality | r | ,434** | ,431** | ,449** | ,482** | ,566** | ,605** | ,361* | ,424* | ,538** |
| | Sig. (2-tailed) | ,008 | ,009 | ,007 | ,003 | ,000 | ,000 | ,036 | ,014 | ,001 |
| Bmotivation | r | ,329* | ,468** | ,662** | ,447** | ,574** | ,552** | ,456** | ,259 | ,579** |
| | Sig. (2-tailed) | ,047 | ,003 | ,000 | ,006 | ,000 | ,000 | ,006 | ,140 | ,000 |
| BoutA | r | ,185 | ,271 | ,412* | ,389* | ,371* | ,456** | ,298 | ,389* | ,536** |
| | Sig. (2-tailed) | ,294 | ,122 | ,017 | ,023 | ,031 | ,008 | ,098 | ,030 | ,001 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

While analysing previous table, one finds that R&D effort presents the biggest number of high statistical significance correlations with benefits. Curiously, as observed in chapter 4.3.4.2.4, R&D was the most recognized effort by respondents. Notice the high correlations between R&D effort and all organizational benefits. The same happens in correlations between R&D effort and R&D / technological benefits.

Benefits vs Results

| | | Rrevenue | Rworkers | Rrdexcellence | Rinnovation | Rnetvalue |
|---|---|---|---|---|---|---|
| Bprofit | r | ,416** | ,333* | ,275 | ,181 | ,204 |
| | Sig. (2-tailed) | ,008 | ,038 | ,099 | ,282 | ,219 |
| Boptimization | r | ,333* | ,274 | ,298 | ,329 | ,257 |
| | Sig. (2-tailed) | ,041 | ,097 | ,078 | ,050 | ,124 |
| Bnewps | r | ,276 | ,268 | ,385* | ,264 | ,218 |
| | Sig. (2-tailed) | ,098 | ,109 | ,022 | ,125 | ,202 |
| Bnewclients | r | ,277 | ,160 | ,338* | ,118 | ,085 |
| | Sig. (2-tailed) | ,092 | ,336 | ,044 | ,493 | ,617 |
| Bunkclients | r | ,043 | -,073 | ,052 | ,070 | -,133 |
| | Sig. (2-tailed) | ,796 | ,664 | ,763 | ,685 | ,432 |
| Bsimclients | r | ,338* | ,243 | ,342* | ,213 | ,161 |
| | Sig. (2-tailed) | ,038 | ,141 | ,041 | ,212 | ,341 |
| Bindnetworks | r | ,501** | ,394* | ,311 | ,340* | ,328* |
| | Sig. (2-tailed) | ,001 | ,013 | ,061 | ,040 | ,044 |
| Bmarketlearn | r | ,129 | ,020 | ,291 | ,123 | ,049 |
| | Sig. (2-tailed) | ,440 | ,905 | ,085 | ,476 | ,774 |
| BrelationESO | r | ,363* | ,297 | ,348* | ,272 | ,384* |
| | Sig. (2-tailed) | ,025 | ,071 | ,035 | ,103 | ,019 |
| Bimage | r | ,449** | ,239 | ,437** | ,333* | ,228 |
| | Sig. (2-tailed) | ,004 | ,143 | ,007 | ,044 | ,169 |
| BttESO | r | ,401* | ,556** | ,481** | ,327 | ,387* |
| | Sig. (2-tailed) | ,013 | ,000 | ,003 | ,052 | ,018 |
| Brdlearn | r | ,329* | ,216 | ,440** | ,242 | ,245 |
| | Sig. (2-tailed) | ,044 | ,193 | ,006 | ,155 | ,145 |
| Bscinetworks | r | ,462** | ,418** | ,462** | ,442** | ,388* |
| | Sig. (2-tailed) | ,003 | ,008 | ,004 | ,006 | ,016 |
| Bsharerisk | r | ,518** | ,502** | ,606** | ,433** | ,450** |
| | Sig. (2-tailed) | ,001 | ,001 | ,000 | ,008 | ,005 |
| Bnewknow | r | ,411* | ,459** | ,517** | ,462** | ,456** |
| | Sig. (2-tailed) | ,010 | ,004 | ,001 | ,005 | ,005 |
| BnewIP | r | ,290 | ,370* | ,266 | ,271 | ,287 |
| | Sig. (2-tailed) | ,073 | ,021 | ,111 | ,105 | ,081 |
| BknowHow | r | ,284 | ,286 | ,451** | ,299 | ,249 |
| | Sig. (2-tailed) | ,084 | ,082 | ,005 | ,077 | ,137 |
| Bprojmanag | r | ,426** | ,483** | ,535** | ,479** | ,393* |
| | Sig. (2-tailed) | ,007 | ,002 | ,001 | ,003 | ,015 |
| Bprocesses | r | ,330* | ,362* | ,449** | ,404* | ,313 |
| | Sig. (2-tailed) | ,040 | ,024 | ,005 | ,013 | ,056 |
| Borganiz | r | ,394* | ,405* | ,444** | ,323 | ,255 |
| | Sig. (2-tailed) | ,014 | ,012 | ,007 | ,055 | ,127 |
| Bquality | r | ,598** | ,557** | ,539** | ,497** | ,407* |
| | Sig. (2-tailed) | ,000 | ,000 | ,001 | ,002 | ,013 |
| Bmotivation | r | ,174 | ,176 | ,353* | ,249 | ,260 |
| | Sig. (2-tailed) | ,295 | ,290 | ,032 | ,137 | ,120 |
| BoutA | r | ,310 | ,159 | ,298 | ,047 | ,025 |
| | Sig. (2-tailed) | ,070 | ,362 | ,092 | ,796 | ,888 |

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Regarding correlations between results and benefits, one finds few statistically significant outputs.

Efforts vs Results

| | | Rrevenue | Rworkers | Rrdexcellence | Rinnovation | Rnetvalue |
|---|---|---|---|---|---|---|
| Eequip | r | ,337* | ,526** | ,541** | ,588** | ,570** |
| | Sig. (2-tailed) | ,044 | ,001 | ,001 | ,000 | ,000 |
| Etest | r | ,431** | ,502** | ,510** | ,608** | ,558** |
| | Sig. (2-tailed) | ,009 | ,002 | ,002 | ,000 | ,000 |
| Etraining | r | ,326 | ,478** | ,454** | ,432* | ,506** |
| | Sig. (2-tailed) | ,056 | ,004 | ,007 | ,011 | ,002 |
| EvisitESO | r | ,510** | ,327 | ,467** | ,368* | ,461** |
| | Sig. (2-tailed) | ,001 | ,051 | ,005 | ,030 | ,005 |
| Ehiring | r | ,411* | ,556** | ,494** | ,453** | ,550** |
| | Sig. (2-tailed) | ,013 | ,000 | ,003 | ,006 | ,001 |
| Enewproc | r | ,331 | ,366* | ,464** | ,485** | ,453** |
| | Sig. (2-tailed) | ,052 | ,030 | ,006 | ,004 | ,007 |
| Ebibresearch | r | ,316 | ,314 | ,277 | ,288 | ,430* |
| | Sig. (2-tailed) | ,069 | ,070 | ,119 | ,104 | ,013 |
| Emktresearch | r | ,303 | ,276 | ,348 | ,233 | ,291 |
| | Sig. (2-tailed) | ,086 | ,120 | ,051 | ,199 | ,107 |
| Erd | r | ,444** | ,371* | ,489** | ,422* | ,475** |
| | Sig. (2-tailed) | ,007 | ,028 | ,003 | ,013 | ,005 |

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Concerning relationships between efforts and results, one calls attention to the considerable number of strong, statistically significant linear associations between the scores attributed to investment in new process equipment and the scores attributed to results. The same happens between the effort related with investment in new test equipment and results. Innovation/competitiveness is the result with strongest linear relation with these two efforts.

9) If benefits are related between each other, do they obey to an underlying structure? Is it possible to extract it?

The strong correlations between various benefits sparked the curiosity of knowing how strong the associations between benefits actually are as a group. A factor analysis between the various benefits is carried out in order to try to uncover the main drivers of grouped benefits' variance.

Factor analysis is a data reduction technique (Pallant, 2005). This technique selects subsets (named factors) of variables from a larger set of variables, based on linear combinations of the original variables and on which original variables have the highest correlations with these factors.

One main requisite for factor analysis is the normality of distributions of variables. One already stated that benefits do not follow a normal distribution. Other requisite is the presence of a strong intercorrelation between variables ($r > 0.3$) (Pallant, 2005), a requisite that is respected by the benefits' set of variables. A third requisite is related with sample size. A rule of thumb is that there should be 5 cases (observations) for each variable to be analyzed (Pallant, 2005). If one follows this rule of thumb, in the present case, the sample should reach at least 23 benefits X 5 = 115 observations, a number much bigger than the 41 observations one got. Despite this adversity one decided to go on with factor analysis. Even if results are not statistically robust they may bring clues about structural benefits. That is, benefits that drive the variance of benefits as a group.

Prior to performing this exercise, the suitability of data for factor analysis was assessed (assuming that data obeyed to the referred requisites). The Kaiser-Meyer-Oklin value was 0.801, exceeding the recommended value of 0.6 (Pallant, 2005) and the Barlett's Test of Sphericity reached statistical significance, supporting the factorability of the correlation matrix.

Note that while performing factor analysis one asked SPSS to replace missing values with the mean of each variable under appreciation.

The chosen extraction method, principal component analysis, revealed the presence of 5 components (factors) with eigenvalues exceeding 1, explaining 48.87%, 10.45%, 6.29%, 5.6% and 4.54% of the variance respectively. An inspection of the scree graphic revealed a break after the second factor. One decided to retain two factors for further investigation.

After several iterations one reached the conclusion that the most suited rotation method was oblique rotation (oblimin) since factors are correlated ($r = 0.477$). Next, one may compare total variance explained after the application of different rotation methods:

**Total Variance Explained**

| | Rotation Sums of Squared Loadings* | | | Rotation Sums of Squared Loadings** |
|---|---|---|---|---|
| Component | Total | % of Variance | Cumulative % | Total |
| 1 | 8.841 | 38.44 | 38.437 | 10.665 |
| 2 | 4.803 | 20.882 | 59.319 | 6.555 |

* Rotation method: Varimax with Kaiser Normalization
** Rotation method: Oblimin with Kaiser normalization

The summary results of the factor analysis after applying an oblimin rotation are shown below. The factors cover at least 60% of the total calculated variance. The highest loading benefits in the two different factors are signaled with black rectangle and white lettering. Original variables are given in the first column. The reduced new variables are marked as Component 1 and Component 2:

**Pattern Matrix**

| | Component | |
|---|---|---|
| | 1 | 2 |
| Bnewknow | 0.877 | |
| Bprojmanag | 0.87 | |
| Bprocesses | 0.834 | |
| Bscinetworks | 0.825 | |
| Bmotivation | 0.824 | |
| BknowHow | 0.82 | |
| Bsharerisk | 0.788 | |
| BttESO | 0.775 | |
| Borganiz | 0.767 | |
| Bnewps | 0.735 | |
| Brdlearn | 0.699 | |
| Bquality | 0.69 | |
| Boptimization | 0.656 | |
| BnewIP | 0.565 | |
| Bindnetworks | 0.55 | |
| BoutA | 0.492 | |
| Bunkclients | | 0.871 |
| Bsimclients | | 0.865 |
| Bnewclients | | 0.861 |
| Bprofit | | 0.821 |
| Bimage | 0.357 | 0.597 |
| Bmarketlearn | | 0.427 |
| BrelationESO | 0.348 | 0.403 |

This exercise did not reveal the underlying structure of benefits. Nevertheless, it was useful to show that the highest loading benefits in factor 1 are associated with organizational benefits. By its turn, factor 2 is linked to commercial / marketing related benefits.