

MODES OF INNOVATION & UNCERTAINTIES IN THE CAPITAL GOODS INDUSTRY¹

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Abstract

Product innovation is a subtle process, frequently leading to shifts in the competitiveness of firms. Developing products in an environment undergoing technological change is given to frequent failure, even in well-established and sophisticated organizations. In order to tackle competitiveness and to deal with innovation uncertainty, firms develop diverse innovation processes. Two modes of innovation are suggested in recent literature: 1) Science, Technology and Innovation (STI) mode, which is based on the production and use of codified scientific and technical knowledge; and 2) Doing, Using and Interacting (DUI) mode, which relies on informal processes of learning and experience-based know-how.

In this paper we analyse product innovation at firm level. We perform an exploratory analysis in four leading equipment and machinery producers from the Aveiro region, in Portugal. Doing so, we explore the main features of the capital goods' industry with implications for innovation, and analyse the dominant uncertainties associated to the innovation process. and modes of innovation. Key findings include the complete absence of DUI mode in the cases studied, and even a low learning characteristic in one company. The paper concludes by considering the implications for firms' competitiveness and for innovation policy.

EAEPE research area : [D] Innovation and Technological Change

Keywords: modes of innovation, uncertainties, R&D, capital goods, SME

JEL Codes: O32 - Management of Technological Innovation and R&D

L6 - Industry Studies: Manufacturing

¹ This research has been conducted under the research project 'Enterprise of the Future' financed by the *Instituto de Investigação* from the University of Aveiro.

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1 Introduction

Manufacturing of capital goods (machinery and equipment) is included in the broad Mechanical Engineering (ME) industry, one of the largest industrial sector in the European Union (EU). Accordingly to recent data on the European industry (see Table 1), the ME sector corresponds to 7 to 8 per cent of the EU (15) manufacturing in terms of production value, employees and value added (ref?). Value-added per person employed is lower in machinery and equipment than in total manufacturing, the only exceptions being Germany, Italy and Portugal (Eurostat, 2003). The EU mechanical engineering industry, is highly export oriented, accounting to over 36 percent of the EU manufacturing exports. (DG Enterprise, 2006a). The EU is the world's largest producer and exporter of mechanical equipment.

Germany is the leading European producer and exporter of ME. Portugal by contrast, has one of the smallest ME sector within the EU, and falling slightly in recent years (as well as in Italy and Ireland).

Table 1. Figures of the ME Sector in Europe and Portugal

Countries	Production		Exports		Value Added		No. employees		R&D
	Million €	% total Manuf. Industry	Million €	% Total Manuf. Industry	Million €	% total Manuf. Industry	1000 units	% total Manuf. Industry	% Intensity
EU (15)	360,086	7	131,517	36	124,668	8	2,244	7	2.3
Portugal	1,899	n.a.	1,236	n.a.	750	¹⁾ 5	26	5	0.5

Portugal data refers to 2005, except 1) that refers to 2000. Sources: DG Enterprise (2006b) and Eurostat (2003). EU data refers to 2003. Source: DG Enterprise (2004).

The relevance and importance of the ME sector is well beyond the figures presented in Table 1. According to several studies (EnginEurope, 2007; DG Enterprise, 2004; IFO, 1997) ME is a highly innovative and globally active industry, where small and medium enterprises (SME), mostly family owned, predominate. This sector plays a key role in the economy as supplier of capital goods for all other sectors. Hence it determines productivity and acts as catalyst for technological innovation. Thus, on the one hand, the performance of all industries is dependent on a highly efficient ME sector. On the other had, the industries included in the sector are particularly vulnerable to cyclical fluctuations in economic activity. Not only are

their main customers other manufacturers but a large part of their sales is directly linked to investment which tends to vary much more than in proportion to activity.

Established producers in Europe face competitive threats from within and from outside Europe. Competition with mechanical equipment supplied from new Member States poses a competitive threat to traditional European producers. The challenges are probably greater for countries like Spain and Portugal who are further away from the centre of gravity of the EU market, supply overlapping product ranges, occupy an overlapping market position, are not far ahead in technology and still compete on below EU-average labour costs (DG Enterprise, 2004).

According to reports mentioned above, the competitiveness of the European firms in this sector rests mainly on the scale of the market, on the ability to solve customers' problems, on the possession of key know-how, and on product quality. Not surprisingly, there is high degree of specialization, and many firms are niche players. After describing the ME sector in general, as the key supplier of capital goods to all other industries and sectors, this paper focused on the limited and specific case of capital goods companies belonging to NACE "SubSection DK.29: Manufacture of machinery and equipment n.e.c." Indeed, in a sectoral classification suggested by OCDE applied by INE (2007), one can distinguish groups of industries according to their main factor of competitiveness, and the capital goods subsector with NACE.29 in particular is described as an industry where the capacity to differentiate products is the main factor of competitiveness.

These factors contribute to and require a competitive and efficient innovation process. Producers of capital goods face high levels of uncertainty, namely in terms of specification, demand, and duration of processes and lead-times, that may difficult the whole planning and control of the innovation process. Hence, it is relevant to study those uncertainty factors and analyze how firms cope with them. Therefore, our focus is on the mode of innovation with relation to risk and uncertainty in the innovation process. In this paper we analyse the present setting regarding the innovation process in four competitive firms located in the Portuguese region of Aveiro.

The paper is organised as follows. The next section explores the theoretical aspects that frame the empirical analysis. It focuses on industries classifications, risk and uncertainties

taxonomies and finally, on modes of innovation. The empirical analysis is conducted in section 3. In section 4 we conclude and discuss our findings,

2 Theoretical framework

2.1 Industries' classifications

The IFO Institut (1997) classifies the companies in the ME sector based on the differences in the market. The authors have discriminated three categories of market type: i) Series product supply; ii) Customized engineering and plant supply; and iii) Key Know-how supply. In the Series product supply, typically the products are not specified for specific customers. Therefore, engineering and design input is not necessary, which may be different with the Customized engineering and plant supply where key parts of the supply have to be developed or reengineered to fulfill the demand. What distinguishes Key know-how supply is that it requires a specific know-how that usually is not freely available, which may be the state of the art in a niche or specific technological solutions.

Sari (1981) classified companies along a continuum in terms of production control situations, their characteristics in relation to the market situation and the nature of the customer orders, and the role they play in the production process: Make to stock (MTS), Assemble to stock (ATO), Make to order (MTO) and Engineer to order (ETO). While MTS produces finished goods from raw materials and semi-finished goods held in inventory, independent of the customer orders, and ATO produces previously defined semi-finished goods and the subsequent assembly of these parts to produce finished goods after the receipt of a customer order, in MTO production of finished goods are done only after the receipt of a customer order, and in ETO type the engineering and production of custom-built products are based upon a customer order.

As this sector is dominated by SME, it is also important to make a distinction between the different types of SME present in the economic environment according to the innovative level. We use Hoffman et al.'s (1998) taxonomy, i.e. Superstar companies, New technology-based firms, Specialized supplier, and Supplier dominated. Superstar companies are small businesses that have benefited from the high levels of diffusion of radical innovations in the

fields of robust technological trajectories such as semi-conductors and software. New technology-based firms are a recent phenomenon and involve small enterprises born thanks to spontaneous spin-off from larger companies and research laboratories, above all in the electronics, software and biotechnology sectors. Specialized supplier, these are traditional businesses focused on the design, development and production of specialized productive input, in the form of machinery, instrumentation, components and software, and capable of interacting proactively and in conjunction with their technical client. Finally many small businesses come within the category of the Supplier dominated. These businesses strongly depend for innovation on their suppliers and clients.

These classification types (sumarised in table 2) are used in the empirical evidence (section 3) and help to understand the uncertainties faced by these companies and their innovation mode, and also may help determining adequate strategies for these particular company types.

Table 2. Summary of industries' classifications

Production control situation and nature of customer order (Sari)	Market type specialization (IFO)	SME type by innovative level (Hoffman)
Make to stock (MTS)	Series Product supply	Superstar companies
Assemble to stock (ATO)	Customized Engineering and Plant supply	New technology-based firms
Make to order (MTO)	Key Know-how supply	Specialized supplier
Engineer to order (ETO)		Supplier dominated

2.2 Risk and uncertainty taxonomy

Producers of capital goods face substantial financial and commercial risks, and uncertainty in terms of specification, demand, and duration of processes and lead-times (Hicks et al. 2000). These uncertainty factors may constraint companies innovative capability, and make difficult the whole planning and control of the innovation process. We analyse those uncertainties and also the approaches used by firms to cope with them.

De Meyer et al. (2006) follow the common definition of risk as the implications of the existence of significant uncertainty about the level of project performance achievable, and is

seen as having the two components of probability of occurrence and the consequences/impacts of occurrence. While the details differ, all established project risk management methods recommend actions to identify risks beforehand, to classify and prioritize them according to probability and impact, to manage them with a collection of preventive, mitigating and contingent actions that are triggered by risk occurrence, and to embed these actions into a system of documentation and knowledge transfer to other projects. De Meyer et al. (2006) observed that the established risk management methods enable us to handle mainly the foreseeable risks and what we will call residual risk or variations, that is the small occurrences that one cannot plan for. However, the authors suggested that current risk management methods does not enable us to handle the unknown or unforeseeable influences, or what engineers refer to as ‘unknown unknowns’ or ‘unk-unks’.

Pich et al. (2002) concluded that there are fundamentally three approaches to managing risk in projects, namely, (i) instructionism, planning and then execution of the plan, (ii) learning, and (iii) selectionism, as explained below:

- Instructionism, in this case contingency plans are drawn up as instructions for the project management team to follow, and contingencies and flexibility are pre-planned and then only “triggered”. This approach works fine as long as all risks are identified and their impact on the project can be predicted.
- Learning ‘as you go’ involves a flexible adjustment of the project approach to the changing environment as it occurs, making adjustments based on information obtained during the development process, as opposed to at planned trigger points.
- Selectionism refers to generating variety (via independent parallel trials) and then choosing the solution with the most favorable outcome.

Current risk management methods for project management coincide to a large extent with instructionism. Existing project management approaches advocate partially conflicting approaches to the project team, such as the need to execute planned tasks, trigger preplanned contingencies based on unfolding events, experiment and learn, or try out multiple solutions simultaneously. While all of these approaches encompass the idea of uncertainty, it is important to analyse on the one hand, which are the current practices in companies and how project managers perceive different risk and uncertainties in the projects, and, on the other

hand, which different approaches they choose and when to prevent project failures like budget and schedule overruns, compromised performance, and missed opportunities.

Table 3. Summary of approaches to managing risk

	Optimization	Selectionism
Learning	<p>Learning Strategies</p> <p>Learning: scanning for 'unk-unks', then new, original problem solving</p> <ul style="list-style-type: none"> • Learn about unforeseen uncertainty • Learn about complex causal effects of actions 	<p>Learning and Selectionism</p> <ul style="list-style-type: none"> • A project may be stopped based on favorable progress of another candidate • Exchange information among candidates to increase learning: candidate projects become complements
No Learning	<p>Instructionist Strategy</p> <p>Decision adequate causal mapping</p> <ul style="list-style-type: none"> • include buffers in plan • plan project <i>policy</i> • monitor project influence <i>signals</i> • trigger <i>contingent action</i> 	<p>Selectionist Strategy</p> <p>Launch multiple "candidate" project efforts and choose the best one</p> <ul style="list-style-type: none"> • Hedge against unanticipated events • Explore larger part of complex action space to find better solution

Source: Adapted from Pich et al. 2002.

2.3 Modes of innovation

According to the results of a study conducted by Jensen et al. (2007) in Denmark, there is a tension between two ideal modes of learning and innovation, both at the level of the firm and of the whole economy. One mode, called Science, Technology and Innovation (STI), is based on the production and use of codified scientific and technical knowledge. A second mode is more informal and experienced-based, and learning is based on Doing, Using and Interacting (DUI). The main objective of this framework has been to demonstrate the usefulness of the conceptual distinction between the DUI- and STI-modes of innovation and to demonstrate that these concepts can be made operational.

These different modes of innovation are connected with different types of knowledge. Jensen et al. (2007) apply the distinction between implicit versus explicit knowledge; local versus global; and 'know-what', 'know-why' versus 'know-how' and 'know-who' types of knowledge. The distinction between implicit and explicit knowledge (or rather tacit and codified elements of knowledge) corresponds to the difference between experience-based knowledge that is not written, mobilized by informal interaction and communication, by communities of practice and between organizations, against the written and codified knowledge

that can be passed to others who can read and understand the specific language. And by making explicit what is implicit may improve the capacity to share and generalize knowledge, thus making global knowledge what is local.

But what is referred to are two ideal types that appear in a much more mixed form in real life. Moreover, it is argued that the zone in between and the complementarities between the tacit and codified elements of knowledge are often what matters most. The same is applied for the distinction between local and global knowledge, between the two modes of innovation and their relation to the different forms of knowledge. Linking these dichotomies to a more elaborate set of distinctions, it is argued that ‘know-what’ and ‘know-why’ corresponds to types of knowledge that may be obtained through reading books or attending lectures, while ‘know-how’ and ‘know-who’ are acquired more with practical experience.

While the STI-mode gives high priority to the production of ‘know-why’ type of knowledge, where ‘know-what’ is often a prerequisite, using and further developing explicit and global knowledge. DUI-mode will typically produce ‘know-how’ and ‘know-who’, which is tacit and often highly localized.

Following the results of the study conducted by Jensen et al. (2007), companies can be generally classified in four different types of learning organizations, resulting from identifying companies implementing one particular mode of innovation or the other, implementing a mix of both, or even neither of them: i) the DUI learning organization; ii) the STI learning organization; iii) the DUI/STI learning organization and, iv) the low learning organization. The authors suggest that there is a tension between the two modes of learning, and that firms combining both modes, in form of DUI/STI learning type, are more likely to innovate new products or service than those relying primarily on one mode or another. This may have important implications for benchmarking innovation systems and for innovation policy, which will be further expanded in the discussion section.

Table 4. Summary Innovation and learning modes

<p>STI mode</p> <p>Based on production and use of codified scientific and technical knowledge: Codified, global, 'know-what' and 'know-why' types of knowledge</p>	<p>STI / DUI mode</p> <p>Tension between the two modes Firms are more likely to innovate than those relying primarily on one mode or another</p>
<p>Static or Low learning</p> <p>Lack of DUI and STI modes</p>	<p>DUI mode</p> <p>Informal and experienced-based knowledge: Tacit, local, 'know-how' and 'know-who' types of knowledge</p>

3 Empirical analysis

3.1 Research methodology

The main goal of this research is to focus on issues regarding manufacturing of machinery and equipment, looking in detail at the innovation process within successful producers. It is an exploratory research with flexible and qualitative method of data collection, using multiple case studies in order to get comparative information between companies.

We selected firms that had more potential to have a competitive innovation process. The approach was as follows. First, we asked experts in the industry to identify leading and competitive companies in the field. In addition, from companies that have gone through the NITEC program³, we selected those that with NACE code DK.29 - Manufacture of machinery and equipment n.e.c. Finally, we selected the firms located in the Aveiro region. In this paper we focused only on the first 4 cases. Further cases are being conducted in order to validate results with remaining firms, so this is work-in-progress.

Our study thus focused on firms' mode of innovation and knowledge, as well as on and identification of the sources of risk and uncertainty in this industry. The information is obtained in a single or multiple visits and complemented by e-mail and telephone interviews.

The empirical study is conducted in the Aveiro region, Portugal, a region where the equipment industry is particularly dynamic and may play an important role acting as catalyst

³ NITEC program is a public funding system of incentives for the creation of small RD&T teams in the enterprise sector, implemented under the surveillance of the Innovation Agency (AdI), which purpose is to support projects that improves productivity, increases competitiveness and the insertion of companies in the global market.

for technological innovation and determining productivity gains. The Aveiro district located in the northern coastal strip is one of the most industrially dynamic regions of Portugal, based mostly on SME specialized in traditional sectors, including the manufacture of capital goods and several supporting services. Previous study indicated that organizational innovations in Aveiro are relatively scarce, tending to be incremental in both product and process, as the innovative effort of firms is mainly guided by reactive response to external and internal factors, rather than by pro-active attitudes reflecting strategies to gain dynamic comparative advantages (Castro et al. 1998). Nevertheless, is argued that firms usually manage to maintain a set of regular clients and the sufficient turnover to survive and, in general, their unique excellence goals are the accomplishment of delivery schedules and of product quality patterns.

This behavior may be rooted in the pattern of specialization based on mature industrial sectors, which are generally characterized by low to medium technological and informational content, and by traditional methods of management and by a preponderance of unskilled labor. This can explain, on one hand, the rather weak co-operation between firms, and between firms and innovation support institutions. However, the existence of a large number of export-oriented SME suggests a strong entrepreneurial spirit and a sign of industrial dynamism with growth potential (Castro et al. 1998).

With the purpose of collecting the most significant features of the industry, both Portuguese and European/global, we carry out a methodological exploration and study of pertinent data sources, both academic and entrepreneurial. Afterwards, we look to validate the conclusions obtained from the first step and gather relevant, up-to-date information directly from the field, as we analyse the equipment development process with entrepreneurs of local equipment firms and relevant institutions.

3.2 The companies under study

Here is presented the background of the companies analysed.

Company A: NACE 2956 - (Manufacture of other special purpose machinery n.e.c.)

Company A is a medium-sized enterprise established in São João da Madeira, specialized in laser and water jet cutting machinery mainly for footwear and stone processing industries. Other equipment products relates to cutting, welding and milling machinery and general

robotic applications. Company A employs about 40 workers, and is part of a group of complementary companies involved in development and manufacturing of test equipments, software and electronics for the same business area. This company is also member of a public funding competence network for fashion related industries, like furniture, textile, footwear and leather goods. Company A uses its own brand and each product is customized according to customer requirements. For instance, the definition of equipment type, performance and dimensions are determined by the customer. The complete engineering design is done internally and most of the parts are purchased parts, like those for control and instrumentation. Process type layout is used.

Company B: NACE 2921 – (Manufacture of furnaces and furnace burners)

Company B is a small-sized enterprise that manufactures mainly electrical furnaces and burners for laboratories and industrial applications, such as institutions from the National Scientific and Technologic System (SCTN) and ceramic industries. This kind of activity was already a family tradition based in Águeda, and it has about 15 employees. Each product is customized according to customer requirements, such as the equipment type and capacity, control functionalities, dimensions and safety compliance. The engineering design is made in-house by the R&D group created in 2004 within a NITEC program. Most of the parts are purchased parts, like valves, pumps and all those for control and instrumentation. Process type layout is used.

Company C: NACE 2956 - (Manufacture of other special purpose machinery n.e.c.)

Company C is a family based medium-sized enterprise established in Aveiro, that specialized in all machinery needed for the wood and cellulose industries, being able to install complete sawmills or any lumber production facilities, including turn key solution, exclusively with equipments produced in its workshop. Elements of the production line include everything from handling the raw lumber all the way to banding stacks, as for instance the sawmilling machines, debarkers and chippers, followed by carriages, band and circular saws, and a wide range of ancillary sawmilling equipment. Company C employs about 40 workers. Each product is customized according to customer requirements, such as the equipment type, capacity, feeding type and control functionalities. The complete engineering design is done

internally. Most of the parts are purchased parts, like valves, pumps and all those for control and instrumentation. Process type layout is used.

Company D: NACE 2956-(Other special purpose machinery, non specified)

Company D is medium-sized enterprise based in Ílhavo, and is a main supplier of robotized integrated systems for industrial applications, and also manufacturer of mechanical peripherals, electrical motors, generators, and special welding machinery. Company D also follows a family tradition in the business. Their main customers are the construction and metalworks industries, and other industries where the productive processes demands high integration of robotized solutions. Company D employs about 100 workers and belongs to the national enterprise rankings like sectoral top 100 with NACE 29 (A.E.P., 2007) and top 1500 SME (Fórum Empresarial, 2004). Each product is customized according to customer requirements, such as the equipment type, capacity and control functionalities. The complete engineering design is done internally by the R&D group created in 2006 within a NITEC program. Most of the parts are purchased parts, like valves, pumps and all those for control and instrumentation as Company D is a partner of a world leading supplier (Fanuc Robotics) of robotic automation for the Portuguese and Spanish markets assuming the position of a System Integrator company⁴. Process type layout is used.

3.3 Analysis of the case studies

3.3.1 Industry classification

We found that companies are highly specialized in specific industry markets, such as leather and stone processing, laboratory furnaces, sawmills, and industrial welding robots.

According to the market type specialization used by IFO Institute (1997) the companies studied can be described generally as ‘customized engineering and plant suppliers’,

⁴ “A System Integrator company is a value-added engineering organization that focuses on industrial control systems, manufacturing execution systems and plant automation that requires application knowledge and technical expertise for sales, design, implementation, installation, commissioning and support.” - CSIA Guide to Control System Specification and System Integrator Selection – Volume 1 REV(00) October 9, 2000

stemming from medium-to-high customization of products, according to the type of product being considered. Thus, they generally produce custom products in very low volume and very small batches (batch and jobbing production), using process-focused and to-order type of production. Moreover, in relation to market strategy, their competition is based largely on meeting clients' needs, keeping delivery promises, quality, and flexibility.

Jobbing production is characterized by low volume (often one-off) production of a wide range of products with demand for any one single product being difficult to forecast. For one-off production, it is not normally expected that a product once produced will be required in that exact form again (or if it is there will be a long period between orders). Plant capacity is difficult to define being dependent on the product mix at any one time. Routings through this type of production facility are dictated by the manufacturing needs of the individual products and work centre layout is based on manufacturing processes. This class of manufacture, usually labor intensive, requires a highly skilled labor force, working in a flexible production facility, often referred to as a job shop.

A typical example of this class of manufacture is the production of capital equipment such as customer specific equipments found in the four companies. Thus, these are mainly identifiable as MTO/ETO type. This classification is based upon the distinction made by Sari, (1981). Thus, the degree of engineering involvement and the design process distinguish both types, and also can be determined by the balance between the generic and specific aspects of product development.

The specialization of the companies can be also probably due to constraint in technical know-how, experience, skills, capacity, production equipment, parts procurement or product design. According to the intensity of customization, the products manufactured by the companies in study vary along a continuum from semi-standard to special product.

Semi-standard products are usually low customized products based in existing design with few changes and adjustments, allowing a great reuse of design specifications with some new requirements. The cost control of this type of product is also easier and known. These products are usually produced in small batches, and are often found in the companies were the products and production situations are closer to MTO reality. All four companies has semi-

standard products in their portfolio, which some of them are manufactured in MTO situation. Companies A, C and D also have a spare part business in a MTO production.

Special products are those which need a greater involvement of engineering in the design, as in pure customization where the formulation of specifications and agreement on the concept and details engineering design are vital in meeting product requirements. Customers must approve every design change before manufacturing. Therefore, these products are usually less frequent but also with higher profit margins, and higher technical and management risk. Production is usually on a one-of basis or in small batches, and are mostly found in the companies where the products and production situations are closer to ETO reality. All four companies in study have their core business settled with ETO production type.

It is also important to clarify the types of SME according to the innovative level. Therefore, the companies are mainly identifiable as ‘specialized supplier’, according to Hoffman et al. (1998) taxonomy these companies are typically traditional businesses focused on the design, development and production of specialized machinery. During the interviews it was also noted that the companies usually use customers as their main sources of information and also as their main drivers of innovations.

As expected, our data also indicates that we are mostly confronted with incremental qualitative change rather than radical change, when we ask the companies in study whether they have introduced new products on the market. This finding confirms the results reported in previous study by Castro et al. (1998).

In defining a project, it can also be evaluated the clients’ needs, which is a crucial moment that leads to the decision to begin the development of a new product and which generally derive from differing company functions. Therefore, it was found during interviews that the role of the entrepreneur is the principal innovative source in company B and C, while internal teams and the market tends to have increasing importance as innovative source for companies A and D, although senior management are still involved. The dimension of companies and workforce composition can explain this tendency, as they seem directly related. According to Calabrese et al. (2003), the individual entrepreneur typically carries out the evaluation of the clients’ requests through the commercial network, by the marketing

function, or by the product manager to whom the task of coordinating the product development activities has been delegated.

Table 5. Classification of capital goods producers

Production control (Sari)	Market specialization (IFO)	SME innovative level (Hoffman)	Additional characteristics	Competitiveness factors
ETO in core business and special products	Customized Engineering and Plant Supply, focused on medium-to-high product customization	Specialized Supplier, focused on design, development and production of specialized machinery	Job Shop and Process-focused production Products with Incremental qualitative change Labor intensive	Flexible production facility Meet clients' needs, keeping delivery, quality and flexibility Highly skilled labor force

3.3.2 Main uncertainties

In the companies covered in our study, products can often be highly customized, and there are always undergoing design changes and frequently involving high complexity concerning volume, variety of different products, components, processes and sources of supply. Nevertheless, system integrator company D manages to reduce supply source complexity with a privileged partnership with a world-leading supplier for robotics and automation.

All four companies identified the design specifications phase as the most critical in their product development process, together with the contract agreement because of legal and commercial consequences. Therefore, it is also common for senior management to become involved in the product specification and contract negotiation processes, as order acceptance is often strategically important.

As ETO oriented, the companies analysed offer a range of products based upon earlier experiences and product developments related to basic technology used in each machine or installation. Consequently, innovation is often related to customer orders, and specifications can only be coordinated for specific customer orders. But during the interviews it was noticed that it was common for these companies to work with poor design specifications from the customers, increasing thus the risks and uncertainties involved in the process. These

difficulties in gathering correct design specifications changes from product to product. Besides product mix, volume and stability of demand uncertainties, the degree of product design rigidity is therefore very important in evaluating uncertainties, as it strongly depends on the customization level and specific customer order specifications, i.e. if the type of product is closer to semi-standard or special products. Along these, a high volatility of product demand, makes product forecast practically unfeasible. Also the overlapping of manufacturing and design activities as well as engineering revisions often complicates production, what can make this is a major source of uncertainty that complicates the management of capital goods manufacturing.

All these uncertainty factors in project management and operations are perceived by the case study companies as variations and foreseeable risks and uncertainties. Uncertainty factors like above mentioned makes very difficult the planning of the process, resources and lead times, and also the cost controlling.

In terms of risk and uncertainty control methods, none of the companies effectively used computerized project management systems based upon techniques such as the Program Evaluation and Review Technique (PERT) or the Critical Path Method (CPM). Although they use some planning maps centered on the project structure, they rather use them mainly for documentation purposes with a simple word processor system or even paper based. The management and control methods are essentially done by the inclusion of cost and time margins in the project plans, drawing of contingency plans, definition and control of specific intermediary goals or milestones and less sophisticated techniques like PDCA (Plan-Do-Check-Act).

To conclude, from the analysis, one can identify predominantly uncertainties of type variation and foreseeable risks on daily basis operations related to project planning and production, in particular when is related to a customer order for semi-standard products. These are managed mainly by adopting an instructionist approach. Planning and learning 'as you go' approach is also used when the level of customization is high or in case of special products. In case of lack of information or higher uncertainty, the detailed planning of activities are done only until the next verification or milestone. The continuous appealing to the ability to improvise is a common characteristic in all four companies. This may also be a result of

traditional management methods and a certain reluctance to plan in detail their business activity.

Table 6. Summary of main uncertainties in capital goods' industry

	Uncertainty type	Mitigation methods	R&D project uncertainties	Additional uncertainties
MTO and semi-standard products	Variation uncertainties	Instructionist approach	Poor design specifications	Tendering process and contract agreement
		PDCA	Low degree of design rigidity	Demand volatility
ETO and special products	Foreseable uncertainties	Senior management involvement	Variety of products and components	Variety of processes and sources of supply
		Planning and learning 'as you go'		Overlapping of manufacturing and design activities
		Improvisation approach	Undergoing design changes	

3.3.3 Modes of innovation

Developing effective systems for capturing and sharing information and knowledge is a critical issue. Although the use of networks could allow for the linking of activities and sharing of information and knowledge, specially in relation to project management, in the cases studied this is done mainly informally. Much of the knowledge is tacit rather than explicit, which can cause problems when personnel changes occur. Coherently, there is also a high predominance of local knowledge rather than global, which can be explained as these companies are typically family owned SME (except company A), and they are basically specialized on mature and traditional industrial sectors.

Although with different strategies and intensities, these companies have been trying to incorporate higher technological and informational content in their products, in order to increase their capacity to differentiate products and offer better and broaden solutions to customers, perceived as a main factor of competitiveness. However, this strategy is challenged by human capital characteristics in this sector, namely patterns of rather unskilled labor and traditional methods of management used, as previously reported in a study made in Aveiro region by Castro et al. (1998). We also consider that the low to moderate employment of scientifically trained personal can be another difficulty, particularly in ETO or engineering

companies, where company A is clearly a positive exception. As described before, the lowest employment of scientifically trained personal were found in company C, where only 8% of total employees have scientifically trained personal. On the other hand, in company A about 30% of total employees have such type of qualifications.

During the interviews it was noted that these companies manage their projects, product customization and operations in rather informal way. Coherently, on daily basis companies tend to use mostly their 'know-how' and 'know-who' knowledge, acquiring 'know-what' and 'know-why' knowledge through technology transfer facilitators, like the Innovation Agency (AdI) as mentioned above, as is the case of companies A, B and D.

If one tries to compare the presented four companies with the results found by Jensen et al. (2007) in their research on Danish companies, there can be generally identified two different types of learning organization: the Low learning mode in company C, and the STI learning mode in companies A, B and D. Thus, neither the DUI nor mixed DUI/STI modes were found in the case study companies. This is so because the indicators in data collected shows that none of these companies has highly developed forms of organization that can support DUI-learning, or have rarely implemented organizational characteristics typical for the learning organization.

During interviews it was clear that the learning organization dimensions are nearly absent, with few exceptions like the cooperation with customers and suppliers. It was found that companies mainly use customers for gathering requirements and ideas about the problems they face, and use suppliers in search of solutions, without losing sight of what the competitors are doing and what is happening in the market. In addition, this is usually done in informal and casual fashion way by the figure of the entrepreneur (companies B and C) and internal teams (companies A and D). Companies A, B and C also acts as OEM - original equipment manufacturer - producing equipments to be marketed usually abroad under another company's brand.

In relation to quality management focused on engaging employees, they said it was not used or rather used informally, "due to small size of the companies where everybody knows each other, and thus feels free to ask, suggest or participate on solving day-by-day problems of the company". This quality management indicator includes the use of quality circles and

systems for collecting proposals from employees. As none of the companies use these systems, it must be difficult to engage the employees in a continuous improvement process.

Also absent are the indicators related to organic and integrative organization, as the use of inter-disciplinary workgroups, autonomous groups, functions integration and softened demarcations between employee groupings.

Companies A, B and D can be described as STI learning organizations, although with different intensities. These companies all share a common characteristic of having cooperation with researchers, in recent past or in the present, and varying from 'at least in some rarely occasions' to 'continuously'. All these companies grabbed the opportunity of public funding programs, that are usually managed by or executed under the surveillance of the Innovation Agency (AdI), and in the process the companies receive key technologic transfer in cooperation with institutions of the National Scientific and Technologic System (SCTN). These programs are of major importance as they help in the assimilation and development of technological competence inside the companies, and stimulate the linkage between the R&D institutions and enterprises. Companies A and B in particular can be described as having regular cooperation with researchers and public funding programs champions, as they developed long term cooperation by investing in strategic and innovative projects in collaboration with SCTN institutions.

For instance, companies B and D participated in NITEC (2003 - 2006) programs in order to set up small internal teams of RD&T in the firms, formed by a maximum of three persons with an exclusive and permanent nature. Company D also involved in a collaborative R&D project, established in 2005 with University of Aveiro, for the implementation of visualization techniques on welding machines. On the hand, Company B has a longer relation with AdI, which started with two consortium projects in 2001 and 2002, where the first one was a pan-European network for market-oriented industrial R&D. Moreover, recently (2003 - 2006) company B participated in applied enterprise R&D involving an SCTN institution associated by consortium contracts, also supported by another public incentive system.

Company A is clearly the one that developed most frequent and stronger cooperation with researchers, and investing in internal R&D is part of the strategy of this company since from the start, for it is aiming to be a technologic leader in its core business in the global

market. Actually, this company has several innovative equipments and solutions in national and international market, achievements resulting from internal R&D and cooperation with SCTN institutions, professional associations and involving cooperation networks.

A long relation with a professional association resulted in developing projects related with the modernization of the industry, in the period from 1996 to 2000, resulting in significant productivity increases. In order to stay competitive and intensify their internationalization strategy company A implemented two projects last year with PRIME incentives. Company A is also member of two cooperation networks with innovation purpose, one is an innovative SME network within an entreprise association and the other a competence network for fashion related industries, both having the participation of SCTN institutions.

Company A is also the only company in study that currently owns valid and effective patents, one applied in 2002 and another in 2004. Company C has also applied for three patents in the past, but currently they are all expired or not valid.

In terms of workforce composition the four companies employs scientifically trained personal, companies A, B, and D has more balanced rates, reaching 17%, 20% and 30% of total employees, although the small-sized company B faces critical dimension problems, as confirmed during interviews. Company A and D on the other hand employs about 12 and 17 graduated employees. Nevertheless, it is a common opinion that there's a general lack of qualified technical manpower and as well that companies competitiveness could be improved with the increase of graduated personal in the companies, principally in companies B and C.

Coherently, another characteristic in common in companies A, B and D is the R&D expenditures and they all developed R&D activities, both internally and externally by contracting R&D services from SCTN institutions, government laboratories, professional associations or other companies. As the public funding programs does not cover all the expenses, these companies have to choose very well the projects in which they participate due to often scarce financial and personal resources.

Company C can be clearly identified as a low learning organization, since it has more similar characteristics with the static or low learning organization, rather than with the others, as suggested by Jensen et al. (2007). During the interviews it was clear that this company does not have neither highly developed forms of organization that can support DUI-learning nor it

is engaged in activities that indicate a strong capacity to absorb and use codified knowledge, the STI mode. It has rather very limited DUI mode indicators and casual or opportunistic STI mode indicators in the past.

This company does not have any policy neither for R&D expenditures nor for cooperating with researchers, as in formal and continuous way. Although in the past this company had some isolated and punctual initiatives with low impact and success, it was evident a complete absence of these policies in their strategy and operations. This situation may be explained by the fact that, even in comparison with the others, this firm have a low employing of scientifically trained personal, as with bachelor degree or plus. Actually, out of 40 employees in the company C, only three are scientifically trained, in which 2 are engineers working directly in the projects, and the remaining person has accounting functions.

Table 7 summarises the main findings regarding modes of innovation at the analysed companies.

Table 7. Summary of modes of Innovation

		Innovation mode	Main indicators found	Main innovation sources
Companies A, B, and D	STI		Cooperation with researchers	Customer orders
			Employment of scientifically trained personal	Competitors and market surveillance
			R&D expenditures	Public funding programs, in cooperation with AdI
			Lack of DUI mode	Cooperation with SCTN institutions
Company C	Low learning		Lack of DUI and STI modes	Customer orders
			Very low employment of scientifically trained personal	Competitors and market surveillance

4 Conclusion and discussion of results

This paper reports the results of an exploratory and comparative study of four capital goods companies located in the Aveiro region, covering the observation of characteristics related with company innovation and learning modes, uncertainties in company process, and presents instruments for company classification.

Regarding limitations and value of the study, as this is a typical exploratory case study using small number of companies, free conclusions can not be generated. Nevertheless, this paper can help in understanding general characteristics of capital goods companies and uncertainties involved in their process and project management. The core of this paper provides key insights on their learning and innovation mode, cooperation and how these four companies handles their innovation process in order to improve competitiveness.

In what regards main findings, companies engaged in capital goods supply can be positioned along a continuum from ETO to MTO. The analysed companies have high levels of both specific and generic design, and predominantly related with the supply of highly customized equipments and special products, which is a distinguishing feature of an ETO company. Generic design predominates in MTO production of spare parts and some of the low customized equipment and semi-standard products. Coherently, they can be considered specialized suppliers, usually depending on customers and suppliers as their main sources of information and also as their main drivers of innovations. And as expected, innovations are usually incremental rather than radical.

These characteristics influence the uncertainty level typically involved and how they are managed. The uncertainty factors in the projects and operations perceived by case study companies are mainly variations and foreseeable uncertainties. And these uncertainties often complicates their innovation process, depending of the level of product customization. The four companies identified the design specifications phase as the most critical in their product development process, together with the contract agreement. The difficulties in gathering correct design specifications makes tendering process an important success factor for these companies and also a major source of uncertainty for them. Tendering is the key business process responsible for producing solutions that are competitive in terms of functionality, price, delivery, and quality (Hicks et al. 2000), and typically 85 to 90 per cent of cost is committed by the tender (McGovern et al. 1999). Nevertheless, companies in study have a rather traditional way to perceive the uncertainties in their business, and which they manage typically with a mix of instructionism and improvisation.

Another finding is the complete absence of DUI learning mode in the four analysed companies, and even a low learning characteristic in one of them. On the other hand, STI

learning mode was identified, together with strategic application of public funding programs and regular cooperation with researchers from SCTN institutions, developing strategic and innovative projects. Nevertheless, it can be argued that there is some dependence of public funding programs as a privileged form of accessing funds, strategic consortium projects, key know-how transfer and cooperation with R&D institutions. This may have implications for policy makers and companies strategy, particularly if these programs cease.

Low learning mode was identified in company C, and the STI learning mode in companies A, B and D. Therefore, neither the DUI nor mixed DUI/STI modes were found in the case study companies. This is mainly due to the lack of quality management focused on engaging employees in a continuous improvement process and lack organic and integrative organization characteristics, which can be explained by rather an informal organization and traditional management methods found in case study. Coherently, STI mode companies reported higher number of successful new product development projects, with qualitative improvement or increasing technological incorporation in products, resulting in greater capacity in customization and differentiation, and thus improving companies overall competitiveness potential. Nevertheless, according the earlier results found by Jensen et al. (2004), the STI-mode needs to be complemented by the DUI-mode. The fact that firms are engaged in R&D-activities does not imply that they can neglect the DUI-mode. Since the capability to absorb and efficiently use new technologies is limited, the speed up of science-based innovation tends to run into bottlenecks, and many innovations with major economic impact had their source in learning by doing, using and interacting. Hence, R&D activities need to be integrated in the complete business environment and anchored by tacit links to procurement, production and sales. Accordingly, any strategy to promote innovation needs to take both of these sources of innovation into account, and firms combining both modes, in form of DUI/STI learning type, are more likely to innovate new products or service than those relying primarily on one mode or another. Thus, with extended studies validating these patterns and findings, important implications may be deduced for benchmarking innovation systems and for innovation policy, as according to Jensen et al. (2007), in the current European 'Innovation Scoreboard' the DUI-mode indicators are almost absent. Moreover, is

argued that policy makers tend to think in terms of the linear model of innovation and give priority to supporting R&D-activities.

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Acknowledgements

This paper is part of a research performed by the “Enterprise of the Future” (EdF) project at the University of Aveiro, included in a wider programme of research on firm competitiveness with specific application to firms located in the Aveiro Region, Portugal.