AGILE PRODUCTION, INNOVATION & TECHNOLOGICAL COOPERATION: OVERLAPPING PRIORITIES OF MANUFACTURING FIRMS

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STRUCTURED ABSTRACT

Purpose – This paper analyzes in a sample of Spanish manufacturing firms the relationship between agile manufacturing and the firm´s management capacities related to innovation and production flexibility. Complementarily the survey addresses the implementation of agile production and its measurement.
Design/methodology/approach – Mail survey to Operations and Human Resource managers of manufacturing firms and telephone interviews to managers from 25 selective firms. The population of the study includes firms from the SABI database with NACE codes 24 to 32 and at least 200 employees. Quantitative methods (linear hierarchical regression and mean differences) were used to test research hypotheses and a qualitative method (interview analysis) was used to analyze an implementation and measurement model of agile production.
Findings - The results of the study show that high-agile firms use more intensively a comprehensive set of agile facilitators (design, manufacturing, and supply). They also innovate and cooperate externally more on innovation than low-agile firms. We have found that external technological cooperation moderates the firm's production flexibility.
Research limitations/implications – The implications of this research indicate, on the one hand, that firms interested in implementing agile production should focus on the agility management of supply chains, the skills and knowledge development of human resources, and in the implementation of agile manufacturing technologies. On the other hand, firms in less cooperative environments should focus more in their internal manufacturing systems to reinforce the relationship between production flexibility and agility which offers broader scenarios to compete under this production paradigm. The main limitations of our research design are the use of cross-sectional data and the use of managerial perceptions to assess most of the variables.
Originality/value – This paper offers a model of agile production implementation that it is complemented with measurement indicators to analyze the firm's evolution towards agility. The combination of multivariate analysis and managers' interviews to obtain and validate results create value for managers interested in agile production.
Paper type – Research paper

Introduction

Agile production is nowadays considered as the new paradigm production of the 21st century and a solid base for the "Smart Factory" (Radziwon et al., 2014). The concept of agile production originated in the 1990s when large firms faced up the challenge to make their manufacturing processes more flexible with shorter production time and greater variety of products. In a few words, agile production may be conceptualized as a production strategy to introduce new products in highly changing markets. In practice, agile production enables the manufacturing of different innovative products in the same production line with very short set-ups. Some studies indicate that firms and plants with agile production systems perform better than firms and plants with mass or lean production systems (Narasimhan et al., 2006) even though its implementation is difficult due to the high investments required and the lack of multi-skilled employees (Thilak et al., 2015).

The main difficulty behind these limitations is that agile production is much more than engineering and flexible manufacturing technology. Ultimately, agile firms have to develop process of internal change and train their employees to innovate and respond quickly to customer and market needs but keeping costs and quality under control (Gligor et al., 2015). Agile production needs several facilitators such as flexible technology, highly trained and qualified employees, or shared information and knowledge systems able to react quickly to unpredictable and frequent market changes. Nevertheless, there is a lack of information about the relative importance of the different groups of agility facilitators. The literature of agile production includes facilitators like robots or concurrent engineering to advance towards agility, but it does not give conclusive clues about specific rankings and focuses in the pivotal role of the latest technologies.

Another related limitation of the literature, due to the difficulties to comprehend the diversity of agility facilitators, lies in not using an integrated approach to analyze agile production. However, empirical studies should pay more attention to the relationship between the core of agile manufacturing and the other management capabilities that facilitate agility, such as innovation or cooperation. For instance, cooperation with strategic suppliers may leverage supply and manufacturing practices into greater firm performance and innovative efforts. Both innovation and cooperation appear implicitly in the conceptualization of agile production because agile firms must innovate to compete in highly customized and changing markets (Gunasekaran and Yusuf, 2002). Firms in need of agility have to innovate in products more frequently and faster than other firms, but in-house efforts may not be enough to keep production processes, technology, and knowledge updated. The technological cooperation with suppliers or R&D centres is necessary to leverage the firm's capability to do unplanned and new activities in response to unpredictable shifts in market demands or unique customer requests.

The literature of agile production recognizes the value of innovation as an output that enables firms to compete in high-unpredictable changing markets but does not include innovation inputs as agility facilitators. Similarly, technological cooperation is implicitly mentioned among agility facilitators like, for instance, supplier partnerships that allow introducing new technology and knowledge into the agile firm. The importance of implicit agility facilitators like these could be assessed by incorporating measures of firm's innovative behaviour into quantitative studies of agile production in order to complement check-lists of agility drivers or facilitators (e.g., Narasimhan et al., 2006; Vázquez-Bustelo et al., 2007; Vinodh et al., 2012). Based on this proposition our paper is aimed to contribute to the literature in two different ways. First, we will analyse if agile production firms have implemented more intensively a comprehensive set of agility facilitators and will establish categories according to their level of importance. Second, our research will study if internal innovation support and external technological cooperation are moderator facilitators of agility in manufacturing firms. Both contributions to the literature of agility may have important managerial implications: for instance, firms seeking agility should focus simultaneously on both internal and external sources of innovation and technology to keep ahead of competitors in dynamic and uncertain environments.

The paper is structured as follows. First, we review the literature and develop the research hypotheses. After that, we explain the methodology of the empirical study followed by the results and their discussion. Finally, we end with conclusions and limitations.

Theoretical foundation and research model

The resource-based view of the firm and the dynamic capabilities perspective

To theoretically develop our arguments we rely on the resource-based view of the firm (RBV) augmented with the dynamic capabilities perspective, since both contribute to explain the competitive implications of agile production and innovation. On the one hand, the basic premise of the RBV is that a firm's competitive advantage lies primarily in the application of bundles of resources that are valuable, rare, in-imitable and non-substitutable (Barney, 1991). The RBV has received considerable attention by scholars in business management, but its popularity has also increased in the field of production and innovation management research.

On the other hand, the dynamic capabilities perspective considers that accumulating resources is not enough. To be competitive, firms need capabilities to integrate, reconfigure, develop, and apply resources (Teece et al., 1997). Although innovation is very important for firms to compete and improve performance, innovation management is not the only success factor. Firms also need dynamic capabilities that allow them to create, expand or modify their resource bases (Kohlbacher, 2013). Effective dynamic capabilities contribute to a firm's competitive advantage by enabling temporary advantages that allow a firm to stay ahead of competitors (Teece, 2007). As such, the possession of dynamic capabilities, enabling for example the speedy reconfiguration of a firm's operations, promises to hold great potential, especially in today's dynamic and fast-changing environment.

Agility and innovation are both considered dynamic capabilities that produce sustainable competitive advantages. Dynamic capabilities are unique, idiosyncratic, and heterogeneous among firms (Teece et al., 1997). They are more built than bought. Neither agility nor innovation is easy to achieve; both are complex, structured, multidimensional, and usually involve long-term commitments to specialised resources. For instance, innovation processes require the development of in-house R&D and new product development facilities plus the management of external relationships to collaborate technologically with other agents. Breznik and Hirisch (2014) discuss the different relationships that innovation capabilities may have within the concept and theory of dynamic capabilities. Similarly, agile production enables the firm to respond to uncertain and changing business environment, and to sustain its position in the market. Agile production is very idiosyncratic and heterogeneous among firms because agile facilities are not make-to-order technologies and require the employment of qualified flexible human resources that are able to learn and contribute to innovation.

Agile Production

Agile production has been mostly adopted in the electronic industry followed by the automobile, machine-tool, and aerospace industries (Thilak et al., 2015). Agility was the emerging and gradually dominating concept introduced to explain these firms' strategies for thriving in uncertain environments and responding to change (Swafford et al., 2006). Although there are several definitions of agile production, some authors like Gunasekaran and Yusuf (2002) indicate that researchers view agile production paradigm as the post-mass production concept which focuses on meeting the global competition by quickly responding to the dynamic demands of the customers. Examining the agility concept in the light of dynamic capability perspective leads to consider that agility is a dynamic capability because it entails the exploitation of other existing internal and external firm-specific capabilities, the development of new ones, and renewing them to respond to shifts in the business environment.

Agile production enables a company to be flexible enough to respond quickly to the dynamic demands of the customers and manufacture products with many varieties and innovative features. A firm's production is more agile if it is able to change volume, variety, or other manufacturing variable without increasing costs or diminishing quality or delivery. Agile environments demand technologies that enable people and machines to share information effectively and efficiently to respond to market needs with speed. The use of robotics, real-time communication systems, etc. has redefined the agile production concept to become an integral component of an agile production framework (Dubey and Gunasekaran, 2015). Empirical studies find that firms in highly dynamic environments use agile technologies more intensively and have better outcomes (Narasimhan et al., 2006; Vázquez-Bustelo et al., 2007; Leite and Braz, 2016). Rapid Prototyping Technology (RPT) and virtual manufacturing are the most mentioned facilitators of agile manufacturing (Thilak et al., 2015).

The review of these studies shows that there are several categories of agility facilitators. A comprehensive list of 19 facilitators, even though they are not categorized, can be found in Narasimhan et al. (2006). They will be used in our empirical study to analyze the mean differences of implementation between high- and low-agile firms because they cover most of the supply and manufacturing practices that firms may adopt to improve their operations. Examples of these practices are concurrent engineering, advanced manufacturing technologies or integrated product design (see table 4 for a complete list of these facilitators). Other scholars have used shorter lists. For instance, Vinodh et al. (2008)'s facilitators focus on organizational structure, manufacturing management, employee agility, advanced technology, and manufacturing strategy. Similarly, Yusuf et al. (1999) analyze core competence management, virtual enterprise formation, capability for reconfiguration, and knowledge driven enterprise. These and other similar studies show that sometimes facilitators outside operations are included to analyze firm's agility. However, we focus our study on supply chain and manufacturing facilitators because the independent and moderator variables of our multivariate study are more related to the firm's operations than to the firm's strategies. Other studies adopt a more comprehensive approach to agility and as a consequence they integrate larger lists of facilitators. For example, Vázquez-Bustelo et al. (2007) take into account 53 facilitators from the categories of design, production, and management practices.

Several empirical studies show (e.g., Vázquez-Bustelo et al., 2007; Zhang, 2011) that firms in need of more agility in their supply and manufacturing systems compete in highly dynamic and complex environments. This environment is also faced by firms that adopt lean flexible practices and this is why some authors consider that agile production is based or supported somehow on lean production (e.g., Narasimhan et al., 2006; Eltawy and Gallear, 2017). Certainly, agile production systems share some facilitators with lean production systems (Narasimhan et al., 2006; Qamar et al., 2018), but lean production usually responds to competitive pressures with limited resources in more stable markets, whereas agile production responds to complexity brought about by constant market changes. Thus, some authors consider lean production to be an antecedent or previous step of agile production (Inman et al., 2011; Elmoselhy, 2013) because of the differences in the implementation intensity of the supply and manufacturing facilitators. However, there are not only different adoption rates of technologies between agile production firms and other production systems. Firms evolving to agile production need a flexible production capability, but also a concurrent capability of new product design and process development, as well as strategic collaborations with suppliers. Therefore, the differences between production systems have to be focused on other competitive priorities; innovation efforts in particular are an underdeveloped research area in the literature of agile production. Agile firms must be organizations with higher stock and flows of knowledge both inside and outside the firm because they have to face up unpredictable competition with more innovative products that are developed inside agile supply chains. Then, firms with agile production systems should invest more in innovation and technological cooperation in order to fulfill agility capacity expectations and performance.

Although facilitators are important in the study of agility, nowadays studies should pay more attention not only to specific agility facilitators but to the relationships between the core of agile manufacturing and the other management capabilities that also facilitate agility through the flows of knowledge and innovation. Given that agile manufacturing seeks to produce more innovative products and faster than competitors, the firm's capacities of product innovation and production flexibility are very relevant for the development of agility (Zhang, 2011). We consider both production flexibility and product innovation capacities as sub-components of agile manufacturing. Agility is more than flexibility (Abdelilah et al., 2018) because flexibility dimensions are usually included in the characterization of agile firms. Agile firms do not only need to be flexible from a manufacturing perspective, they also have to innovate more and faster because the markets for agile firms are more complex and demanding, at least from an innovation perspective. Therefore, the capacities of production flexibility and product innovation are going to be drivers of agility in our study. Product innovation capacity refers to the firm's capacity of developing and adapting new products able to satisfy market needs (Adler and Shenbar, 1990), whereas production flexibility capacity is the firm's ability to manage production changes in terms of volume, product varieties, and product changes in time.

Even though production flexibility and product innovation are sub-components for agility, there are no empirical studies, to the best of our knowledge, which had analyzed moderator effects on their relationships with agility. Therefore, we propose the research model of Figure 1 with a moderator effect for each capacity: external cooperation on innovation and organizational support to innovation. The next section explains this model and why moderators are important.

Research hypotheses

Our research model analyzes if external technological cooperation moderates the relationship between the firm's capacity of production flexibility and agility, and if organizational support to innovation moderates the relationship between the firm's capacity of product innovation and agility. We focus our research on moderator effects because they are important to study. Moderators are commonly used in topics related to flexibility (e.g., Martínez-Sánchez et al., 2011) and manufacturing (e.g., Wickramasinghe and Wickramasinghe, 2017; El Mokadem, 2017) although not so frequent in agility studies. However, moderator effects would enable to analyze which contingent effects apply in the relationship between agility facilitators and agility performance. This relationship between facilitators and performance has been tested previously (e.g., Narasimhan et al., 2006; Vázquez-Bustelo et al., 2007; Leite and Braz, 2016) with positive results and now it is time to take into account that agile manufacturing approaches are contingent of internal and external management capabilities (Gunasekaran et al., 2018; Potdar et al., 2017). The absence of moderators in agility studies narrows the perspective and implications that could be of interest to managers of this new production paradigm. More precisely, 'external cooperation on innovation' and 'organizational support to innovation' are important moderators to study because both are core complements of the firm's resources invested in innovation. Agile firms are also innovative firms (Ravichandran, 2018) and so it would be important to analyze which innovation-related variables could influence on the facilitators-agility link. Managers need to know how their innovation-related decisions may enhance or diminish the positive effects of investment in facilitators that are positively associated to agility capacity.

Regarding the first moderator effect, we have defined production flexibility capacity as the firm's ability to manage production changes in terms of volume, product varieties, and product changes in time. Agile firms are more customer-responsive (Bernardes and Hanna 2009; Gligor et al., 2015) because the agile facilitators are able to reduce time-to-market and enhance the newness of product innovations. For example, rapid prototyping and 3D printers increase the number of options that can be tested in a shorter period of time which enhances the probability of new product success. Thus, the firm's efforts to improve its production flexibility capacity may contribute to enhance agility and we might expect to find a positive relationship between both capacities. Now, how external cooperation on innovation may influence on that positive relationship?

For the purposes of our research model, we define "external cooperation on innovation" broadly as the level of cooperation with other agents in the firm's supply chain (customers, suppliers,…), industry (competitors, clusters,…), and technology environment (Universities, R&D centers,…) to develop innovations. Firms with a greater level of external cooperation on innovation can provide stronger organizational mechanisms in terms of recognizing, communicating, and assimilating relevant external and internal knowledge (Clausen, 2013). This knowledge exchange, in turn, may inspire new ideas for new products, processes, and improved operations that mean not only better innovation performance, but also a greater competitive advantage in agile environments. If greater technological cooperation is able to improve the efficiency and efficacy of operations through the adoption and improvement of new technologies, then firms could compensate their deficits of production flexibility with external flows of knowledge to become more agile. Nowadays, firms operating in the same industry do not compete only with one another but with their own supply chains behind them (Lee, 2004). Firms that cannot cooperate so intensively with other agents would have to overcome resource constraints and develop more reliable and production systems. In-house production manufacturing systems and external supply chain facilities are not always complementary. Firms must take strategic decisions which influence their mix of external and internal efforts that influences on production flexibility. Agility needs production flexibility but agility may come directly from external cooperation as well. However, when firms have less resources or abilities to develop external relationships with other agents, they have to focus more on internal resources to enhance their agility capacity. Based on these arguments, we propose a negative moderator effect of 'external cooperation on innovation' in the relationship between the level of production flexibility and agility capacity. If facilitators like flexible production technologies (robotics, rapid prototyping, etc.) contribute to develop agile production, firms with less access to external knowledge from other agents would have to rely more in internal facilitators to develop such agility.

> *H1. External cooperation on innovation moderates negatively the positive relationship between the firm's capacity of production flexibility and the firm's agility capacity.*

The second moderator effect in Figure 1 proposes that the positive relationship between the capacities of product innovation and agility is moderated positively by the organizational support to innovation. Although the external access to new knowledge is important, firms must also develop flexible organizations that support employees' contribution to innovation and facilitate the change required by agile organizations. Agile production needs more deployment and access to knowledge than other production systems because they have to innovate better and faster to accommodate changes in the business environment and the increasingly demanding needs of well-informed customers (Potdar et al., 2017). Initially, both in-house innovation and external technological cooperation may support the assimilation and transformation of external knowledge into in-house knowledge to manage production systems in an agile and competitive way. Nevertheless, investing resources is not enough if, for instance, the organization is bureaucratic and delays the decision-making process or discourages risk-taking.

Therefore, organizational support to innovation is an important issue for developing agile capacities. West (1990, p. 38) defines the support for innovation as "the expectation, approval, and practical support of attempts to introduce new and improved ways of doing in the work environment." Organizations that support innovation are more receptive to new ways of doing things and do not penalize employees for ideas that do not work. This organizational support can leverage the firm's innovation efforts into greater agility capacity by promoting innovative behaviors and facilitating quick decision-making (Choi et al., 2013). Organizational support to innovation has been used as moderator in different organizational settings, but since our study focuses on agile manufacturing we analyze its moderator effect on the relationship between product innovation capacity and agility capacity. Product innovation capacity refers to the firm's capacity of developing and adapting new products able to satisfy market needs (Adler and Shenbar, 1990). It has been frequently used as a proxy variable for the degree of a firm's overall innovativeness, and in our study it represents the most important output needed by those firms that face unpredictable changing environments. Agile firms must develop innovations more frequently and faster than firms in stable environments (Gunasekaran and Yusuf, 2002). Product innovation capacity may contribute positively to agility by making the firm more proactive to substitute obsolete products, expand product range, and reduce new product development time. Firms that highly support employees' innovation could find a more positive contribution of product innovation capacity to agility than firms with less organizational support to innovation. This positive moderation effect would imply that innovation faces less obstacles and runs smoothly within the organization.

> *H2. The firm's organizational support to innovation moderates positively the positive relationship between the firm's capacity of product innovation and its agility capacity.*

After developing these hypotheses we should also explain why "external cooperation on innovation" and "organizational support to innovation" are singly introduced in each moderator link instead of jointly. There are two main reasons. First, we wanted to keep the model simple. Second, we wanted to focus each moderator on its specific core of agility. Thus, the role of organizational support as moderator is more specific to product innovation than to production flexibility because production flexibility does not involve comprehensive processes of innovation. The improvement of production flexibility capacity may require sometimes the contribution of in-house employees to implement advanced manufacturing technologies or to facilitate changes in the production process. However, for the purpose of improving the firm's manufacturing capacity it is more important the cooperation with external organizations like suppliers of advanced manufacturing technologies or Technological Centers that carry out technical essays and may develop process innovations. Regarding the focus of organizational support as moderator on product innovation and agility we consider that product innovations are more risky and require more investment and time than process innovations. Of course, we do not even try to compare a minor product innovation with a major process innovation but similar scopes of change in order to justify our focus of organizational support on product innovation. Organizational support could also influence innovation but there are other stronger determinants such as R&D expenditures or competitors' pressure. However, the role of organizational support could be enhanced as moderator because the effect of innovation on improving agility capacity is not easy to achieve. Similarly, we do not consider the moderating effect of external cooperation between innovation capacity and agility capacity because external cooperation is a determinant of innovation capacity according to the literature. There are other corpuses of literature, i.e., Open Innovation, that have already analyzed the relationships between company internal innovativeness and external cooperation. Our research focuses more on issues related to production agility and a few of its drivers, although we acknowledge that other hypotheses could have included but they are rather postponed for future research. After these explanations, the next section describes the methodology to test our research model (Figure 1) and to explore the implementation of agile production.

Methodology

We carried out a mail survey to Operations and Human Resource managers of Spanish manufacturing firms. Operations managers answered the questions related to agile production and Human Resource managers answered those questions related to flexibility, innovation, and performance. The population of the study includes firms from the SABI (*Sistema de Análisis de Balances Ibéricos*) database with NACE codes 24 to 32 and at least 200 employees to be sure they had specialized departments in engineering or innovation. The population included 619 firms with such characteristics. The process of obtaining information with the initial mailing and two reminder contacts lasted from January to May 2017. We finally could use questionnaires from 227 firms (Table 1) after matching responses from Operations and from Human Resource managers. Each one of these 227 firms provided a complete response to the questionnaire by both managers. Partial responses from only one of the managers discarded the firm to be included in our analyses. The results of the survey are then by organization and not by individual. The 36% response rate is good in comparison to other agile production studies and within the return rate established as a norm by Baruch (1999) in academic studies directed toward top managers or representatives of organizations.

We assessed non-response bias by testing whether early and late responses differ significantly on a range of variables, with late respondents serving as a proxy for non-respondents (Armstrong and Overton, 1977). Mann-Whitney *U*-Tests did not reveal any statistically significant differences between the two groups ($p<0.05$) across demographic variables and the main constructs, suggesting non-response bias not being a significant concern. After validating the questionnaires we selected a sample of 25 firms for a telephone survey to obtain additional information about the implementation and measurement of agile production. These firms were selected based on two main criteria: 1) their managers had fully completed the questionnaire, and 2) they showed higher values of agility capacity and agility facilitators' implementation. Both selection criteria were relevant in order to make assessments about the implementation sequence of agility facilitators (firms with greater implementation could offer a broader picture of the issue) and about how firms measure their evolution to agility (firms with greater agility should have a more comprehensive check-list of measurement items).

The variables included in the empirical study have been adapted from other studies. First, the supply and manufacturing practices that facilitate agility in the production process (agility facilitators) have been adapted from Narasimhan et al. (2006). These scales assess the degree of implementation in the manufacturing plant of different techniques in comparison to the industry average according to a 7-point Likert scale from 1 (much less implemented than industry average) to 7 (much more implemented than industry average). The constructs of our study are (number of items between brackets): Workforce development (8); Teams (5); TQM culture (4); Supplier information sharing (3); Supplier development (3); Supplier partnerships (4); Supply base rationalization (3); Strategic supplier selection (3); Supplier certification (2); Advanced MRP/ERP (2); Integrated product design (7); Advanced manufacturing technologies (6); In-house technology (4); JIT flow (6); Cellular manufacturing (2); Concurrent engineering (4); Customer orientation (7); Manufacturing strategy integration (6); Benchmarking (2). Our study compares whether firms with high-agility capacity have implemented these supply and manufacturing practices (agility facilitators) more intensively than low-agility firms.

Table 2 indicates the variables used in the multivariate study (linear hierarchical regression) to explain the firm's level of agility according to the firm's capacities of innovation and production flexibility with the two moderator effects of external cooperation on innovation and organizational support to innovation. In order to highlight the contribution of the independent variables to explain agility we introduce two control variables -firm size (number of employees) and export intensity (ratio of exports to sales)- and two agility drivers: environmental dynamism (8 items) and market hostility (3 items). Before testing the hypotheses, the dimensionality, discriminant validity, and reliability were evaluated for each scale. All tests for discriminant validity were supportive; specifically, the estimated correlations between construct were not 1.00, and the square roots of the AVE values for the latent constructs were found to be greater than the correspondent correlations.

Reliability analyses indicate that Cronbach's coefficient alpha exceeds 0.8 for all constructs, and average variance extracted (AVE) exceeds 0.5, which indicates satisfactory simple reliability; the factor loadings of items are above 0.5 in all cases. Alternatively we computed composite reliability scores (CR) to assess construct reliability. In all cases, factors have CR greater than the minimum level of 0.6 recommended (see also Table 2 for AVE, CA and CR values). Confirmatory factor analysis (CFA) confirmed the composition of scales (RMSEA=0.034, NNFI=0.96, CFI=0.97).

Results

This section shows the quantitative results from the empirical study to 227 firms, whereas the managerial opinions and assessments obtained during the telephone interviews are integrated in the next section of managerial implications because they are more related to the implementation and measurement of agile production. Regarding the quantitative results, Table 3 shows descriptive statistics, and Table 4 shows the mean differences in the implementation of supply and manufacturing practices (agility facilitators) according to the firm´s level of agility. The results indicate that high-agile firms have implemented facilitators more intensively than low-agile firms. These practices are used in most of the firms but the difference lies in the degree of implementation which is greater in high-agile firms in comparison to industry averages. Agility facilitators and agility capacity are strongly correlated ($p<0.01$). This result supports other similar studies in the literature but what really makes a contribution is the relative importance of agility facilitators. Thus, the three main facilitators are related to supply chain management practices in topics about information integration (MRP/ERP), certification and supplier selection. An intermediate group of facilitators are those related to employees' empowerment such as employees' development or TQM. The last third of the table is where we find most of agile manufacturing technologies like concurrent engineering or cellular manufacturing. A simplified lecture of Table 4 points out that the implementation of agile production in the surveyed firms is focused on the agility of supply chains, in the development of employees' skills and knowledge, and in the implementation of agile manufacturing technologies. In other words: Supply Chain – Human Resources – Manufacturing Technologies. They would be the three main categories of agility facilitators in the surveyed firms.

Secondly, Table 5 indicates that high-agile firms have developed more intensively other management capacities than low-agile firms. The management capacity with the largest mean difference between the two groups is the 'organizational support to innovation'. That is to say, to get agility the surveyed manufacturing firms pay attention first to 'organizational support to innovation', second to 'production flexibility capacity' and 'manufacturing management capacity', and third to 'product innovation capacity' and 'external cooperation on innovation'.

Finally, Table 6 shows the hierarchical regression analysis that explains the firm's level of agility according to the two moderator effects of external cooperation on innovation and organizational support to innovation. There are three models: model 1 only includes control variables and agility drivers, model 2 adds the independent variables, and model 3 shows all variables with the moderator effects. We report here the results of model 3 because models 1 and 2 are only partial models. First, model 3 shows that the only statistically significant agility driver is market hostility: high-agile firms face up more hostile markets ($\beta=0.168$, $p<0.01$). Export intensity (control variable) is only marginally related to agility capacity. Regarding the independent variables that explain agility capacity (model 3), both production flexibility capacity ($\beta=0.359$, $p<0.01$) and product innovation capacity ($\beta=0.074$, $p<0.05$) are positively related. The last part of model 3 includes the moderator effects of external cooperation on innovation and organizational support to innovation. The results indicate that both moderators are positively related to agility capacity: external cooperation ($\beta=0.224$, $p<0.01$) and organizational support ($\beta=0.416$, $p<0.01$); high-agile firms cooperate externally more and support internally more to innovation than low-agile firms. However, only external cooperation is a significant moderator because its interaction variable with the production flexibility capacity (PFCxECI) is statistically significant in the regression (β=-0.204, p<0.05), whereas the interaction effect of organizational support on product innovation capacity (PICxOSI) is not statistically significant (β=0.012, p>0.1). External cooperation is a negative moderator because the beta value of the interaction effect (PFCxECI) is negative which means that the positive relationship between production flexibility and agility capacities is less positive in high-cooperative environments than in low-cooperative environments. These results support H1 but they do not support H2. We have carried out also another model analysis in order to differentiate the contribution of moderators as independent variables from the interaction terms but the results indicate that the interaction terms are able to explain additional variance by themselves.

Discussion and implications

We are going to discuss first the results and implications related to the agility facilitators and second the implications of the multivariate analysis. First, the results of the survey support other studies (e.g., Narasimhan et al., 2006; Vázquez-Bustelo et al., 2007) about the greater adoption of supply, HR and manufacturing practices by agile firms in comparison to other firms. Our data indicates that high-agile firms have implemented facilitators more intensively than low-agile firms. There is not any single group of agility facilitators that had been less implemented among agile firms. However, our study goes beyond the support of previous studies and indicates that the importance of agility facilitators is not the same because it seems there is a ranking of facilitators. The results indicate that to advance towards agility, firms focus more on the supply chain, then on human resources management, and third on manufacturing technologies (Table 4).

This ranking of facilitators suggests some useful managerial implications about where to focus the efforts of adopting agile manufacturing. However, it is not only the 'quantitative ranking' but the remarks of surveyed managers from the phone interviews that highlight what it is more important. For instance, one of the managers stated: "…*our firm had to align simultaneously with three international supply chains that made us to implement new information technology and adapt some of our production processes* …" After integrating supply chains, managers remarked the importance of human resources particularly through organizational learning and training that enhances workforce agility. It is difficult to achieve agility without leveraging employees' knowledge and skills. Firms in pursuit of agility should train workers on the use of technology. Another statement from a phone interview: "…*the company organized seminars on agility management for production staff after the reduction of lead times from our main customer*…." The importance of human resources stated by phoned managers corroborates other studies on workforce agility. For instance, Muduli (2016) in a study of selective Indian industries found that some human resource practices were very influential on workforce agility like teamwork, employee involvement, or organizational learning and training.

Based on the quantitative results of Table 4 and the statements from the phone interviews, we propose Figure 2 as a model to implement agile production following the three categories of supply chain, human resources and technologies. For simplicity reasons, Figure 2 only shows a few areas of interest to managers that are more representative of the agility facilitators in Table 4. The three categories of facilitators in Figure 2 could be interrelated as suggested by the depicted rows. There are bidirectional rows between the blocks of Supply Chain and Human Resources, and between the blocks of Human Resources and Technologies. This indicates the interrelation and mutual dependence between each one of these blocks. However, there is only a unidirectional relationship between Supply Chain and Technologies because manufacturing must rely on the supply chain. Nowadays, global competition focuses more on supply chains than on the firms themselves, and consequently the needs of supply chains influence strongly the adoption of manufacturing and design technologies inside each firm. Our results confirm the important role that supply chain management plays in the development of innovation capabilities according to other studies (e.g., Martinez-Sánchez and Lahoz-Leo, 2018).

The agility cores of Figure 2 may be used as a conceptual framework to measure agility. Other authors have proposed instruments to assess production agility and there are already several metrics and agility models in the literature (e.g., Vinodh and Devadasan (2010); Vinodh et al. (2012); Rameshwar and Angappa, 2015). Table 7 adapts these check-lists of agility measurement criteria to the results found in our study related to the three groups of agility implementation: supply chain, human resources and technologies. These measurement criteria are more useful to assess the evolution of a firm towards production agility than the constructs used in Table 4 because they were assessed by managerial perceptions and only relatively to industry averages. However, firms need to include measurement criteria within their information systems like Balance Scorecards. Thus, our paper suggests links between the groups of agility facilitators and the check-lists of agility measurement criteria that can be useful to managers. We think that agility criteria should be measured by quantitative indicators and not by subjective measures in order to control the firm's degree of evolution towards greater agility. Agile manufacturing is a complex production paradigm that it does not only need manufacturing technology and cannot be focused just on internal operations. Our paper has highlighted the importance of supply chain management and the core role of human resources to facility the development of agility capacities. The management of agile production requires integrative analytic frameworks and our paper offers some guidelines to establish managerial priorities along the implementation process.

The second part of the discussion analyzes the implications of the multivariate analysis of agility capacity. We think that our study offers some singular results that extend previous studies. First, we have found that 'organizational support to innovation' is positively related to agility (Table 6) but this capacity is also the most implemented management capacity and with the largest mean difference between high-agile and low-agile firms (Table 5). The firm's organizational support to innovation is an intangible resource that contributes to agile production through innovative and knowledge-intensive value chains. The design of a value chain that responds to markets with highly customized products and very short lead times is something extremely crucial. That kind of environment not only needs high manufacturing flexibility but also a fluid interaction between marketing, product design, and customized manufacturing. Such interactions need an adequate organizational support that links processes with agility. This organizational support may facilitate some of the practices adopted to manage value chains like ERP systems based on Internet (Elmoselhy, 2013).

Another singular result and contribution of our research is the moderator effect of external cooperation. The literature acknowledges the positive effects of collaboration to share innovation costs and reduce time-to-market for product innovation. Inter-organizational cooperation on innovation has been used as moderator in studies of human resource flexibility (e.g., Martinez-Sánchez et al., 2011) to differentiate the contribution of each flexibility dimension. Our study is the first empirical test of this moderator effect applied to another important flexibility dimension that is the firm's capacity of production flexibility. We have found a negative moderator of external cooperation on the positive relationship between production flexibility and agility which indicates that this positive relationship is stronger among firms with lower cooperation values. Therefore, higher external cooperation means higher agility but lower external cooperation implies a stronger positive relationship between production flexibility and agility. Cooperative environments are fruitful to agility, then why does production flexibility need lower cooperative environments to enhance agility? A possible reason is that our definition of production flexibility capacity (see Table 2) focuses only on internal manufacturing systems that need accurate data to forecast aggregate production. Firms in lower cooperative environments would have to rely more on the efficiency and ability of their manufacturing systems to change because they cannot rely on other firms to face dynamic environments. Our result suggest a trade-off between production flexibility capacity and external cooperation which means that firms in less externally cooperative environments should invest more in flexible manufacturing systems to enhance agility. This implication relates to the implementation model of Figure 2, more precisely in the unidirectional arrow that links supply chain and technologies. The characteristic of a firm' supply chain influences on the type of technologies required by that firm.

Regarding the lack of support to hypotheses H2 (moderating effect of internal support to innovation), a possible explanation is that maybe this support is a direct antecedent of innovation capacity as it is of agility capacity. This means that internal support is needed indeed to develop the dynamic capabilities of innovation and agility. Anyway, organizational support to innovation is positively related to agility which corroborates the importance of human resources in the development of agility capacity. The model of Figure 2 highlights the pivotal role of human resources and how some of these HR facilitators may contribute to integrate technologies and supply chain.

In summary, we think that our research offers managers a few important implications regarding the management of agility manufacturing. First, to advance towards agility, firms should focus initially more on the supply chain, then on human resources management, and third on manufacturing technologies. This ranking of implementation seems to be more related to greater agility capacity. Second, it is helpful to introduce specific measures to control the different agility facilitators in order to analyze the implementation of the agile production system. Measuring the evolution of agility facilitators is important because agility is a complex and more interrelated process that needs comprehensive check-lists of indicators to control its evolution and performance. Finally, firms should cooperate externally to innovate and also support innovation internally in order to improve their agility capacity. Both are direct facilitators of agility but managers should be especially careful with external cooperation because in lower cooperative environments firms would have to rely more on the efficiency and ability of their manufacturing systems to change because they cannot rely on other firms to face dynamic environments.

Conclusions and limitations

Our study indicates than high-agile manufacturing firms have implemented a comprehensive bundle of supply and manufacturing management practices more intensively than low-agile firms. In a simple way, there are three important groups of facilitators for the surveyed firms: the agility management of supply chains, the skills and knowledge development of human resources, and the implementation of agile manufacturing technologies. However, the main conclusion and objective of our research has been to support the proposition that high-agile firms cooperate externally more to innovate than low-agile firms. Such external cooperation moderates the firm's level of production flexibility. This indicates that thanks to external cooperation for innovation, firms with less production flexibility may achieve greater agility capacity.

The main limitations of our research design are the use of cross-sectional data and the use of managerial perceptions to assess most of the variables. Future studies could use longitudinal and real data to confirm the relationships found in the study. A larger sample of firms could also be useful to test more research hypotheses, for instance external cooperation as moderator of product innovation and agility, or organizational support as moderator of production flexibility and agility. We also recognize the difficulty to generalize results based only on Spanish firms and therefore larger databases with European firms would be needed to extend our propositions.

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Table 1. Distribution of manufacturing firms in the sample by industry

NACE	Nº firms	% total
C24 - Manufacture of basic metals	23	10.1
C25 - Manufacture of fabricated metal products, except machinery and equipment	34	15.0
C26 - Manufacture of computer, electronic and optical products	22	9.7
C27 - Manufacture of electrical equipment	23	10.1
C28 - Manufacture of machinery and equipment	29	12.8
C29 - Manufacture of motor vehicles, trailers and semi-trailers	56	24.7
C30 - Manufacture of other transport equipment	19	8.4
C31 - Manufacture of furniture	12	5.3
C32 - Other manufacturing	9	4.0
Total firms	227	100.0

Table 2. Measures (AVE =Average Variance Extracted; CA=Cronbach's Alpha; CR=Composite Reliability)

Agility Capacity.- AVE= 83%, CA=0.966, CR=0.93 Likert scale from 1 "very little important" to 7 "extremely important". 7 items from Zhang (2011): Proactiveness—the capability to act proactively instead of reactively in attacking threats and opportunities Responsiveness—the capability to identify, respond to and recover from changes Competency—the capability to operate efficiently, produce high quality and high performance products, deliver on time, innovate, and manage core competency Flexibility—the capability to perform different tasks and achieve different objectives with same resources/facilities Quickness—the capability to operate at high speed Customer focus—ability to have a strong customer focus Partnership—the capability to form concrete relationship with suppliers and partner
Production flexibility capacity.- AVE = 80%, CA=0.918, CR=0.89 Likert scale from 1 "totally disagree" to 7 "totally agree". 4 items, own elaboration: Our firm is able to increase or decrease effectively aggregate production in response to customer demands Our firm has a manufacturing system that is able to produce effectively a broad variety of different products Our firm has a manufacturing system that is able to handle increases and decreases of product portfolio in time Our firm has a manufacturing system that is able to implement small product changes in response to changes in customer needs or from corrective actions
Product innovation capacity.- AVE=76%, CA=0.881, CR=0.85 Likert scale from 1 "totally disagree" to 7 "totally agree". 5 items, own elaboration: Our firm is able to substitute obsolete products Our firm is able to expand product range Our firm is able to develop environmental-friendly products Our firm is able to improve products' design Our firm is able to reduce new product development time before commercialization
External cooperation on innovation.- AVE=78%, CA=0.952, CR=0.93 Likert scale from 1 "Extremely lower than industry average" to 7 "Extremely higher than industry average". 7 items, own elaboration: Cooperation with Universities Cooperation with other R&D centers Cooperation with suppliers Cooperation with customers Cooperation with joint-venture partners Cooperation with industry clusters Cooperation with competitors
Organizational support to innovation.- AVE=84%, CA=0.938, CR=0.92 Likert scale from 1 "totally disagree" to 7 "totally agree". 4 items adapted from Verdú-Jover et al. (2005): Technological innovation is willingly accepted in this organization Our organization searches actively new ideas for innovative products New ways of doing things are willingly accepted in our organization This organization does not penalized employees for ideas that do not work
Environmental dynamism.- AVE=80%, CA=0.967, CR=0.87 Likert scale from 1 "strongly disagree" to 7 "strongly agree". 8 items from Klaas et al. (2001): Technological changes are very difficult to anticipate in this industry Marketing practices change very quickly in this industry Competitors' behavior is very difficult to anticipate in this industry Product become obsolete very quickly in this industry Changes in the production system are very difficult to forecast in this industry Customer needs are very difficult to forecast in this industry

Technology changes very quickly in this industry Market demand is very difficult to forecast in this industry
Market hostility.- AVE=85%, CA=0.910, CR=0.84 Likert scale from 1 “strongly disagree” to 7 “strongly agree”. 3 items: Our plant faces up strong competition at global level There is strong competition in our industry to occupy market niches The competition to increase market share is very intense

Table 3. Descriptive statistics (means, standard deviations and correlations)

	Mean	S.D.	1	2	3	4	5	6	7	8
1.Agility capacity	4.13	1.98								
2.Firm size	380	185	-.062							
3.Export intensity	29.3	23.5	.408*	-.053						
4.Dynamism	3.96	2.01	.557**	-.053	.245+					
5.Market hostility	4.02	1.96	.378*	-.054	.218+	.362*				
6.Production flexibility	4.07	2.00	.486*	-.049	.500*	.559**	.478**			
7.Product innovation	4.28	1.39	.650**	.118	.465*	.527*	.535**	.458*		
8.External cooperation	3.42	1.65	.444**	.160	.527*	.116	.325*	.517**	.589**	
9.Organizational support	3.59	1.41	686**	-.076	.132	.357*	.213+	.425**	.633**	.541**

+p<0.1 *p<0.05 **p<0.01

Table 4. Mean differences in the implementation of supply and manufacturing practices (agility facilitators) according to the firm´s level of agility capacity

Agility facilitator	High-agility firms (n=121)	Low-agility firms (n=106)
Advanced MRP/ERP (SC)	6.44**	3.95
Supplier certification (SC)	6.07**	4.26
Strategic supplier selection (SC)	5.76**	2.34
Integrated product design (SC)	5.76**	2.28
In-house technology (HR)	5.75**	2.33
Advanced manufacturing technologies (T)	5.73**	2.20
Workforce development (HR)	5.71**	2.19
Benchmarking (HR)	5.70**	2.46
TQM culture (HR)	5.69**	2.35
Supply base rationalization (SC)	5.68**	2.45
JIT flow (SC)	5.67**	2.28
Supplier information sharing (SC)	5.66**	2.28
Supplier partnerships (SC)	5.63**	2.32
Concurrent engineering (T)	5.61**	2.20
Customer orientation (HR)	5.60**	2.26
Cellular manufacturing (T)	5.59**	2.12
Manufacturing strategy integration (T)	5.56**	2.40
Supplier development (SC)	5.48**	2.15
Teams (HR)	5.44**	2.13

**p<0.01

The constructs are simple average values of the practice items assessed in a 7-point Likert scale from 1 (much less implemented in our plant than the industry average) to 7 (very much implemented in our plant than the industry average). The firms are classified in low- and high-agility according to the variable Agility that assesses the agility capacity required by the environmental changes of the firm; the average value (4.13) of this variable divides the sample in two groups: low-agility (≤4.13) and high-agility (>4.13). The first column (Agility facilitator) also indicates which agility factors are supply chain (SC), which are Human Resources (HR) and which are Technologies (T)

Figure 1. Research model

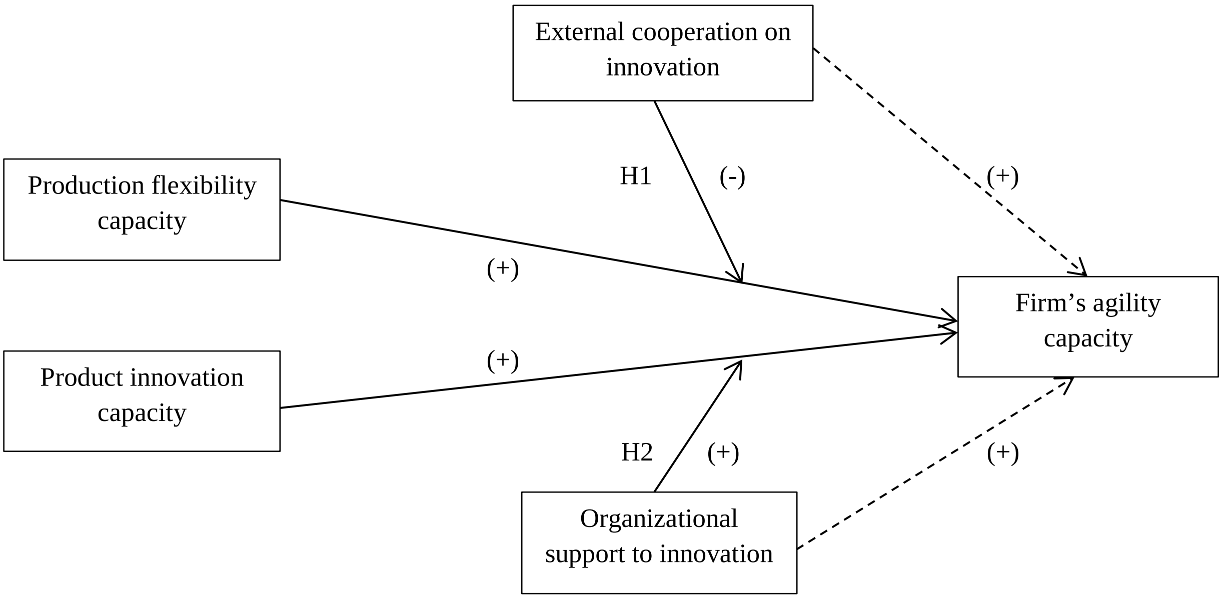

Figure 2.- Model of agile production implementation based on surveyed results