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Technical paper

Product mix strategy and manufacturing flexibility

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ABSTRACT

The manufacturing industry is facing a turbulent and constantly changing environment, with growing complexity and high levels of customisation. Any investment solution should address these problems for a dynamic market and within limited budget boundaries, so that companies try to remain competitive. The authors propose a real options model to support firms making important investment decisions, specifically decisions associated with the acquisition of new equipment aimed at allowing firms to increase their manufacturing flexibility for the production of both standard and customized products. This paper is partially based on a real operating experience related to visual finishing technology features in an industrial company that conforms to the definitions of the product mix. The authors' motivation for this work is driven by firms' desire to satisfy specific customer needs, and to respond to them quickly under uncertain demand. Our goal, using theories from finance, production management, and product offering management, is to conclude that there is a relevant difference between the evaluation of the technology that is to be chosen, and the potential value due to product mix adaptations that are able to provide the maximum return from investment. We address problems related to standard and customized production systems, and the decision to invest in a set of resources that will enable this choice.

1. Managerial relevance

Today's firms are constantly trying to figure out better ways of exploiting economies of scale, while also satisfying the increasing demand for highly customized products. Most of the existing equipment was designed for large-scale production, and it was evaluated using the considerations of economic order quantities. These problems result from strategic definitions of whether or not a company is focused on a low cost approach, or if the firm is prepared for small quantities and customized orders. This dilemma is timely in the industry, mainly referring to our numerical example related to flooring. The challenge is about the choice of flexible equipment features that should be balanced with reasonably customized offers.

2. Introduction

In recent years, in order to satisfy finely targeted niche markets, with an increasing number of product variants, decreasing lot sizes, accelerated lead-times, and shorter products' life cycles, companies have dramatically increased their product mix. As a result, a high degree of equipment flexibility is now required, and companies must incorporate this need into discussions of new investments.

Despite the way managers think, traditional approaches that are based on discounted cash flows techniques, and which compare future profits with the cost of investment for a certain demand's quantity, do not actually consider the value of product mix flexibility. As a consequence, volume increase or economies of scale are still the more attractive argument to use in a project payback. The problem of the traditional approach is that investing in more flexible equipment that is able to produce smaller and more customized batches, does not generate the required profitability over the expected period of time in order to cover the initial costs. Investments in flexible equipment are generally more costly than those for inflexible equipment, and the potential benefits are difficult to value with accuracy at the initial time. This is particularly true in the presence of high levels of uncertainty, when it is difficult to predict if a certain option will be exercised or not.

Any company offers a mix of standardized and customized products. The strategic problem of offering only standard products is the fact that the other suppliers could easily copy the solutions; on the other hand, the operational dilemma of the company is about the use of the equipment under analysis, and whether it can be used for standard products that are based on big orders, or for smaller, customized orders.

Investments tend to be evaluated considering a single measurement and associated yield of the particular machine under analyses; these is considered the same for all the products, despite

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different batch volumes. Smaller batches are seen as unpopular and customized products the exception, but normally they are at the core of the reasoning for some additional investments that argue for more flexibility and market requirements. Managers have to initially decide whether to invest in a flexible manufacturing system that has the possibility of producing customized products, or in dedicated systems, which are inflexible concerning customisation. In other words, the firm has to consider whether it is valuable and convenient to spend additional money to acquire equipment features that offer flexibility. In short, the model is more valuable if the benefits resulting from the product offer flexibility are greater than the costs of the initial investment.

The investment in flexible manufacturing equipment and the subsequent ability for customized products is generally greater than the investment in equipment that aims a standard mix based on a limited range of products. Flexibility gives the management some freedom [1].

Flexible manufacturing equipment is designed to produce a wide variety of product variants (in our work, the product property with the greatest potential is the surface design), each of which has small lot sizes, with the efficiency of mass production. For our purposes, our choice in industrial equipment is based on cost effectiveness and customisation [2].

Specifically, we propose a method that uses real options for the overall economic figure of an investment in new equipment, primarily, and aiming the visual finishing at an industrial company. The firms customize their product mix to meet market needs, yet also to provide a quick response times.

The main challenges are calculations of managerial flexibility to support the decision whether or not to accept an investment that is able to provide additional customisation by adding costs. Our motivation comes from an investment problem that was encountered by an industrial company. The alternatives are either a flexible or an inflexible product line. To simplify our approach, an item group represents a number of items with similar manufacturing characteristics, which is applied to the equipment under analysis (common simplification in capacity problems).

We will investigate the differences between evaluating an investment in new equipment for an industrial company, and consider alternative scenarios for the product mix. The problem we present is formulated by two questions: (i) what is the value of product mix customisation? (ii) How much money is a firm inclined to spend in order to have a more flexible equipment? And we will consider two situations affecting the profit function: (i) in which the supplier does not let themselves be exposed to risk (charging the customers with additional costs by using a premium on selling price), and (ii) in which the supplier allows themselves to be partially exposed to risk (charging the customers only with the initial costs related to equipment adaptation, assumed as sunk costs). To answer these questions, an appropriate methodology to support investment decisions, taking into account these characteristics, needs to be used. We aim to conclude that there is a relevant difference in the evaluation of decisions about what equipment to choose, considering the potential value related to changes in the standard mix that are able to provide the maximum return from investment and fulfil the market demands.

3. Literature review

Valuing manufacturing flexibility has been done for more that two decades. In this paper, however, we will focus on the flexibility related to product mix.

Traditionally, investment appraisal is based on net present value and other discounted cash flows techniques. These techniques ignore the value of flexibility related with management adaptation, or the influence of new information during the project life time [3]. Another relevant problem is the increase of variables affecting the decision process, despite the required profitability under demand fluctuation [4], such as flexibility, cost adaptability, equipment's requirements and eventual reconfiguration [5], mainly linked with the diversified customer base, product models and variants extension, smaller lot sizes, accelerated time to market and shorter life-cycles [6,7]. Recent developments in technology, like flexible manufacturing systems, can provide benefits that are not properly captured by traditional approaches; we refer mainly to economies of scope [8]. The Real options approach, on the other hand, requires expected discounted future cash-flows to be significantly above the investment costs, by addressing the limitation of traditional approaches and valuing the flexibility of management decisions along the project period [9].

Traditional techniques admit that management makes an irrevocable decision on the basis of future market expectations, assuming that the deterministic discounted cash flows are known at the initial moment. The traditional techniques can be used and are valid in the absence of uncertainty, but their use is not correct when managers are able to react in the presence of new information from the market and, therefore, to improve the value of the project.

Manufacturing flexibility is the ability to deal with a changing environment and can be seen as a competitive priority [10–12], but acquiring flexibility has a cost [13] and should be valued [14]. The literature reports several methods to measure the manufacturing flexibility (see, e.g. [15–21]).

Different studies on managerial flexibility have been done for almost two decades, using real options and other techniques (see, e.g. [3,22–26]). The bases of the developments are the decisions whether to buy flexible or non-flexible equipment and how much capacity should be acquired, with regard to the fact that investment is irreversible.

Different types of flexibility can be evaluated such as the “volume”, “process” and “product mix”, which can be, respectively, defined as the ability to operate profitably at different outputs or scales, with different designs and routes or in the presence of several products being manufactured without causing set-ups increase (e.g. [27,28]). We refer specifically to product mix flexibility and the capacity of production equipment to handle the product mix changes [29], and we follow Berry and Cooper [29] that defined product mix flexibility as the ability to manufacture a wide range of products or variants with expected low changeover costs. Gerwin [30] focused on equipment and features related to volume and mix flexibility. Slack [31] discussed the implications of the resources on flexibility, e.g., process technology versus volume and mix flexibility. Olhager [32] mapped, among others, set-up time as a source of volume and/or mix flexibility. Chang et al. [33] studied, e.g., the ratio of manufacturing technology to the mix and volume flexibility. Hutchison and Das [34] listed the ability to produce a wide range of products and quick changeover times as capabilities to achieve mix flexibility. Finally, we can refer Wang et al. [35], who put the attention on the relationship between mix optimisation and manufacturing complexity.

In 1996, Trigeorgis [3] proposed a real option approach to value the managerial flexibility and Suarez and Cusumano [36], examined the use and implementation of manufacturing flexibility, showing that the degree of flexibility depends on what the firm is aiming to achieve concerning product-demand characteristics. In 1998, Chryssolouris, Anifantis and Karagiannis [37] presented some flexibility measures, considering the manufacturing system ability to react to dynamic changes in inputs. Koren et al. [38] evaluated manufacturing systems, considering the configuration of machines and material handling. In 2004, Kurtoglu [39] used the cost of changing a system, aiming the production of new products/variants and

Wiendahl and Heger [40] referred to the concept of changeability. Wahab [41] studied measures for machine and product mix flexibility.

Typically, scale economies are used to support investment decisions; in contrast, scope economies are not directly incorporated in assessment techniques. However, exceptions can be found in literature, as the percentage of products that are standard or customized [42], the number of complementary technologies/standards employed [43] and the modularity of the product [44]. Generally, allied arguments have faced flexibility as outcomes of management know how [45].

The research in this paper differs from previous literature regarding three aspects: (i) we quantify the investment decision under demand uncertainty; (ii) we examine the impact of different equipment features on investment flexibility value; and (iii) our model incorporates the problematic of product mix distribution between standard and customized items, making a closer approach to the reality. Although previous research has addressed one or two of the above points, nothing has been found integrating all three aspects. Thus, our research provides additional contributions to the literature.

4. General problem identification

A recent trend is that commodity-producing companies try to fit the market requirements to the existing production facilities. This is because consumers have become more demanding when it comes to finding a suitable product for their needs.

The company we will use in our example has an extensive product portfolio, containing more than one thousand articles. The company divides its customers into three different segments: specialty, chains and contracts. The fact that the company has a wide variety of products, but wants to maximize batch volumes, in order to minimize the unit cost, will lead to a new reality in investments evaluation. The problem with this strategy is that the company has to extend its product portfolio further, which leads to higher overhead costs and a need for greater flexibility in production facilities. The company faces a problem related with surface finishing variant, as the initial costs are very high. This causes small and customized orders to be expensive to produce. New techniques for surface finishing need to be evaluated. In this new design technique project is discussed whether it should be used only for development of new standard products or if it should be used as a production machine for small customised products.

Today, the production tries to minimize the total time of set-ups. The factor that has greater impact on the total set-up time is the number of changes in production orders. Consequently the production tries to minimize the number of production orders by maximizing the batch sizes.

5. Model

In this section, we will derive our model focusing on the research questions outlined in the introduction. We relate our problem with the equipment acquisition function; however, we realize the importance of extending the issue to future resources argument configuration. We focus our approach on assembly systems, where the set-up time is a relevant activity, consuming resources and costs, to endure the process flexibility.

It is stated that the most important factor influencing manufacturing investment decisions, is product demand. Therefore, the uncertainty in demand (quantity) is recognized as the only source of uncertainty in our valuation framework, which will be represented by D. Also, Cobb and Charnes [46] or Rabbani et al. [47] and other authors used the demand as a source of uncertainty to support manufacturing investment decisions. The change in demand (stochastic variable) is modelled as a geometric-Brownian motion (assumption also used by [26,48–50]).

We assume that the product demand can be based on standard or customized products, for a certain period of time, the possibility of sequential investment is not considered within the review period, and we consider the existence of a salvage value at the end of the investment period. We stress that the strategy of splitting demand between standard and customized products is influenced by the company.

We restrict our model to buying resources perspective, considering that there are no outsourcing alternatives for the specified activities, and we ignore the inventory planning influences in the equipment performance.

Considering the equipment and process analysis, we assume that features like processing times, the set of product types that the system is capable to produce and their required operations are known. Based on this information, we interpret flexibility as the ability to switch between different products, without incurring major changing costs (based on [51–53]).

We will use two relevant indicators related with integration and impact of set-ups. Equipment effectiveness depends on the integration of various stations, taking into account the buffer sizes, the loading conditions and the balanced workload up and downstream of the chain. Integration aims to significantly reduce part waiting times and work-in-process inventory [54,55]. There is also an impact from different scheduling policies on the performance of each process configuration. For limited or not allowed buffers, our main performance measure is the expected throughput rate, while for systems with infinite buffers is the equipment flow time. For both systems we can use an integration flexibility factor as presented in the model. We derived the indicator considering the technical equipment features, mainly the output rate, and the up and downstream process stations capacity. We used the worst situation as the basis (minimum boundary) and then we derive to other alternatives considering the global flow output improvements, but always subject to a maximum boundary according to the investment budget. The integration costs are calculated as the inverse of flexibility factor, and are applied to the cost of lost or unused flow capacity. This means that if we choose equipment with lower output within up and downstream stations, and limited buffers, we should book an opportunity cost. An example is provided in Table A.3.

On the other hand, set-up time is usually incurred each time a machine switches from one item type to another type, which affects the flexibility of the equipment [56]. The set-ups may be due to exchange of tools, designs, dimensions or programs. The frequency of set-ups is determined by the number of items being processed in the same machine and the used scheduling policy, which is being affected by lower and more frequent orders. Although it is difficult to extend the analytical models for zero set-up times, we did not restrict the model to capture the effect, when applicable. We derived the indicator, considering the time of change required in each task to be performed, in accordance with the technical parameters of equipment under consideration, but subject to budget constraints (upper limit). We use the worst case (minimum boundary) as the basis and derived the alternatives using a flexibility ratio, which we apply in the reverse order for the set-up cost function. An example is presented in Table A.2.

For a general application of the model, we consider the possibility of dividing a complex investment in different homogeneous units, in the same way as the integrated equipment.

The demand process is written as:

$$dD = \alpha D dt + \sigma D dz \tag{1}$$

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Table 1
Notation.

$I_i = I_{i-1} \cdot \gamma i_i \cdot \gamma s_i \; ; \; i \geq 1$	Investment in flexible technology (equipment or homogeneous unit) index, *i*
I_b	Maximum allowed investment budget
I_0	Investment in inflexible equipment (or homogeneous unit)
S	Salvage cost (% of investment value)
T	Time to expiration
i	Index for technology flexibility. $i = 0$; equipment (or homogeneous unit) dedicated to standard products; $i \geq 1$; flexible technology able to produce customized items
γs_i	Flexibility factor for additional investment value regarding set-up costs
γi_i	Flexibility factor for additional investment value regarding integration costs
λs_i	Flexibility factor for set-up costs optimisation
λi_i	Flexibility factor for integration costs optimisation
x	Offer index for standard products
pv_x	Selling price standard products
p_y	Selling Price premium for customized products
cv	Variable production unit cost
Δcf	Development costs of customized products for a single unit
y	Customer index participation in Δcf
r	Risk-free interest rate
$ks_i = ks_{i-1} \cdot \lambda s_i \; ; \; i \geq 1$	Fixed set-up cost by order for option technology, *i*
$ki_i = ki_{i-1} \cdot \lambda i_i \; ; \; i \geq 1$	Integration cost for option technology, *i*
ks_0	Fixed set-up cost by order for inflexible technology
ki_0	Integration cost for inflexible technology
φ	Average quantity by order for standard products
θ	Average quantity by order for customized products

where $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0, 1)$; α is the instantaneous drift; σ the volatility; dz is the increment of a wiener process and $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable.

From Eq. (1) it follows that the demand D is log-normally distributed with a variance that grows with the time horizon (also an assumption of the model presented by [1]). The demand is modelled as a continuous process that can be applied realistically, considering that the manufacturer accepts any order, despite the economic lot size, and there is no relevant influence of inventory buffers between the equipment production output and the market demand. We assume that the product mix is defined by the company, which cannot influence the overall demand quantity but influences the selling price, within a set price corridor. The parameters used in the model are described in Table 1.

We will model two situations, considering the flexibility and inflexibility of the equipment concerning the product mix. This can be applied for the same volume of demand, assuming different indices in the product mix. We consider that there is always a balance between the volumes and prices for each index. This is a realistic assumption, considering the existence of a higher price (premium) for customization. We derived the model Eqs. (2) and (13) based on the reasoning described in Table A.1.

5.1. Product mix flexible model

When studying an investment acquisition, which expires at the end of time T, and gives us the opportunity to buy more flexible technology, whether the benefits of the possibility of manufacturing customised products, exceed the costs for acquiring the additional equipment resources, respecting the maximum allowed investment budget; the optimal alternative (value matching), which we denote as "flexible investment acquisition", at the end of T, can be expressed as:

Table 2
Numerical parameters.

I_b	$I_0 \times 1.5 \times 10^3$ €
I_0	1200×10^3 €
S	$10\% \times I_0$
D	250×10^3 un
T	10
γi_i	1.02 (see Table A.3)
γs_i	1.1 (see Table A.2)
λi_i	$1/\gamma i_i$
λs_i	$1/\gamma s_i$
x	90%
pv_x	$cv \times 1.2$ €/un
p_y	2.5 €/un
cv	10 €/un
Δcf	1 €/un
y	20%
r	6%
ks_0	240.57 €/un
ki_0	0.3 €/un
φ	1500 un/order
θ	150 un/order
σ	20%

$$D \cdot \left[x \cdot \left(pv_x - cv - ki_{i-1} \cdot \lambda i_i - \frac{ks_{i-1} \cdot \lambda s_i}{\varphi} \right) + (1-x) \cdot \left(pv_x + p_y - cv - ki_{i-1} \cdot \lambda i_i - (1-y) \cdot \Delta c_f - \frac{ks_{i-1} \cdot \lambda s_i}{\theta} \right) \right] - I_{i-1} \cdot \gamma i_i \cdot \gamma s_i + S \qquad (2)$$

Then we calculate the $FIA_i(T)$ as the expected terminal value of the condition (expiration optimal condition):

$$FIA_i(T) = \max \left\{ D \cdot \left[x \cdot \left(pv_x - cv - ki_{i-1} \cdot \lambda i_i - \frac{ks_{i-1} \cdot \lambda s_i}{\varphi} \right) + (1-x) \cdot \left(pv_x + p_y - cv - ki_{i-1} . \lambda i_i - (1-y) \cdot \Delta c_f - \frac{ks_{i-1} \cdot \lambda s_i}{\theta} \right) \right] - I_{i-1} \cdot \gamma i_i \cdot \gamma s_i + S \right\} \qquad (3)$$

where, $FIA_i(T)$ is the additional value of flexible investment acquisition; $D \cdot x \cdot (pv_x - cv - ki_{i-1} \cdot \lambda i_i - (ks_{i-1} \cdot \lambda s_i)/\varphi)$ represents the profit function for standard products within a certain demand level D and the offer mix x; $D \cdot (1-x) \cdot (pv_x + p_y - cv - ki_{i-1} \cdot \lambda i_i - (1-y) \cdot \Delta c_f - (ks_{i-1} \cdot \lambda s_i)/\theta)$ represents the profit function for customized products within a certain level of demand D and the offer mix $1-x$; $I_{i-1} \cdot \gamma i_i \cdot \gamma s_i$ represents the investment in technology for a flexible combination of products, considering integration flexibility factor γi_i and production flexibility factor γs_i; finally, S represents the salvage value.s.t.

$$i \geq 1 \qquad (4)$$

$$p_y \geq 0 \qquad (5)$$

$$0 \leq x \leq 1 \qquad (6)$$

$$I_i \leq I_b \qquad (7)$$

$$\gamma i_i \geq 1 \qquad (8)$$

$$\gamma s_i \geq 1 \qquad (9)$$

$$\lambda i_i \leq 1 \qquad (10)$$

$$\lambda s_i \leq 1 \qquad (11)$$

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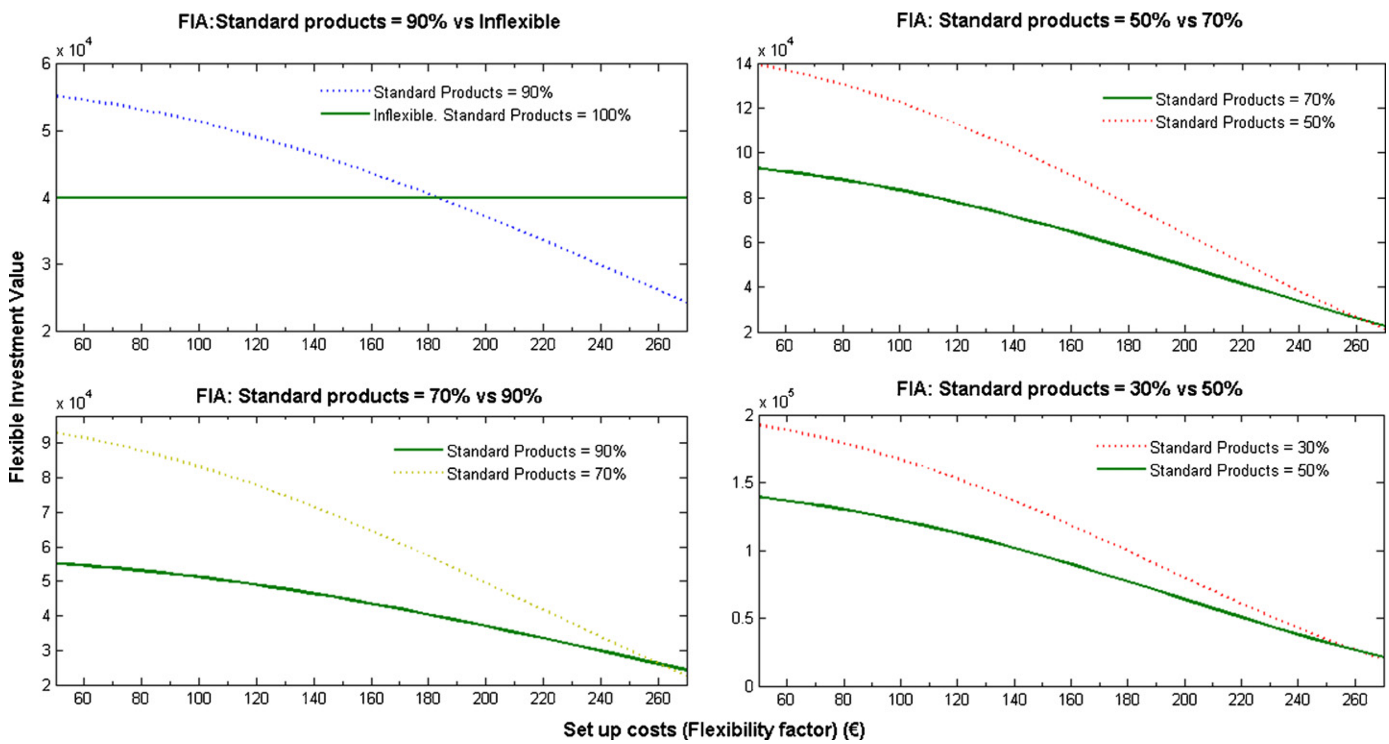

Fig. 1. Inflexible investment, flexible investment acquisition value (FIA) and set-up costs, for different mix alternatives.

Thus, the value of the alternative can be expressed as a European call option with the following differential equation:

$$\alpha \cdot D \cdot \frac{dFIA_i}{dD} + \frac{1}{2} \cdot \sigma^2 \frac{dFIA_i{}^2}{d^2D} - rFIA_i = 0 \tag{12}$$

5.2. *Product mix inflexible model*

$$IA_0(T) = \max \left\{ D \cdot \left(pv_x - cv - ki_0 - \frac{ks_0}{\varphi} \right) - I_0 + S \right\} \tag{13}$$

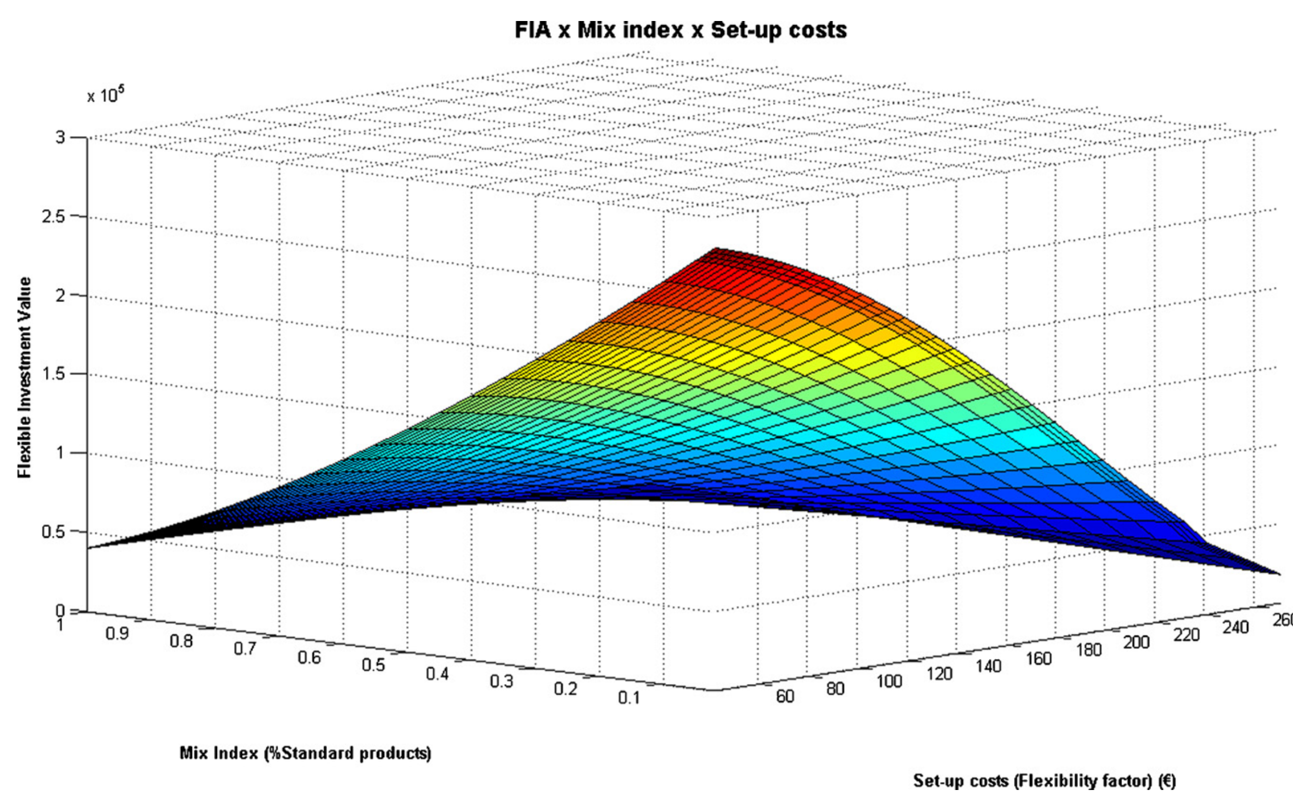

Fig. 2. Flexible investment acquisition value (FIA), mix index and set-up costs.

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Table 3
Relationship between set-up costs reduction and the flexible investment acquisition.

Equipment specification (set-ups)			Mix Index (% standard products)/FIA (10^3 €)				Additional investment (10^3 €)	Maximum value (10^3 €)
Equipment type	Flexibility factor (set-ups)		95%	80%	50%	25%		
	Additional investment	Costs optimisation						
Flexible								
M1	1.0	1.0	28.5	30.9	36.0	40.6	1200.0	1800.0
M2	1.1	0.9	31.7	37.6	51.0	63.7	1320.0	1800.0
M3	1.6	0.6	39.8	55.3	94.0	132.9	1920.0	1800.0
M4	2.2	0.5	43.6	64.2	116.5	169.6	2604.0	1800.0

Where, $IA_0(T)$ represents the additional value of inflexible technology, $D \cdot (pv_x - cv - ki_0 - ks_0/\varphi)$ represents the profit function for standard products within a certain level of demand D, I_0 accounts for the investment in inflexible equipment and S represents the salvage value.

6. Model application

To generate some insights to the model we will present an example based on real data. Some of the numbers presented in Table 2 are adapted for confidentiality reasons. The most important indicators are computed in Table A.4. We assume that a company has the opportunity to invest in new equipment, in a dynamic market, where customised products are available.

6.1. Brief description of the market and the company

To enhance the understanding of the example, we will make a brief description of the market and the products within the firm's scope.

For the production of innovative products, surface decoration players want faster turnaround time, shorter runs and more flexibility in the surface finishing process. Considering ultimate surface finishing technology, endless products with different patterns and colours can be created, using multiple designs simultaneously. This situation allows the development of new products and the offer of customized solutions. New trends in design are requiring more realistic patterns. The trend is random printing for unlimited number of items from existing and conceptualised surface patterns. Specifically, it is in the contract market where customers are demanding more customized products.

The company divided its customers into three different segments: specialty, mass chains and contracts. The specialty segment refers to dedicated stores and the contract market refers to construction segment. The market can also be divided into a consumer market and a contract market, where consumer market encompasses sales through retail shops, like specialty shops and home centres. On the other hand, the contract market comprises public environments. The market is highly fragmented with a large number of players and the company offers products to the large-scale home centres as well as to the small-scale specialty retailers. The company tries to offer a broader scope of products for specialty retailers that can get exclusive products. The problem with this strategy is that the company has to extend its product

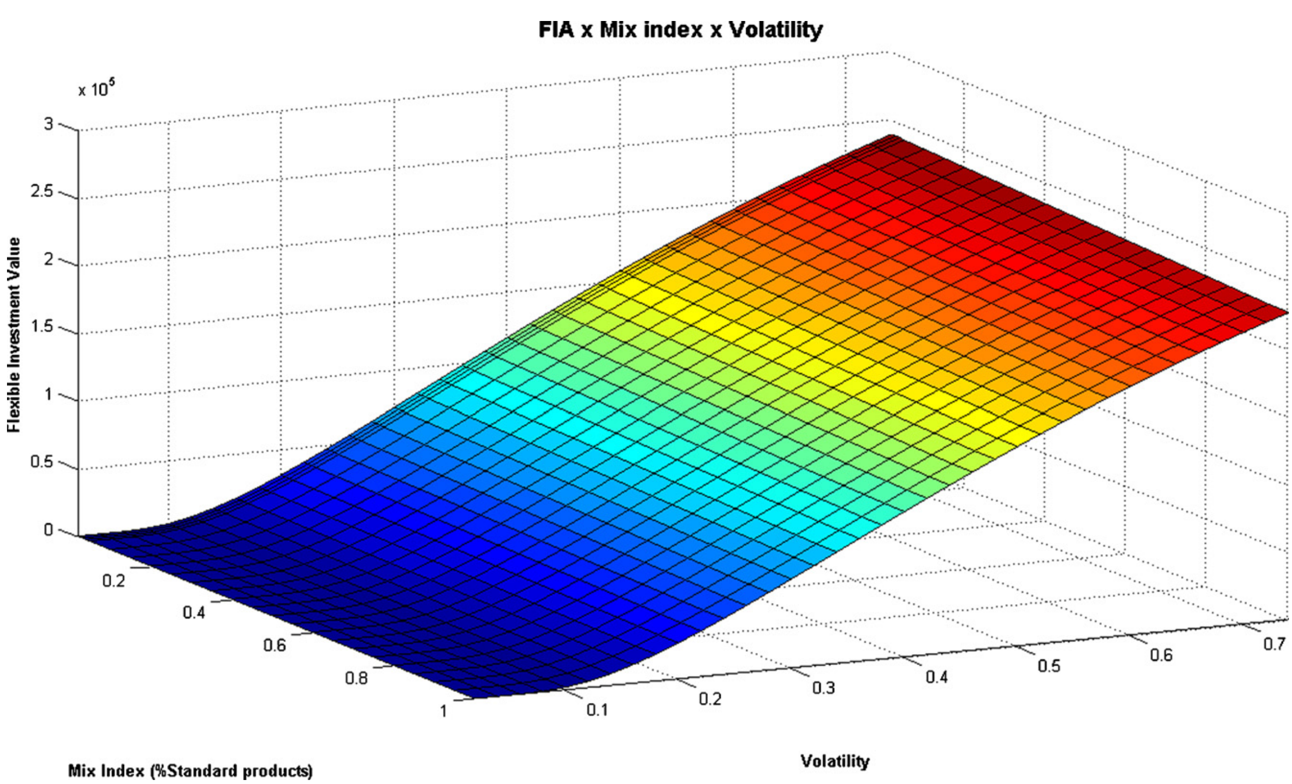

Fig. 3. Flexible investment acquisition value (FIA), mix index and demand volatility.

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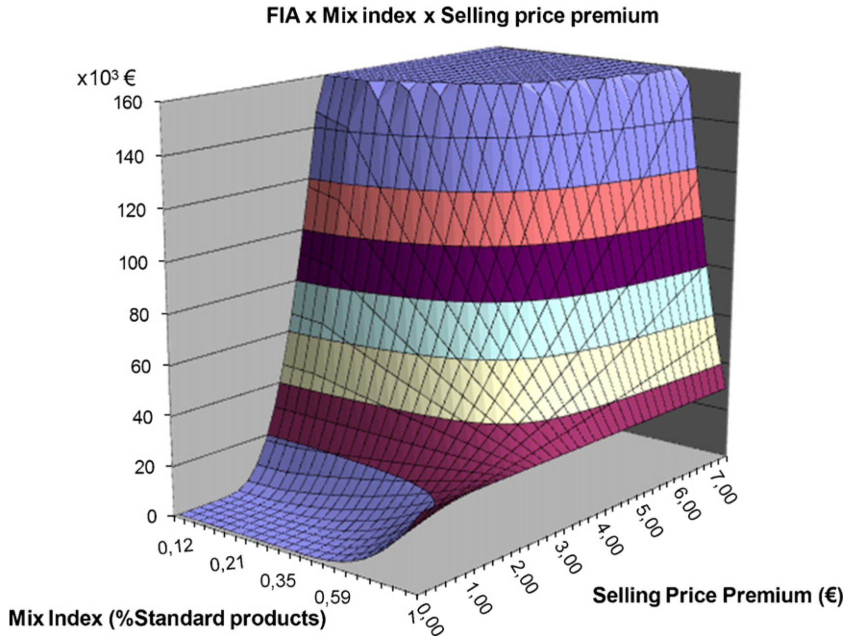

Fig. 4. Flexible investment acquisition value (FIA), mix index and selling price premium.

portfolio further, which leads to greater complexity in the innovation process, as well as in the production facilities.

The product offering consists of standard and customized products. The undertaking of the customer is either a mandatory concept, where the customer agrees to contract a certain volume such as a complete chain of stores, or a prescribed concept. Consequently the risk for the company is much higher in the latter case. When it comes to custom orders, the company's concerns are related with volumes, with prices and technical properties, as well as how the company should deal with the customisation process, leading to internal adjustments in the manufacturing department.

The production equipment under analysis uses a layer preparation, a design printing process and a wear layer finishing. The final step is a quality check for mechanical defects. The equipment type is based on high productivity, design flexibility, set-up time and costs, economical printing of short runs, lower production costs and reduced inventory and storage space. Compared with the limitations of conventional techniques of surface finishing, this new technology offers a wide variety of image variations, reduced set-up costs (reducing the need to manufacture minimum quantities), superior quality and a dynamic range of items.

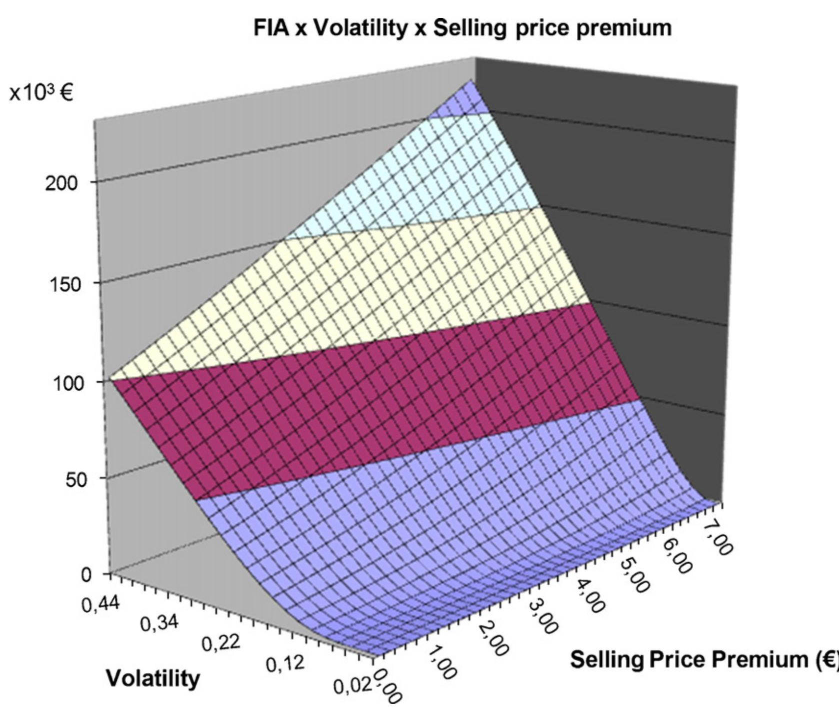

Fig. 5. Flexible investment acquisition value (FIA), demand volatility and selling price premium.

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6.2. Numerical illustration

We will evaluate five hypotheses. Mix definition impacts on investments evaluation and on the model dynamics: H1 – specialization in standard products and H2 – mixed offer. H3 – flexibility technology, measured as a reduction on set-up costs, has a relevant influence on investment evaluation. H4 – demand uncertainty impacts the investment value and H5 – selling price premium can also support a mix strategy aligned with more flexible equipment in uncertain environments.

We will consider that more flexible equipment has shorter time consuming set-ups, as it is less sensitive to possible production changes (also defended by [57–60]).

7. Results and discussion

Mix definition impacts on investments evaluation and on the model dynamics: H1 – specialization in standard products and H2 – mixed offer.

From Fig. 1, we can say that the flexible investment acquisition value (FIA) increases as the index for standard products decreases. The impact is smaller when the set-ups are more time consuming and expensive, which means a low level of equipment flexibility according to our assumptions. Considering that the company aims to achieve a minimum flexible investment acquisition value of 31×10^3 €, the optimal mix index for standard products should be 75%; in the case the company wants to offer 90% as standard products, FIA is 29×10^3 €, which means less flexibility in the mix. We found the level of flexibility, using the set-up costs, so that the value of flexible investment is higher than the inflexible one. These results are important for the real operational environment used to model the problem, as well as to support the mix strategy, which is influenced by the technical solution to install.

H3 – flexibility technology, measured as a reduction on set-up costs, has a relevant influence on investment evaluation.

From Fig. 2 we can conclude that there is a relevant link between set-up costs reduction, due to less time required for changes, and the flexible investment acquisition value, considering the equipment features. Theoretically, the equipment is designed to produce specific types of outputs, with the most efficient capacity. However, when the firm expands its product range, the efficiency is reduced, i.e. increasing the cost and time to produce the same amount of output, or decreasing the level of output with the same amount of cost and time. Therefore, the changeover cost due to product range variety can decrease the flexibility. In practice, if equipment additional features can reduce the cost and time of the changeover, the product offer management will be more flexible; so, the range of customized products can be expanded. On the other hand, if the product range can be expanded by reducing disabilities when switching from one item to another, the equipment is more flexible.

Complementing the analysis of Fig. 2 with Table 3, we can make a real calculation approach: if the value of the inflexible investment is 1200×10^3 euros and if 80% of the mix are related with standard products, the buyer is not willing to pay more that 1357.6×10^3 euros (1320×10^3 euros, with a premium of 37.6×10^3 euros) to acquire equipment technology “M3”, considering a budget limitation of 1200×10^3 euros $\times$ 1.5.

H4 – demand uncertainty impacts the investment value.

The Fig. 3 shows that the flexible investment value is higher for markets facing increasing uncertainty levels. These results are in line with the literature on the evaluation of investments using real options (e.g. [9,61,62]), where is stated that, for environments with higher uncertainty, there are more opportunities to be valued along the project life time. The difference in the mix, between standard and customized products, is more significant for environments under high uncertainty levels. This confirms that the high flexible investment value is not driven only by the general and often used argument to “invest later” but strengthened by the high percentage of products’ customisation.

H5 – selling price premium can also support a mix strategy aligned with more flexible equipment in uncertain environments.

The existence of a selling price premium can support the mix strategy between standard and customized products. A company that wants to endow the mix with more customized products should request a selling price premium, able to compensate the factory complexity. We investigated different profit function scenarios: the supplier does not expose to risk (charging the customers with additional costs, using a selling price premium), supplier exposes partially to risk (charging the customers only with the initial costs related with equipment adaptation, assumed as sunk costs). The results from Figs. 4 and 5 show that a higher selling price premium has more impact as the standard products percentage decreases (more customized products). In the presence of a lower selling price premium, the additional value is related only with set-up costs reduction (flexibility).

8. Conclusions

The aim of this work was to be an investigation of the decisions and evaluations about the equipment to be chosen, considering the mix index impact. In general terms, our conclusions are in line with past studies in terms of what affects the use of real options in investments evaluations, considering the impact of demand volatility. The novelty refers to additional equipment flexibility that is dependent on the technology flexibility factor and on the impact of mix index and demand volatility, which is in line with actual concerns as markets become more competitive and unpredictable. We also simulate the results for both situations, considering and not considering the existence of a selling price premium applied to customised products.

The numerical example shows that the opportunity for additional equipment flexibility can be quantified, and that there is a relevant link between investment choice, product mix strategy, and selling price positioning.

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Appendix A.

Table A.1
Model reasoning.

Management issue	Issue interpretation	Issue measurement	Model
Investments evaluation	Based on cash flows (profit functions)	We used a marginal approach: difference between selling price and variable production costs. We compare additional revenues with net investment (we considered a salvage value)	$Q \cdot (pv_x - cv) - I_{i-1} + S$
Market uncertainty	Uncertainty source related with demand	Traditional known variable sales quantity Q transformed in unknown quantity D	$Q \to D$
Mix versatility	The ability to changeover to produce a new (set of) product(s) very economically and quickly	We used product range relation: between standard and customised products	x ; $(1 - x)$
Equipment flexibility	Ability to changeover and adapt equipment to produce different parts (products)	We use the concept of set-ups to translate a relevant cost, in the profit function, affecting the decision process	$(ks_{i-1} \cdot \lambda s_i)/\varphi$; $(ks_{i-1} \cdot \lambda s_i)/\theta$; γs_i
Equipment integration	Routing or process design and flexibility	We translated the impact of process configuration in the balance between linked equipment outputs	$ki_{i-1} \cdot \lambda i_i$; γi_i
Selling price policy	Based on price positioning	Selling price premium	$(1 - y) \cdot \Delta c_f$

Table A.2
Surface finishing equipment specification regarding set-ups time.

Equipment specification (set-ups)																
Equipment type	Surface preparation		Textile design ink		Ceramic design ink		Wood design ink		Printing presses cleaning	Colour and design tuning	Surface finishing		Worst case		Flexibility factor (set-ups)	
	Same pattern	Different pattern	Standard format	Specific format	Standard format	Specific format	Standard format	Specific format			Standard finishing	Specific finishing	Standard finishing	Specific finishing	Additional investment	Costs optimisation
Inflexible																
M0	0″	na	5″	na	5″	na	8″	na	2′	3′	0″	na	5′	na	1.0	1.0
Flexible																
M1	0″	15′	10″	10′	9″	10′	20″	15′	8′	5′	0″	20′	13′	63′	1.0	1.0
M2	0″	14′	8″	6′	6″	8′	15″	14′	6′	5′	0″	18′	11′	57′	1.1	0.9
M3	0″	10′	6″	4′	6″	6′	10″	8′	4′	5′	0″	12′	9′	39′	1.6	0.6
M4	0″	8′	5″	2′	5″	2′	8″	6′	2′	3′	0″	10′	5′	29′	2.2	0.5

Table A.3
Internal process framework for a single shift.

Equipment type	Available output			Flexibility factor (integration)	
	Glue & pressing station	Surface finishing	Cutting & profiling station	Additional investment	Costs optimisation
M0 = M1	140 pcs/min	120 pcs/min	150 pcs/min	1.00	1.00
M2		122 pcs/min		1.02	0.98
M3		128 pcs/min		1.07	0.94
M4		135 pcs/min		1.13	0.89

No buffers between stations. No buffers inside surface finishing operation.

Table A.4
Computation of some relevant parameters and indicators used in the example.

Period	D_t ($\times 10^3$)	$R_t = \ln(D_t/D_{t-1})$	$R_m = R_t{}^2$	$(R_t - R_m)^2$	% standard mix	N° orders (standard mix items)	N° orders (customized items)
1	261.59			0.00	79	133	223
2	296.36	0.12	0.02	0.01	84	192	178
3	261.95	−0.12	0.02	0.02	89	185	120
4	372.73	0.35	0.12	0.12	93	128	150
5	305.45	−0.20	0.04	0.04	98	132	210
6	325.00	0.06	0.00	0.00	95	194	267
7	272.32	−0.18	0.03	0.03	86	165	298
8	314.18	0.14	0.02	0.02	98	209	123
9	445.45	0.35	0.12	0.12	82	187	235
10	319.18	−0.33	0.11	0.12	83	165	220
11	309.09	−0.03	0.00	0.00	89	134	256
12	317.68	0.03	0.00	0.00	94	191	150
13	449.55	0.35	0.12	0.12	92	155	265
14	316.27	−0.35	0.12	0.13	86	215	140
15	262.50	−0.19	0.03	0.04	85	138	254
16	358.64	0.31	0.10	0.09	92	165	292
17	332.23	−0.08	0.01	0.01	84	201	263
18	367.27	0.10	0.01	0.01	98	212	146
19	284.77	−0.25	0.06	0.07	88	272	300
20	301.23	0.06	0.00	0.00	87	197	165
21	352.64	0.16	0.02	0.02	94	203	180
22	362.73	0.03	0.00	0.00	98	216	204
23	356.68	−0.02	0.00	0.00	91	210	290
24	338.64	−0.05	0.00	0.00	96	437	265
25	313.18	−0.08	0.01	0.01	88	279	289
	R_m	0.01					
		Sum	0.98	0.98			
	8197.32	VH	19.80%	20.19%	90	4914	5483
			Average quantity by order			1500	150
			Volatility	20%			
			Offer index for standard products		90%		

VH, historical uncertainty; D_t, demand for period t.

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