Manufacturing Postponement: reducing upstream vulnerability by means of an improved flexibility

Jury Gualandris[1], Matteo Kalchschmidt[2]
[1] Corresponding Author - Department of Economics and Technology Management, Università degli Studi di Bergamo, 24044 Dalmine (Italy), Email: jury.gualandris@unibg.it, Phone: 0039 035 2052010, Fax: 0039 035 2052310
[2]Department of Economics and Technology Management – Università degli Studi di Bergamo (Italy), matteo.kalchschmidt@unibg.it

Abstract: As supply chain vulnerabilities and the dependence of companies to their partners (i.e., suppliers) intensify, companies are adopting manufacturing postponement in order to reduce potential negative effects of supply risks. Indeed, manufacturing postponement allows firms to properly manage point of differentiations along their production lines, improving companies' reactions capabilities. This study built a framework that relates the adoptions of postponement underlying tactics (i.e., product modularity and process re-sequencing) to the development of flexibility and to the achievement of competitive advantage (i.e., reduced exposition to supply risks). Based on data collected from54 Italian manufacturing companies we show that the adoption of manufacturing postponement directly influence firms' resiliency. Furthermore, we show that this relationship can be partially explained by an indirect path through flexibility.

Keywords: manufacturing postponement, Upstream vulnerability, flexibility, supply risk, resiliency

1 Introduction

In the last decades many firms have tried to improve their economic performance (i.e., market share, return on sales, return on investments) by focusing on initiatives (i.e., Lean Production, Just in Time, off-shore manufacturing) aimed to improve speed and reduce cost of supply chain operations. This has induced companies towards outsourcing processes thus increasing their dependence from external parties (i.e., suppliers, distributors and retailers). Consequently both product and operations performance are now strongly determined by the suppliers' behaviour and in the last few years major concern has been given to the relevance of supply chain risks i.e., vulnerabilities related to the behaviour of customers and suppliers (e.g., Lee, 2004; Tang, 2006; Wagner and Bode, 2006; Tang and Tomlin, 2008; Wagner et al., 2009).

Attention has thus been paid on how properly manage internal operations in order to reduce the potential negative effects of supply chain vulnerabilities and simultaneously gain competitive advantage. Literature has devoted much attention in providing effective practices to cope with supply chain risks. Among several, typical practices are:

- choosing the appropriate type of relationship with suppliers by adopting the strategic sourcing practice (Kraljic, 1983; Tang, 2006);
- using vendor rating programs and monitoring the behavior of partners (de Boer et al., 2001; Micheli et al., 2009)
- designing contracts (Cohen and Agrawal, 1999; Cachon, 2003);
- designing and using a system of information-sharing and integration practices (Wen-li et al., 2003; Paulraj et al., 2006; Krause et al., 2007; Zhou and Benton Jr, 2007);

In this work attention is paid on one specific supply chain risk management practice (SCRM), i.e. postponement (Zinn and Bowersox, 1988; Swaminathan and Lee, 2003; Lee, 2004).

Many authors (e.g., Zinn and Bowersox, 1988; Van Mieghem and Dada, 2001) describe different types of postponement that could be implemented by companies. These include labelling postponement, packaging postponement, manufacturing postponement, time postponement and price postponement. Labelling postponement is a situation where a standard product is stocked and differently labelled based on the realized demand. In packaging postponement products are not individually packaged until final orders are received. Assembly and manufacturing postponement refer to situations where assembly or manufacturing activities may be delayed to the end of the production process. Time postponement refers to the concept that products are not shipped to the retail warehouses but are held at a central warehouse and are shipped to customers directly. Finally, price postponement prescribes to use the price as a response mechanism to change demand so that the modified demand can be better matched given the company production capability.

Here, we focus on Manufacturing Postponement as a flexible strategy allowing firms to properly react when a supply chain risk occurs by managing decoupling points along their production lines. Lee and Tang (1997) describe how delayed differentiation along the production lines can be achieved via product modularity and re-sequencing of production sub-processes. Many contributions collected by Tang (2006) provide analytical evidence concerning the effectiveness of these postponement tactics in generating inventory savings and in improving the ability of the firms to cope with supply chain vulnerabilities: in this sense postponement was defined by the author as a lever of robustness and efficiency.

Furthermore, many authors (e.g., Lee, 2004; Tang and Tomlin, 2008; Reichhart and Holweg, 2009) have discussed postponement as a strategy enabling firms to effectively increase their flexibility, i.e. the ability of any system to adapt to internal or external influences, thereby acting or responding to achieve a desired outcome (Ackoff, 1971; Zelenovic, 1982). Flexibility allows companies to achieve superior performance and become leaders in an increasingly competitive and uncertain market (Lee, 2004).

Limited empirical evidence however is provided by literature about the effectiveness of postponement in influencing resiliency both directly and indirectly through firms' flexibility. This work is aimed at exploring in deeper detail the relationship among postponement, flexibility and company's exposition to supply chain risks. In particular, the remainder of the paper is structured as follows: in the next section we present the theoretical framework on which the paper is based and the specific research propositions we consider, then the research methodology adopted is described. Empirical results are then presented, and based on these discussions and conclusions are drawn.

2 Theoretical framework

The theoretical framework to be examined in this study is depicted in Figure 1. The concepts of Postponement, Flexibility, and Upstream Vulnerability are discussed in the following subsections.

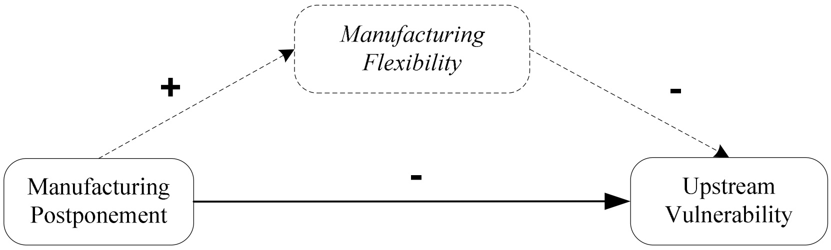

Figure 1: *Theoretical model*

2.1 Manufacturing Postponement

In this work we refer to postponement as the proactive strategy allowing firms to enhance their ability to manage points of differentiation along their production lines (i.e., manufacturing postponement). In this section we introduce two practices widely recognized as postponement's enablers: product modularity and process re-sequencing (e.g., Swaminathan and Lee, 2003; Tu et al., 2004).

Product Modularity is the practice of using standardized product modules so they can be easily reassembled/rearranged into different function form, or shared across different product lines. The key to successful product modularization is product architecture, a scheme by which functional elements of a product are allocated structurally independent physical components. An effective architecture is created when interfaces between functional components are standardized and specified to allow the substitution of a range of components without requiring changes in the designs of other components (Tu et al., 2004).

Process Re-sequencing is the practice of standardizing manufacturing sub-processes so that they can be re-sequenced easily in response to environmental changes. Feitzeinger and Lee (1997) suggested that process re-sequencing is based on the process standardization principle (i.e., break down the process into standard sub-processes that produce standard base units and customization sub-processes that further customize the base units shared by products) and allow companies to postpone processes and managing points of differentiation.

2.2 Flexibility

Flexibility is often conceptualized based on the seminal contribution by Slack (1993) and Upton (1994). Consistently with them, a systems' flexibility is based on internal resources (e.g. machinery and technology, material handling, operations, programs, etc.), that can be used to achieve different type of internal flexibility, which in turn can support the system's ability to demonstrate external flexibility to environmental changes. Within manufacturing literature there is no general agreement on the number of internal flexibility types, while is already clear which types of external flexibility can characterize manufacturing systems (Reichhart and Holweg, 2009). Consistently with Slack (1993), we can observe four types of external flexibility: product, mix, volume and delivery. Product flexibility describes the ability to introduce new products or changes to existing products. Mix flexibility is the ability to alter the product mix that the system delivers. Volume flexibility refers to the ability to change the system's aggregated output. Finally, delivery flexibility is the ability to alter agreed delivery agreements (e.g., shortening lead-times or even changing the products' destination). Obviously, these different facets of flexibility have been emphasised by various authors and this has lead to varied views reflected in the literature. For example Tang and Tomlin (2008) refer to flexibility as the agility of companies operating in a supply chain context, i.e. the ability to respond to short-term changes in demand or supply quickly, handling external disruption smoothly. Moreover, others authors use the concept of external flexibility in order to clearly define the concept of responsiveness. By relying on previous contributions (Matson and McFarlane, 1999; Holweg, 2005), Reichhart and Holged (2009) define responsiveness as "the speed with which the system can adjust its output within the available range of the *four external flexibility types*: product, mix, volume and delivery, in response to external stimulus, e.g. a customer order".

Anyway, in this work we are interested in studying the influence of postponement tactics on resiliency of companies facing supply chain disturbances (i.e., supply risks and demand risks). Consequently, we specifically focus on the capability of the production process to effectively respond to uncertainty. In order to do so, we consider manufacturing flexibility as the ability to rapidly adapt to external changes (i.e., supply problems, fluctuation of mix and volume of demand) by relying on the external flexibility of the manufacturing system (i.e., capability to effectively alter products, mix, volume and deliveries). This definition is similar and coherent to the one proposed by previous authors (Zelenovic, 1982; Slack, 1993; Upton, 1994; Lee, 2004; Tang and Tomlin, 2008). Essentially we consider a company to be flexible when it is able to respond to short-term changes in demand and supply effectively.

2.3 Upstream Vulnerability

According to Hendricks and Singal (2005), companies experiencing supply chain disruptions suffered from 33-40% lower stock returns relative to their industry benchmarks. In this sense, the success of companies operating in a supply chain context is strongly related to their ability to manage supply chain risks, damping the variability of their earnings caused by operational and disruption uncertainties. In order to move a step forward toward the understanding of how postponement tactics (i.e., product modularity, process re-sequencing) can help firms to achieve competitive advantage, in this work attention has been paid on companies' upstream vulnerability i.e. the potential risk due to the behaviour of suppliers.

We rely on the definition provided by Zsidisin (2003) according to whom, supply risk can be defined as "the potential occurrence of an incident associated with inbound supply from supplier failure or the supply market, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety". This type of vulnerability has become very relevant during the last ten years and many contributions have been provided by the current literature (e.g., Kraljic, 1983; Sodhi and Chopra, 2004; Kleindorfer and Saad, 2005; Wagner and Bode, 2006). Nevertheless, as well described in the following sub sections, the relationship between the adoption of postponement and upstream vulnerability is scarcely investigated and limited empirical evidence is provided about the influence of this strategy in mitigating upstream risks.

2.4 Research propositions

In this work we are interested in the study of the relationship between the adoption of postponement and the reduction of upstream vulnerability. We are also interested in investigating whether this relationship can be partially explained by the mediation effect of flexibility. As we are going to discuss in the following sub sections, many contributions allow to support the idea of the existence of influences among postponement, flexibility and companies' exposition to supply chain risks but scarce empirical evidence is provided until now.

Furthermore, postponement and flexibility are usually related to the mitigation of downstream vulnerability i.e., uncertainties coming from the fluctuation of demand and the unpredictability of changes in customer's needs. On the contrary, in this work we are interested in investigating the relationship among postponement tactics, flexibility and upstream vulnerability.

2.4.1 The impact of postponement on upstream vulnerability

Tang and Tomlin (2008) describe how postponement can be an effective way to reduce the expected negative effects coming from process and demand risks (i.e., reduced capability of specific production lines, overstocking, unpredictable demand and customer needs).

As manufacturing processes become more flexible in consequence of the adoption of postponement (i.e., different production lines are capable of producing all products because of standardized and modularized components and sub-processes), different kinds of products can be manufactured in the same production line. As a result companies can shift production quantities across internal resources reducing process risks significantly.

Postponement also enables firms to reduce the impact of demand risks. For example, to reduce the overstock and under-stock costs of different versions of DeskJet Printers, HP redesigned its product by delaying the point of differentiation. HP first manufactured according to a make-to-stock system and then shipped generic printers to the distribution centres where are customized in a make-to-order manner. This assembly postponement strategy allowed HP to become more efficient and simultaneously to quickly respond to demand changes (Lee and Tang, 1997).

Literature mainly addresses postponement to cope with process and demand risks, however postponement can also be adopted in order to manage supply risks. In this work we specifically focus on the empirical evaluation of this relationship. Hopkins (2005) describes that the adoption of the tactics underlying the postponement approach (i.e., product modularity, processes re-sequencing) allows companies to adopt new configurations of the production process, typically by postponing the operations involving unavailable components, so to manage those situations where purchases are temporally unavailable. For example, after Philip's semiconductor plant was damaged in a fire in 2000, Nokia was facing a serious supply disruption of radio frequency chips. Since Nokia's cell phones are designed according to the modular design concept, Nokia was able to postpone the insertion of the unavailable components until the end of the assembly process. Due to this manufacturing postponement strategy, Nokia was able to reconfigure the design of their basic phones so that the modified phones could accept slightly different chips from other suppliers. Consequently, Nokia satisfied customer demand smoothly and obtained a stronger market position (Hopkins, 2005).

Based on the contributions here discussed we can formulate the following research propositions:

RP1. Manufacturing postponement is correlated with a lower perception of supply risks.

2.4.2 The influence of postponement on upstream vulnerability through flexibility

Postponement tactics allow companies to increase their capability for reconfiguration of the production process and at the same time allow a more effective use of the existing production capacity (Swaminathan and Lee, 2003). Considering these effects, literature frequently describes postponement as a method that may increase the flexibility of companies and of the entire supply chain (e.g., Lee, 2004; Skipworth and Harrison, 2004). As described by Reichhart and Holweg (2009), product modularity and process re-sequencing can be also considered as internal determinants and operational factors of companies' potential responsiveness. The authors also highlighted how within literature the concept of responsiveness is very close to the one of flexibility and how flexibility and responsiveness describe in practice similar capabilities. In this sense, manufacturing postponement would be considered a firm's internal determinant of flexibility. Therefore, we formulate the following research proposition:

RP2. Manufacturing postponement is correlated with a higher degree of flexibility.

There is an increasing recognition that flexibility is a necessary condition for competiveness (e.g., Lee, 2004; Tang and Tomlin, 2008). Goldman and Nagel (1993) defined flexibility as the ability of a business to grow in a competitive market of continuous and unanticipated changes, to respond effectively to rapidly changing markets driven by customers and suppliers. In this sense, flexibility can be considered as a source of both robustness and continuity. Therefore, we formulate the following research propositions:

RP3. Flexibility is correlated with a lower perception of supply risks;

RP4. The direct relationship between manufacturing postponement and supply risks is mediated by flexibility.

3 Research methodology

3.1 Data

In order to test our research propositions we adopted a survey approach. In particular, based on an extensive literature review a questionnaire was designed in order to operationalise the mentioned variables. The questionnaire was refined by means of five pilot cases in order to determine the validity of the model and test the discriminant ability of the questionnaire. In appendix the specific questions that have been used for the purpose of this paper are provided.

Once the questionnaire was refined and its thoroughness verified, we managed a survey analysis on a sample of Italian companies. 300 Italian companies were selected according to following criteria:

i. Manufacturing companies. We focus on the machinery manufacturing industry.
ii. Upstream supply chain relevance. We selected firms by considering the importance of the supply chain to their operations in order to obtain an heterogeneous sample. This selection was made based on the purchasing costs.

Companies were contacted by phone calls in order to identify a reference person (i.e., purchasing manager, plant manager or who are in charge to manage the supply chain network) and to describe the research. Participants were provided with an electronic version of the questionnaire and support was given in order to guarantee full understanding of the questionnaire. Data were collected between the firsts of May and the end of August 2010. We run ANOVA on collected data in order to check for late respondent bias. The analysis shows that no bias affects the collected data (P-values are all higher than 0.29).

Finally, 54 companies provided useful and complete information for this research (thus with a response rate of 18%). The sample is described in table 1. Companies are mainly medium sized (48.2% of the sample) but also small and large are represented. Different industrial sectors from the assembly industry are considered, mainly from the manufacturing of machinery and equipment. Concerning the incidence of the purchasing cost on revenues, the sample is rather heterogeneous.

(a)

Size*	**N**	**%**
Small	22	40.7
Medium	26	48.2
Large	6	11.1
Total	**54**	**100**

(b)

Ateco**	**N**	**%**
Ateco 22	10	18.5
Ateco 26	3	5.6
Ateco 27	6	11.1
Ateco 28	29	53.7
Ateco 29	5	9.3
Ateco 31	1	1.8
Total	**54**	**100**

(c)

Purchases	**N**	**%**
>= 70%	9	16.7
60% - 69%	16	29.6
50% - 59%	11	20.4
40% - 49%	8	14.8
<40%	10	18.5
Total	**54**	**100**

Table 1:*. Descriptive statistics in terms of (a) size, (b) industrial sector (ATECO 2007), (c) purchasing cost.*

* Size: Small: less than 250 employees, Medium: 251-500 employees, Large: over 501 employees;

** ATECO 2007 Code: 22: manufacture of rubber and plastics; 26: manufacture of computers and electronic products, optical, medical electrical equipment, apparatus for measuring and watches; 27: manufacture of electrical appliances and electrical equipment for non-domestic; 28: Manufacture of machinery and equipment not classified elsewhere; 29: Manufacture of motor vehicles, trailers and semi-trailers; 31: furniture manufacture

3.2 Measures

In order to measure model's variables we applied Principal Component Analysis (PCA) to build specific constructs. Reliability of constructs was checked by means of Cronbach's Alpha and by checking the theoretical validity of the constructs (Nunnally, 1994). Variables and measures of manufacturing postponement, flexibility, and upstream vulnerability are discussed below.

3.2.1 Manufacturing Postponement

In this paper we investigate postponement practices enabling companies to become more flexible so as to reduce the negative implications of the occurrence of supply risks (e.g., Lee, 2004; Hopkins, 2005; Tang, 2006). Specifically, by adopting Product Modularity (PM) and Process Re-sequencing (PR), companies improve their capabilities to shift production quantities across internal resources and across different products (Lee and Tang, 1997; Tang and Tomlin, 2008).

We measured postponement's underlying tactics (i.e., product modularity and process re-sequencing) by means of 8 items all deriving from the flexible manufacturing literature (Graves and Tomlin, 2003; Swaminathan and Lee, 2003; Tu et al., 2004; Yang et al., 2004; Tang and Tomlin, 2008). Items were measured on a 1-5 Likert scale where 1 equals to "no use" and 5 represents "high level of adoption". Table 2 shows results of principal component factor analysis, reliability tests (Cronbach's Alpha) and descriptive statistics on postponement's constructs.

Construct	*Items*	*Average*	*Std. Dev*	*Loading*
Product Modularity Eigen value: 2.00 R^2: 0.67 Alpha: 0.75	Products used modularized design	2.76	1.36	0.80
	Product modules could be assembled by different sequences	2.50	1.20	0.80
	Different modules as Different features	3.04	1.27	0.85
Process Re-sequencing Eigen value: 3.63 R^2: 0.73 Alpha: 0.90	Production process used modularized design	3.36	1.03	0.76
	Subprocess could be added or removed	3.14	1.13	0.92
	The Production process modules can be adjusted for changing in production needs	2.88	1.19	0.89
	The Production process can be broken down into standard and customization sub-processes	3.04	1.10	0.92
	The Production process modules can be rearranged so that customization sub-process occur last	2.78	1.19	0.76

Table 2: *Postponement constructs*

Results are coherent with contributions of previous works (Tu et al., 2004).

3.2.2 Flexibility

In this research flexibility (F) is measured by one item available from the questionnaire. It was assessed using the question, “please indicate your current degree of flexibility (i.e., ability to adapt your products, mix, volume and deliveries) on a 1-5 likert scale where 1 represents lower than your competitors and 5 higher than your competitors”. This measure is consistent with the definition of external flexibility discussed in the previous section. Table 3 shows descriptive statistics on flexibility.

Variable	*Average*	*Std. Dev*	*Min*	*Max*
Flexibility	3.16	0.82	1	5

Table 3: *Descriptive statistics on Flexibility*

3.2.3 Upstream Vulnerability

Consistently with Zsidisin (2003), our attention was focused on two specific supply risks: supplier failure risk (SF) and purchases unavailability risk (PU). The first one is related to the cases in which a supplier becomes unavailable as a consequence of the vendor financial instability (Wagner and Johnson, 2004) or of the vendor’s vertical integration by a direct competitor of the focal firm, forcing the end of the relationship (Sodhi and Chopra, 2004). The second supply risk is related to the cases in which there’s no possibility to supply a specific component because of capacity constraints or shortages in the supply markets. In both cases supply risks can lead to a strong reduction of the firm’s efficiency and ability to cope with the needs of the final market (Wagner and Bode, 2006). Hence, supplier failure risk and purchases unavailability risk can be considered two of the most relevant forms of upstream vulnerability (Thun and Hoenig, 2009). Trying to address the risk assessment issue many authors (e.g., Mitchell, 1995; Ellis et al., 2010) point out the importance of the subjective judgement of risk as the significant determinant of managerial and customer choice. Consequently, in order to measure these two supply risks, we collected information about the managers' perception regarding potential negative effects of risk on company’s performance. Specifically, the impact of supply risks was measured on a 1-5 Likert scale where 1 represents scarce negative impact to the organization and 5 severe negative impact to the organization. Table 4 shows descriptive statistic about supply risks:

Variable	*Average*	*Std. Dev*	*Min*	*Max*
Supplier failure risk	2.91	1.07	1	5
Purchases Unavailability risk	3.52	0.85	1	5

Table 4: *Descriptive statistic on Supply risks*

4 Empirical Results

In order to test our model and achieve our objectives we adopt a two step approach. First we applied OLS regression analysis to assess the direct relationships between postponement’s underlying tactics and companies’ exposition to supply risks. Then, only when estimates are significant, we applied path analysis in order to evaluate the mediation impact of flexibility. Specifically, path analysis is conducted by means of two subsequent OLS regression models: in the first one flexibility is regressed for postponement tactics, in the second one supply risks are regressed by both postponement tactics and flexibility (Holland, 1988). If the relationship between manufacturing postponement and supply risks is fully mediated, then all of the significant variance

of that relationship will be accounted for by the direct effect from flexibility to upstream vulnerability. A partially mediated relationship is identified whether the direct effect of the mediator construct, Flexibility, accounts for a significant amount of variance in upstream vulnerability, but the relationship between manufacturing postponement and supply risks remains significant (Little et al., 2007).
We also used standardized control variables (i.e., Size, Industry). Size was measured considering the number of employees of the company. Industry was measured by means of dummy variables, one for each ATECO 2007 sector. Anyway, the analysis didn't show any significant estimate for control variables and details are not reported here for briefness sake.

4.1 Direct relationship between postponement and upstream vulnerability

Table 5 shows the results of the regression analysis between postponement practices and upstream vulnerability.

Interestingly, we can partially accept our first research proposition. Indeed, we can see that process re-sequencing is significantly related to upstream vulnerability, thus the more companies adopt this practice the less they feel to be at risk. On the contrary, product modularity is not directly related to upstream vulnerability (see models 3a and 3b). This result can be understood by considering correlations among variables (table 6) and the path analysis (table 7) reported above. Correlation analysis show how both product modularity and process re-sequencing influence the expected impact of supply risks on organizations. Nevertheless, path analysis show how the direct relationship between product modularity and supply risk is completely mediated by process re-sequencing.

	Supplier's Failure			*Purchases Unavailability*		
	1a	2a	3a	1b	2b	3b
Constant	3.91	4.66	4.68	4.26	4.59	4.69
p-value	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Product Modularity	-0.37	-	-0.03	-0.29	-	-0.13
Std. Err.	0.154		0.173	0.121		0.149
P-value	(**0.021**)		(0.840)	(**0.020**)		(0.386)
Process Re-sequencing	-	-0.57	-0.56	-	-0.37	-0.29
Std. Err.		0.151	0.184		0.132	0.160
P-value		(**0.000**)	(**0.005**)		(**0.006**)	(**0.074**)
R-squared	0.12	0.27	0.27	0.13	0.16	0.19
Adj R-squared	0.10	0.25	0.24	0.10	0.15	0.15

Table 5: *Supply risks regressed on postponement's underlying tactics*

	PM	PR	SF	PU
Product Modularity (PM)	1	-		
Process Re-sequencing (PR)	0.55***	1		
Supplier's Failure (SF)	-0.35**	-0.52***	1	
Purchases Unavailability (PU)	-0.36**	-0.41***	0.23	1

*** p<0.01, ** p<0.05, * p<0.1

Table 6: *Pairwise correlation among postponement tactics and supply risks*

Indirect path	Direct path

Product Modularity	--->	*Process Re-sequencing*	--->	*Supply Risk*
PM	+0.59*** R^2= 0.034	PR	-0.50*** R^2= 0.27	SF
PM	+0.59*** R^2=0.034	PR	-0.33* R^2= 0.19	PU

*** p<0.01, ** p<0.05, * p<0.1

Product Modularity	--->	*Supply Risk*
PM	-0.03 R^2= 0.27	SF
PM	-0.15 R^2= 0.19	PU

Table 7: *Path Analysis on postponement underlying practices and supply risks*

4.2 Indirect relationship through Flexibility

In the light of the results presented in the previous subsection, we now considering only the indirect relationship between process re-sequencing and supply risks. First, correlation analysis (table 8) show that manufacturing flexibility is strongly related both to higher adoptions of process re-sequencing and to lower expected impact of supply risks.

	PR	*Flexibility*	*SF*	*PU*
Process re-sequencing	1	-		
Flexibility	0.42***	1		
Supplier's failure	-0.52**	-0.44***	1	
Purchases Unavailability	-0.41**	-0.36**	0.23	1

*** p<0.01, ** p<0.05, * p<0.1

Table 8: *Pairwise correlation among process re-sequencing, flexibility and supply risks*

We can then analyse the indirect path between process re-sequencing and supply risks through flexibility (table 9 and table 10).

	Supplier's failure 4a	Supplier's failure 5a	Purchases unavailability 4b	Purchases unavailability 5b
Constant	4.67	5.37	4.63	5.11
p-value	(0.000)	(0.000)	(0.000)	(0.000)
Process Re-sequencing	-	-0.44	-	-0.30
Std. Err.		0.167		0.151
P-value		(**0.013**)		(**0.054**)
Flexibility	-0.56	-0.33	-0.38	-0.24
Std. Err.	0.194	0.195	0.168	0.176
P-value	(**0.007**)	(**0.077**)	(**0.031**)	(0.018)
R-squared	0.20	0.33	0.13	0.22
Adj R-squared	0.17	0.29	0.10	0.18

Table 9: *Supply risks regressed on Process re-sequencing and flexibility*

Indirect path				
Process Re-sequencing	--->	*Flexibility*	--->	*Supply Risk*
PR	+0.39** R^2= 0.016	F	-0.35* R^2= 0.33	SF
PM	+0.39** R^2=0.034	F	-0.24 R^2= 0.22	PU

*** p<0.01, ** p<0.05, * p<0.1

Direct path		
Process re-sequencing	--->	*Supply Risk*
PR	-0.44** R^2= 0.33	SF
PR	-0.30* R^2= 0.22	PU

Table 10: *Path analysis on process re-sequencing, flexibility and supply risks*

The above results (table 9 and table 10) support our last three research propositions: the indirect path through flexibility can partially explain the direct influence of manufacturing postponement on companies' resiliency. Indeed, consistently with (Little et al., 2007), we identify a partial mediation effect of flexibility on the direct relationship between process re-sequencing and the supplier's failure risk: first, the indirect path through the mediating variable (i.e., flexibility) is significant (see first row of table 9). Second, the direct influence of process re-sequencing on the supplier failure risk is still significant but with lower magnitude and significance (see model 2a in table 5 and model 5a in table 9). Anyway, the indirect relationship between process re-sequencing and the expected impact of product unavailability through flexibility appears being not significant (table 10). Consequently, we can assert that flexibility does not produce any mediation effect on this specific relationship.

5 Discussion and Conclusion

This work provides evidence of the effectiveness of postponement in reducing perceived supply risks. Furthermore, we empirically demonstrate that these relationships can be partially explained by an indirect path through companies' flexibility.

Based on the presented analyses, we documented that companies can directly reduce the negative impact of supply risks on their organization by developing postponement tactics. Indeed, when supply risks occur, the adoption of postponement allows companies to partially cope with that by re-sequencing internal operations (i.e., gaining time) and by modifying the final product design, increasing the probability to find consistent suppliers (Swaminathan and Lee, 2003; Hopkins, 2005). Furthermore, we empirically demonstrated that only the process re-sequencing practice can be considered an effective risk management lever, while product modularity represent a needed investment. Interestingly, these results confirms what previous contributions conceptually pointed out: Lee and Tang (1997) stated that in order to standardize and postpone a process step, one needs first to modularize the product's architecture and standardize product's components. Moreover, Reichhart and Holweg (2009) describe that adjusting product architecture can be considered as a way to employ decoupling points in order to manage uncertainties. In this sense, product modularity can be seen as an enabler of process re-sequencing and its adoption indirectly influence companies' resiliency.

Finally, we provide empirical evidence about the effectiveness of postponement strategies in enhancing companies' flexibility as well as the ability to manage internal resources to effectively respond to external unexpected events. In this sense, consistently with the definition by Slack (1993), process re-sequencing and product modularity can be considered as two determinants of internal flexibility, which in turn can support the system's ability to demonstrate external flexibility to environmental changes.

This paper thus contributes to the literature by combining previous contributions coming from both supply chain risk management and manufacturing literature (e.g., Lee and Tang, 1997; Swaminathan and Tayur, 1998; Swaminathan and Lee, 2003; Lee, 2004; Hopkins, 2005; Tang and Tomlin, 2008). Most importantly, we provide empirical evidence concerning the power of postponement tactics in reducing supply risks. Moreover, we show how manufacturing flexibility partially mediate the positive effect of manufacturing postponement on companies' resiliency. Finally, we can argue that this research, even if limited to a small sample of companies, can support practitioners in evaluating decisions concerning new possible manufacturing investments. Indeed, our results clearly show the benefits coming from the adoption of manufacturing postponement (i.e., improved flexibility, reduced supply chain vulnerability)

In the end we would also like to address the limitations of this work. First of all, the sample is limited to only 54 companies. Thus, future works should refer to wider datasets so to ensure statistical validity of the mentioned relationships. We should also consider that only flexibility has been considered as a mediation factor for the relationship between postponement and resiliency. Furthermore, this variable is measured by only one item. Future works should build a more reliable construct and take other capabilities into consideration in order to confirm and extend our results.

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Appendix A. Metrics from the questionnaire

1. Please indicate the current performance for your business on the following scale (where 1 equals to "much worse than competitors" and 5 represents "much better than competitors):

Economic Performance	lower				higher
Market share	1	2	3	4	5
Return on sale	1	2	3	4	5
Return on interest	1	2	3	4	5

2. Please indicate the current performance for your manufacturing process on the following scale (where 1 equals to "much worse than competitors" and 5 represents "much better than competitors):

	lower				higher
Flexibility (i.e., Product, Mix, Volume and Delivery)	1	2	3	4	5

3. please indicate the perceived negative impact of the following risks to your organization:

Supply Risk	Scarse				Severe
Supplier Failure (e.g., as a consequence of bankruptcy or vertical integration with a your competitor)	1	2	3	4	5
Purchases Unavailability (e.g., because of capacity constraints of supply markets)	1	2	3	4	5

4. How much do you agree with the following claims?

Postponement	Strongly disagree				Strongly agree
Products use modularized design	1	2	3	4	5
Product modules could be assembled by different sequences	1	2	3	4	5
Different modules as Different features	1	2	3	4	5
Production process used modularized design	1	2	3	4	5
Sub-process could be added or removed to the production process	1	2	3	4	5
The Production process modules can be adjusted for changing in production needs	1	2	3	4	5
The Production process can be broken down into standard and customization sub-processes	1	2	3	4	5
The Production process modules can be rearranged so that customization sub-process occur last	1	2	3	4	5

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