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Supply Chain Finance: A supply chain-oriented perspective to mitigate commodity risk and pricing volatility

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ABSTRACT

This study addresses the Supply Chain Finance challenge of Commodity Price Volatility (CPV) by adopting a supply chain-oriented perspective. In particular, the effectiveness of two Supply Chain Risk Management (SCRM) strategies in mitigating CPV, namely, *Switching suppliers* and *Substituting Commodities*, and the main factors that may affect their value, are investigated with a simulation analysis. A Real Option Valuation (ROV) model was developed and tested on real cases of CPV mitigation, as experienced by a large multinational company (Fortune 100) leader in the Fast Moving Consumer Goods (FMCG) industry. The results show the effectiveness of *Switching suppliers* and *Substituting Commodities* in mitigating CPV, highlighting that the convenience of adopting such strategies is strongly influenced by some specific conditions, like the relative values of the long-term prices of the commodities, the purchasing volume, and the sunk cost needed to build flexibility.

1. Introduction

Supply Chain Finance (SCF) is a recent stream of research aimed at optimizing financial flows at an inter-organizational level (Hofmann, 2005) through solutions implemented by financial institutions (Camerinelli, 2009) or technology providers (Lamoureux and Evans, 2011). The ultimate objective is to align financial flows with product and information flows within the supply chain, improving cash-flow management from a supply chain perspective (Wuttke et al., 2013).

Following the increased interest in SCF reserved by practitioners (see, as an example, the case of “Supply Chain Finance scheme” developed by the UK government (Gov.uk, 2012)), the literature exploring SCF is growing, with an increased number of scientific articles published over the last decade. Several and often unclear and contrasting definitions have been proposed in the literature for SCF (Carter et al., 2015; Huff and Rogers, 2015). As Gelsomino et al. (2016) pointed out, the literature review highlights the existence of finance-oriented and supply chain-oriented perspectives to SCF. The first focuses on financial aspects and considers SCF approaches as a set of financial solutions. The latter emphasizes the role of collaboration amongst supply chain members and extends the boundaries of SCF beyond financial solutions. In such sense, SCF presents also supply chain solutions to mitigate financial risks. In doing so, SCF focuses on supply chain and financial partnerships to obtain savings, create profits and efficiently manage assets for all members of the supply network (Huff and Rogers, 2015).

The events of the last few years confirm that one of the SCF challenges is the exposure to commodity risk and pricing volatility. Trends in commodity prices, in fact, have shown abrupt changes with very high fluctuations: in the 20th century, average commodity prices fell by about half a percent per year; since 2000, they more than doubled first, while in 2014 they have plunged 34%, leaving prices at 2009 levels (Zumbrun and Cui, 2015). Also, over the past 10 years, the average annual volatility of commodity prices has been almost three times what it was in the 1990s (Dobbs et al., 2013), creating significant challenges to industrial firms. The exposure to such risk increases with the supply chain complexity, since it links to directly sourced raw materials and energy as well as upstream supply chains, i.e., commodities purchased by tier-n suppliers (Zsidisin et al., 2015). Risk can also come from the price of other products, since commodities often represent a consistent portion of their input costs.

Higher commodity prices, and higher commodity price volatility, introduce risks to top-line revenues, as well as to the cost structure, and wreak havoc on net cash flow and profitability. In fact, raw material price volatility (due to CPV) drives volatility in direct costs and margins as well. Thus, net exposures that are not managed put cash flow and EBIT at risk (Finley and Pettit, 2011). In the case of very high commodity price volatility, which is rather common, the consequences of the cash flow can seriously impact also the financial balance of the firm, particularly when the payment terms and the credit facilities are not negotiable and/or enlarged, at least as quickly as it would be necessary to cope with the new cost structure. The increasing exposure of

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organizations at all levels, including those in the private sector, non-profit entities and governmental agencies, with the expectation that high prices and increased volatility will continue in many global commodity categories, confirm the need for many organizations to cope with CPV. Sourcing and hedging should be at the top of the strategic agenda for many companies (Finley and Pettit, 2011).

While the financial literature deeply discusses the use of (financial) hedging to offset future commodity price changes (Pindyck, 2001; Nissanke, 2010; Guay and Kothari, 2003), the attention of academics to sourcing as a non-financial strategy to mitigate CPV is still very limited. Contrarily, from a business perspective, the empirical evidence reveals that most of the industrial firms do not use financial hedging due to a lack of knowledge and experience (Zsidisin et al., 2015). Only a recent study report that firms often leverage sourcing strategies, as non-financial instruments, to manage or mitigate their risk exposure for price-volatile commodities (Zsidisin et al., 2014; Gaudenzi et al., 2017).

These evident research gaps and the existent mismatch between literature and business practice offer a strong motivation for our work.

The purpose of the paper is to investigate the effectiveness of sourcing as a non-financial strategy to mitigate CPV. We analyze the impact of sourcing strategies on the firm's cash flow and therefore on its profitability. We also explore the main factors which affect the effectiveness in mitigating CPV. Hence, our paper contributes to the nascent literature on SCF by highlighting how and under which conditions the adoption of sourcing strategies as CPV mitigation strategies may improve the financial performance of the firm.

The paper is organized as follows. Section 2 provides a brief review of the relevant literature, and introduces the research questions of our paper. We present the model for estimating the effectiveness of sourcing strategies in mitigating CPV in Section 3, whereas the application of the model to the real case of a large multinational company (Fortune 100) leader in the Fast Moving Consumer Goods (FMCG) industry and the plan of experiments to provide answers to our research questions is discussed in Section 4. Some final remarks close the paper.

2. Literature review and paper positioning

2.1. Commodity price volatility and risk mitigation literature

This paper links to the literature on commodity price volatility and risk mitigation.

In the mid-2000s, significant increases of CPV made firms aware of the importance of managing this risk (Gaudenzi et al., 2017). If not effectively managed, CPV may severely mine the ability to meet customer requirements, create challenges for product pricing decisions, make budget planning difficult, and wreak havoc on net cash flow and profitability (Matook et al., 2009; Finley and Pettit, 2011).

This justifies the increasing attentions reserved by several researchers on this topic, either from a financial perspective or from a supply chain one.

The financial literature, which traditionally considers commodity price risk as a financial risk (Allen, 2013), since it may impact cash flows, profitability and the ability to meet financial obligations (Horcher, 2005; Carter et al., 2011; Symeonidis et al., 2012), deeply investigated the issue of CPV mitigation. It proposes financial instruments (financial hedging), consisting of futures, options and other derivatives that offset future commodity price changes (Pindyck, 2001; Nissanke, 2010; Guay and Kothari, 2003). Despite the academia' attention to financial strategies, firms seem to be not completely confident in their use due to a lack of knowledge. Specialized financial expertise is needed to design and execute hedging strategies, which usually do not fall under the responsibility of supply chain managers. Hence, organizations have to leverage their finance departments when adopting such strategies (Gaudenzi et al., 2017).

The supply chain management literature reports CPV as a sub-category of supply chain risk, related to operational or resource risk (Harland et al., 2003). A significant increase of commodity prices may also lead to an operational risk, i.e. a supply chain disruption when the organization does not have the financial resources to buy the commodity (Tazelaar and Snijders, 2013). Also, significant decreases of commodity prices may cause financial difficulties to a supplier, by hurting its profit, and, at the extreme, force the supplier to exit the business (Bandaly et al., 2014). The effective management of CPV is an emerging task in the supply chain risk management (SCRM) literature (Zsidisin and Hartley, 2012a, 2012b; Fischl et al., 2014). Although research on SCRM has been growing in several areas, such as natural disasters and disruptions (Craighead et al., 2007), intentional disruptions (Duhadway et al., 2017), risk propagation (Garvey et al., 2015), risk mitigation (Costantino and Pellegrino, 2010; Carbonara and Pellegrino, 2017a, 2017b; Colicchia and Strozzi, 2012; Manuj et al., 2014), financial health of the supply base (Bode et al., 2014), studies on CPV and its mitigation strategies are still limited. The literature on Supply Chain Risk Management (SCRM) is nascent in describing the relationship between commodity price risk mitigation and supply chain strategies.

To the best of the authors' knowledge, the very few studies focusing on CPV and supply chain risk mitigation investigate the dependence of a company on a commodity, the company's exposure to CPV and the importance of its mitigation (Zsidisin and Hartley, 2012a, 2012b), or empirically review the main mitigation strategies adopted to mitigate CPV (Zsidisin et al., 2015, 2014). A recent study developed by Gaudenzi et al. (2017), which explores the main factors influencing the choice of CPV mitigation strategies, found that beyond financial strategies (hedging, most of all), sourcing and contracting strategies are common approaches adopted by companies to mitigate CPV. Sourcing strategies involve traditional supply management approaches to mitigate risk, such as supplier switching and substituting commodities (Gaudenzi et al., 2017; Costantino et al., 2016). In the food industry, companies invest in R&D in order to find flexible formulas that enable a switch of raw materials when convenient (Almeida and Abrahams, 2012). Contracting strategies rely on the use of contractual agreements and contract clauses to pass, share or absorb commodity price volatility (e.g., escalator clauses). Although all these studies in SCRM literature represent a significant progress towards the adoption of supply chain strategies in mitigating CPV, they do not find a particular hierarchy of tools to use. It empirically appears that approaches to use depend on the spending of the organization, the commodity type, the industry and the supply chain, the available resources and the external environment (Zsidisin et al., 2014; Gaudenzi et al., 2017). Also, while sourcing and contracting strategies are well-established SCRM approaches proposed for mitigating supply disruptions and ensuring supply continuity (see for example Tang and Tomlin, 2008 and the works by Chopra and Sodhi, 2004, 2014), their effectiveness in mitigating CPV has been only hypothesized on the basis of empirical evidence. All the identified mitigation strategies, in fact, were not quantitatively assessed and/or benchmarked to see whether they are really effective in mitigating CPV and under which conditions they prove to be effective, in terms of their impact on cash flows and profit. A first effort has been done by Costantino et al. (2016), which propose a theoretical model to quantify such strategies, without applying it to real cases. They do not provide any investigation on their actual effectiveness in mitigating CPV under different conditions.

2.2. Real Option Valuation literature

Most of the non-financial strategies adopted by firms for mitigating CPV (Gaudenzi et al., 2017) leverage the concept of flexibility, defined as the firm's ability to react to environmental changes with little or negligible penalty and sacrifice in terms of time, operational efforts, cost or performance (Upton, 1994; Pérez Pérez et al., 2016; Lu et al., 2017). Operationalizing and assessing these mitigation strategies requires modeling the managerial flexibility of the decision maker, considering both the price of commodities and the cost of flexibility itself. For instance, in the case of sourcing, the decision maker will choose whether substituting commodities or switching suppliers on the basis of the commodity prices and the cost of enabling such flexibilities. The same happens for contracting strategies, where the decision maker will decide to build and exploit a given clause (for instance, lower the price) when convenient.

Traditional approaches, such as those based on Discounted Cash Flows (DCF) analysis (NPV most of all), cannot be used to properly model and price the value of managerial flexibility provided by the non-financial strategies.[1] A better evaluation approach, to support decision making in uncertain environments, should incorporate the uncertainty and the active decision making required for a strategy to succeed (Luehrman, 1998), namely it should quantify the managerial flexibility. Any attempt to quantify this flexibility leads almost naturally to the concept of options (Trigeorgis, 1996), which have revolutionized how we use flexibility to deal with uncertainty in the financial world (Myers, 1977). Each source of flexibility is, in technical terms, a real option, which is defined as a right without an obligation to take specific future actions depending on how uncertain conditions evolve (Amram and Kulatilaka, 1999). The basic principle of real option theory is that when future is uncertain and changing strategy is not possible or is highly costly, then flexible strategies and delayed decisions can create value. This managerial flexibility exists when managers may decide, for instance, to start, change, increase or decrease the use of a particular resource, depending on how the conditions evolve and based on information that are available at that time. Options can be purely contractual in monetary terms, which form the basis of financial options that confer rights to buy or sell financial assets at the exercise price, or physical, in which case they are known as real options (Trigeorgis, 1996).

Both financial and real options are defined as rights, but not obligations, to take certain actions at some points in time, but they are different. Whereas the exercise price or the expiration date for a financial option are specified contractually, those for real options are generally not explicitly specified and depend on both the property and the context of the real option (Dixit and Pindyck, 1994; Trigeorgis, 1996; Copeland and Antikarov, 2001; Mun, 2006).

Having real options would always be advantageous, if they were free. However, having real options, i.e. flexibility, always involves costs, because it involves building additional capabilities that enable such flexibility. Furthermore, while the costs to develop such flexibility are almost always certain, benefits are potential and uncertain since the exploitation of the flexibility (i.e., undertaking an action or not) depends on the evolution of the uncertainty. Therefore, when systems or strategies that enable flexibility are designed, the key questions become: what is the value of the different forms of flexibility that might be included into the system? And are their costs properly justified? Estimating the values of different forms of flexibility is the task of a real option approach.

The application of ROV methods to supply chain risk management is not new, since the introduction of the real options inside a supply chain is simply conceived as a way to introduce a greater level of flexibility in the network (Nembhard et al., 2001, 2005; Kamrad and Siddique, 2001; Cucchiella and Gastaldi, 2006; Costantino and Pellegrino, 2010; Carbonara et al., 2014). Such flexibility may prove useful to cover the damages of market volatility, coming from several sources of uncertainty (Cucchiella and Gastaldi, 2006). In particular, with a specific focus on non-financial strategies adopted for CPV mitigation (as reviewed in Gaudenzi et al., 2017), some authors have used ROV to assess the value of these strategies in presence of supply chain disruptions. For example, with reference to sourcing, Costantino and Pellegrino (2010), Pochard (2003), Tang and Tomlin (2008), Ho et al. (2015) investigate the value of switching the supplier (i.e., multiple sourcing vs. single sourcing strategy) to mitigate supply disruptions, while other researchers have applied ROV for assessing the flexibility of substituting inputs indirectly, for instance through a postponement strategy, to mitigate demand or supply disruptions (Yang and Yang, 2010; Carbonara et al., 2016; Carbonara and Pellegrino, 2017a).

Although these studies operatively model the managerial flexibility to react to a supply chain disruption, they do not assume any volatility in prices, hence, they neglect the ability of such strategies to react to the price volatility. Those few studies that assume uncertain prices, such as the work of Tang and Tomlin (2008), do not assess the value of the strategies to react to volatility by changing the course of action.

As for the option pricing, the financially-based approaches traditionally proposed by the real options literature (Black and Scholes, 1973; Merton, 1973; Boyle, 1977; Cox et al., 1979; Longstaff and Schwartz, 2001; and others), are often not acceptable in practice (de Neufville et al., 2006; Pellegrino et al., 2011). As reported by Lander and Pinches (1998), first, the types of models currently used are not well known or understood by corporate managers and practitioners, which do not have (as well as many academics) the required mathematical skills to use the models comfortably and knowledgeably. Second, for their financial origin, many of the required assumptions are not valid in the practical applications of the real world. Third, the needed assumptions required for mathematical tractability limit the scope of their application. For example, most of the traditional methods are one-factor models: if there are two uncertain inputs, they are usually modeled as a ratio and then treated as a single uncertainty. Contrarily, simulation-based research is preferred for this complex and expanded problem with several factors and interactions. Simulations are able to incorporate random occurrences into a system, to estimate their effects. Changes to the underlying simulation model or inputs can be made to answer to “what-if” questions while always keeping complete control of the system (Evers and Wan, 2012). In this sense, computer simulations become an attractive way to understand a system's behavior when a real life controlled experimentation of logistics and supply chain systems is extremely difficult (Chang and Makatsoris, 2001). Empirical research did not seem to be as appropriate as simulations when the behavior of real world systems has to be reproduced. The investigation of the behavior of such artificial systems enables the prediction of what might happen should such a system come into existence in the real world (Goldspink, 2002).

The application of simulation to supply chain settings is also well established given the stochastic nature of supply chains (Goldsby et al., 2006; Wan and Evers, 2011; Evers and Wan, 2012; Manuj et al., 2009, 2014).

2.3. Research questions and paper positioning

The literature discussed above clearly shows that there is a prominent gap in the SCRM literature dealing with CPV mitigation since, to the best of the authors' knowledge, no studies investigate and quantitatively measure the impact of non-financial strategies for mitigating CPV on the financial performances of a company. Also, no one investigates how the effectiveness of these strategies change under

[1] See Appendix A for an overview of the limits of traditional Discounted Cash Flows (DCF) analysis to model and price the value of managerial flexibility.

different operating conditions. This gap offers strong motivation for this work.

With the aim of filling this gap in literature, we focus on sourcing as a non-financial strategy to mitigate CPV; in particular, we investigate two main sourcing strategies, namely, *Switching suppliers* and *Substituting Commodities*. Referring to these strategies and in light of the discussed open issues, we want to answer to the following research questions:

- How do sourcing strategies perform in mitigating CPV? I.e., how do switching suppliers or commodities impact a firm's cash flows and profit?
- Which are the main factors that affect the effectiveness of these CPV mitigation strategies?

From a methodological perspective, to model the flexibility of these two sourcing strategies, the ROV method is a powerful tool for estimating their value. Although the investigated strategies have been studied through real options in a supply chain disruptions domain (as reviewed in the previous section), to the best of our knowledge, no one has used ROV methods for assessing the value of switching suppliers as well as substituting commodity as mitigation strategies of CPV. Our paper differs from the previous researches by focusing on the evaluation of switching suppliers and substituting commodity as CPV mitigation strategies. Finally, the literature of ROV methods and their application to supply chains convinced us to use simulations, essentially for two reasons. First, these strategies, which are well-known in the SCRM literature, have been studied so far to assess their capability to mitigate supplier failure risk or demand risk, rather than price volatility. Second, those few studies that introduce these SCRM strategies for mitigating CPV are conceptual and the benefits of adopting such strategies to mitigate CPV and risk have not been tested.

3. The ROV simulation model to assess the value of flexibility-driven strategies

In this paper, we focus on two sourcing strategies as non-financial strategies to mitigate CPV (see Zsidisin et al., 2014 and Gaudenzi et al., 2017 for a comprehensive review), namely *Switching suppliers* and *Substituting Commodities*, with the aim of testing their effectiveness in mitigating CPV and understand how this effectiveness varies under different conditions.

Both strategies are two supply chain flexibility-based strategies. A manager can take action, to avoid losses due to CPV, rather than passively accept all the consequences. For example, if product design or production processes are flexible (to use different commodities as input or switch suppliers) and customers are open to the change or the change is not visible to them, the organization can substitute commodities or switch suppliers, based on the price of commodities as well as the cost of executing this substitution. The opportunity of making such a substitution or switch gives an option to react to CPV when conditions are in favor, producing uncertain potential benefits, fully exploited only when the action (substitution) proves valuable. At the same time, however, to open such an option, i.e., to make a substitution technically and commercially viable, there is generally the need to make an upfront investment in R&D, market research and material/supplier qualification, as well as the need for sustaining on-going supply chain costs to manage such flexibility. Thus, it is essential to incorporate an option evaluation method when pricing the value of these flexibility-driven strategies and their suitability in mitigating CPV, to make sure that the upfront costs are fully justified (Sodhi and Lee, 2007; Tang and Tomlin, 2008; Tomlin, 2006).

While *Switching suppliers* is a kind of commercial flexibility (a flexibility within the contract) that allows a company to shift volumes among more suppliers with different pricing structures (e.g., same commodity but different suppliers, located in different geographies or with different underlying assets for the price indexes), *Substituting Commodities* is more of a technical flexibility that enables the purchasing company to use different materials in the final product. In both cases, however, the pattern of these strategies may be easily assimilated to a real option: after an initial up-front investment in R&D and market research to make a substitution technically and commercially viable and to qualify more than one supplier and material, the company has the right – but not the obligation – to make a milestone payment at each period to change the sourcing option if the alternate sourcing turns out to be more convenient than the current one, based on the new market conditions (typically based upon the price movements of the commodity itself). The simulation model that we developed is thus based on real options, as detailed in the following section.

3.1. Mathematical formulation

The model uses the following parameters to describe the problem of flexibility-driven strategies

t = 0, 1, 2, T	switching period t (week, month, quarter, according to the commodity price periodic fluctuation and/or commodity characteristics), up to the total time horizon T, which depends on the length of the contract with suppliers
SC_i and SC_j	the two alternative sources available in case of flexibility, namely, the two alternative commodities (in case of assessment of the commodity substitution strategy) or the two suppliers (in case of assessment of the switching supplier strategy)
$p^{NF}(t)$	the price paid at *t* to buy the commodity in absence of flexibility
$p^{F}(t)$	the price paid at *t* to buy the commodity, in the case with flexibility, to switch from SC_i to SC_j and vice versa, when convenient
Q	periodic quantity requested for the commodity
p_{SC_i} and p_{SC_j}	prices of the commodity SC_i to SC_j respectively, at time *t*
SwitchingCost	the cost of making the switch from SC_i to SC_j and vice versa (e.g., tooling, process modifications, and inventory costs)
Material qualification cost	the (sunk) cost needed to “implement the flexible system”, namely, the upfront investment which the company made in R&D and market research for having flexible products or processes and being able to change commodity or supplier

$p^{NF}(t)$ and $p^{F}(t)$ represent the prices of the commodity in the absence of flexibility (NF) and in the presence of flexibility (F), to switch from SC_i to SC_j and vice versa, respectively. Forecasts for commodities may rely on historical time series to predict the future. Depending on the historical prices, statistical forecasting models can be applied. Also, there may be correlations or not; in case of a correlation, it can be modeled by a correlation coefficient determined on the basis of historical time price series too. As for the periodic quantity requested for the commodity Q, it can be certain or uncertain, depending of the specific contract with the commodity supplier. The same goes for other inputs, such as switching cost or material qualification cost.

Let us assume that at time t the source chosen is SC_i.

At next time t + 1, the model assesses whether the alternate source (SC_j) is cheaper. The two possible scenarios are:

- At t + 1, the alternate SC_j is cheaper than SC_i: $p_{SC_j}(t+1) < p_{SC_i}(t+1)$
  The purchasing manager will decide to switch to the commodity source j or not (that is, continuing to buy the source i) if the payoff resulting from exercising the option is positive, computed as in (1); otherwise, he/she will continue to use the current source i.

$$\max\left\{\left[p_{SC_i}(t+1) - p_{SC_j}(t+1)\right]\cdot Q - SwitchingCost; 0\right\} \tag{1}$$

  Therefore, following such a decision process, the price paid at t + 1 will be determined as in (2).

$$p^F(t+1) = p_{SC_j}(t+1) \text{ if } \Omega_t = 1 \ \vee \ p^F(t+1) = p_{SC_i}(t+1) \text{ if } \Omega_t = 0 \tag{2}$$

  where Ω_t is the binary variable representing the exercise of the option in t ($\Omega_t = 1$ if the option is exercised, $\Omega_t = 0$ otherwise).
- At t + 1, the alternate SC_i continues to be cheaper than SC_j: $p_{SC_i}(t+1) < p_{SC_j}(t+1)$
  The purchasing manager will continue to use alternative SC_i, without switching. Hence, the price paid at t + 1 will be provided by (3).

$$p^F(t+1) = p_{SC_i}(t+1) \tag{3}$$

Finally, choosing at each t the best alternative according to the process previously described, the model will calculate the impact of this decision on the firms' cash flow and, eventually, the total value created by the flexibility in terms of net cost savings compared to the situation without flexibility. It represents a measure of the effectiveness of the strategy in mitigating CPV, which is expressed as the firm's profit generated by such strategies, as in (4).

$$Value\ of\ flexibility = \sum_{t=1}^{T} \frac{[p^{NF}(t) - p^F(t)]\cdot Q - SwitchingCost\cdot\Omega_t}{(1+r_p)^t} - Material\ qualification\ cost \tag{4}$$

where r_p is the periodical discount rate.[2]

Coherently with the real options theory, SwitchingCost is the exercise price of the options that will be borne by the firm only whether the option is exercised (i.e., $\Omega_t = 1$), while the Material qualification cost is the cost of the option, that is, the upfront investment which the company made in R&D and market research for having flexible products or processes, independently on the option exercise at each t.

Finally, the number of switches done in the time period T will be calculated as in (5).

$$\#\ of\ switches = \sum_{t=1}^{T} \Omega_t \tag{5}$$

Once the simulation model is in place, to ensure it was developed in accordance with the problem statement, we proceeded with the model verification and validation (Sargent, 2013).

Verifying a simulation model means determining whether the computer implementation of the conceptual model is correct.@Risk, the risk analysis software using Monte Carlo simulations for MS Excel, was used to build the simulation model. Given the complexity of the model, we compared the output of parts of the model with manually calculated solutions to ensure that the simulation logic works as desired. We also proceeded with test running of the simulation with no probabilistic elements to identify any errors in coding or logic.

After the simulation was run, the results were also validated. Model validation is the process of ensuring that the simulation accurately portrays the system under investigation (Law, 2006). Beyond mere face validity, which was established by perusing the flowchart, we validated the model by applying it to a real supply chain and reviewing the model and its outputs in a structured walk-through with company management. Next section describes the model applications and discusses the related results.

4. Experiments and analysis

4.1. The base-line model

In this research, the case study of a Fortune 100 company leader in the Fast Moving Consumer Goods (FMCG) industry is considered. The identity of the company is concealed here to protect its business interests. The company will be called *Gamma* in rest of the paper. *Gamma* is a multinational company and offers a range of products across the world.

The base-line model application is based on data adapted from two full-scale case studies of two different purchasing situations faced by *Gamma* in EMEA (region including Europe, Middle East and Africa), with realistic operational conditions and market values, adjusted by a specific coefficient for reason of confidentiality. They represent two pilot projects recently assessed by the company to empirically test the effectiveness of the strategies in mitigating CPV.

Once the model was implemented, a structured walk-through of the model was carried out with a set of purchasing managers involved in the two projects. Data on the inputs required by the model were collected during 2016 by interviewing two managers actively involved in the two cases. Finally, a review of the simulation results was carried out to test their solidity.

In the first case (case A), *Gamma* buys high-density polyethylene (HDPE) from Germany to make the bottles for some of its products, while in the second case (case B) *Gamma* buys polyethylene terephthalate (PET) from UK to make the bottles for other products. These are the base plans of purchasing in the absence of flexibility.

For both these cases, we investigated the implementation of the two discussed strategies, *Switching suppliers* and *Substituting Commodities*.

In particular, in the Case A, *Gamma* may switch supplier by buying the same commodity (i.e., HDPE) from another region or substitute the commodity for making the bottles, thus buying PET instead of HDPE. These two strategies are characterized by their own switching costs and material qualification costs. The Switching cost, which is the cost for exercising the option any time it is convenient, is obtained as the sum of the following cost components: (1) set up adjustments for the production machines/equipment when there is the switch from one material to another; (2) workers/manual handling needed to physically do the work and clean machines, load the new material etc.; (3) extra silo needed to store the second material, since the two commodities cannot be physically mixed. The material qualification cost, which is the sunk cost to build such flexibility, is obtained as the sum of: (1) cost to produce test products with the alternative material (mainly personnel cost for people that work on the qualification), and (2) the cost of the material itself for the test. The same happens for case B, where *Gamma* may switch the supplier by buying the same commodity (PET) from another region or substitute the commodity by using Recycled PET instead of PET. Even in this case, each strategy has its own switching and material qualification costs associated, also determined as previously explained.

A time period T of 12 months with a time bucket of 1 month was considered for the analysis (since the contracts with suppliers are usually one year long for Gamma for these commodities and the switch

[2] See Appendix B for details on discount rate calculation in real option literature.

Table 1
Description of the analyzed cases.

	Case A	Case B
T	12 months	
Annual volume	25,000 t	30,000 t
Type of commodity	HDPE	PET
Purchasing without flexibility: $p^{NF}(t)$	*Buy HDPE from Germany*	*Buy PET from UK*
Purchasing with flexibility: $p^{F}(t)$		
a) Switching supplier:		
▪ *Alternate 1:* SC_i	*Buy HDPE from Germany*	*Buy PET from UK*
▪ *Alternate 2:* SC_j	*Buy HDPE from KSA*	*Buy PET from Asia*
▪ Switching cost	50,000$	5,000$
▪ Material qualification cost	150,000$	50,000$
b) Substituting commodity		
▪ *Alternate 1:* SC_i	*Buy HDPE from Germany*	*Buy PET from UK*
▪ *Alternate 2:* SC_j	*Buy PET from UK*	*Buy Recycled PET from Germany*
▪ Switching cost	100,000$	15,000$
▪ Material qualification cost	500,000$	100,000$

Table 2
Parameters of commodities prices.[a]

	s*	α	σ	S_o
Case A – Switching Supplier *(HDPE from Germany vs. HDPE from KSA)*				
SC_i	1215$	1.25	198.5	1190$
SC_j	1284$	1.41	205.9	1140$
Case A – Substituting Commodity *(HDPE from Germany vs. PET from UK)*				
SC_i	1215$	1.25	198.5	1190$
SC_j	1123$	2.13	171.4	1200$
Case B – Switching Supplier *(PET from UK vs. PET from Asia)*				
SC_i	1123$	2.12	171.4	1200$
SC_j	1249$	2.91	165.1	1267$
Case B – Substituting Commodity *(PET from UK vs. Recycled PET from Germany)*				
SC_i	1123$	2.12	171.4	1200$
SC_j	1118$	2.23	116.	1146$

[a] Notice that the commodity prices are generally obtained as the sum of a specific Index and a spread (cost plus or discount to the Index). Since they are indexed to some specific indexes, they may be correlated. In the present cases, the commodity prices are not correlated.

of the commodity source is possible every month for the case of the considered commodities), while the discount rate was not considered since the time horizon was one year.

Table 1 summarized the characteristics of the two cases.

As for the commodity prices, we have assumed that they will vary stochastically in time following a mean reverting process (MRP), as widely accepted by the literature (Blanco and Soronow, 2001a, 2001b; Blanco et al., 2001; Deng, 2000). The stochastic evolution of prices (S) that follows a MRP can be modeled as per the following equation:

$$dS_t = \alpha\cdot(s^* - S_t)dt + \sigma dW_t$$

where:

s*	is the long run mean (the mean reversion level)
σ	is the annual volatility of the price
α	is the mean reversion rate
dW_t	is a Brownian motion (so $dW_t \approx N(0\sqrt{dt})$).

This model implies that the prices can never be negative and their evolution can be completely specified considering only the initial value S_0, the long run mean, the mean reversion rate and the volatility of the prices. All these parameters were estimated by considering the historical data of commodity prices paid by *Gamma* in the period June 2013–May 2015. For chemical commodities, there are few standards in the market when it comes to pricing, like for example ICIS in the case of resins (www.icis.com). These standards have been used as a source of historical prices in the present study. The parameters of commodities prices are shown in Table 2.

Notice that in our case, only the price of the two commodities is uncertain. For the sake of generality, however, it is important to highlight that in other cases, other factors may be uncertain too, e.g., the periodic quantity requested for the commodity, switching cost, material qualification cost. This kind of uncertainty may be easily added in our simulation-based approach (by simply changing the definition of the uncertain input data), while it could not be considered if any other financially-based approach was used.

Our computational model has been used to simulate these two real cases. For this purpose, we have measured the net benefits of the two strategies as the additional benefits produced by such strategies (i.e. presence of flexibility) compared with those obtained in the absence of such strategies (i.e., absence of flexibility).

The simulation was carried out by using the model described in Section 3. The simulation model of the two CPV mitigation strategies, namely *Switching suppliers* and *Substituting Commodities*, is constructed using the @Risk software. The inputs to the simulation are the data on the commodities, the switching cost and material qualification cost. These parameters and their setting for the base-line model are reported in Tables 1, 2.

The Monte Carlo simulation approach was used for calculating the value of each strategy. In particular, in each computer iteration the random values of the stochastic input variables are generated on the basis of their statistical distributions, as established in input data modeling. Each simulation consists of 10,000 computer runs.

Figs. 1 and 2 show the simulation results for the base-line model, namely the probability distributions of the Value of flexibility and the number (#) of switches during the considered time period.[3]

As shown in Figs. 1 and 2, in 3 out of the 4 cases selected, it is interesting to note that the net benefits associated to these strategies are positive, namely, these strategies are effective in mitigating CPV, with a certain risk level (measured by the probability that the value of flexibility is lower than 0).

It can be interestingly observed that the findings cannot be predicted simply looking at the cost structure in Table 1. In case A, in fact, we have that both Switching cost and Material qualification cost related to *Substituting commodity* are higher than the ones related to *Switching supplier*. One can expect that, according to this cost structure, *Switching supplier* will be more advantageous than *Substituting commodity* in mitigating CPV. Actually, contrarily to this expectation, *Substituting commodity* is more effective in mitigating CPV than *Switching supplier*. This is due to the relative values of the commodities prices, their relative fluctuation and, hence, to the number of times in which the option (substitution of source) is exercised and the relative payoff.

[3] See Appendix C for the statistics of the distributions for the base-line model.

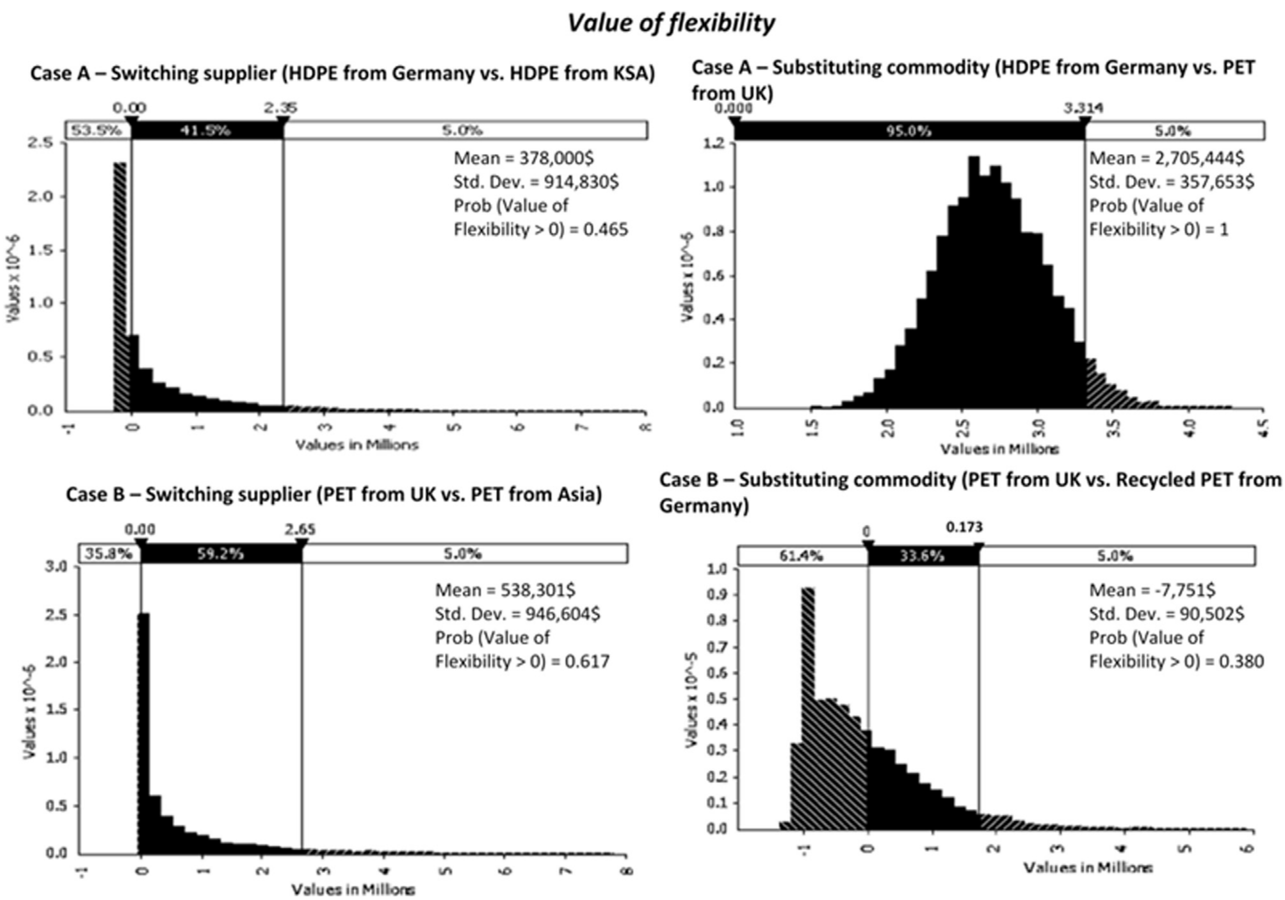

Fig. 1. Results of the base-line model: probability distributions of the value of flexibility.

Furthermore, contrarily to what one can expect on the relation between the strategies effectiveness in mitigating CPV and the purchased volume of the commodity, from our results, we cannot conclude that the strategies increase their effectiveness when the purchased volume of the commodity increases (the higher value of the flexibility is obtained for *Substituting commodity* in case A, although the volume of the commodity purchased in case A is lower than in case B). Hence, the finding confirms the importance for the managers to adopt quantitative approaches in order to assess the net benefits associated with CPV mitigation strategies, and to properly select the preferable mitigation approach under the specific operating conditions.

Beyond the specific numbers found for the Value of flexibility in the two cases, the findings show that both these SCRM strategies are valuable in mitigating CPV, namely, they may positively impact on firm's cash flow and profit. This first result confirms the insights of previous studies that empirically found that companies reported these strategies to mitigate CPV, without providing, however, any evidence about their contribution in terms of cash flows and profit. Therefore, the answer to the first research question is that both *Switching supplier* and *Substituting commodity* may be effective in mitigating CPV, with a certain risk level. From our findings, it is not possible to conclude that one strategy performs better than the other. In both the cases considered, it is possible to note that the value of the flexibility is different. Specifically, *Substituting Commodities* seems to create higher value in case A (with a mean value of 2,705,444$ vs. 378,000$ in case of switching suppliers), while *Switching suppliers* is preferable in the case B (with a mean value of 538,301$ vs. a mean value of − 7751$ in case of *Substituting Commodities*). Actually, beyond the specific result that cannot be generalized, the finding confirms that there is no specific hierarchy of tools to use, since different approaches are appropriate under different criteria (Zsidisin et al., 2014).

Also, the finding highlights that these strategies need to be carefully assessed before being implemented, since they are characterized by high implementation costs that need to be justified by the materialized cost savings. In fact, in almost all cases analyzed, there is still a probability that the value of the flexibility is less than 0. It is absolutely essential to take into account the value of the managerial flexibility to decide whether it is convenient to switch sourcing option, when properly assessing their value. This proves the importance of adopting ROV methods to model such managerial flexibility and account for its value.

As already mentioned, all the simulation results were reviewed through a structured walk-through with a set of purchasing managers of the firm involved in the two projects, which considered them as reasonable.

4.2. Simulation analysis

Once the base-line model was tested on real cases of CPV mitigation experienced by *Gamma*, we used the model to conduct a simulation analysis to answer the second research question: which are the main factors that affect the effectiveness of adopting Switching suppliers and Substituting commodities as CPV mitigation strategies?

With this aim, we designed a plan of experiments consisting of four experimental settings (in total 107 scenarios), each aimed at investigating the effect that key inputs of the model have on the net benefits created by such strategies when adopted to mitigate CPV. The

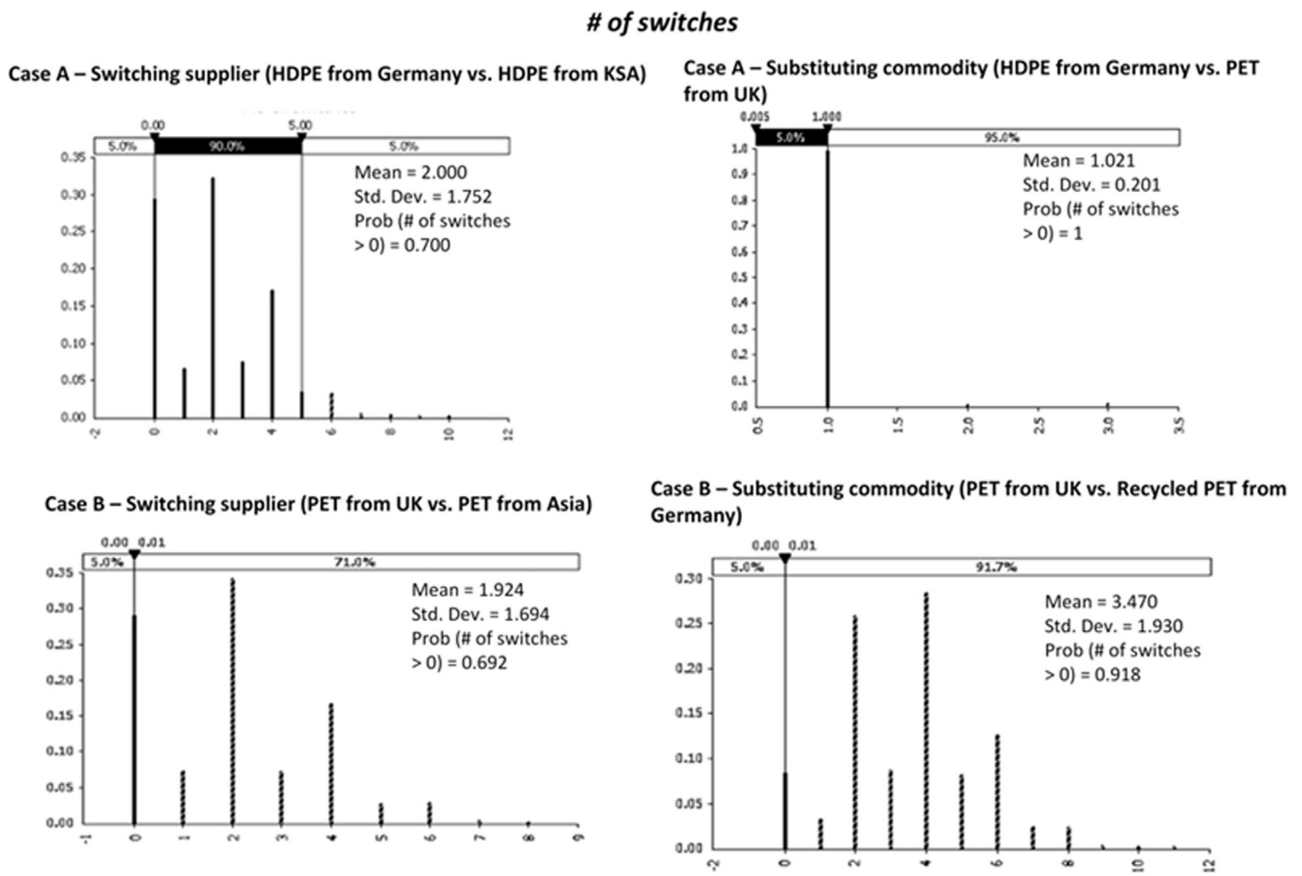

Fig. 2. Results of the base-line model: probability distributions of the number of switches.

four experimental settings are briefly described in the following:

- The first experimental setting aims at investigating the effect of the commodity price change on the strategies effectiveness in CPV mitigation. Operatively, we changed the long run means of the commodity prices so that their ratio, defined as $\rho = s^*_{SC_i}/s^*_{SC_j}$, ranges between about 0.8 and about 1.2.
- The second experimental setting aims at analyzing the effect that the spending on the specific commodity has on the value of the considered SCRM strategies. Operatively, since the spending results from the combination of both volume and commodity prices, we considered three different levels for the volume (Low, Medium and High, where Medium represents the volume of the base case, while Low and High scenarios are obtained by adding ± 15,000 t to the base case volume), and three different levels for the commodity prices (namely, ρ = [0.8 1 1.2]). The scenarios of these experimental setting result from the match between these three levels of volume and three levels of commodity prices.
- The third experimental setting is finalized to investigate the effect that the volatility of the commodity prices has on the effectiveness of these strategies in CPV mitigation. Operatively, we changed the volatility of the commodity prices, so that the ratio of the volatilities, defined as $\theta = \sigma_{SC_i}/\sigma_{SC_j}$, ranges between 0.7 and 1.3.
- The fourth experimental setting is aimed at investigating the impact that the Switching cost (i.e., exercise price of the option) and Material qualification cost (i.e., option cost) have on the value of the considered SCRM strategies. Operatively, we increase the Switching cost and decrease the Material qualification cost simultaneously by 50%, 25% and 15% compared to the base case, and vice versa. Then, we observed the variation of the value of the strategies when the ratio $\varepsilon = SwitchingCost/MaterialQualificationCost$ changes. For instance, let us consider the base case of the case A (switching supplier), where ε = 50,000/150,000 = 0.33. Starting from the values of the base case, we decrease the Switching cost of the 25% (i.e., Switching cost = 37,500$) and increase the Material Qualification cost of the same amount (i.e., Material Qualification cost = 187,500$). Hence, we obtain ε = 37,500/187,500 = 0.2.[4]

The simulation results achieved by 10,000 runs for each experimental setting and the related managerial implications are discussed above.

The results of the first experimental setting (i.e., analysis of the effect of commodity prices change) are shown in Figs. 3 and 4 for the two cases.

It is interesting to note that independently from the specific commodity considered, the trend of the flexibility value, when ρ grows, is the same, for both the SCRM strategies under investigation. The higher the value of ρ, the higher the effectiveness of these strategies in mitigating CPV. In particular, the value of the flexibility (mean value) presents a trend that is almost exponential. Specifically, for low values of ρ, the value of the flexibility is very low (even negative in some cases). When $\rho = 0.8$, in fact, the number of switches to the alternative source over the period considered is equal to 0. This result is quite intuitive: it is not convenient to use the alternative source (i.e., alternative supplier or substitute commodity) when the long-term (mean) price of the commodity currently used is lower. The value of the flexibility increases exponentially when $\rho \to 1$, and the mean value of the flexibility continues to grow (almost in linear way) when ρ increases. This has an interesting managerial implication: these SCRM strategies "start" to create a value when applied to sourcing alternatives (commodities or suppliers) that present similar values for long-term prices or

[4] See Appendix D for the plan of experiments related to the fourth experimental setting.

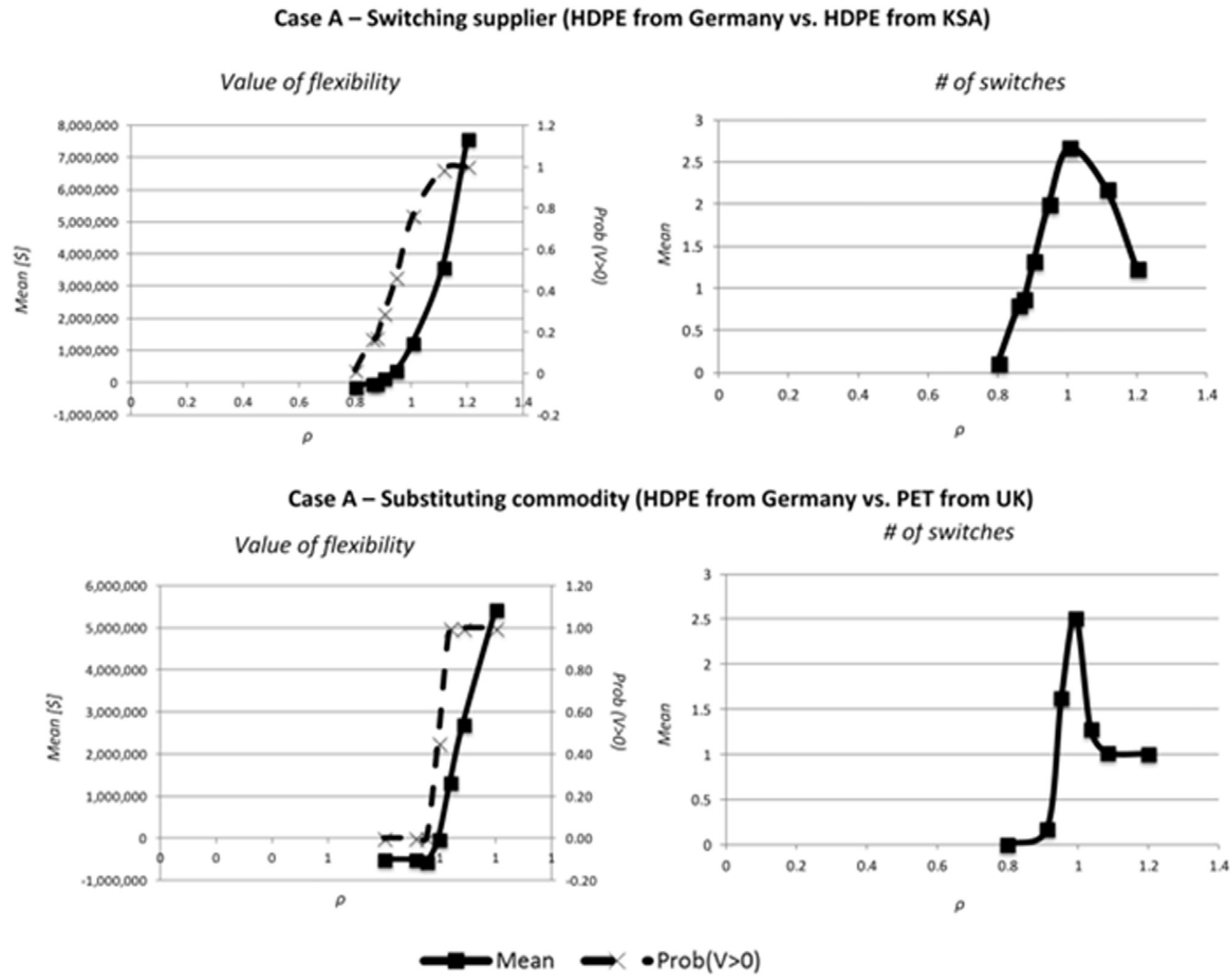

Fig. 3. Results of the first experimental setting: Case A.

when the long-run mean of the alternate commodity is lower than the original one. The number of switches, in fact, reaches its maximum value when $\rho = 1$, and then decreases until 1 when ρ increases. In this last case, the alternative source (i.e., alternative commodity or supplier) becomes more convenient than the first. Hence, the switch to the alternative is almost sure: the higher the value of ρ (namely, the cheaper the alternative sourcing), the higher the value created by the strategy. Also, since this behavior is evident in all the cases we analyzed, this means that, when adopting these SCRM strategies for CPV mitigation, the long-term prices of the commodities are not so important for their absolute value, but for their relative value.

This finding has also an interesting implication in the business practice: contrarily to the volatility and the mean reversion rate that are exogenous variables (which are not-controllable by the buyer since they mainly depend upon the specific commodity used), the long run mean is a parameter that the buyer can, in a certain way, leverage during the negotiation with the supplier, and that can be changed according to the negotiated agreement. Since the final commodity prices borne by the purchasing organization are generally obtained as the sum of a specific Index and a spread (cost plus or discount to the Index) negotiated with the supplier, the final long run mean price of the commodity may be changed by varying such a spread.

The results of the second experimental setting (i.e., the analysis of the effect of spending) are reported in Table 3.

As shown in Table 3, when the purchasing volume increases, the value of the flexibility, namely the effectiveness of these strategies generally, increases too, and the higher the value of ρ, the quicker is its growth in volume. This result is in line with insights of previous studies stating that adopting mitigation strategies is needed when the level of dependence on a commodity (measured, for example, through the spending on commodity) increases. We found that such strategies may prove effective in mitigating CPV even when commodities show a similar long run mean ($\rho = 1$); also, such effectiveness increases with the volume. Such a result is very interesting for the decision maker since it confirms the effectiveness of the analyzed strategies in mitigating CPV even in a critical situation (that is the one with $\rho = 1$, where there is no clear advantage between one alterative or the other). However, the convenience of adopting these strategies is not only linked to the volume, but to the ratio between the long-term prices of the commodities. In other words, even when the commodity purchasing volume is high (the level of dependence on commodity, is, therefore, high), it may happen that the strategies are not effective in mitigating CPV. In fact, we found that they are not effective when $\rho < 1$. Instead, when $\rho > 1$, the higher the purchasing volume is, the higher the convenience of

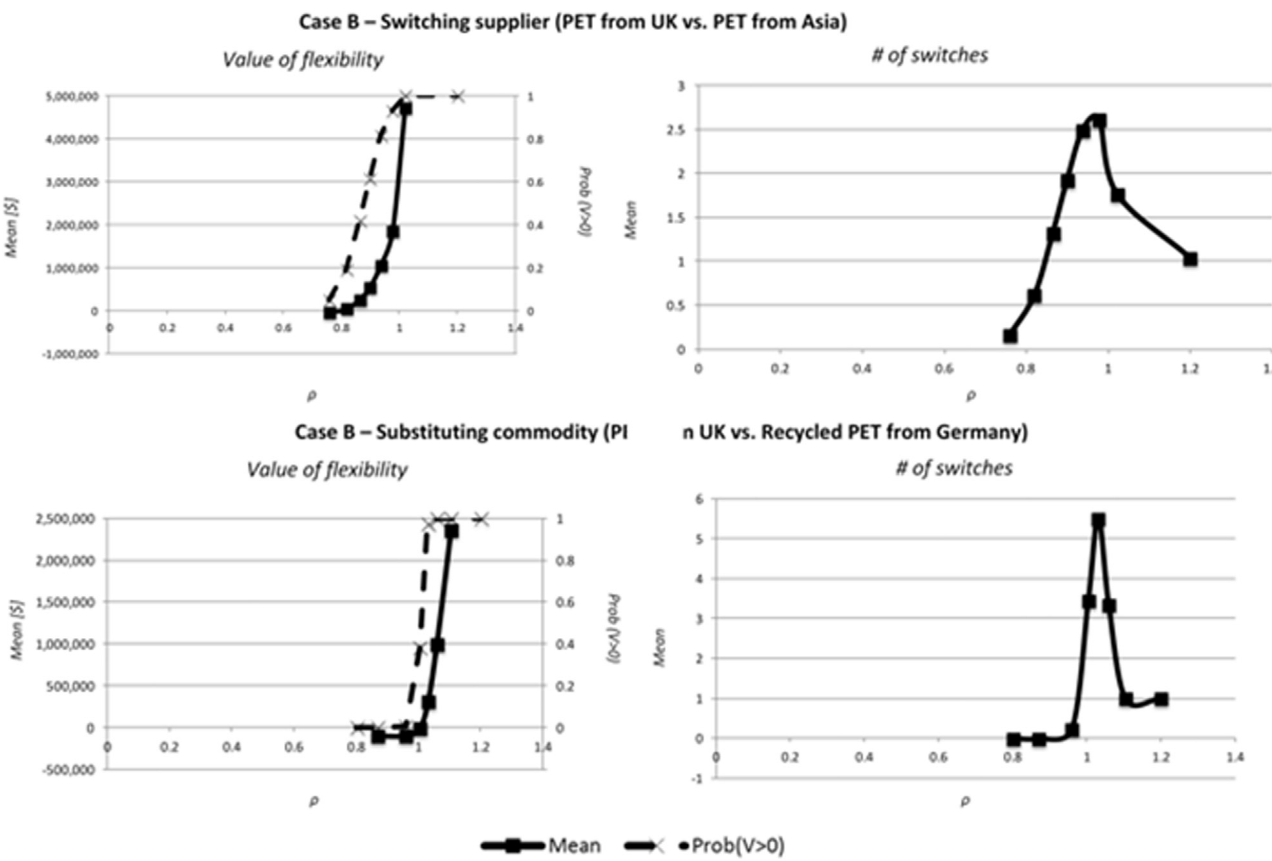

Fig. 4. Results of the first experimental setting: Case B.

Table 3
Results of the second experimental setting.

	Long run mean ratio/case	NPV for flexibility (Mean value) [$] Case A – switching supplier	Case A – substituting commodity	Case B – switching supplier	Case B – substituting commodity
Low Volume	0.8	− 146,555	− 500,000	138,697	− 100,000
	1	173,279	1,373,958	3,148,215	− 52,972
	1.2	2,062,646	3,024,835	7,396,426	3,717,832
Medium Volume	0.8	− 141,281	− 500,000	253,664	− 100,000
	1	378,000	2,705,443	4,726,578	− 7751
	1.2	3,601,687	5,441,333	11,084,531	5,634,702
High Volume	0.8	− 106,271	− 500,000	326,521	− 100,000
	1	1,600,028	4,030,532	6,306,442	40,311
	1.2	7,220,275	7,865,536	14,821,381	7,544,377

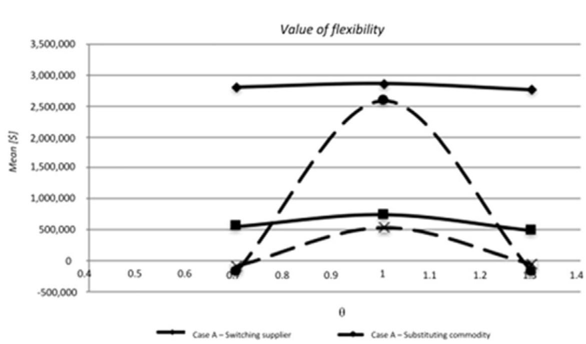

Fig. 5. Results of the third experimental setting.

adopting such SCRM strategies is. In this case, in fact, the switching to the alternate source becomes almost sure, and the value created increases as the ratio ρ increases (the unitary cost savings using the alternate commodity increases if the alternate commodity is cheaper).

The results of the third experimental setting (i.e., the analysis of the commodity prices volatility) are reported in Fig. 5.

As Fig. 5 shows, the results appear to be identical for the two cases, but at a different scale (which depends on the specific commodity considered).

This means that, independently of the specific commodity considered (and therefore on the specific values), the trend showed by the value of the flexibility is the same in all the cases and for both strategies: the value created by each strategy is maximum when the volatility ratio $\theta = 1$. The result is coherent with what we have found in the other experimental settings: the analyzed SCRM strategies increase their

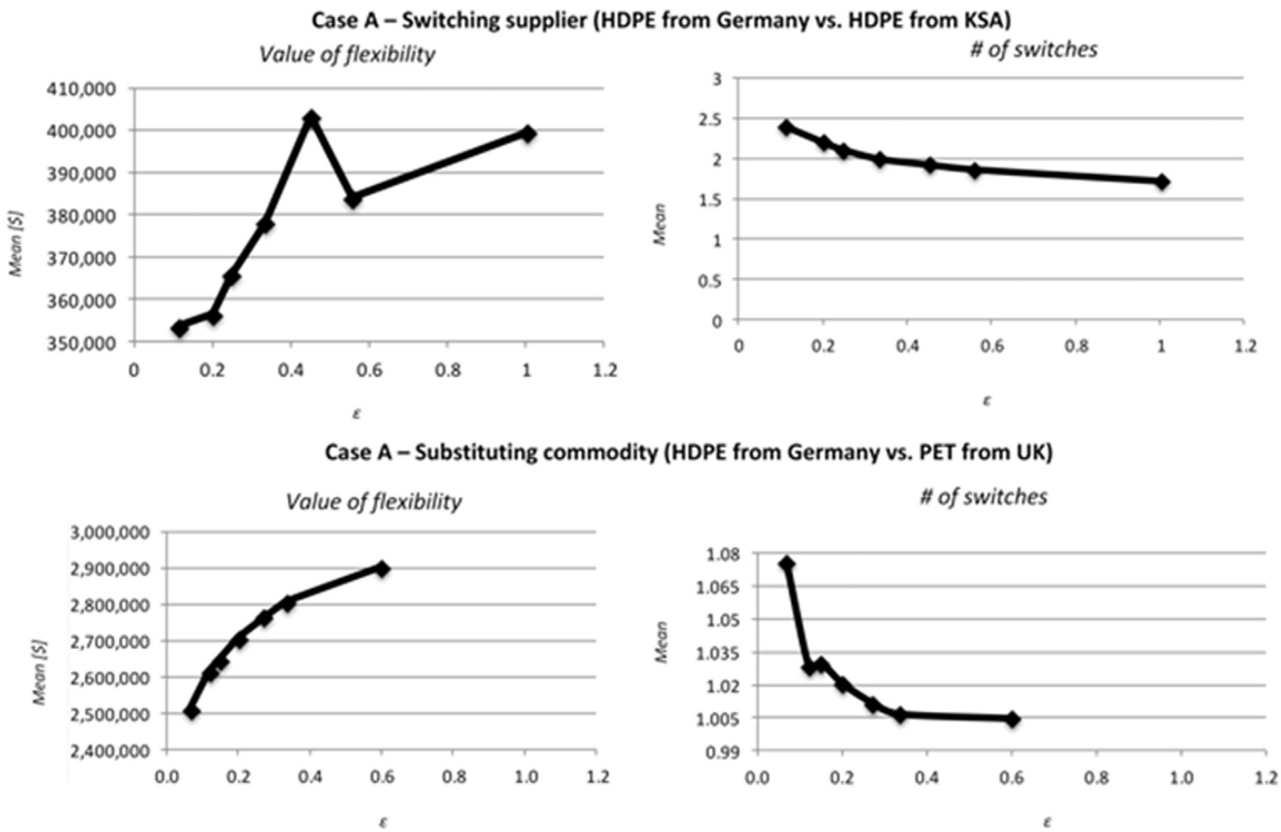

Fig. 6. Results of the fourth experimental setting: Case A.

effectiveness in mitigating CPV risk when they are applied to commodities or sources that show the same or similar price behavior (in this experimental setting, same volatility $\theta \rightarrow 1$), since this similarity increases the chance of having a switch among the commodities and thus repaying the initial (sunk) cost. Indeed, as a confirmation of this, in the case of *Substituting commodity*, the strategy ceases to be effective, causing even a loss, when the volatility of commodities or sources is different.

Finally, the results of the fourth experimental setting are depicted in Figs. 6 and 7.[5]

The results of the fourth experimental setting suggest that in both the analyzed cases, when the ratio $\varepsilon = SwitchingCost/MaterialQualificationCost$ increases, the number of switches (i.e., number of times the option is exercised) in T decreases for both the strategies. This is quite intuitive: the option exercise is less convenient when the exercise price of the option (i.e., the switching cost) increases. At the same time, the value of the flexibility (strategies effectiveness in mitigating CPV) increases for *Substituting commodity*, while it shows a non-monotone trend for the *Switching* supplier, especially in case B.[6] The result of a growing trend of the flexibility value, that might seem counterintuitive, actually confirms the validity of the ROV method adopted. In fact, as it is in practice, the manager switches to the alternative source only when convenient, and the outcome of such a decision strongly depends on the value of the switching costs (if the switching costs are high, most probably the net benefits will not be positive and the switch will not be made). On the other side, once the manager ensures that the switching is convenient, the benefits created by such switch that are by definition higher than 0 (added up to the benefits of other switches in all the period T) will be compared with the initial (sunk) cost to build such flexibility. The lower the sunk cost, the higher the value of such strategies. The increasing trend of the value of the flexibility with ε, together with the decreasing trend of the number of switches, suggests that the material qualification cost, more than the switching costs, impacts the value of the flexibility. When the material qualification cost decreases and the switching cost increases with the same (in percentage) amount (that means at higher values of ε), the number of switches decreases (i.e., the higher switching cost reduces the number of times in which the option is exercised). However, although the option is exercised fewer times, the value of the flexibility increases due to the reduction of the material qualification cost. The main managerial implication is that it is not valuable to have a "too flexible" process, which enables the switch of the commodity easily (through low switching costs), if very expensive to build. In terms of business practice, it may not always be convenient to ask the R&D department to design a production process in a way that all or almost all the activities (and related costs), to enable the flexibility, are done at the very beginning and less activities/costs are left at the time of making the switch, thus reducing the switching cost and increasing the material qualification costs.

5. Conclusions

Our study addressed the Supply Chain Finance challenge of

[5] Notice that while the scale for the horizontal axis (x-axis) is the same (since it is the value of the parameter on which we perform the sensitivity analysis), the scale of the vertical axis (y-axis) is different for the various cases (either for the Value of flexibility or for the # of switches), since it depends on the specific commodity under consideration.

[6] Notice that the deviations of the flexibility value with respect to a monotonous trend occurring in the case of Switching suppliers may be explained as follow. The uncertain benefits (linked to volatile prices) of the strategy weigh more in the case of Switching suppliers where the (certain) costs of the strategy (i.e. material qualification cost and switching cost) are lower than in the case of Substituting commodities, thus making the value of Switching suppliers more sensitive to price volatility. Also, the deviations of some points with respect to a pure monotone trend do not undermine the general conclusion of the growing trend.

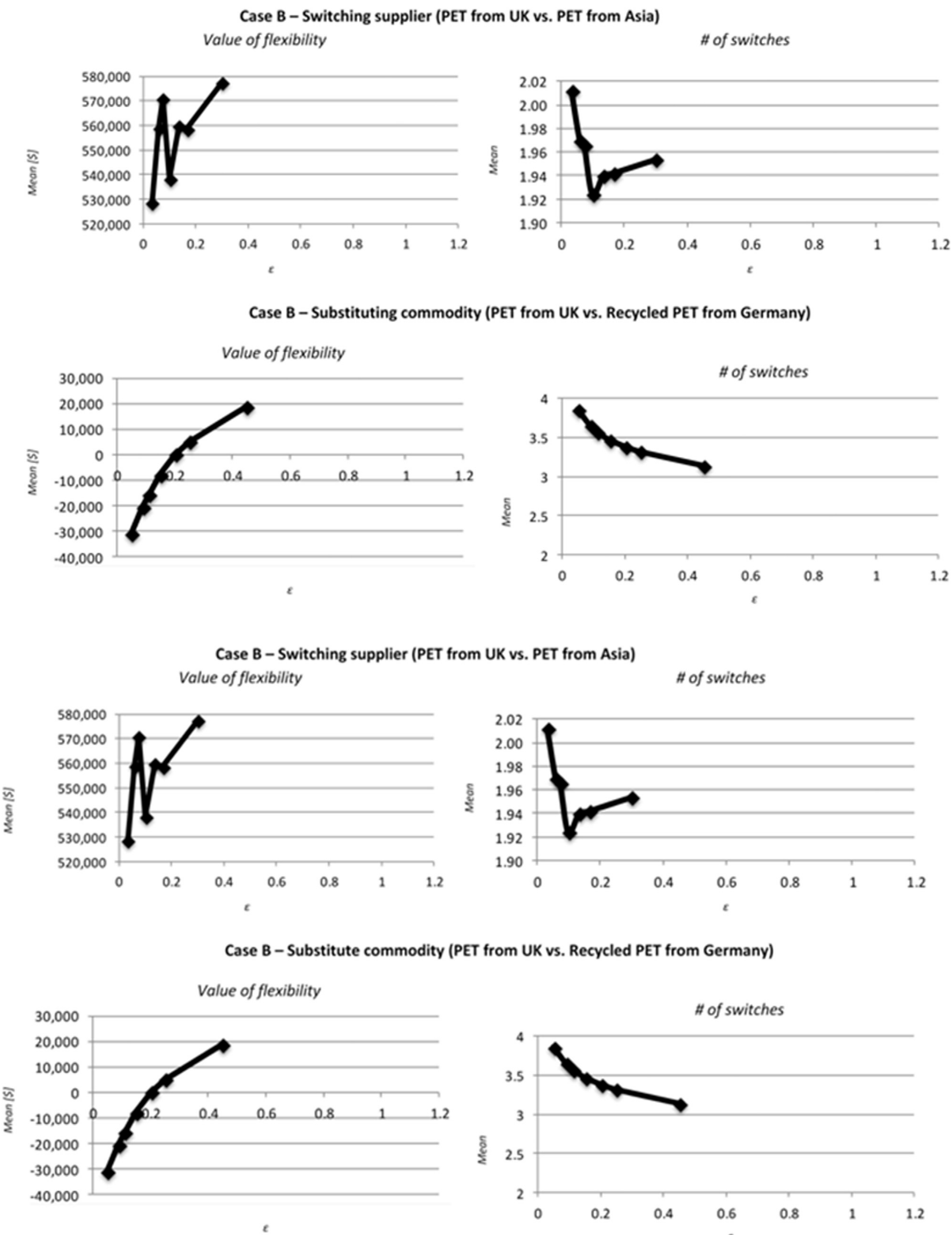

Fig. 7. Results of the fourth experimental setting: Case B.

Commodity Price Volatility (CPV), by adopting a supply chain-oriented perspective. In particular, the paper investigated the effectiveness of two SCRM strategies in mitigating CPV, namely, *Switching suppliers* and *Substituting Commodities*, and the main factors that may affect their value, with a simulation analysis. A ROV model was developed and tested on real cases, as experienced by a large multinational company (Fortune 100) leader in the Fast Moving Consumer Goods (FMCG) industry.

The paper offers two main contributions to the academic literature, by enriching the literature on SCF and on ROV methods applied to SCRM.

We contributed to the nascent theoretical debate in SCF literature on the effectiveness of SCRM strategies in mitigating CPV. We quantitatively demonstrated that sourcing strategies, and specifically *Substituting commodity* and *Switching suppliers*, may be effective non-financial strategies to mitigate CPV under opportune conditions, but that their value should be carefully assessed before adoption, since under some conditions they may result in a loss for the company.

We also contributed to the literature of ROV methods applied to SCRM. Firstly, we developed a real options-based model for assessing the effectiveness of two well-established SCRM approaches to tackle CPV. Secondly, we applied the simulation research as an option pricing technique for confirmation and prediction purposes. Our simulation model has been developed to test the nascent theory proposing SCRM strategies, namely *Substituting commodity* and *Switching suppliers*, as effective strategies for mitigating CPV, but also to understand how their effectiveness in mitigating such a risk changes under different operating conditions.

Our research also has practical implications. With the proposed model, we equipped managers and practitioners with a powerful tool to evaluate the effectiveness of adopting the two sourcing strategies for mitigating CPV under different conditions and, hence, to choose the most appropriate mitigation strategy depending on the context. Findings show that the convenience of adopting such strategies in mitigating CPV is strongly influenced by the relative values of the long-term prices of the commodities (or sources selected). In fact, it is convenient to adopt such flexibility-driven strategies when the long-term prices of both commodities/sources are similar, and also when they show similar behavior in terms of volatility. In such cases, the effectiveness of these strategies in mitigating CPV increases when the level of dependence on the commodity increases. Contrarily, when the long-term prices of the selected commodities are different (i.e., distant among them), independently from the purchasing volume, these strategies are not effective in mitigating CPV. This confirms that managers should implement these strategies only when they are valuable, thus avoiding burdening the company with their initial sunk costs without any expected benefits. As another insightful result, we found that the convenience of adopting such strategies is influenced more by the sunk cost borne at the very beginning to build flexibility than by the switching cost due only when the switch has to be executed.

Further research will assess other SCRM strategies in order to give managers a powerful toolset, in order to select the appropriate strategies on a commodity-by-commodity basis. Also, while in this paper we investigated the effectiveness of two sourcing strategies in mitigating CPV and how it varies under different operating conditions, one may also find valuable to assess how supply managers may combine these strategies into a portfolio of risk mitigation strategies, and investigate the value of their combined use. This is beyond the scope of the present paper, but it can be the objective of future research.

As for the method adopted to operationalize the mitigation strategies (i.e., ROV method), it is broadly acknowledged that the quantification of managerial flexibility leads almost naturally to the concept of options. Nonetheless, other methods could probably be investigated to model the decision-making behavior for mitigating the effect of price volatility in commodities (over time, by changing sources), e.g., leveraging Bayesian analysis or modeling the process as a Markov decision process and solve it via dynamic programing. Future works could be devoted to address this computational issue.

Appendix A. Overview of the limits of traditional Discounted Cash Flows (DCF) analysis to model and price the value of managerial flexibility

Traditional approaches, such as those based on Discounted Cash Flows (DCF) analysis (NPV most of all), assume implicitly that a strategy or project will be undertaken and operated for a set time scale, until the end of its expected useful life, even though the future is uncertain. Therefore, the assessment is static and underestimates the upside value of investments (Kogut and Kulatilaka, 1994) by assuming management's passive and inflexible commitment to a certain operating strategy. The assessment is also deterministic since there are implicit assumptions concerning a certain expected scenario of cash flows. In the real world, because of uncertainty and competitive interactions, the realization of cash flows will probably differ from what management originally expected. As new information is available and uncertainty about the market conditions and future cash flows is gradually resolved, management should revise the operating strategy it originally designed in order to achieve the initially desired goals (Boute et al., 2004). Hence, traditional managerial techniques arisen from stable environments less useful in uncertain contexts. They do not capture the value of the flexibility of changing the operating strategy to capitalize on favorable opportunities or to cut losses in the case of adverse developments (Olafsson, 2003).

Appendix B. Discount rate calculation in real option literature

The periodical discount rate r_p can be assessed as $r_p = (1 + r)^{1/p} - 1$, where r is the annual discount rate and p the number of periods in a year. Notice that the definition of the discount rate is an open issue in the real options literature. The main concern is that ROV changes the risk profile of the project, hence the discount rate (which takes into account exactly the project risk), should change accordingly. The definition of the 'correct' discount rate is not an easy task. Since Monte Carlo simulations take into consideration risks and uncertainties in the probability distributions of project variables, the appropriate discount rate may be risk free (Brealey and Myers, 2000). This avoids double counting risk, as it is already included in the cash flows that depend on the randomly chosen values of the input parameters. The risk-free interest rate corresponds generally to an observable market rate, such as US Treasury Bills.

Appendix C. Simulation results for the base-line model: statistics of the probability distributions of the *value of flexibility* and *# of switches*, with lower and upper bounds for each distribution at 95% confidence

	Value of flexibility					**# of switches**				
	Mean	Std. Dev.	Lower bound	Upper bound	Prob (Value of Flexibility > 0)	Mean	Std. Dev.	Lower bound	Upper bound	Prob (# of switches > 0)
Case A – Switching supplier *(HDPE from Germany vs. HDPE from Asia)*	378,000$	914,830$	360,070$	395,930$	0.465	2.000	1.752	1.966	2.034	0.700
Case A – Substituting commodity *(HDPE from Germany vs. PET from UK)*	2,705,444$	357,653$	2,698,434$	2,712,454$	1	1.021	0.201	1.017	1.025	1
Case B – Switching supplier *(PET from UK vs. PET from Asia)*	538,301$	946,604$	519,748$	556,854$	0.617	1.924	1.694	1.891	1.957	0.692
Case B – Substituting commodity *(PET from UK vs. Recycled PET from Germany)*	− 7751$	90,502$	− 9525$	− 5977$	0.380	3.470	1.930	3.432	3.508	0.918

Appendix D. Plan of experiments of the fourth experimental setting

Fourth experimental setting		$\varepsilon = SwitchingCost/MaterialQualificationCost$			
Variation of the Switching cost	**Variation of the material qualification cost**	**Case A – switching supplier**	**Case A – substituting commodity**	**Case B – switching supplier**	**Case B – substituting commodity**
− 50%	+ 50%	0.11	0.07	0.03	0.05
− 25%	+ 25%	0.20	0.12	0.06	0.09
− 15%	+ 15%	0.25	0.15	0.07	0.11
0%	0%	0.33	0.20	0.10	0.15
+ 15%	− 15%	0.45	0.27	0.13	0.20
+ 25%	− 25%	0.55	0.33	0.17	0.25
+ 50%	− 50%	1	0.60	0.30	0.45

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