Modeling a Multinational Firm’s Manufacturing Network as a Portfolio of Options

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Abstract

To fill the gaps in research on the portfolios of real options, I adopt analytical modeling and simulation that allows complex and interacting relationships in parameters. I employ two stochastic variable models to examine how a firm's strategic decision is shaped in the perspective of portfolios of options with the consideration of production cost or market demand uncertainty and how the valuation of portfolios changes with both positive and negative nation-level correlations, switching/coordination costs, and capacity constraint of manufacturing facilities. This study brings fruitful insights to the understanding of the effect of production cost or market fluctuations on switch or growth and contraction options and can become the forefront of real options research. By recognizing the effect of market uncertainty on switching option value in the presence of capacity constraint, I also construct a three stochastic variable model to examine how both market uncertainty and production cost uncertainty affect the value of the options embedded in a multinational firm's portfolio of manufacturing facilities located in different countries. This research yields a more complete understanding of a multinational firm's international activities through lens of portfolios of real options and accentuates a broader portfolio perspective that augments the existing Internationalization theory and Internalization theory. In addition, this work extends the application of Internationalization theory to embrace switching opportunities across borders, and thus widens the research subject from one focal location to portfolios of locations in the context of global supply chain. Moreover, the results shed light on how growth and switching options interact in the presence of different types of uncertainty.

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Keywords**:** portfolios of options, uncertainty, multinational firms, manufacturing networks

1 Introduction

Real options confer upon managers the right, but not the obligation, to proactively limit associated downside risk and preserve upside potential, which accrues to a possible foothold investment (Sharpe, 1991). There has been a growing body of research on real options that enable firms to contain downside costs and exploit upside economic gains in the presence of uncertainty. There has long been recognized that uncertainty serves as a critical or necessary condition for a real option to exist. Rivoli and Salorio (1996) emphasize that there are two types of uncertainty, exogenous and endogenous uncertainty. Exogenous uncertainty would not be affected by firms' actions (Chi and Seth, 2001), while the actions of firms can resolve endogenous uncertainty over time.

Real options embedded in firms' international strategic planning have a variety of forms (Trigeorgis, 1997). For instance, Growth options, or "call options on real assets", implies firms' discretionary future investment opportunities (Myers, 1977). By extending the real options theory into the joint venture context, Kogut (1991) views joint ventures as a platform to capture potential growth options in unanticipated conditions. More specifically, this type of business arrangement would allow firms to enter the market at reduced risk before making large commitments but provide them with an opportunity to grow in the future after assessing unfolding circumstances (Cuypers and Martin 2010; Kogut, 1991; Kogut and Kulatilaka, 1994b; Kogut and Chang, 1996; Tong et al., 2008a; Song et al., 2014).

Kogut and his colleagues (Kogut and Chang, 1996; Kogut and Kulatilaka, 1994a) have demonstrated the capabilities of international joint ventures as "within-country flexibility" or "within-country growth options" that begin with reduced investment to exploit growth options by adjusting their investment flexibly in the face of unanticipated macroeconomic fluctuations.

Scholars have asserted that international investments can provide preferential growth options embedded in host countries (Kogut and Chang, 1996; Kogut and Kulatilaka, 1994a; Kogut, 1991; Tong et al., 2008b; Kulatilaka and Perotti, 1998).

Besides that firms have chances to purchase additional equity from their joint venture partners (Kogut, 1991; Kumar, 2005), growth options can also be exercised in many other ways: increase or expand the scale of an affiliate (Kogut, 1983), and open new establishments (Fisch, 2008; Kogut and Kulatilaka, 1994a). Thus, contraction options realized through a decrease in the scale of an affiliate and growth/expansion options are two opposing options that might be subject to the same uncertain condition (Chung et al., 2010). As growth or expansion options are call options and contraction options are put options that can be determined by the same type of uncertainty, our study embodies both the option to contract and the option to grow or expand. For the purpose of simplicity, I might call growth/contraction options scaling options later in this dissertation.

Kogut (1983) posits that unlike their domestic counterparts, multinational firms possess the abilities to switch input sourcing, production, and marketing activities within their international subsidiary networks, more specifically, with shifting production capacity to locations with falling input costs from ones with rising costs due to potential exchange rate fluctuations (Kogut and Kulatilaka, 1994a). Kogut and Kulatilaka (1994a) further apply an analytical model to evaluate the opportunity to benefit from uncertainty through the coordination of subsidiaries that are geographically dispersed and term it as “operational flexibility” retained by multinational firms.

A large body of studies have empirically explored the connection between switch options and exchange rate uncertainty. Research has found support for the notion that under exchange rate uncertainty, firms indeed switch production outputs or sourcing inputs across facilities located in different countries (Rangan, 1998; Belderbos and Zou, 2009) and operational flexibility enhances firms' values (e.g., Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Oriani, 2007; Sakhartov and Folta, 2014). Operational flexibility also confers upon managers the ability to shift the production possibility frontier outward, which increases expected future cash flows, and thus growth (Mello et al., 1995). Thus, it is logically consistent with the view that a portfolio of competing growth options (Anand et al., 2007) are associated with switch options. However, the relationship between operational flexibility and growth options has been given little attention in the extant literature.

Moreover, in the case of the coexistence of growth options and switch options in the variation of the exchange rate, each option requires a specific condition to generate value, and thus the notion that one type of option can have a masking effect on (Song et al., 2014) or interact with the other option (Anand et al., 2007; Trigeorgis, 1993b; Vassolo et al., 2004) needs to be carefully taken care of in the study of portfolios of real options. Scholars in strategic management or international business have rarely examined the effect of the same type of options at the portfolio level on strategic decision making (Belderbos et al., 2019), not to mention the impact of portfolios of different types of options with some exceptions (Chung et al., 2010; Lee and Makhija, 2009; Song et al., 2014; Belderbos and Zou 2009) that however strive to put a clear cut between growth option and switch options under distinct sources of uncertainty. Chi, Li, Trigeorgis, and Tsekrekos (2019) define switch options as "an option to switch as a hybrid option that effectively combines or transitions between two interrelated options: the option to scale down one operation and the option to scale up another." In this regard, switch options are inseparable from growth/expansion options and contraction options. Moreover, portfolios of switch options include portfolios of growth options and contraction options and their interactions. Therefore, the consideration of growth/contraction options and switch options complicates the complexity of portfolios of options by integrating portfolios of the same kind of options and portfolios of different types of options where the two different types of portfolios are correlated.

In addition, growth options are highly associated with market or demand uncertainty, whereas switch options, options to scale down one operation and the option to scale up another simultaneously (Chi et al., 2019), have been largely explored with the exchange rate uncertainty by researchers (e.g. Dasu and Li, 1997; Rangan, 1998; Belderbos and Zou, 2009; Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Oriani, 2007; Sakhartov and Folta, 2014). As growth options and contraction options are call and put options that can both be subject to market uncertainty, I argue that switching options that embrace the complexity of managing the call and put options simultaneously can be related with market or demand uncertainty as well. I further suggest that a necessary condition for a switch option to exist under demand uncertainty is the presence of manufacturing facilities' capacity constraint.

Various terms have been employed to express switch and growth options. For instance, Kogut and Kulatilaka (1994a) differentiate "within-country growth options" from "across-country options." Moreover, scholars have studied switch and growth options under different sources of uncertainty. Growth options are highly associated with market or demand uncertainty (Belderbos et al., 2019; Tong et al., 2008b), while a growing body of research have theoretically and empirically explored the connection between switch options and exchange rate uncertainty. However, a collection of competing and related growth/contraction options should be highly associated with switch options embracing simultaneously "the option to scale down one operation and the option to scale up another" (Chi et al., 2019). In this research, I address impacts of different types of uncertainties on both values of switch options and growth/contraction options. In addition, I investigate how these options interact in the face of production cost and market volatility.

To fill the gaps, I conduct research adopting analytical modeling and simulation that allows complex and interacting relationships in parameters. I employ two stochastic variable models to examine how a firm's strategic decision is shaped in the perspective of portfolios of growth options and switch options with the consideration of production cost or market demand uncertainty across countries and how the valuation of portfolios changes with correlations in production costs or market demands, switching/coordination costs, and capacity constraint of manufacturing facilities. As positive and negative correlations in production costs or market demands in different countries might potentially generate systematically different results, it pays to scrutinize them separately to get new insight. Thus, I consider the impact of both positive and negative correlations of cost or demand developments on portfolios of options firms attained by optimizing production operations across nations. By adopting a network perspective instead of an atomic view, I study the effect of multinational firms' cost or demand volatilities on potential growth opportunities and switch flexibility that would keep firms operate both efficiently and flexibly in multiple country environments. Besides the potential effect of production cost fluctuations on growth options, I also discover the possible relationship between multinational firms' capabilities to optimally shift productions around their internationally dispersed facilities and the volatility of demand uncertainties in their network countries. This work brings nuances into the current understanding of real options philosophy by analyzing the effects of cost or market uncertainty on both switch options and growth options. Managers have been aware of multinational firm's capabilities to reap profits from potential production shifts among their manufacturing facilities when confronting with production cost differentiations in their networks. This work thus sheds new managerial insights on multinational firm's possible switching opportunities in the face of different demand developments across countries.

Furthermore, I apply a three stochastic process model to study a multinational firm's geographically dispersed manufacturing network in the global supply chain context (Connelly et al., 2013). The model examines how a multinational firm's international activities are determined by both production cost and market demand uncertainties in the perspective of portfolios of growth/contraction options and switch options and how the valuation of portfolios changes with cost correlations, demand correlations, switching/coordination costs, and capacity constraint. In the presence of macroeconomic fluctuations, multinational firms manage their international configurations to exploit options in various nations, which would in turn contribute to sources of competitive advantage and firm heterogeneity as fundamental issues in strategy research (Trigeorigis and Reuer, 2017). In addition, on top of Internalization theory (Buckley and Casson, 1976) and Internationalization theory (Johanson and Vahlne, 1977), I add another layer on the understanding of multinational firms' international activities by applying the perspective of portfolios of options. Instead of focusing on a focal location, this paper also extends the application of the Uppsala model to embody both within country scaling options and across country switch options with the consideration of portfolios of locations.

The rest of the paper is organized as follows. I discuss the literature review in section 2 and present my model specification in section 3. In section 4, I discuss the simulation results from the three models. Section 5 presents discussions of findings in this dissertation and directions of future research.

2 Literature Review

2.1 Literature Review

Although originating from financial economics, real options theory has made its unique and distinct appearance in strategic management studies by underscoring “real assets” as underlying assets. Since its inception envisioned by Myers (1977) to integrate with the realm of strategic decision making, real options confer upon managers the right, but not the obligation, to proactively limit associated downside risk and preserve upside potential, which accrues to a possible foothold investment (Sharpe, 1991).

There has been long recognized that uncertainty serves as a critical or necessary condition for a real option to exercise. The level of uncertainty would affect the value of an option, which in turn would have an impact on option related investment (Dixit and Pindyck, 1994; Chi and McGuire, 1996). Scholars have convincingly argued that there are two different types of uncertainty, exogenous or endogenous uncertainty (Rivoli and Salorio, 1996; Cuypers and Martin, 2010). Exogenous uncertainty would not be affected by firms’ actions (Chi and Seth, 2001), while activities of firms can resolve endogenous uncertainty over time. Exogenous uncertainty is not predictable, but sometimes can be resolved by the passage of time, such as the occurrence of earthquakes. Unlike passive learning in exogenous resolution, endogenous uncertainty also involves proactive learning and actively engage in the related business context. In other words, exogenous uncertainty is highly associated with a conservative action, whereas endogenous uncertainty would induce the firm’s aggressive behavior. Scholars have argued that multinational firms that enter or operate in foreign markets are more likely to undertake high levels of exogenous uncertainty (Cuypers and Martin, 2006; Chari and Chang, 2009), the resolution of which is not affected by firms' course of actions (Cuyers and Martin, 2006; Chi and Seth, 2001).

Real options embedded in firms' international strategic planning have a variety of forms (Trigeorgis, 1996). Trigeorgis and Reuer (2017) identify five basic types of stand-alone real options that can affect investment behavior: the option to defer the market entry or a "wait to see" strategy when confronting unanticipated exogenous or market uncertainty (e.g., Dixit and Pindyck, 1994; McDonald and Siegel, 1986); the option to grow that an initial investment in a foreign country serves as a platform to potentially expand with uncertainty resolved in the future (e.g., Kulatilaka and Perotti, 1998); the option to expand or contract production capacity (e.g., Leiblein and Miller, 2003); the option to switch production activities through multinational firms' facility networks in response to exchange rate uncertainty (e.g., Huchzermeier and Cohen,1996; Kogut and Kulatilaka,1994a); the option to exit a market or abandon a technology if expected outcomes are not attained (Chi, 2000; Dixit, 1989). Among the five real options, growth options and switch options have been extensively investigated.

Growth options or "call options on real assets" trace its intellectual roots to Myers's (1977) description of firms' discretionary future investment opportunities, and are advocated by Kogut (1983) as "an important contribution to the value of the firm." McDonald and Siegel (1986) further argue that this option to invest in assets represents the flexibility of time. That firms preserve economic potential by making a small amount of investment to avoid irreversible costs premised on discretions at the right timing is valuable (Dixit and Pindyck, 1994). Multinational enterprises (MNEs) or corporations (MNCs) reap profits from growth options by limiting their initial investment in a foreign market and exercises the options by subsequent investments with the receding uncertainty (Fisch, 2008). The current literature in the configuration of multinational firms' networks has primarily applied growth option logics to the case that firms have chances to purchase additional equity from their joint venture partners (Kogut, 1991; Kumar, 2005), whereas growth options can be exercised in many other ways: increase or expand the scale of an affiliate (Kogut, 1983); open new establishments (Fisch, 2008; Kogut & Kulatilaka, 1994a). More specifically, Chang's work (1995, 1996) indicates that initial entries by Japanese electronics firms in the U.S. provide platforms for their further direct investment, and the evolution of firms' multinational process in the U.S. benefits from reaping the possibility of growth prospects through sequential entry processes. Driouchi and Bennett (2012) claim that a sequential entry fashion confers a multinational firm's foreign operations growth options to capitalize the value of waiting while obtaining upside potentials. A sequential direct investment, however, does not only indicate that growth options can be realized through the purchase of additional equity from joint venture partners, but also the expansion of a foreign manufacturing factory's scale can be another mean to materialize on growth options possessed by a multinational firm operating in different countries. For instance, Campa (1994) examines the relationship between demand uncertainty and the expansion of capacity in a specific country. Kester (1984) also argues that investment decision of tomorrow hinges on the decision made today to lead to the ultimate achievement of strategic objectives, and growth opportunities embedded in this long range planning include expanding capacity besides acquiring other companies or making new production introduction.

Furthermore, unlike the option to grow, scholars have fewer incentives to investigate explicitly the option to contract but imply that contraction options and growth/expansion options are two opposing options that might be subject to the same uncertain condition (Chung et al., 2010). When the demand is as strong as originally envisioned, a foothold investment preserves upside growth opportunity. By the same token, the initial investment can be reduced if the market does not turn out to be optimistic. Therefore, the same set of factors can influence the values of growth and contraction options. In addition, Jiang and his colleagues (2009) agree that "strategic growth options are compound options for future international activities". Thus, growth options can be a call option on a call option (a series of expansion) or a call option on a put option (growth after contraction). Moreover, Kogut and Kulatilaka (1994a) apply the strategic management concepts of incremental options to the multinational firm context as "within-country option" attained through foreign investment that initiates a platform in host countries to "identify and exploit" future growth opportunities (Kogut, 1991; Kogut and Chang, 1996; Tong et al., 2008; Song et al., 2014). Incremental options indeed consist of both put and call options on a real investment (Sharp, 1991; Bowman and Hurry, 1993; Chung et al., 2010). For instance, when a upside potential emerges, a firm can realize its call options or growth options by expanding future commitments; while when the condition becomes unfavorable, the firm might exercise a put option or contraction option and reduce its initial investment. Increasing or decreasing the investment scale in exiting affiliates or technologies (Coucke, Pennings, and Sleuwaegen, 2007; Hurry, 1993) are both examples of incremental options. Discussions in this paragraph, thus, offer us incentives to examine growth/expansion and contraction/scaling down options together. I might use the term "growth options" or "scaling options" to refer to both growth options and contraction options to avoid the clutter.

Cohen and Huchzermeier (1992) bring up the notion of "exchange rate uncertainty" when extending the work by Cohen and Lee (1988). Kogut (1983) posits that unlike their domestic counterparts, multinational firms possess the abilities to switch input sourcing, production, and marketing activities within their international subsidiary networks, more specifically, with shifting production capacity to locations with falling input costs from ones with rising costs (Kogut, 1985). Kogut and Kulatilaka (1994) apply an analytical model to evaluate the opportunity to benefit from uncertainty through the coordination of subsidiaries that are geographically dispersed and term it as “operational flexibility” retained by multinational firms.

Various terms have been employed to express these two options. Kogut and Kulatilaka (1994a) differentiate “within-country growth options” from “across-country options.” Trigeorgis (1996) refers to the incremental option, an opportunity to undertake profitable follow-up investments, as “option to expand,” and the flexibility option originating from existing manufacturing facilities as “option to switch use.” As mentioned before that under real options lens, firms manage their cross-border activities in the way that downside risk is limited with the exploitation of upside potential, studies in either growth or switch option, however, have discovered mixed and complicated findings regarding the relationship between mutlinationality and risk (Tong and Reuer 2007; Reuer and Leiblein 2000; Kim et al., 1993).

In the case of the coexistence of growth options and switch options in the variation of the exchange rate, each option requires a specific condition to generate value, and thus the notion that one type of option can have a masking effect on (Song et al., 2014) or interact with the other option (Anand et al., 2007; Trigeorgis, 1993; Vassolo et al., 2004) needs to be carefully taken care of in the study of portfolios of real options. Additionally, that portfolios of options embedded in firms’ international investments have the feature of sub-additive indicates the value of a portfolio of options may be less than the summation of the values of these options if they were independent, which has been empirically studied and supported (e.g., Anand et al., 2007; Trigeorgis, 1993; Vassolo et al., 2004; Belderbos et al., 2014). Scholars in business strategy or international business have rarely examined the effect of the same type options at the portfolio level on strategic decision making (Belderbos et al., 2019), not to mention the impact of portfolios of different types of options with some exceptions (Chung et al., 2010; Lee and Makhija, 2009; Song et al., 2014; Belderbos and Zou, 2009). For instance, Belderbos, Tong, and Wu (2019) argue that a firm's entry decision to a new market would help increase operational flexibility of its manufacturing network by enhancing portfolios of options to switch derived from the possession of geographically dispersed affiliates in the presence of diverging labor cost developments. This is an example of examining the same type of options at the portfolio level. In the case of portfolios of different types of options (e.g., portfolios of across country switch options and within country growth options), Belderbos and Zou (2009) examine foreign affiliate divestment decisions in response to adverse environmental change. Chung, Lee, Beamish, and Isobe (2000) further strive to put a clear cut between growth options and switch options under distinct sources of uncertainty. Chi, Li, Trigeorgis, and Tsekrekos (2019) define switch options as "an option to switch as a hybrid option that effectively combines or transitions between two interrelated options: the option to scale down one operation and the option to scale up another." In this regard, switch options are inseparably scrutinized from growth/contraction options. Moreover, portfolios of switch options include portfolios of growth options and contraction options and their interactions. Thus, the consideration of growth/contraction options and switch options complicates the complexity of portfolios of options by integrating portfolios of the same kind of options and portfolios of different types of options where the two different types of portfolios are correlated as well as mentioned previously that portfolios of competing growth options are highly related with switch options.

2.2 Literature Review under Production Cost Uncertainty

Earlier work has distinguished risk diversification from real options in explaining multinational investment (Kogut, 1983, 1985, 1989; Kogut and Kulatilaka, 1994a, 1994b), although the two views can be related. More specifically, Kogut and Kulatilaka (1994a) document the noticeable difference between the two perspectives in the analysis of switch options potentially possessed by multinational firms geographically dispersed across country borders that "the benefits of diversification are created by the reduction in the variance of the overall portfolio of subsidiary results. An option, on the other hand, is valuable because it gives managerial discretion to respond profitably to the realization of uncertain events." In accordance with their argument, Trigeorgis (1996) proposes that real options theory is a better approach than risk diversification theory to evaluate the influence of uncertainty on firms' investment decisions. The contention on multinational companies' investing behavior under uncertainty by Campa (1994), however, supports that these companies invest abroad in the purpose of risk diversification, gained through risk pooling or diversification of manufacturing facilities in places with negatively correlated economic conditions, rather than operation flexibility conferred by real options.

Although the valuation of switch options that embrace the complexity of managing the call and put options simultaneously is challenging, Dasu and Li (1997) model when and how much to alter production quantities when firms face exchange rate variability. A large body of research, however, have empirically explored the connection between switch options and exchange rate uncertainty. Chang, Kogut, and Yang (2016) find that operating flexibility is more salient during times of high volatility, even after controlling for endogenous problems. Significant evidence shows that firms or managers tend to appreciate the real options logic in the decision-making process (Kogut and Kulatilaka, 1994b; McGrath, 1997; McGrath and Nerkar, 2004) which might ascribe to investors' positive attitudes toward the existence of operational flexibility (Tang and Tikoo, 1999). Research has found to support the notion that under exchange rate uncertainty, firms indeed switch production outputs or sourcing inputs across facilities located in different countries (Rangan, 1998; Belderbos and Zou, 2009) and operational flexibility enhances firms' values (e.g., Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Oriani, 2007; Sakhartov and Folta, 2014). The media also captures the interesting phenomenon triggered by multinationality that Fleming (1998) documents during the Asian financial crisis in the late 1990s, multinational firms such as ABB and GE move part of the productions to Asia to exploit a relatively low input cost due to currency depreciation. Management awareness of risk implications under the real options perspective has been brought to attention in multinational investment (e.g., Driouchi and Bennett, 2011). Unlike Driouchi and Bennett's work (2011) that uses survey data and self-reported information, there emerges empirical research that favors archival data to scrutinize the practical exercise of options (Bowman and Hurry, 1993; Tong and Reuer, 2007). A growing body of research has recorded the evidence of the embeddedness of switch options conferred by firms that have geographically distributed facility locations, and of the impact of exercising these options on firms' value or performance (e.g., Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Belderbos and Zou, 2009; Fisch and Zschoche, 2012; Lee et al., 2012; Chung et al., 2013). For internationally operated firms, labor cost development is a crucial driver of foreign direct investment (e.g., Kouvelis et al., 2001), of which the minimization is the primary objective in operating internationally dispersed plants (e.g., Belderbos et al., 2014; de Meza and van der Ploeg, 1987; Fisch and Zschoche, 2012). Furthermore, having a portfolio of production affiliates delivers a portfolio of switch options in response to cost development movements in different locations. In cases of highly positive correlations of cost development in countries where production facilities are located, however, a production affiliate might provide redundant rather than valuable switch options (e.g., McGrath, 1997; Trigeorgis, 1996). Consistent with this idea, in the context of multinational operations and switching options, correlations in labor costs among the countries in which the firm operates have been proposed as a significant source of redundancy (e.g., Belderbos and Zou, 2009; Dasu and Li, 1997; de Meza and van der Ploeg, 1987**).** By the same token, this paper also takes into consideration correlations of cost uncertainty surrounding countries where firms' manufacturing facilities are located when examining switch options firms attained by optimizing production operations across nations. Previous studies have focused on a positive relationship in production cost developments across nations but entangled a potential distinct result that comes from the negative relationship. This dissertation investigates the impact of both negative and positive relationships of production cost developments in different countries on the switch option value.

Operational flexibility confers upon managers the ability to shift the production possibility frontier outward, which increases expected future cash flows, and thus growth (Mello et al., 1995). It is logically consistent with the previous discussion on the portfolio of competing growth options that are considerably associated with switch options. Belderbos and Zou (2007) claim that "As market demand and labour costs are the environmental changes that are most influential in attracting investments, changes in market demand and labour costs are also likely to lead MNEs to extend or reduce operations of existing affiliates.', and point out the positive value effect of labor cost volatility on the growth option value. Belderbos and Zou (2009) further examine the value of growth or switch option under conditions of macroeconomic uncertainty, even though the two authors are unable to distinguish growth options from switch options under fluctuated exchange rate movements. Despite their work, little attention has been devoted to evaluating the influence of exchange rate volatility on the valuation of growth options. It might be due to the fact that a tremendous amount of work on growth options have their emphasis on firms cooperating with partners in a joint venture format so that growth options are exercised by purchasing additional equity stake from the other parties in joint ventures (Kogut, 1991; Kumar, 2005). Exercising growth options, however, can take different forms, such as increasing the scale of an affiliate (Kogut, 1983), or opening new establishments (Fisch, 2008; Kogut and Kulatilaka, 1994a). Another contribution of the dissertation is to bring precision into the current understanding of real options philosophy by addressing the impact of production cost uncertainty on both switch options and growth options.

In the model 1, I investigate how portfolios of growth/contraction options and switch options embedded in the multinational subsidiary networks can affect firms' international strategic planning in the first place, such as market entry decision, which has been aggressively studied by researchers applying stand-alone option perspective (e.g., Campa and Goldberg, 1995; Chi and McGuire, 1996; Chi and Seth, 2009; Kouvelis et al., 2001), as switching options that attain both options to scale up and down simultaneously cannot be studied alone without consideration of growth or contraction options. This work adopts analytical modeling, enabling the simulation of complex and interacting relationships, and takes a dyadic analysis to examine how a firm's strategic decision is shaped in the perspective of portfolios of growth options and switch options by the consideration of production cost uncertainty across countries and how the valuation of portfolios changes with cost correlation, switching/coordination costs, and capacity constraint of manufacturing facilities.

2.3 Literature Review under Market Uncertainty

By extending the real options theory into the joint venture context, Kogut (1991) views joint ventures as structural mechanisms that proactively help firms manage uncertainties. More specifically, an initial smaller-scaled investment would allow a firm to enter the market at reduced risk by gaining a greater understanding of the local environment before making large commitments and provide the firm an opportunity to assess unfolding circumstances (Cypers and Martin 2010; Kogut, 1991; Kogut and Kulatilaka, 1994b; Kogut and Chang, 1996; Tong et al., 2008; Song et al., 2014). If the economic condition turns out to be advantageous, joint ventures enable firms to materialize the positive market shock by exercising the growth option by acquiring more or all ownerships from partners (Kogut, 1991; Folta, 1998; Folta and Miller,2002). By limiting the initial outlay, companies possessing growth options benefit from simultaneously containing downside risk and capturing upside potential according to evolving environment (Kester, 1984; Chi and McGuire, 1996). Kulatilaka and Perotti (1998) further contend that with the resolution of a macroeconomic uncertainty, firms positioned in a limited initial investment can capture potential growth opportunities that are however not available to other firms without such a strategy. Thus, that firms preserve economic potential by making a small amount of investment to avoid irreversible costs premised on discretions at the right timing is valuable (Dixit and Pindyck, 1994).

Consistent with the above, scholars have demonstrated the capabilities of international joint ventures that begin with reduced investment to exploit growth options by adjusting their investment flexibly in the face of unanticipated macroeconomic fluctuations (Cuypers and Martin, 2010; Tong and Reuer, 2007; Tong et al., 2008; Song et al., 2014). Kogut and his colleagues (Kogut and Chang, 1996; Kogut and Kulatilaka, 1994a) view this capability as “with-country flexibility" or "within-country growth options" that confer international joint ventures to leave open the possibility of subsequent expansion as the uncertainty gets resolved. When a multinational firm is subject to market turbulence in a host country, it might confront difficulties of developing an appropriate investment strategy (Song et al., 2014). Song and his coauthors (2014) further confirm that in order to achieve this "within-country" growth options or flexibility, the firm can stake out its initial position and "wait and see" until conditions become clear before making any large scaled or subsequent investment. Kogut (1983, 1989) posits that a multinational firm can attain growth opportunities from different host countries that are not accessible to domestic operations. Thus, scholars have asserted that international investments can provide preferential growth options embedded in host countries (Kogut and Chang, 1996; Kogut and Kulatilaka, 1994a; Kogut, 1991; Tong et al., 2008; Kulatilaka and Perotti, 1998). Multinational enterprises or corporations reap profits from growth options by limiting their initial investment in a foreign market and exercise the options by subsequent investments with the receding uncertainty (Fisch, 2008).

In general, a high level of exogenous uncertainty would impose on a multinational firm a high degree of foreign investment risk, which makes it economized to start with a smaller amount of equity shares and adopt "wait and see" strategy to see how the uncertainty resolves (Folta, 1998). On the one hand, if the result turns advantageous, the firm can scale up by further increasing investment or even acquiring a target firm or equity shares from joint venture partner(s). On the other hand, if the condition does not turn out to be originally envisioned, the firm can scale down its commitment or even exit the market.

As the primary source of exogenous uncertainty, country risk contains economic, financial, and political risk (Gatignon and Anderson, 1988; Barkema and Vermeulen, 1998; Pan, 1996; Zhao et al., 2004; Cuypers and Martin, 2006). Among different types of exogenous uncertainty, growth options are highly associated with market or demand uncertainty. Kester (1984) suggests that growth options are created by investment in uncertain markets. In line with it, Campa (1994) investigates the impact of demand uncertainty on decisions to expand capacity in a host country. Moreover, Folta and O'Brien (2004) discover the positive relationship between market uncertainty and the valuation of growth option. Empirical evidence has also demonstrated the view of value creation of growth options in firms investing affiliates in multiple countries under high market uncertainty (Belderbos et al., 2019; Tong et al., 2008). In a portfolio of growth/contraction options, the options may be mutually exclusive (Anand et al., 2007) or substitutable. As suggested by Chi, Li, Trigeorgis, and Tsekrekos (2019), switch option entails "the option to scale down one operation and the option to scale up another" simultaneously, Thus, a collection of competing and related growth/contraction or scaling options are highly associated with switch options. Switch options embrace the complexity of managing the call and put options simultaneously as well and have been largely explored with the exchange rate uncertainty by researchers (e.g. Dasu and Li, 1997; Rangan, 1998; Belderbos and Zou, 2009; Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Oriani, 2007; Sakhartov and Folta, 2014). However, based on the relationship between switch options and scaling options, this paper shows that market uncertainty can be a condition that makes switching options valuable in the presence of capacity constraints, even if there is no uncertainty about product costs or exchange rates across countries.

As it has long been recognized that multinational firms that expand in a contingent fashion to avoid a large upfront investment and take advantage of future growth opportunities gain a competitive advantage (Kulatilaka and Perotti, 1998; Hayes and Garvin, 1982), there has been a growing body of literature that study growth options under market uncertainty. They mainly begin with the premise that either foreign affiliates have already been built up (Bartlett and Ghoshal, 1989; Doz and Prahalad, 1991; Hedlund, 1986) or an already existing subsidiary take places to test the environment of a target country (Reuer and Tong, 2005). Even though real options logic follows a path dependent manner (Rangan, 1998; Kogut and Kulatilaka, 1994b), too much attention has been devoted to understand a multinational firm's incremental entry process into a particular host country in the presence of market or demand uncertainty. Instead of an atomic view, in Model 2, I employ a network approach to study the effect of multinational firms' demand volatilities on potential growth opportunities and switch flexibility. In this way, this paper sheds new light on the understanding of multinational firms' dynamic adjustments in manufacturing activities through lens of real options theory.

2.4 Literature Review under Both Uncertainties

Among different types of exogenous uncertainty, growth options are highly associated with market or demand uncertainty that empirical evidence has demonstrated the view of value creation of growth options in firms investing affiliates in multiple countries under high market uncertainty (Belderbos et al., 2019; Tong et al., 2008), while a large body of research have theoretically and empirically explored the connection between switch options and exchange rate uncertainty. For instance, Dasu and Li (1997) model when and how much to alter production quantities when firms face exchange rate variability. Moreover, research has found to support the notion that under exchange rate uncertainty, firms indeed switch production outputs or sourcing inputs across facilities located in different countries (Rangan, 1998; Belderbos and Zou, 2009), and operational flexibility enhances firms' values (e.g., Allen and Pantzalis, 1996; Tang and

Tikoo, 1999; Oriani, 2007; Sakhartov and Folta, 2014). Thus, the current literature has only examined switch options and growth/contraction options under distinct sources of uncertainty.

However, a collection of competing and related growth/contraction options should be highly associated with switch options that embrace the complexity of managing the call and put options simultaneously. In line with it, operational flexibility confers upon managers the ability to shift the production possibility frontier outward, which increases expected future cash flows, and thus growth (Mello et al., 1995). Therefore, based on the connection between those options, I propose that both switch and growth/contraction options can be subject to the same type of uncertainty under certain circumstances. Little attention, however, has been devoted to evaluating the influence of product cost volatility on the valuation of growth options or market fluctuation on switch option value. One major contribution of this dissertation is to bring precision into the current understanding of real options logic by addressing the impact of production cost or demand uncertainty on both switch options and growth/contraction options.

Firms generally hold a portfolio of strategic or operating options or flexibility capabilities that provide firms the right but not the obligation to benefit from upside opportunities and mitigates its downside risk (Trigeorgis, 1996; Driouchi and Bennett, 2012). Instead of an atomic view, I propose a holistic view to examine how a multinational firm’s manufacturing network in the global supply chain context (Connelly et al., 2013) that confers possible growth opportunities or switch flexibility in the face of demand and cost uncertainties helps keep the firm operate both efficiently and flexibly in multiple host country environments. In model 3, I adopt a three stochastic variable model to examine how a firm’s international activities are shaped in the perspective of portfolios of growth/contraction options and switch options with different types of exogenous uncertainties across countries and how the valuation of portfolios changes with production cost correlations, market demand correlations, switching/coordination costs, and capacity constraint.

A large number of studies applying real options perspective in business strategy tend to have their focus on either firm-level or industry-level analysis (e.g., Kester, 1984; Tong and Reuer, 2006; Trigeorgis, 1996). Tong, Alessandri, Reuer, and Chintakananda (2008) stress the importance of country-to-country differences in productive inputs and technologies, consistent with the theory of comparative advantages that contribute to explain international trade and the globalization of production (e.g., Krugman and Obstfeld, 1997). As production cost or demand movements are out of a multinational firm's control and subject to macroeconomic circumstances both domestically and internationally in countries where affiliates are located, one of the motivations of this dissertation work is to examine the adaptive capabilities of organizations on the exploitation of options in various nations, which would in turn contribute to sources of competitive advantage and firm heterogeneity as fundamental issues in strategy research (Trigeorigis and Reuer 2017).

A large number of compelling theoretical work has explained international activities of multinational enterprises. Consistent with Transaction Cost Economics, scholar have regarded multinational firms as internal methods of transactions (Teece, 1981) and suggested that the internalization process is undertaken up to the point where benefits are equal to costs (Buckley and Casson, 1976). For instance, with the existence of market imperfections for various types of knowledge, multinational firms are better in coordinating interdependent R&D activities across nations. On the other hand, behavioral theory posits that due to the lack of information in foreign markets (Hymer, 1960), Johanson and Vahlne (1977) propose a graduate or incremental increase in internationalization with learning in each step during the process. However, the Uppsala model emphasize the relationship between a focal firm and a focal location. In addition, in the language of real options theory, this internationalization process focuses on growth/contraction or scaling (up or down) options within a country. This paper extends the application of their theory to include switch options across nations, and thus considers portfolios of locations. Another major contribution of this work is by employing real options logic to add another layer on the understanding of multinational firms' international activities besides Internalization theory (Buckley and Casson, 1976) and Internationalization theory (Johanson and Vahlne, 1977).

3 Model Specification

3.1 Model Specification

For simplicity, the model focuses on a firm's two potential affiliates in country A or B, or $i = A, B$. There exist four starting modes with the two subsidiaries, mode 0: investing no plant in either country; mode 1: building up a production facility only in country A; mode 2: building up a production facility only in country B; mode 3: building up a production facility in each of the two countries A and B. I assume that a firm chooses to start its manufacturing configuration in one of the four modes and has the ability to dynamically adjust its production loadings in each country accordingly in the future in order to maximize the net present value from backward induction. In a dynamic programming approach, backward induction is the process of reasoning backwards in time, from the end of a problem or situation, to determine a sequence of optimal actions. Moreover, suppose a configuration decision is made at the beginning of each period T_t, where $t = 1,2,3$.

Suppose country C as a reference country has the most stable currency. $c_{A,t}$ or $c_{B,t}$ represents variable production costs per unit that encompass labor costs in country A or B respectively at time t. Both $c_{A,t}$ and $c_{B,t}$ have been adjusted using the nominal exchange rate between country A or B and C, and thus $\frac{c_{B,t}}{c_{A,t}}$ highlights the real exchange rate (Kogut and Kulatilaka, 1994) at time t.

I assume an affine demand function,

$$q_{i,t} = m * v_{i,t} - k * p_{i,t}$$

Where both k and m are constants; $q_{i,t}$ is the demand in the country i at time t; $p_{i,t}$ is the unit price of the output in country i. $v_{i,t}$ reflects a country's demand for products. $m * v_{i,t}$ represents the maximum demand when the price $p_{i,t}$ is zero.

In line with Chi and Seth's (2009) work, I define a general functional form for each plant's profit,

$$\pi_{i,t} = q_{i,t}(p_{i,t} - c_{i,t}) + q_{i',t}(p_{i',t} - c_{i,t} - h_{i,t}) - j_{i,t}(q_{i,t} + q_{i',t})^2 - F$$

Where $q_{i,t}$ is the demand in the country i at time t while $q_{i',t}$ is the demand in the country other than i. Consistently, $p_{i,t}$ is the unit price of the output in country i, while $p_{i',t}$ is the unit price of the output in the country other than i. $c_{i,t}$ is the production unit cost if the manufacturing facility in the country i is in place. $h_{i,t}$ represents transportation cost per unit incurred if products are produced in country i but transported to the other country to satisfy its (partial) demand. I further assume that the transportation costs from country A to B and from country B to A are the same and keep constant over periods. $j_{i,t}$ is used to take into consideration the capacity constraint of manufacturing plants and means capacity cost per unit in country i's production plant. By the same token, I presume that capacity cost per unit in country A and B has no difference and keep the same along the time. Then the profit function can be simplified to,

$$\pi_{i,t} = q_{i,t}(p_{i,t} - c_{i,t}) + q_{i',t}(p_{i',t} - c_{i,t} - h) - j(q_{i,t} + q_{i',t})^2 - F$$

I also apply a quadratic format of quantities on the capacity cost, as not only it is consistent with the reality that the capacity of a factory becomes more constrained when it produces more, but also it results in the fact that both average total costs or average variable costs will first decrease a bit and then increase with diminishing marginal benefits. F shows fixed costs including annual debt or utility costs, when the factory is in place over time.

In mode 0 that no factories in neither county, the profit is zero. In mode 1 that a manufacturing facility is in country A, the gains have two parts: produce and sell in country A, and produce and sell in country B, the specific function is,

$$\pi 1_t = q_{A,t}\left(p_{A,t} - c_{A,t}\right) + q_{B,t}\left(p_{B,t} - c_{A,t} - h\right) - j(q_{A,t} + q_{B,t})^2 - F$$

Similarly, in the case of an affiliate in country B (mode 2), the profits at time t is as follows,

$$\pi 2_t = q_{B,t}\left(p_{B,t} - c_{B,t}\right) + q_{A,t}\left(p_{A,t} - c_{B,t} - h\right) - j(q_{B,t} + q_{A,t})^2 - F$$

When a production plant exists in each country (mode 3), the case is complicated, as the production in country A may satisfy a part of its domestic demand, rest of which can be provided from country B's production facility, and maybe transported to country B to meet fully or partially its needs even country B has its factory. Thus, the potential earnings from mode 3 at time t are expressed as,

$$\pi 3_t = \lambda_A q_{A,t}\left(p_{A,t} - c_{A,t}\right) + (1 - \lambda_A) q_{A,t}\left(p_{A,t} - c_{B,t} - h\right) + \lambda_B q_{B,t}\left(p_{B,t} - c_{B,t}\right) + (1 - \lambda_B) q_{B,t}\left(p_{B,t} - c_{A,t} - h\right) - j(\left(\lambda_A q_{A,t} + (1 - \lambda_B) q_{B,t}\right)^2 + ((1 - \lambda_A) q_{A,t} + \lambda_B q_{B,t})^2) - 2F$$

Where λ_i represents the percentage of domestic demand in country i that is produced by local production plant, while $1 - \lambda_i$ shows the percentage of the domestic market in the country i is served by the other country's facility.

Suppose the setup fee of an affiliate in either country is I, and if the firm decides to abandon the factory in one country, the cost is the loss of the initial investment I. In the purpose of calculation consistency, costs are incurred, and earnings are realized at the end of each period. If at the beginning of any period the firm's affiliate configuration is mode 1 with a production plant only in country A, the net present value at any time t can be defined as,

$$J0_t = \max\left(0 + E(J0_{t+\Delta t})e^{-r(\Delta t)}, \pi 1_t + E(J1_{t+\Delta t})e^{-r(\Delta t)}, \pi 2_t + E(J2_{t+\Delta t})e^{-r(\Delta t)}, \pi 3_t + E(J3_{t+\Delta t})e^{-r(\Delta t)}\right)$$

Where $J1_t, J2_t$, or $J3_t$ is net present value if starting with mode 1, 2, or 3 at the beginning of time t, and $E(J0_{t+\Delta t})$, $E(J1_{t+\Delta t})$, $E(J2_{t+\Delta t})$, or $E(J3_{t+\Delta t})$ represents the maximized net present value at time $t + \Delta t$ for starting mode 0, 1, 2, or 3, respectively. r is the annulized instantaneous interest rate for the discount.

Similarly, the net present value with starting mode 1, 2, or 3 at the beginning of time t is,

$$J1_t = \max\left(-I + E(J0_{t+\Delta t})e^{-r(\Delta t)}, \pi 1_t + E(J1_{t+\Delta t})e^{-r(\Delta t)}, \pi 2_t + E(J2_{t+\Delta t})e^{-r(\Delta t)} - I, \pi 3_t + E(J3_{t+\Delta t})e^{-r(\Delta t)}\right)$$

$$J2_t = \max\left(-I + E(J0_{t+\Delta t})e^{-r(\Delta t)}, \pi 1_t + E(J1_{t+\Delta t})e^{-r(\Delta t)} - I, \pi 2_t + E(J2_{t+\Delta t})e^{-r(\Delta t)}, \pi 3_t + E(J3_{t+\Delta t})e^{-r(\Delta t)}\right)$$

$$J3_t = \max\left(-2I + E(J0_{t+\Delta t})e^{-r(\Delta t)}, \pi 1_t + E(J1_{t+\Delta t})e^{-r(\Delta t)} - I, \pi 2_t + E(J2_{t+\Delta t})e^{-r(\Delta t)} - I, \pi 3_t + E(J3_{t+\Delta t})e^{-r(\Delta t)}\right)$$

Based on the above definitions, the net present value of the firm's plant configuration potentially located in country A or/and B at its very beginning is,

$$J = \max(J0_1, J1_1, J2_1, J3_1) * e^{-r}$$

At the same time, the optimal starting mode at the very beginning can be calculated from the model. Furthermore, as suggested by Chi, Li, Trigeorgis, and Tsekrekos (2019) that switch option encompasses “the option to scale down one operation and the option to scale up another” simultaneously, which can be confounded by scaling up or down options, I closely monitor the optimal production quantities in each mode and production exchange between countries, and further compare them with loadings in the previous time period to differentiate the effect of growth/contraction option from switch option. Therefore, the existence of switch option can be confusing. For instance, a decrease of production in country A and an increase of production in country B does not guarantee a switch option unless there exists a change in production exchange between the two countries. Both a change to a different mode and an adjustment in the currently occupied mode would spawn different types of interacted and correlated options. For instance, a change from mode 0 to either mode 1, 2, or 3 is to scale up or grow, or on the other hand, an alteration from mode 1, 2, or 3 to mode 0 is to scale down or even exit. However, to avoid the complexity of exiting (or potentially reentering) a market, in this model, I eliminate the possibility for a firm to exit an existing country. A modification of the plant configuration from mode 1 to mode 2 or vice versa ascertains a shift of production loadings in the two countries. However, an alteration of production loadings in the current mode does not necessarily mean a stand-alone scaling activity. For instance, when the firm possesses plant affiliates in both countries A and B, the opposite loading adjustments in two plants would lead to a shift in production.

The static net present value from deterministic scaling or/and switch is predetermined and would not change with the level of uncertainty. Thus, it is possible to isolate the option values and the static net present values from the total net present values. Since switch options embody scaling up options (growth options) and scaling down (contraction) options, it is inapplicable to extract the value of switch options from the option values by controlling for scaling up and scaling down. The value of growth/contraction options, however, can be calculated by controlling for switching with high transportation costs h. Thus, the value of switch options and the interaction of switch options and growth/contraction options are left out. Switch options cannot be separated from the option to grow and the option to scale down. If there is no growth option, there is no switch option. Therefore, the switch option contains the interaction of the growth/contraction option and the switch option. Due to the unique feature of switch option as a hybrid option that embraces both growth and contraction options, the value of the switch option is not a sheer stand-alone option value but indicates the interaction of the three options. However, if there is no switch option, the growth/contraction option can still exist. Based on the above discussion, the decomposition of net present value (NPV) is shown below.

NPV= static NPV+ the value of growth and contraction options+ the value of switch options

Where the static NPV involves the value from deterministic growth/contraction and switch. From the model, I propose that the value of switch options represents the marginal switching opportunities under uncertainty compared to the case when there is no uncertainty. To better understand the relationship between switch option value and uncertainty, I assume that expected annualized production costs and expected annualized market demands in the two countries A and B are the same. To better understand the impact of cost or demand uncertainty on the value of portfolios of option, I develop 3 different stochastic models. Model 1 considers production cost uncertainty, Model 2 studies market demand uncertainty, Model 3 examines both types of uncertainties.

3.2 Model 1 with Production Cost Uncertainty

The consideration of uncertainty in both c_A and c_B decomposes the uncertainty in the real exchange rate $\frac{c_B}{c_A}$ and adopts a dyadic look into the real exchange rate uncertainty. The correlation between c_A and c_B is ρ that satisfied the condition that $-1 \leq \rho \leq 1$, where when $\rho = 1$, cost developments in country A and B are to the same extent subject to an exogenous shock, for instance, Asian countries experienced currency depreciation that would result in lower labor costs during Asian financial crisis, while as $\rho = 0$, domestic shock within each country might be the primary driver of cost differentiation in country A and B. Based on a method proposed by Kamrad and Ritchken (1991) and extendedly applied by Chi and his colleagues (Chi, 2000; Chi and McGuire, 1996; Chi and Seth, 2009), I model the evolution of production costs in the two countries, c_A and c_B as geometric stochastic variables with the correlation coefficient to be ρ that follow the below equations,

$$lnc_A(t + \Delta t) = lnc_A(t + \Delta t) * \xi_A(t)$$

$$lnc_B(t + \Delta t) = lnc_B(t + \Delta t) * \xi_B(t)$$

Where $\xi_A(t)$ or $\xi_B(t)$ is a normal random variable with mean $\mu_A \Delta t$ and variance $\sigma_A^2 \Delta t$, or with mean $\mu_B \Delta t$ and variance $\sigma_B^2 \Delta t$ respectively.

The transformation of the two continuous stochastic processes with the correlation ρ into discrete-time variables at each time interval Δt represents a joint 5-jump probability distribution below:

Outcome	Both up	A up/B down	No change	A down/ B up	Both down
$c_{A,t+\Delta t}$	$c_{A,t} * u_A$	$c_{A,t} * u_A$	$c_{A,t}$	$c_{A,t}/u_A$	$c_{A,t}/u_A$
$c_{B,t+\Delta t}$	$c_{B,t} * u_B$	$c_{B,t}/u_B$	$c_{B,t}$	$c_{B,t} * u_B$	$c_{B,t}/u_B$
Probability	p_{UU}	p_{UD}	p_{HH}	p_{DU}	p_{DD}

Where $u_A > 1$ and $u_B > 1$ and u_i is denoted to the "jump" that captures the potential downward and upward movements in c_i in a given time of period. In this regard, in any time interval, each affiliate's cost per unit either jumps up to $c_{i,t} * u_i$, stays the same or jumps down by a factor to $\frac{c_{i,t}}{u_i}$. The joint change of production costs in the two countries have five possibilities: both countries' costs move up by a factor u_i with probability p_{UU}; cost in country A moves up by a factor u_A and cost in country B moved down by a factor $\frac{1}{u_B}$ with probability p_{UD}; both countries' costs keep the same with probability p_{HH}; cost in country B moves up by a factor u_B and cost in country A moved down by a factor $\frac{1}{u_A}$ with probability p_{DU}; both countries' costs move down by a factor $\frac{1}{u_i}$ with probability p_{DD}. I specify $u_i = \exp\,(\kappa * \sigma_i * \Delta t)$ consistent with Kamrand and Ritchken (1991), and κ that works as a "stretch parameter" in jumps is set to be 1 for simplicity. Accordingly, the expected annualized rate of change in u_i over Δt is,

$$\exp\,(\mu_i \Delta t + \frac{\sigma_i^2 \Delta t}{2})$$

which captures the expected rate of change in production costs per unit in the two countries.

3.3 Model 2 under Market Uncertainty

The consideration of uncertainty in both v_A and v_B adopts a dyadic look into market demand uncertainty in the two countries. Similarly, the correlation between v_A and v_B is ρ that satisfied the condition that $-1 \leq \rho \leq 1$. In Model 2, I model the evolution of market demands in the two countries, v_A and v_B as geometric stochastic variables with the correlation coefficient to be ρ that follow the below equations,

$$lnv_A(t + \Delta t) = lnv_A(t + \Delta t) + \xi_A(t)$$

$$lnv_B(t + \Delta t) = lnv_B(t + \Delta t) + \xi_B(t)$$

Where $\xi_A(t)$ or $\xi_B(t)$ is a normal random variable with mean $\mu_A \Delta t$ and variance $\sigma_A^2 \Delta t$, or with mean $\mu_B \Delta t$ and variance $\sigma_B^2 \Delta t$ respectively.

The transformation of the two continuous stochastic processes with the correlation ρ into discrete-time variables at each time interval Δt represents a joint 5-jump probability distribution below:

Outcome	Both up	A up/B down	No change	A down/ B up	Both down
$v_{A,t+\Delta t}$	$v_{A,t} * u_A$	$v_{A,t} * u_A$	$v_{A,t}$	$v_{A,t}/u_A$	$v_{A,t}/u_A$
$v_{B,t+\Delta t}$	$v_{B,t} * u_B$	$v_{B,t}/u_B$	$v_{B,t}$	$v_{B,t} * u_B$	$v_{B,t}/u_B$
Probability	p_{UU}	p_{UD}	p_{HH}	p_{DU}	p_{DD}

Where $u_A > 1$ and $u_B > 1$ and u_i is denoted to the "jump" that captures the potential downward and upward movements in c_i in a given time of period. In this regard, in any time interval, each affiliate's demand per unit either jumps up to $v_{i,t} * u_i$, stays the same or jumps down by a factor to $\frac{v_{i,t}}{u_i}$. The joint change of demands in the two countries have five possibilities: both countries' demands move up by a factor u_i with probability p_{UU}; demand in country A moves up by a factor u_A and demand in country B moved down by a factor $\frac{1}{u_B}$ with probability p_{UD}; both countries' demands keep the same with probability p_{HH}; demand in country B moves up by a factor u_B and demand in country A moved down by a factor $\frac{1}{u_A}$ with probability p_{DU}; both countries' demands move down by a factor $\frac{1}{u_i}$ with probability p_{DD}. Similarly, the expected annualized rate of change in u_i over Δt is,

$$\exp\,(\mu_i \Delta t + \frac{\sigma_i^2 \Delta t}{2})$$

which captures the expected rate of change in market demands in the two countries.

3.4 Model 3 under Both Uncertainties

Instead of two stochastic process variables that are commonly used in strategy research, I adopt a three stochastic variable model to consider the impact of both production cost and demand uncertainties simultaneously on the valuation of switch options and growth/contraction options. However, to reduce the complexity of the simulation of four stochastic developments simultaneously (fluctuated production costs in country A or B, and fluctuated demands in country A or B, or $c_{A,t}$, $c_{B,t}$, $v_{A,t}$, and $v_{B,t}$), Model 3 is simplified to consider three stochastic developments in two scenarios.

In scenario A, I consider volatilities in the two countries' demand developments (v_A and v_B) and in country B's production cost development (c_B), and assume that production cost in country A is a constant ($c_{A,t} = 1$). The correlation between v_A and v_B is ρ_1 that satisfied the condition that $-1 \leq \rho_1 \leq 1$, where when $\rho_1 = 1$, demand developments in country A and B are to the same extent subject to an exogenous shock, while as $\rho_1 = 0$, domestic shock within each country might be the primary driver of demand differentiation in country A and B. Similarly, the correlation between v_A and c_B is ρ_2, and the correlation between v_B and c_B is ρ_3. I model the evolution of market demands in the two countries and production cost in country B, v_A, v_B and c_B as geometric stochastic variables with the correlation coefficient to be ρ_1, ρ_2, and ρ_3 that follow the below equations,

$$lnv_A(t + \Delta t) = lnv_A(t + \Delta t) + \xi_A(t)$$

$$lnv_B(t + \Delta t) = lnv_B(t + \Delta t) + \xi_B(t)$$

$$lnc_B(t + \Delta t) = lnc_B(t + \Delta t) + \xi_C(t)$$

Where $\xi_A(t)$, $\xi_B(t)$, or $\xi_C(t)$ is a normal random variable with mean $\mu_A \Delta t$ and variance $\sigma_A^2 \Delta t$, with mean $\mu_B \Delta t$ and variance $\sigma_B^2 \Delta t$, or with mean $\mu_C \Delta t$ and variance $\sigma_C^2 \Delta t$ respectively.

The transformation of the three continuous stochastic processes with the correlation correlation $\rho_1, \rho_2,$ and ρ_3 into discrete-time variables at each time interval Δt represents a joint 9-jump probability distribution below:

Outcome	All up	up up down	up down up	up down down	No change	down up up	down up down	down down up	All down
$v_{A,t+\Delta t}$	$v_{A,t} * u_A$	$v_{A,t} * u_A$	$v_{A,t} * u_A$	$v_{A,t} * u_A$	$v_{A,t}$	$v_{A,t}/u_A$	$v_{A,t}/u_A$	$v_{A,t}/u_A$	$v_{A,t}/u_A$
$v_{B,t+\Delta t}$	$v_{B,t} * u_B$	$v_{B,t} * u_B$	$v_{B,t}/u_B$	$v_{B,t}/u_B$	$v_{B,t}$	$v_{B,t} * u_B$	$v_{B,t} * u_B$	$v_{B,t}/u_B$	$v_{B,t}/u_B$
$c_{B,t+\Delta t}$	$c_{B,t} * u_C$	$c_{B,t}/u_C$	$c_{B,t} * u_C$	$c_{B,t}/u_C$	$c_{B,t}$	$c_{B,t} * u_C$	$c_{B,t}/u_C$	$c_{B,t} * u_C$	$c_{B,t}/u_C$
Probability	p_{UUU}	p_{UUD}	p_{UDU}	p_{UDD}	p_{HHH}	p_{DUU}	p_{DUD}	p_{DDU}	p_{DDD}

Where $u_A > 1$, $u_B > 1$, and $u_C > 1$ and u_i is denoted to the "jump" that captures the potential downward and upward movements in v_A, v_B, and c_B respectively in a given time of period. In this regard, in any time interval, each affiliate's demand per unit either jumps up to $v_{i,t} * u_i$, stays the same or jumps down by a factor to $\frac{v_{i,t}}{u_i}$, and country B's production cost either jumps up to $c_{B,t} * u_C$, stays the same or jumps down by a factor to $\frac{c_{B,t}}{u_C}$. The joint change of these three stochastic variables have nine possibilities: all move up by a factor u_i with probability p_{UUU}; demands in both countries move up by a factor u_A and u_B, and cost in country B moves down by a factor $\frac{1}{u_C}$ with probability p_{UUD}; demand in country A moves up by a factor u_A, while demand in country B moves down by a factor of $\frac{1}{u_B}$, and cost in country B moves up by a factor u_c with probability p_{UDU}; demand in country A moves up by a factor u_A, while demand in country B moves down by a factor of $\frac{1}{u_B}$, and cost in country B moves down by a factor $\frac{1}{u_C}$ with probability p_{UDD}; both countries' demands and the production cost in country B keep the same with probability p_{HHH}; demand in country B moves up by a factor u_B, while demand in country A moves down by a factor of $\frac{1}{u_A}$, and cost in country B moves up by a factor u_c with probability p_{DUU}; demand in country B moves up by a factor u_B, while demand in country A moves down by a factor of $\frac{1}{u_A}$, and cost in country B moves down by a factor $\frac{1}{u_C}$ with probability p_{DUD}; both countries' demands move down by a factor $\frac{1}{u_i}$ and cost in country B moves up by a factor u_c with probability p_{DDU}; all move down by a factor $\frac{1}{u_i}$ with probability p_{DDD}. Again, expected annualized rate of change in u_i over Δt is,

$$\exp\left(\mu_i \Delta t + \frac{\sigma_i^2 \Delta t}{2}\right)$$

which captures the expected rate of change in demands in the two countries and production cost in country B.

In scenario B, I consider volatilities in the two countries' production cost developments (two stochastic variables) and in both countries' demand development (one stochastic variable). I assume that demands in both countries follow the same stochastic process. The correlation between c_A and c_B is ρ_1 that satisfies the condition that $-1 \leq \rho_1 \leq 1$, where when $\rho_1 = 1$, cost developments in country A and B are to the same extent subject to an exogenous shock, while as $\rho_1 = 0$, domestic shock within each country might be the primary driver of cost differentiation in country A and B. Similarly, the correlation between v_i and c_A is ρ_2, and the correlation between v_i and c_B is ρ_3. I model the evolution of production costs, c_A and c_B, and market demands, v_i, in the two countries as geometric stochastic variables with the correlation coefficient to be ρ_1, ρ_2, and ρ_3 that follow the below equations,

$$lnc_A(t + \Delta t) = lnc_A(t + \Delta t) + \xi_A(t)$$

$$lnc_B(t + \Delta t) = lnc_B(t + \Delta t) + \xi_B(t)$$

$$lnv_i(t + \Delta t) = lnv_i(t + \Delta t) + \xi_C(t)$$

Where $\xi_A(t)$, $\xi_B(t)$, or $\xi_C(t)$ is a normal random variable with mean $\mu_A \Delta t$ and variance $\sigma_A^2 \Delta t$, with mean $\mu_B \Delta t$ and variance $\sigma_B^2 \Delta t$, or with mean $\mu_C \Delta t$ and variance $\sigma_C^2 \Delta t$ respectively.

The transformation of the three continuous stochastic processes with the correlation ρ_1, ρ_2, and ρ_3 into discrete-time variables at each time interval Δt represents a joint 9-jump probability distribution below:

Outcome	All up	up up down	up down up	up down down	No change	down up up	down up down	down down up	All down
$c_{A,t+\Delta t}$	$c_{A,t} * u_A$	$c_{A,t} * u_A$	$c_{A,t} * u_A$	$c_{A,t} * u_A$	$c_{A,t}$	$c_{A,t}/u_A$	$c_{A,t}/u_A$	$c_{A,t}/u_A$	$c_{A,t}/u_A$
$c_{B,t+\Delta t}$	$c_{B,t} * u_B$	$c_{B,t} * u_B$	$c_{B,t}/u_B$	$c_{B,t}/u_B$	$c_{B,t}$	$c_{B,t} * u_B$	$c_{B,t} * u_B$	$c_{B,t}/u_B$	$c_{B,t}/u_B$
$v_{i,t+\Delta t}$	$v_{i,t} * u_C$	$v_{i,t}/u_C$	$v_{i,t} * u_C$	$v_{i,t}/u_C$	$v_{i,t}$	$v_{i,t} * u_C$	$v_{i,t}/u_C$	$v_{i,t} * u_C$	$v_{i,t}/u_C$
Probability	p_{UUU}	p_{UUD}	p_{UDU}	p_{UDD}	p_{HHH}	p_{DUU}	p_{DUD}	p_{DDU}	p_{DDD}

Where $u_A > 1$, $u_B > 1$, and $u_C > 1$ and u_i is denoted to the "jump" that captures the potential downward and upward movements in c_A, c_B, and v_i respectively in a given time of period. In this regard, in any time interval, each affiliate's cost per unit either jumps up to $c_{i,t} * u_i$, stays the same or jumps down by a factor to $\frac{c_{i,t}}{u_i}$, and demand in both countries either jumps up to $v_{i,t} * u_C$, stays the same or jumps down by a factor to $\frac{v_{i,t}}{u_C}$ $(v_{A,t} = v_{B,t})$. The joint change of these three stochastic variables have nine possibilities: all move up by a factor u_i with probability p_{UUU}; costs in both countries move up by a factor u_A and u_B, and demands in both countries move down by a factor $\frac{1}{u_C}$ with probability p_{UUD}; cost in country A moves up by a factor u_A, while cost in country B moves down by a factor of $\frac{1}{u_B}$, and demands move up by a factor u_c with probability p_{UDU}; cost in country A moves up by a factor u_A, while cost in country B moves down by a factor of $\frac{1}{u_B}$, and demands move down by a factor $\frac{1}{u_C}$ with probability p_{UDD}; both countries' demands and the production costs keep the same with probability p_{HHH}; cost in country B moves up by a factor u_B, while cost in country A moves down by a factor of $\frac{1}{u_A}$, and demands move up by a factor u_c with probability p_{DUU}; cost in country B moves up by a factor

u_B, while cost in country A moves down by a factor of $\frac{1}{u_A}$, and demands move down by a factor $\frac{1}{u_C}$ with probability p_{DUD}; both countries' costs move down by a factor $\frac{1}{u_i}$ but demands move up by a factor u_c with probability p_{DDU}; all move down by a factor $\frac{1}{u_i}$ with probability p_{DDD}. The expected annualized rate of change in u_i over Δt is,

$$\exp\left(\mu_i \Delta t + \frac{\sigma_i^2 \Delta t}{2}\right)$$

which captures the expected rate of change in demands and production costs in the two countries.

4 Results

4.1 Results from Model 1

Empirical evidence has demonstrated the view of value creation of growth options in firms investing affiliates in multiple countries under high market uncertainty (Belderbos et al., 2018; Tong et al., 2008). However, I discover that potential growth and contraction options can be attained via operational or strategic flexibility embedded in a firm's manufacturing network in case of diverging production cost developments. When the production cost developments in the two countries are subject to the same level of uncertainty with positive correlation, fluctuations in production costs in the two countries may affect optimal quantities produced in each mode and thus affect the growth or contraction options. Unlike a large number of studies on the topic of options that have neglected the impact of labor cost or exchange rate movements on the growth or the contraction of affiliates within a multinational firm's manufacturing network, I argue that production cost uncertainty can have an impact on the growth/contraction option when no switch is allowed as shown in Figure 1.1. Furthermore, the value of the growth/contraction option is an increasing function of uncertainty that exhibits asymptotic behavior. The asymptotic behavior might be due to the limitation of each affiliate plant in production or capacity constraint with extreme demand. Even though the interaction between the growth option and the contraction option can affect whether the firm will exploit the growth or contraction option to the fullest extent, growth option and contraction option act independently in the absence of switch when production costs in the two countries are positively correlated. Therefore, the correlation of production costs intuitively having an emphasis on the shift of production within the network, however, would not affect the value of growth option when controlling for switching. Therefore, I propose that besides market uncertainty, production cost uncertainty that originates from domestic and international market can also influence the value of growth and contraction options.

Proposition 1: The value of growth and contraction option is an increasing function of production cost uncertainty that exhibits asymptotic behavior.

As production costs are perfectly correlated, or switching costs are prohibitively expensive, there exists no switch at all, and thus the NPV contains only the value of the growth option and the value of the contraction option. Moreover, if the level of compacity constraint is high, each country would satisfy its own demand rather than fulfill the other country's needs, and thus the switch is less likely to take place. Figure 1.2 shows how the value of switch options (y axis) changes with the production cost uncertainty (x axis) in the different levels of production cost correlation and capacity constraint between the two countries. Rho represents the production cost correlation while j means the capacity cost. In the graph, the solid line shows the optimal starting mode is to build up a factory in either country, while the dotted line means it is optimal to start with setting up affiliates in both countries. Figure 1.2 depicts that when production costs in the two countries are to some extent correlated, the value of switch option concavely increases with uncertainty. This finding is consistent with previous research that under exchange rate uncertainty, firms can be expected to switch production outputs or sourcing inputs across facilities located in different countries (Rangan, 1998; Belderbos and Zou, 2009; Chang et al., 2016) and operational flexibility enhances firms' values (e.g., Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Oriani, 2007; Sakhartov and Folta, 2014). An explanation of the concave shape at different levels of capacity constraint is the negative effect of production cost uncertainty on the interaction of switch options and growth/contraction options, which seems strengthened by the correlation of production costs as switching becomes less likely when the economic circumstances in the two countries are highly correlated. In this case, production cost uncertainty and correlation work to the same direction in defining the interaction value of switch options and growth/contraction options.

Proposition 2: When production costs in the two countries are to some extent correlated, the value of switch option concavely increases with the level of production cost uncertainty.

Proposition 3: Uncertainty can have a negative impact on the interaction of switch options and growth/contraction options. The correlation of production costs strengthens this negative relationship

To keep the stochastic distribution of production cost consistent, I calculate the values with no uncertainty with a trivial amount of fluctuation in production costs that ensures no options generated. When the uncertainty is trivial, or there is little uncertainty, as the average production costs are the same, the correlation does not change the net or static present value, growth value, and switch value, but capacity cost decreases these three values. In the presence of uncertainty, however, I discover that the correlation of production costs makes switching impossible and would result in a less valued switch option even considering the interaction term, which echoes well with exiting findings that in the context of multinational operations and switching options, correlations in labor costs among the countries in which the firm operates have been proposed as a significant source of redundancy (e.g., McGrath, 1997; Trigeorgis, 1996; Belderbos and Zou, 2009; Dasu and Li, 1997; de Meza and van der Ploeg, 1987**).** Moreover, net present value increases with the uncertainty of labor costs in both countries when the average production costs in the two countries are the same no matter how correlated their production costs are. Therefore, I propose the following,

Proposition 4: The more correlated their production costs in the two countries are, the lesser the net present value is, and the lesser the switch option value is.

Figure 1.3 illustrates how uncertainty influences the net present value (NPV) and the growth and contraction option value (GOV) under different combinations of production cost uncertainty, production cost correlation (rho in the graph), and capacity cost (j in the graph). It is intuitive to articulate that both net present value and the value of growth and contraction options decrease with capacity costs regardless of production costs correlations. However, the interactions of the switching option value with uncertainty, capacity constraint and production cost correlation are more complex. Figure 1.4-1.7 shows the variation in the value of switch option with different combinations of production cost correlation (rho in the graph), production cost uncertainty, and capacity constraint (j in the graph). More specifically, shown in Figure 1.4 when production costs are less correlated, the value of the switch option decreases with an increase in capacity cost. As the level of capacity constraint is high, it becomes more optimal to possess manufacturing plants in both countries and produce to serve domestic markets, which in turn would lead to less switching even without redundancy and thus a decrease in switch option value. As shown in Figure 1.7, the value of the switch option, however, has a S-shaped relationship with capacity costs (first drop, then increase, and last decrease) when production costs are highly correlated. Figure 1.5, 1.6 and 1.7 also illustrate that as production cost uncertainty increases, this S-shaped relationship becomes more salient. These figures also show that as production costs in the two countries are more correlated, the S-shaped relationship is strengthened with respect to the value range in different production cost correlations. With a more highly correlated production costs in the two countries, switching becomes less likely. Even though an increase in capacity cost would decrease both the value of switch options and growth/contraction options, the decreasing rates for the value of switch options and the value of growth/contraction options become more divergent as production cost uncertainty level is higher, which in turn affects the value of the interaction of switch options and growth/contraction options and thus the value of switch options. The S-shaped relationship captures the different influences of capacity cost and production cost development on switch options and growth/contraction options.

Proposition 5: When production costs are less correlated, the value of the switch option decreases with capacity costs.

Proposition 6: The value of the switch option has an S-shaped relationship with capacity costs when production costs are highly correlated. Production costs and production cost correlation uncertainty magnify this effect.

Figure 1.8 shows how the net present value (NPV), growth and contraction option value (GOV), and switch option value (SOV) change with uncertainty when production costs are negatively correlated with a constant capacity cost (j). Consistent with my previous finding that growth option and contraction option act independently in the absence of switch, the value of growth/contraction options after controlling for switching does not change with production cost correlation no matter if the correlation is negative or positive. However, the net present value and the switch option value increase as the production costs become more negatively correlated. Switch option values shown in Figure 1.2 and Figure 1.8 with the same level of capacity constraint represent that the values decrease as production costs become more positively correlated. Previous studies have focus on a positive relationship in production cost developments across nations but entangled a potential distinct impact from the negative relationship. Moreover, the imperfect correlation of uncertain production costs, either positive or negative, with the same average costs in the two countries offers an appropriate platform to straddle between risk diversification perspective and real options theory. When production costs in the two countries are imperfectly correlated and switch is prohibited, it is difficult to distinguish the value of risk diversification from the value of real options in the value of growth and contraction options. However, when switch is allowed, Campa (1994) contends that risk diversification is gained through risk pooling or diversification of manufacturing facilities in places with negatively correlated macroeconomic conditions. As represented in Figure 1.2 the value of switch option is all positive even when the production costs are highly and positively correlated in the absence of risk diversification portfolios, which leads to a strong belief in real options logic that switch options indeed exist due to production cost fluctuations and contribute to a firm's value. Here comes the next proposition,

Proposition 6: Switch option value increases as production costs are more negatively correlated.

I further discover that capacity cost would make mode 3 (having manufacturing facilities in both countries) a more attractive starting mode than mode 1 or 2 (having a facility in only one country), as it is better to produce and serve partially or fully domestic markets in the face of capacity constraint and transportation cost. The impact of capacity cost on the optimal starting mode is strengthened by production costs correlation, while uncertainty can mitigate the impact of capacity cost on the optimal starting mode. An explanation is that with high production cost correlation, switching yields a lower benefit, and the best mode is to produce and sell in its own market, which reinforces the impact of capacity cost on the optimal mode choice. However, extreme fluctuations in production costs can compensate the influence of capacity costs by obtaining gains from larger amount of production quantities due to favorable production cost.

Figure 1.9 depicts snapshots of the switch option value under different levels of uncertainty and correlations and their optimal starting mode. The horizontal axis in the graph shows the relative difference in cost uncertainty in the two countries. The dotted and dashed line shows the optimal starting mode with a production affiliate located in the country with higher level of uncertainty, the solid line represents the mode with a plant in the country with less degree of uncertainty, and the dotted line represents mode 3. When there is no capacity constraint or capacity cost is low, it is optimal to start with the country that has more uncertainty. With the increase of capacity cost, when uncertainty difference is small, it becomes better off to start with the country with less uncertainty, but when the difference is significant, the one with more uncertainty. When the capacity constraint level is high, it is optimal to start at the beginning with mode 3, when uncertainty is small. The optimal starting mode is chosen with consideration of three forces-production cost uncertainty, correlation and capacity cost, which seem work against one another. Among these three forces, capacity constraint would favor mode 3, as it would be optimal to serve domestic needs in both countries rather than satisfy both countries' needs or only one country's demand in either location (mode 1 or 2). Production cost uncertainty, however, that leads to extreme changes in optimal quantities produced would compensate the capacity cost and thus act against capacity constraint. Figure 1.10 illustrates the net present value (NPV), switch option value (SOV), and growth and contraction option value (GOV) when the level of production cost uncertainty in country A (sigmaA) keeps a constant (.1) but cost uncertainty in country B (sigmaB) varies from .01 to .5. It shows that GOV increases with the cost uncertainty in country B, while NPV and SOV first falls and then increase. The findings indicate that when the levels of production cost uncertainty in the two countries are not the same, the net present value and switch option value hinge on the relative level of uncertainty while growth and contraction option value depends on the absolute degree of uncertainty. On the one hand, growth and contraction options depend on the absolute level of cost fluctuation which affect optimal quantities produced in each plant. On the other hand, switch options hinge on the divergence of cost developments in two countries. For instance, if production costs in two countries increase to the same level, decrease in production quantities would lead to contraction, while there is no switch as the costs are still the same in the two countries. Moreover, I find that all values decrease with capacity costs. All previous discussions demonstrate the following proposition,

Proposition 7: A decision of an optimal starting mode is made by taking into consideration of capacity cost, production cost uncertainty, and correlation.

Proposition 8: the net present value and switch option value hinge on the relative level of uncertainty, while growth option value depends on the absolute degree of uncertainty.

4.2 Results from Model 2

Figure 2.1 to Figure 2.6 illustrate how the value of switch options (vertical axis) in a multinational firm changes with different combinations of product demand uncertainty (y-axis), manufacturing facility's capacity constraint or cost (j, x-axis), and market demand correlation in the two countries (rho). This paper assumes that levels of demand uncertainties in the two countries A and B are the same, and there is no difference in terms of capacity constraint for potential factories located in either country. Empirical evidence has demonstrated the view of value creation of growth options in firms investing affiliates in multiple countries under high market uncertainty (Belderbos et al., 2018; Tong et al., 2008). Switch options have been largely explored with the exchange rate uncertainty by researchers (e.g. Dasu and Li, 1997; Rangan, 1998; Belderbos and Zou, 2009; Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Oriani, 2007; Sakhartov and Folta, 2014). Scholars, thus, have strived to put a clear cut between growth option and switch options under distinct sources of uncertainty (Chung et al., 2010; Lee and Makhija, 2009; Song et al., 2014; Belderbos and Zou 2009).

However, Switch options embrace the complexity of managing the call and put options simultaneously (Chi et a., 2019), and growth/contraction options are compound options that consist of both the two options as well (Sharp, 1991; Bowman and Hurry, 1993; Chung et al., 2010; Jiang et al., 2009). Thus, I show that both growth/contraction options and switching options can arise from the same type of uncertainty, market uncertainty here. Furthermore, I propose that the necessary condition for a switch option to exist under market or demand uncertainty is the presence of capacity constraint of internationally dispersed manufacturing facilities possessed by a multinational firm. In the graphs 2.1-2.6, I observe that as the capacity cost is zero (j=0), the value of switch option stays at zero regardless of the level of uncertainty. Nevertheless, when there exists capacity constraint of factories around the world, the valuation of switch options fluctuates with demand uncertainties in countries where a multinational firm operates. Therefore, I argue that capacity constraint is a necessary condition for a switch option to exist under market or demand uncertainty.

Proposition 1: When there is no capacity constraint, switch option does not exist under market uncertainty.

Figure 2.6 shows the change of the valuation of growth/contraction options with market uncertainty and capacity cost. Scholars have asserted that international investments can provide preferential growth options embedded in host countries (Kogut and Chang, 1996; Kogut and Kulatilaka, 1994a; Kogut, 1991; Tong et al., 2008; Kulatilaka and Perotti, 1998). I discover that demand correlations in two countries would not affect growth/contraction option value. This finding is consistent with the current literature that have examined the connection between the value of incremental flexibility and macroeconomic fluctuations in a particular country for multinational companies. For instance, if a multinational firm operates its business in multiple countries, as demand correlations in those countries would not affect potential scaling up/down opportunities in each country, it is reasonable to study growth/contraction option in the face of demand uncertainty in different locations separately. However, with the existence of capacity cost, demand correlations would affect the value of switch options possessed by multinational firms that have internationally dispersed locations, which I discuss later in this section. Furthermore, Folta and O'Brien (2014) discover the positive relationship between market uncertainty and the valuation of growth option. In line with their work, my simulation results show that the value of growth/contraction options increases with the level of demand uncertainties in the two countries. Moreover, the level of flexibility to grow or contract with the change of market uncertainty becomes less as manufacturing facilities are more capacity constrained. Therefore, I conclude with the following proposition.

Proposition 2: Market demand correlation does not affect the value of growth/contraction options. While demand uncertainty increases the value of growth/contraction options, capacity cost decreases it.

Figures 2.1-2.6, it depicts how the valuation of switch options in the presence of capacity constraint evolves with the change in the two countries' demand correlations and levels of demand uncertainties. More specifically, as shown in Figures 2.1-2.3 (rho=-.8, -.2, and 0, respectively) and most parts in Figures 2.4 and 2.5 (rho=.2, and, .8, respectively), the more unanticipatedly fluctuated demands are in both countries, in most cases, the more valuable switch options gained by firms that are able to alter productions within its internationally located facilities become. However, negative values of switch options appear when the level of demand uncertainty is high (Figure 2.4, rho=.2) or/and the two countries' demand correlation is high (Figure 2.5 and 2.6, rho=.8 and 1, respectively). As discussed before, the switch option value represents marginal switching opportunities under market uncertainty compared to no uncertainty. Therefore, a negative switching option value in the model still guarantees positive switching opportunities, but instead shows a decrease in switching opportunities under market uncertainty compared to the case when there is no uncertainty at all. As mentioned earlier, the value of switch options includes the value of stand-alone switch options and the value of the interaction of switch options and growth/contraction options. From the perspective of real options theory, uncertainty would make stand-alone switch options more valuable. Observations of negative values of switch options in the graphs thus would result from the negative effect of the interaction of options. For instance, demand increases in a firm's manufacturing locations would reduce the switching possibility between the two locations. Moreover, based on the evolvement of switch option value with market uncertainty and correlation, I propose that the interaction of switch options and growth/contraction options would depend on the degree of convergence /divergence of switch option (alone) value and growth/contraction option value with consideration of both market uncertainty and demand correlation. As market uncertainty rises, if the increasing rate of switch option (alone) value becomes more divergent from that of growth/contraction option value, the value of the interaction of options would become more negative which would in turn affect the value of switch options (including the interaction value). For instance, in the case of Figure 2.5 (rho=.8), when the level of capacity cost is low to moderate, the value of switch option (alone) is trivial, but the growth/contraction value (Figure 2.6) increases significantly with market uncertainty. Thus, under this circumstance, the value of switch option (alone) becomes more divergent from the value of growth/contraction as the level of demand uncertainty becomes higher, which would cause the value of the interaction of switch options and growth/contraction options and then the value of switch options more negative. Figure 2.5 and shows that with a low level of capacity constraint in manufacturing facilities, when demands are highly and positively correlated, an increase in the level of demand uncertainty would result in a decrease in the value of switch options. Therefore, I come up with the following two propositions,

Proposition 3: In general, market uncertainty will increase switch option value with the existence of capacity constraint.

Proposition 4: However, when market demands are highly and positively correlated in the two countries, with the existence of capacity constraint, market uncertainty can have a negative impact on switch option value (the interaction of switch options and growth/contraction options).

On the one hand, in Figure 2.1 (rho=-.8), demands in the two countries are greatly negatively correlated. There exists a bump around the area when the capacity cost is around .12 (j=.12). The bump results from a change in the optimal starting mode that has a different magnitude of switch option value. Before and after the bump, it shows that the value of switch options increases with the level of capacity constraint (j). As discussed in Proposition 1 that the necessary condition for a switch option to exist under market volatility is the presence of manufacturers' capacity constraint, when demand correlation in the two countries is significantly negative, an increase in capacity cost would create more opportunities for multinational firms to move their productions around within their manufacturing networks to satisfy market demands in other host countries. On the other hand, in Figure 2.5 (rho=.8), demands in the two countries are highly or perfectly and positively correlated, the value of switch options has an S-shaped relationship (first drop, then increase, and last decrease) with capacity costs. These figures also show that as demands in the two countries are more correlated, the S-shaped relationship is strengthened with respect to the value range in different demand correlations. The S-shaped relationship can also be observed in Figure 2.3 and 2.4 (rho=0 and .2) with scrutinization, especially when the level of market uncertainty is high. An increase in capacity cost might increase the value of switch options (alone) but decrease the value of growth/contraction options, and the value of switch options (alone) and the value of growth/contraction options become more divergent as demand uncertainty level is higher, which in turn affects the value of the interaction of switch options and growth/contraction options and thus the value of switch options. Even an increase in capacity cost might decrease the value of both switch options (alone) and growth/contraction options, since switching might become less likely with a more highly correlated demands in the two countries, the change in the switch option (alone) value can be trivial compared to the one in growth/contraction option value. This divergence of the option value would have a similar impact on the value of the interaction of options. In this regard, the S-shaped relationship captures the different influences of capacity cost and market demand development on switch options and growth/contraction options. The results indicate that the value of the switch option has an S-shaped relationship with capacity cost in the case of highly correlated demand developments and/or heightened demand variations in the two countries.

Proposition 5: When market demands are more negatively correlated, the value of switch option tends to increase with capacity costs.

Proposition 6: The value of the switch option has an S-shaped relationship with capacity costs when market demands are highly and positively correlated. Market uncertainty magnifies this S-shaped effect.

Three graphs in Figure 2.7 illustrates how the value of switch options evolves with the change in demand correlations (rho) in the two countries under different levels of capacity constraint (j). I consider both negative and positive relationships of demands in the two countries and thus the demand correlation (rho) ranges from -.8 to .8. As shown in the top two graphs (j=.02 and .05), when the level of capacity cost is relatively low, as the market developments in the two countries get more correlated, switch options become less valuable. As mentioned earlier, with the existence of low capacity constraint, high level of demand correlations in the two countries would create less incentives to produce and shift productions among internationally dispersed locations, which in turn affects the value of switch options. However, in the bottom graph (j=.1), the relationship between market demand correlations and the value of switch options becomes complex as the level of capacity constraint is relatively moderate. An explanation is capacity constraint that creates switching opportunities for multinational firms can also restrain productions in factories. Thus, there is no simple conclusion to summarize the impact of demand correlations on the valuation of switch options with the consideration of different levels of capacity constraint.

Proposition 7: market demands correlation does not have a monotonic relationship with the value of switch options

4.3 Results from Model 3

Figure 3.1 shows how the valuation of growth/contraction options changes with fluctuations of both production cost and demand developments in the two countries under Scenario A (SceA) and Scenario B (SceB). On the one hand, Scenario A considers the case of production market uncertainties in both countries, but only addresses production cost volatility in country B while holding the production cost in country A constant over the time. On the other hand, in Scenario B, I consider stochastic movements of production costs and demands in both countries but assume market demands in the two countries are subject to the same stochastic process with perfect correlation. In both cases, I discover that growth/contraction option value does not change with either production cost or demand correlation between country A and B and is only determined by the magnitude of cost or demand uncertainty. In Figure 3.1, it shows that consistent with the current literature, the value of growth/contraction options increases with the level of uncertainties when I consider both production cost and demand uncertainties in the two countries.

From the graph, I also observe that the growth/contraction option value in Scenario B is greater than the one in Scenario A. In Scenario B, I consider volatilities in both countries' costs and demands. But in Scenario A, production cost in country A is assumed to be a constant, and only cost uncertainty in country B and market uncertainties in both countries are studied. The difference in the number of uncertainties between the two scenarios can help explain that it generates more growth/contraction value in Scenario B. This finding might also result from the fact I discovered in Model 1 that besides market uncertainty, production cost uncertainty helps promote scaling opportunities. I consider uncertain production cost developments in both countries in Scenario B, but only country B's production cost uncertainty in Scenario A. Thus, the difference in the number of cost uncertainty between the two scenarios can be another reason that the growth/contraction option value is less in Scenario A. Therefore, I propose the following.

Proposition 1: The value of growth/contraction option is not affected by either production cost correlation or market demand correlation.

Figure 3.2, 3.3, and 3.4 depict how the switch option value fluctuates with different levels of capacity costs incurred in each manufacturing facility and different levels of demand uncertainties in both countries and production cost uncertainty in country B when production cost in country A is a constant in Scenario A in the case of different levels of market correlations. In Figure 3.2 to 3.4, rho stands for the market correlation in the two countries (rho=-.7, 0, and .9, respectively), and j means capacity cost imposed on each factory. Figure 3.5, 3.6, and 3.7 illustrate when production cost correlation in the two countries are negatively correlated, uncorrelated, and positively correlated, respectively, how the value of switch option changes with capacity cost and volatilities in both two countries' production cost and demand movements as demands in the two countries follow the same stochastic process in Scenario B. Similarly, in Figure 3.5 to 3.7, rho means the cost correlation in the two countries (rho=-.7, 0, and .9, respectively), and j represents capacity cost.

In both scenarios, I consider the impact of two different types of uncertainties (cost or demand) together on the valuation of switch option. In order to better understand the impact of uncertainty on switch option value from a real options perspective, I further assume that the level of market uncertainty and the degree of cost uncertainty are the same, and thus uncertainty hereinafter refers to both of these two types of uncertainties in different scenarios. In Figure 3.2 to 3.7, it shows that the value of switch option rises as levels of demand and cost uncertainties increase. In Model 1, I found that production cost uncertainty in the two countries might have a negative impact on the interaction of switch options and growth/contraction options and thus the value of switch options. Consistent with it, Model 2 also discovered that demand uncertainty would have the same effect on switch option value, and moreover the value can decline with an increase in market demand uncertainty under some circumstances. I pointed out that this negative relationship can be due to possible divergent values of switch options and scaling options under either market or cost uncertainty. However, when I examined the value of switch options in the presence of both market and cost uncertainty, we did not observe the negative relationship between uncertainty and switch option value. An explanation can be with the existence of both uncertainties, switch option value and scaling option value should not significantly diverge, which thus results in either a positive impact of uncertainty on the interaction of switch options and growth/contraction options or a trivial negative effect that can then be offset by the value of (stand-alone) switch options. Therefore, I propose the following.

Proposition 2: With the existence of both uncertainties, switch option value increases with uncertainty.

In Scenario A, I consider only production cost development in country B, as holding the production cost in country A constant. Thus, in this case, production cost movements in the two countries are uncorrelated. In Model 1, I showed that when the correlation of the two countries' production costs was zero, with an increase in the degree of capacity constraint in manufacturing operations, switch option value declined. Moreover, in Scenario A, market demands in the two countries are two stochastic processes that are subject to the correlation ρ_1. I proposed in Model 2 that as market demands in the two countries were negatively correlated, switch option value increased with capacity cost. On the other hand, when the correlation of two countries' demands is positively high, the relationship between the value of switch options and capacity cost is S-shaped. Figure 3.2, 3.3, and 3.4 show in the different levels of uncertainty (both market uncertainties in the two countries and production cost uncertainty in country B) and market correlation, how the switch option value changes with capacity cost. More specifically, Figure 3.2 illustrates that when market correlation is negatively low, capacity cost has a S-shaped (first decrease, then increase, and last decrease) effect on the value of switch options. From the graph, the curve line between the blue zone and the orange zone shows that with a low level of uncertainty, when capacity cost is low, switch option value decreases with an increase in capacity cost. In the case of low capacity constraint, the impact from cost uncertainty on the switch option value is greater than that from market uncertainty. Moreover, switch option value decreases with capacity cost under cost uncertainty but increases under market uncertainty. Thus, a certain higher level of capacity constraint can result in an increasing switch option value under both types of uncertainties. Consistent with it, in the graph, I observe a bump in the area where capacity cost is between .12 and .15 (j=.12, j=.15), as a relative high level of capacity constraint can yield higher switch option value under market uncertainty. Furthermore, when capacity cost is extremely, it is optimal to start and stay with mode 3 (facilities in each country), which results in less switch opportunities under both types of uncertainties. Therefore, switch option value decreases with capacity cost when the level of capacity constraint is high. Figure 3.2 also illustrates that as the uncertainty level increases, the edge between two different colored zones becomes less curved or the bump gets smoother. Thus, the result shows that the S-shaped relationship gets strengthened when the uncertainty level is low but flattened with the relative high degree of uncertainty. As the market demands in the two countries become more correlated, the bump gets less obvious in Figure 3.3 and 3.4 and the curve line between blue and orange zone gets smoother, which shows that the S-shaped relationship between the value of switch options and capacity cost gets weaker or flattened. In addition, in the case of high market demand correlation, in the presence of high uncertainty, switch option value drops as capacity cost increases, as the impact from cost uncertainty starts to dominate the value.

In Scenario B, demand developments in the two countries are subject to one stochastic process and thus market demands are highly correlated in country A and B. Model 2 investigating the impact of market uncertainty on the value of switch options found that as the correlation of the two countries' markets is high, there exists an S-shaped relationship between switch option value and capacity cost. In addition, I consider production cost volatilities in the two countries in this scenario. I discovered in Model 1 that when production costs in country A and B were negatively correlated, the valuation of switch options decreased with an increase in capacity cost. While when two countries' cost developments are highly correlated, the relationship of switch option value and capacity cost is S-shaped and cost uncertainty magnifies this relationship. In Scenario B, when I take into consideration both production cost uncertainties and market volatilities in the two countries, I find in Figure 3.5 that as cost developments in the two countries are negatively correlated, the effect of capacity cost on the value of switch options is S-shaped with a relative low degree of uncertainty, while switch option value decreases with an increase in capacity cost with a relative high level of uncertainty. As shown in the first two models, cost uncertainty generates more valuable switch options than demand uncertainty, especially in the case of negatively correlated production costs. Thus, when uncertainty is low, switch option value decreases first with capacity cost. However, I observe that with a low level of uncertainty, there exists a bump around where capacity cost is .12 (j=.12). With a greater level of capacity constraint, switch opportunities become more available under market uncertainty, which results in switch option value increasing with capacity cost. When capacity cost is extremely high, switching becomes less likely and thus decreases with capacity cost. In Figure 3.5, when uncertainty level is high, switch option value decreases with capacity cost, as the impact from cost uncertainty instead of market uncertainty dominates. Furthermore, in Figure 3.6 and 3.7, when the uncertainty is low, as the production costs in the two countries become more correlated, the magnitude of the bump (around where capacity cost is .12) in the blue zone becomes much smaller. Thus, in this case, the S-shaped relationship becomes flattened. On the other hand, when the uncertainty is high and production cost movements are highly correlated in country A and B, S-shaped relationship between switch option value and capacity constraint appears.

Based on the above discussions, the consideration of both production cost and market demand uncertainties in the countries complicates the relationship between switch option value and capacity cost, as production cost uncertainty or demand volatility would affect the relationship in a distinct way. As I mentioned that switch options are portfolios of scaling up and down options, not to mention that in this paper the value of switch options includes the interaction of switch options and growth/contraction options. Therefore, the simultaneous existence of two different types of uncertainties brings the different portfolios of options under distinct conditions together. I discover that in the presence of both cost and demand uncertainties, when the uncertainty level is low, the relationship between switch option value and capacity cost hinges on the two different forces from the two different types of uncertainties. For instance, in Scenario A, when market movements in the two countries are negatively correlated and the level of uncertainty is low, under only market uncertainty the existence of capacity constraint creates more switching opportunities, whereas an increase in capacity cost would result in a decrease in switch option value with the existence of only cost uncertainty. With the existence of both uncertainties, the value of switch options in Figure 3.2 is related with capacity cost in an S-shaped. This S-shaped relationship might be due to the divergent impact from the two different types of uncertainties. However, in Figure 3.4 when demand correlation in the two countries is high and the level of uncertainty is high, the value of switch options decreases with an increase in capacity cost. In this case, I propose that under high levels of both types of uncertainties, the effect of capacity cost on switch option value is mainly determined by cost uncertainty. Similarly, in Scenario B, I discover that when uncertainty level is low, the divergent effect from two distinct types of uncertainties on the relationship of capacity cost and switch option value is S-shaped. On the other hand, when uncertainty level is high, the relationship between capacity cost and the value of switch options is determined by cost uncertainty. It is consistent with observations from the first two models that with high level of uncertainty, cost volatility generates more values on switch options than the same level of demand uncertainty. Based on the change from Figure 3.2 to 3.4 in Scenario A, and from Figure 3.5 to 3.7 in Scenario B, I further propose that market demand correlation weakens this effect when uncertainty is low but strengthens when uncertainty is high. As in Figure 3.2, when demands are negatively correlated and the uncertainty level is high, the relationship between capacity cost and switch option value is a flattened S-shaped with a tendency to decrease instead of a monotonic decreasing line. Moreover, from Figure 3.2 to 3.4, as market demands become more correlated, the S-shaped relationship becomes more flattened. However, when the level of uncertainty is high, high market correlation would magnify the dominating effect from cost uncertainty. I further discover that cost correlation between the two countries works the different way from demand correlation on the relationship between capacity constraint and switch option value. An explanation might be that in general, an increase in cost correlation would result in a decrease in switch option value, which thus makes the lower value of switch options under market volatility (compared with the one under cost uncertainty) less valuable and more trivial. Thus, I propose the followings.

Proposition 3: When both cost and demand uncertainties are low, the relationship between capacity cost and switch option is S-shaped. The effect would be weakened by either production cost or market demand correlation.

Proposition 4: When both cost and demand uncertainties are high, the relationship between capacity cost and switch option is determined by cost uncertainty. This effect would be weakened by either production cost but strengthened by market demand correlation.

In Figure 3.8, the graph shows that the comparison of impacts of the difference in cost uncertainty in the two countries on the switch option value in Scenario B and Model 1. In this case, in Scenario B, production cost uncertainty in country A and market uncertainty in both countries are .1, while cost uncertainty in country B varies from .25 to .2. In the similar case of Model 1, I only considered cost uncertainty, and assumed cost uncertainty in country B varies from .25 to .2, and cost uncertainty in country A is .1. And I found that switch option value hinges on the relative degree of cost uncertainties in the two countries shown in the orange line of the graph. In Scenario B, with the existence of both types of uncertainty, I still observe similar relationship between switch option value and difference in cost uncertainties in the two countries. However, the value of switch options tends to be greater with consideration of both uncertainties, as in the graph the blue line is above the orange line. Moreover, the impact from differences in cost uncertainties in two countries on switch option value becomes smaller, as the blue line has a much flatter or smoother shape than the orange line when cost uncertainty in country B is less than .1. These two differences between the blue line and the orange line or between consideration of both types of uncertainties and only cost uncertainty may result from the impact of market uncertainty on switch option value. However, from Model 2, I concluded that when market demands are perfectly correlated, switching opportunities under market uncertainty should be trivia. However, with the consideration of both types of uncertainties, an obvious jump in the switch option value shows the possibility of super-additivity effect of the value of portfolios of options besides sub-additivity effect that have been proposed by other scholars. The super-additivity effect means that the value of portfolios of options is greater than the sum of individual option values. Thus, I propose the followings.

Proposition 5: With the existence of both types of uncertainties, 1) the value of switch options becomes greater (blue line shift up); 2) the impact of differences in cost uncertainties in the two countries on switch option value become less pronounced (blue line flattened).

5 Discussions and Future Research

By identifying a variety of forms of actions that can be taken to exercise growth options, it brings to attention that industry-level cost uncertainty or real exchange rate fluctuations can have an impact on the value of growth options, which have been neglected by studies that emphasize the linkage between exogenous market uncertainty and growth options on real options theory. The recognition of switch options as a hybrid of options (Chi et al., 2019) that can be highly interacted and correlated with growth and contraction options complicates the investigation in the relationship between production costs volatility and operational flexibility exploited by holding a potential portfolio of geographically dispersed affiliates. That examining fluctuating and potentially positively and negatively correlated production costs in different countries helps better understand the effects of risk diversification and real options on firms' value. Furthermore, the findings in the paper tend to straddle real options perspective, that firms possessing a network of production plants are always able to contain downside risks and preserve upside economic potential even when the cost developments in different countries are profoundly and positively correlated, and risk diversification theory, that higher returns are companied with more negatively correlated economic environments. The formal model taking into account two potential affiliates simultaneously in the strategic decision making adopts a dyadic look into the option value and proposes that a relative degree of uncertainty of the two countries' production costs is a more appropriate approach than the absolute level to evaluate the net present value and switch option value. Last but not least, the study of portfolios of options with consideration of plants' capacity, production cost variations and correlations bring fruitful insights to the understanding of the effect of both industry-level cost and real exchange rate fluctuations on switch or growth options and can become the forefront of real options research.

Following the same logic that growth and contraction options can be affected by fluctuations in cost developments, multinational firms might take advantages of foreign operations to manage their manufacturing configurations to attain potential flexibility through scaling up or scaling down investment under variations of demand uncertainty. In line with that growth and contraction options can be affected by fluctuations in demand developments, I demonstrate besides production cost volatility, market uncertainty can have an influence on switch option, which have been neglected by studies that emphasize the linkage between exogenous market uncertainty and growth options or between exchange rate uncertainty and switch options on real options theory. That examining fluctuating and potentially positively and negatively correlated demands in different countries helps better understand the effects of real options on firms' value. I propose that the necessary condition for a switch option to exist under market uncertainty is the presence of capacity constraint. Moreover, I investigate how the value of portfolios of options change with market uncertainty and correlation, switching costs, and capacity cost. For managerial insights, I argue that the exposure to exchange rate or production cost uncertainty across countries is not necessary for multinational firms to gain profits from operational flexibility. Multinational firms that possess manufacturing facilities across borders are able to benefit from switching their productions around within their operation networks when confronting with different market developments in different nations.

Instead of investigating a multinational firm's international activity in a focal location, I consider portfolios of locations in examining the effect of cost and demand uncertainties on portfolios of options possessed by the firm that manages geographically dispersed facilities across nations. This paper sheds light on the Internationalization theory (Johanson and Vahlne, 1977) which has a focus on incremental or scaling option between a focal firm and a focal location by extending its application to include both scaling options within countries and switch options across nations. Furthermore, besides of transaction costs economics or Uppsala model, this work brings a more fruitful understanding of multinational firms' international activities by adopting a real options perspective. I apply a dynamic view to examine a multinational firm's potential international manufacturing network in the global supply chain context with the consideration of portfolios of options. More specifically, I identify impacts of two different types of uncertainties, cost and demand uncertainties, on the option value. I discover how different types of options reacts differently under different types of uncertainties. Moreover, I study how cost and demand uncertainties affect the switch option value together. I discover that when both cost and demand uncertainties are low, the relationship between capacity cost and switch option is S-shaped; when both cost and demand uncertainties are high, the relationship between capacity cost and switch option is determined primarily by cost uncertainty. I also find that a potential super-additivity effect in the value of portfolios of options. In addition, results show that the impact from differences in two countries' cost uncertainties on switch option value becomes less pronounced in the face of both cost and market uncertainties.

Managers have been aware of multinational firms' flexibility to shift production around within their internationally located facilities in the presence of cost differentiations across countries. In line with Model 2, I further suggest managers to consider the possibility of switching opportunities in the case of different market developments within their operation networks with the consideration of possible capacity constraint of each manufacturing factory. Furthermore, the interaction of these two different types of uncertainty on options would provide novel insights for managers to look into multinational firms' configurations as a whole and benefit from efficiently managing portfolios of operation locations in their networks instead of running business in each focal location separately.

In this research, I employ an analytical modeling to study the impact of different types of uncertainties on portfolios of options along with other factors. It is advantageous to conduct a formal modelling when the number of variables of interest is various and relationships among the variables are mixed and hard to detect. However, after studying the simulation results from my models, I come up with proposition that are also empirically testable. Therefore, future research should focus on testing propositions in this dissertation using archival data and thus linking findings in the research with real life or managerial practice.

In this dissertation, I also apply a three stochastic process model with 9 jumps instead of a two stochastic process model with 5 jumps to examine how the value of portfolios of options is affected by both production cost and market demand uncertainties. However, in my case of two countries, if I consider volatilities in both costs and demands, the number of stochastic variables should be 4. Thus, the 3 stochastic variable model has its limitations. For instance, in Scenario A, production cost in country A is a constant, or in Scenario B, market demands in the two countries are highly correlated. Moreover, the 3 stochastic variable model can only examine the effect of product cost or market demand correlation separately, while the model with four stochastic processes that represents cost and demand uncertainties in the two countries could investigate or even distinguish impacts of these two correlations on switch option value along with capacity cost and uncertainty. In addition, the current model only allows us to study the difference in either production cost uncertainty or market demand uncertainty in the two countries, while I believe that the four stochastic process model would enhance the understanding of the impact of differences between cost and demand uncertainties on the portfolios of options value. Furthermore, comparing the model with four stochastic variables representing cost and demand uncertainties in the two countries with the two models using two stochastic processes can also provide us with insights to examine the value of portfolios of options parameter by parameter and better decompose the value from the two distinct sources of uncertainty. In conclusion, I would conduct a research using four stochastic variables to bring more fruitful findings to understand multinational firms' manufacturing networks from the perspective of real options

To formalize a valid model, I also make certain assumptions to justify it. In addition, in this research, I have a focus on flexibility optimism rather than flexibility pessimism or flexibility realism (Rangan, 1998). The practical relevance and organizational realities that are of interest to some scholars and practicing firms are assumed away. Further work on portfolios of real options can attempt to assess the impact of the human or behavioral nature of management and the constraints on the adaptive capabilities of organizations on the exercise or maintenance of the options, which would contribute to sources of competitive advantage and firm heterogeneity as fundamental issues in strategy research (Trigeorigis and reuer 2017).

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Figure 1.1

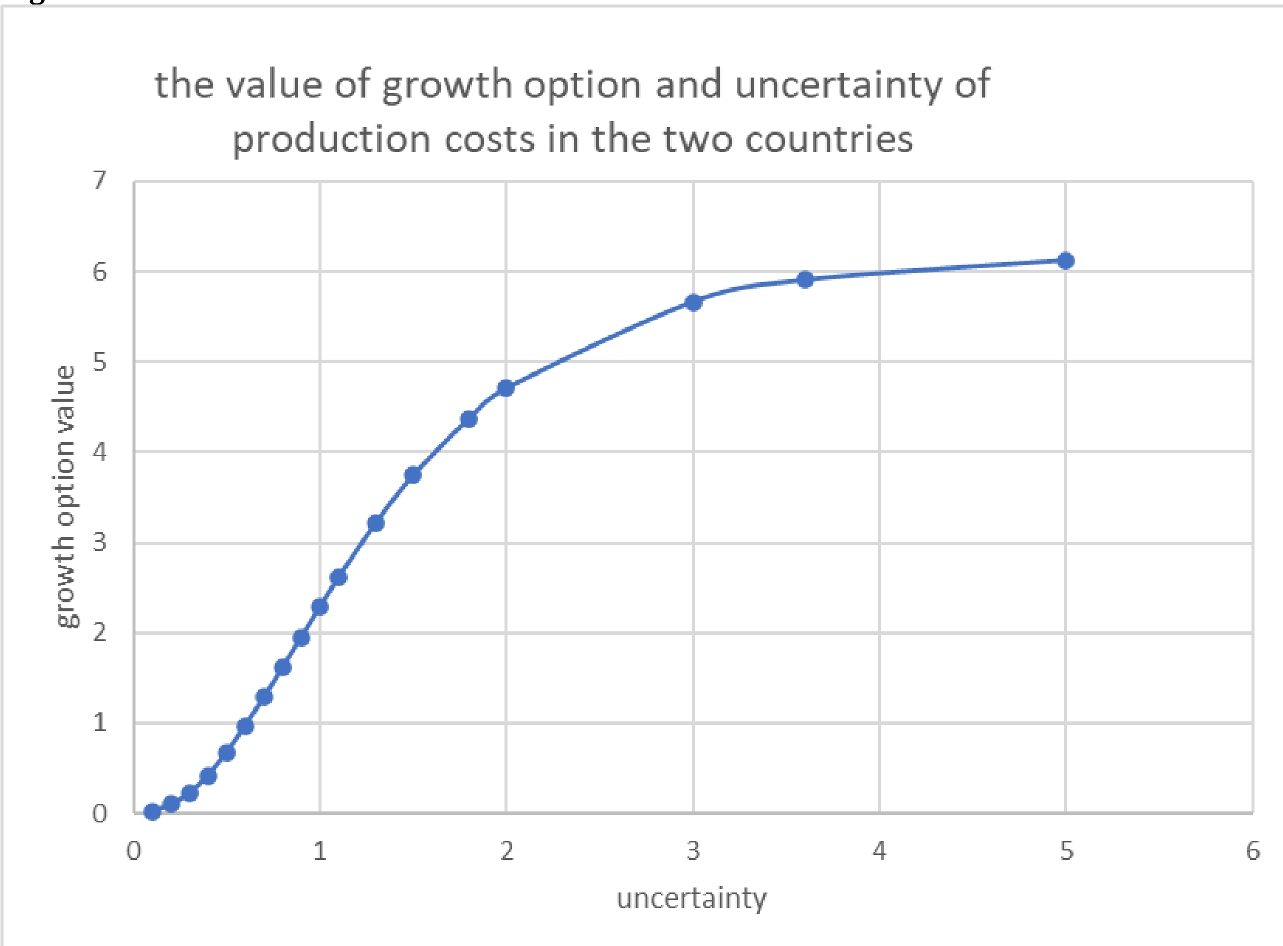

the value of growth option and uncertainty of production costs in the two countries
growth option value
uncertainty
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6

Figure 1.2

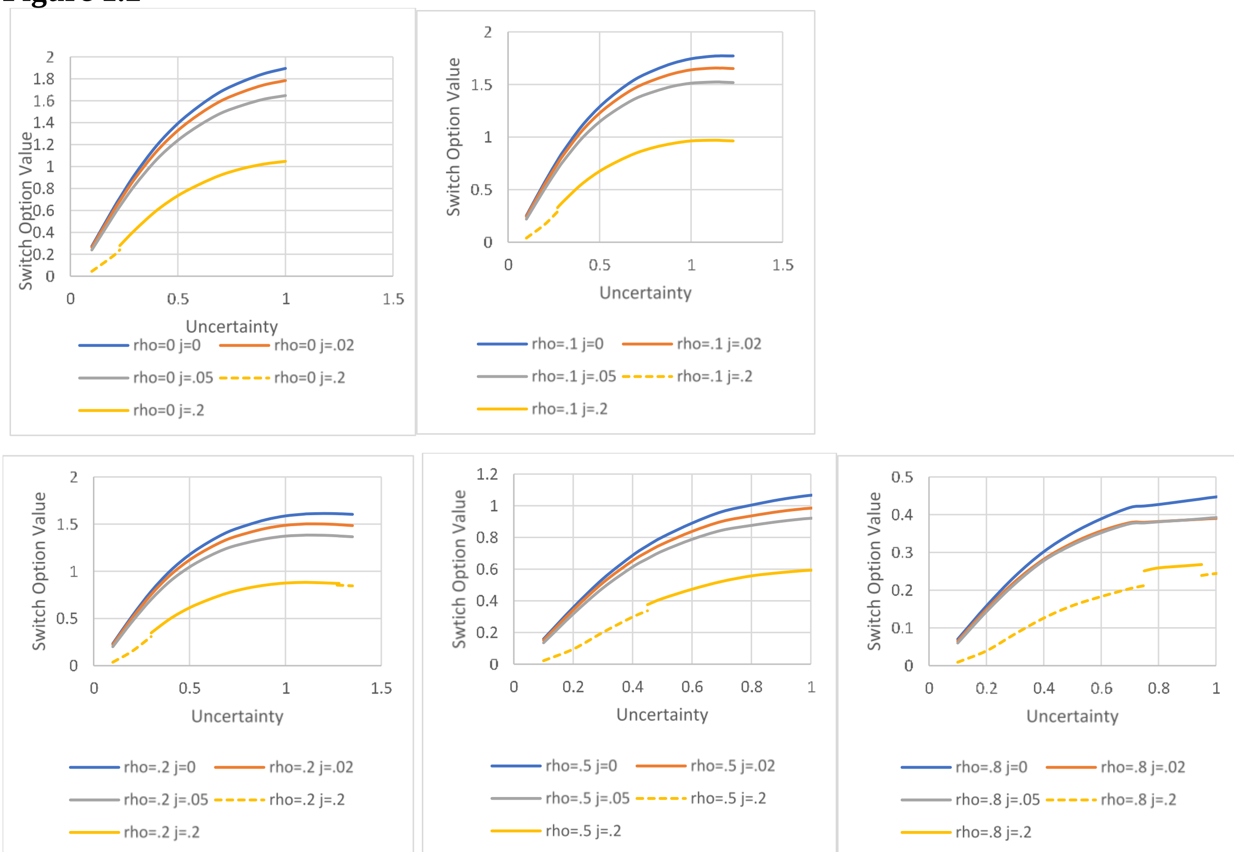
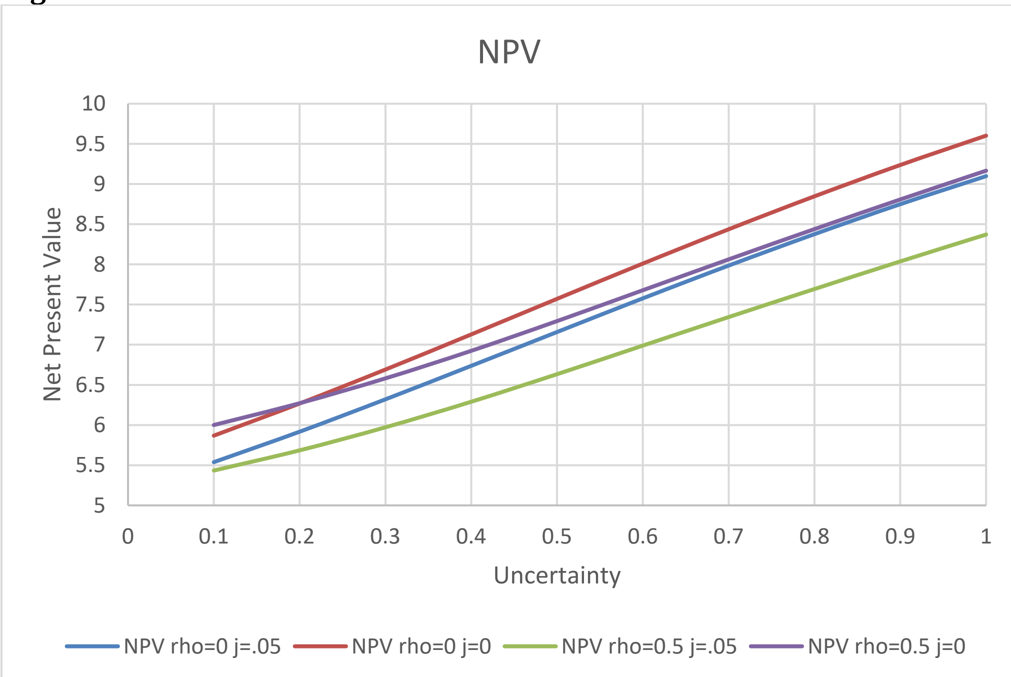

Switch Option Value
Uncertainty
rho=0 j=0
rho=0 j=.02
rho=0 j=.05
rho=0 j=.2
rho=0 j=.2
Switch Option Value
Uncertainty
rho=.1 j=0
rho=.1 j=.02
rho=.1 j=.05
rho=.1 j=.2
rho=.1 j=.2
Switch Option Value
Uncertainty
rho=.2 j=0
rho=.2 j=.02
rho=.2 j=.05
rho=.2 j=.2
rho=.2 j=.2
Swtich Option Value
Uncertainty
rho=.5 j=0
rho=.5 j=.02
rho=.5 j=.05
rho=.5 j=.2
rho=.5 j=.2
Switch Option Value
Uncertainty
rho=.8 j=0
rho=.8 j=.02
rho=.8 j=.05
rho=.8 j=.2
rho=.8 j=.2

Figure 1.3


NPV
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
Net Present Value
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Uncertainty
NPV rho=0 j=.05
NPV rho=0 j=0
NPV rho=0.5 j=.05
NPV rho=0.5 j=0

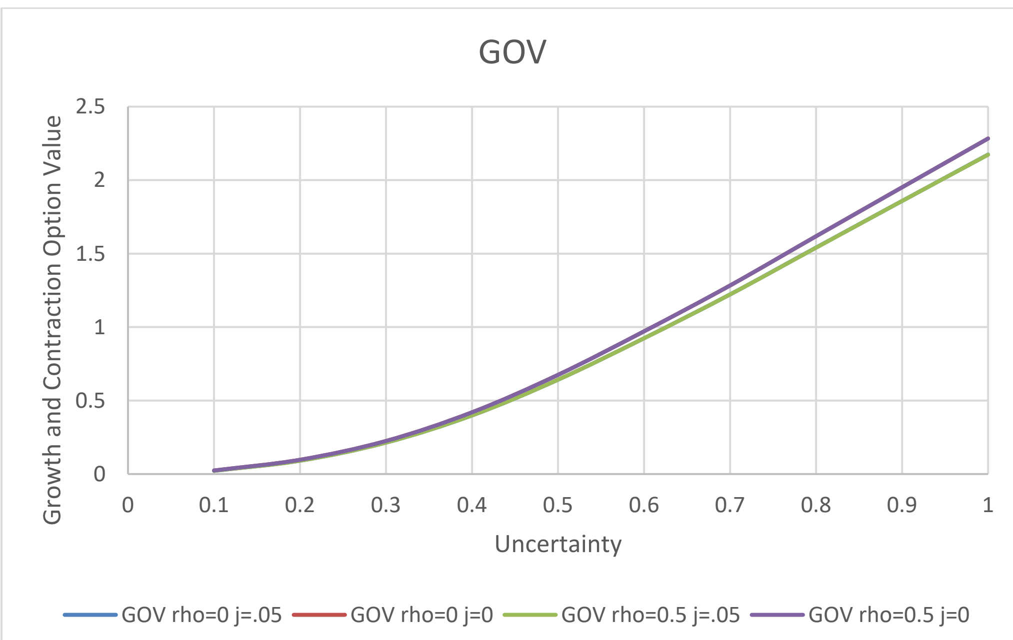
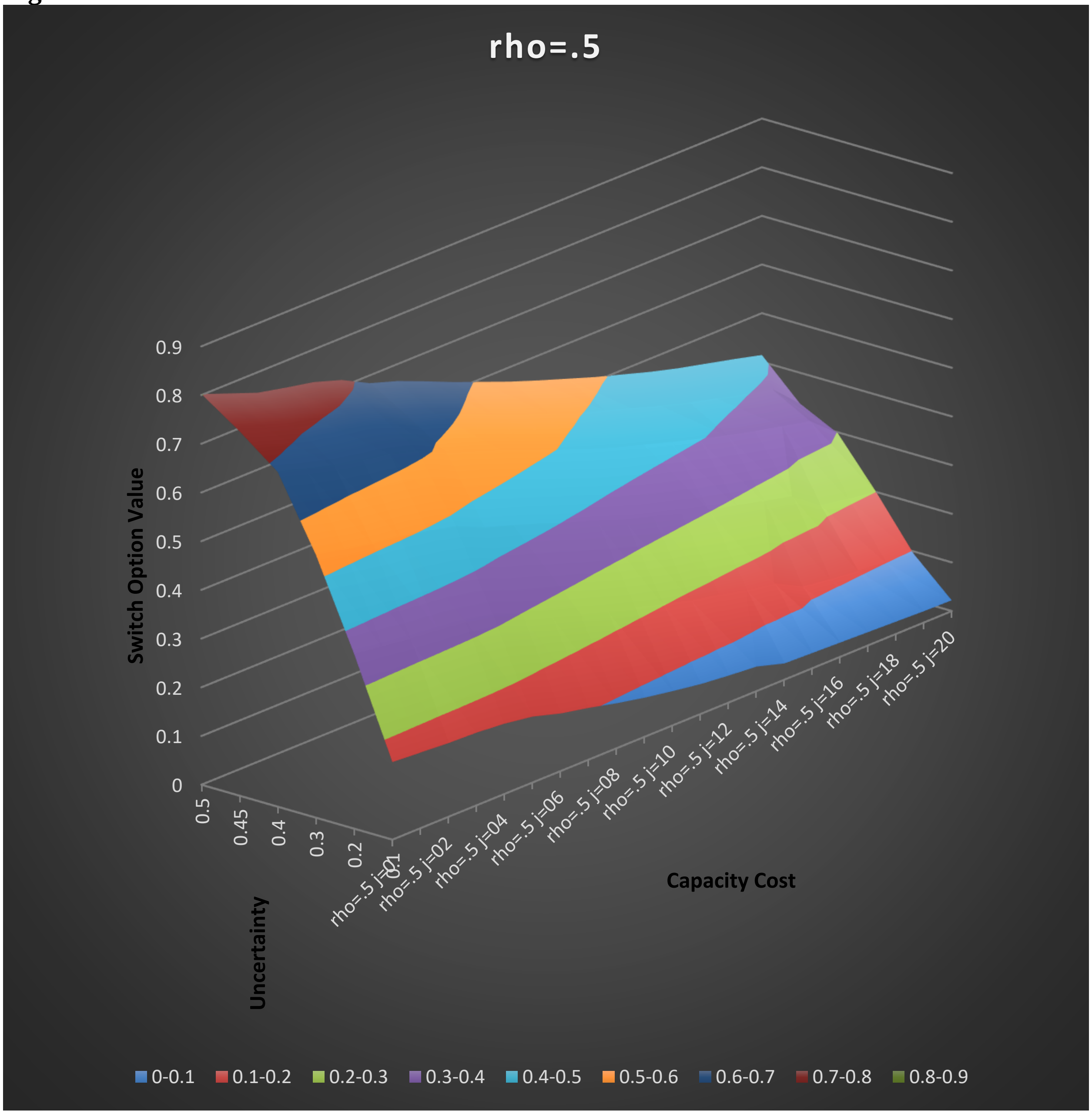

GOV
2.5
2
1.5
1
0.5
0
Growth and Contraction Option Value
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Uncertainty
GOV rho=0 j=.05
GOV rho=0 j=0
GOV rho=0.5 j=.05
GOV rho=0.5 j=0

Figure 1.4



rho=.5
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Switch Option Value
0.5
0.45
0.4
0.3
0.2
0.1
Uncertainty
rho=.5 j=01
rho=.5 j=02
rho=.5 j=04
rho=.5 j=06
rho=.5 j=08
rho=.5 j=10
rho=.5 j=12
rho=.5 j=14
rho=.5 j=16
rho=.5 j=18
rho=.5 j=20
Capacity Cost
0-0.1
0.1-0.2
0.2-0.3
0.3-0.4
0.4-0.5
0.5-0.6
0.6-0.7
0.7-0.8
0.8-0.9

Figure 1.5

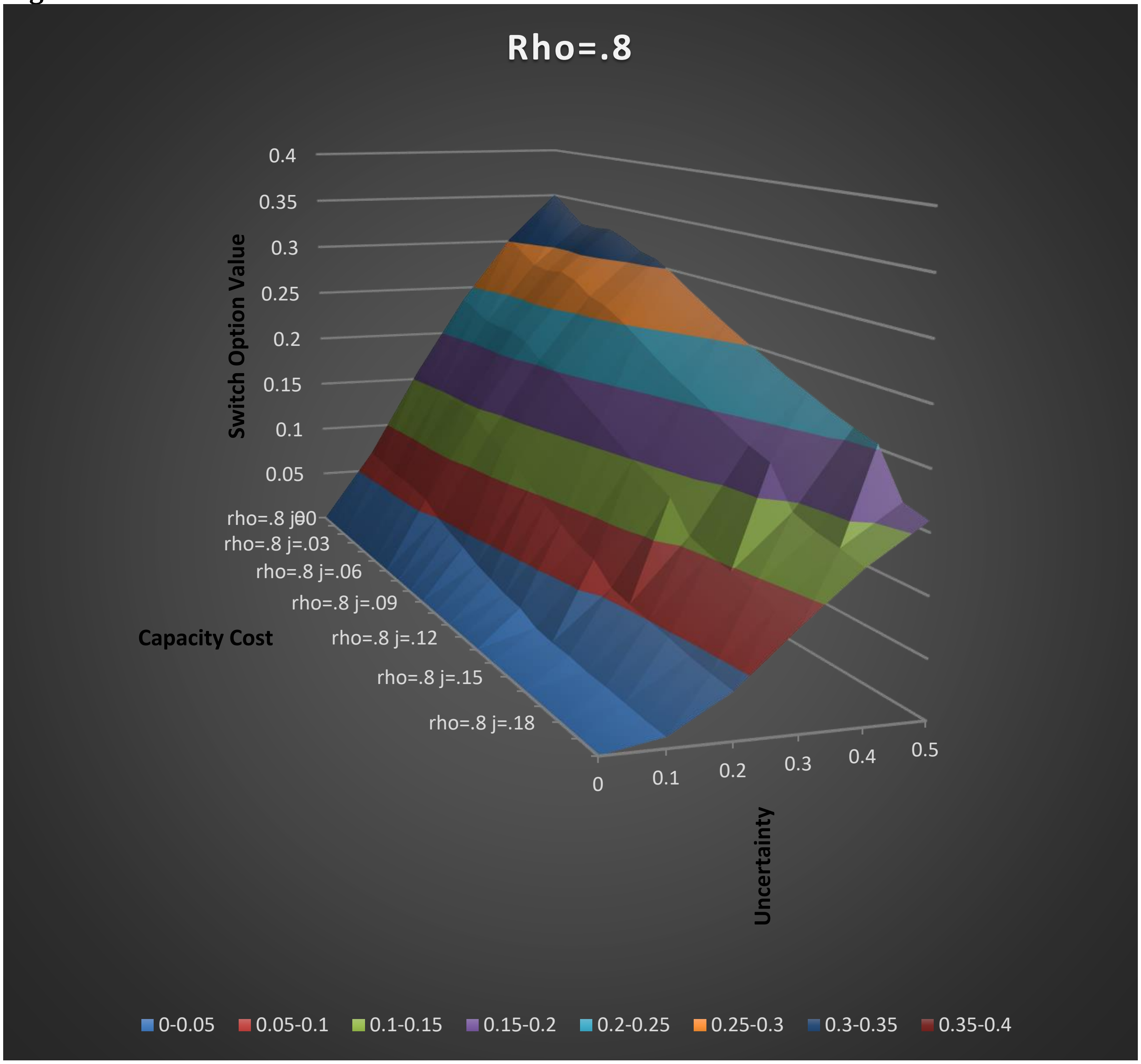
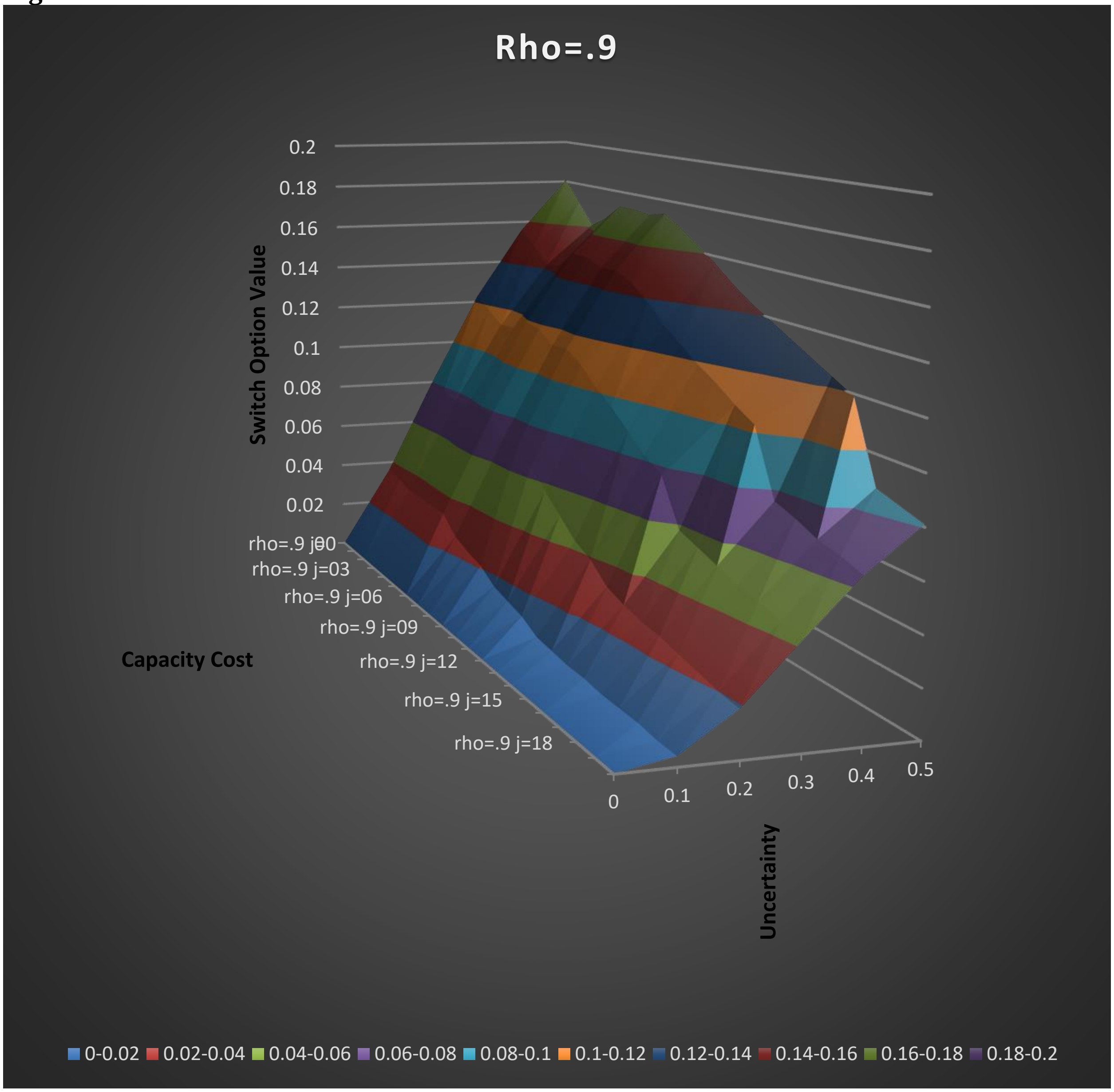
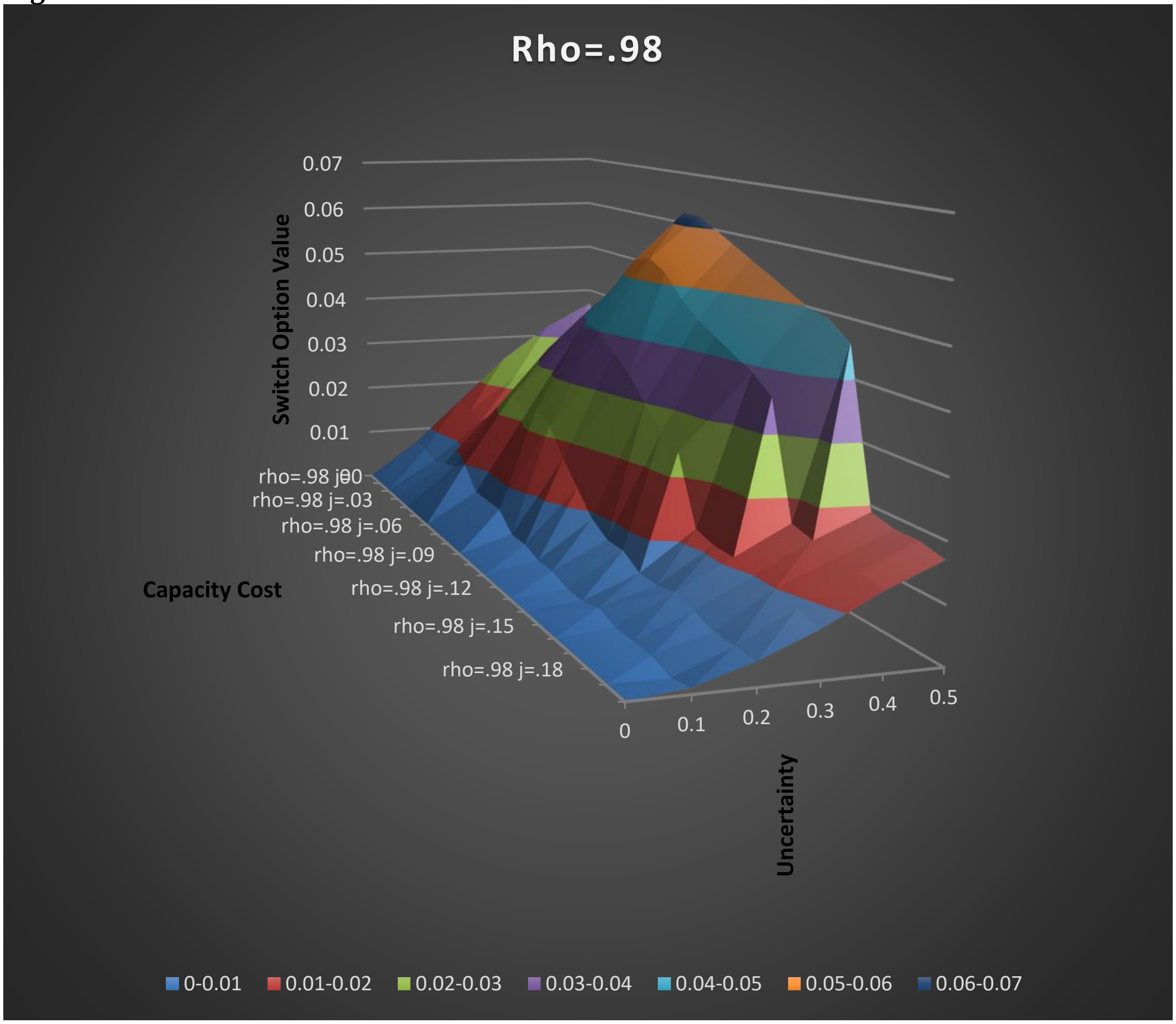

Rho=.8
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Switch Option Value
rho=.8 j=0
rho=.8 j=.03
rho=.8 j=.06
rho=.8 j=.09
rho=.8 j=.12
rho=.8 j=.15
rho=.8 j=.18
Capacity Cost
0
0.1
0.2
0.3
0.4
0.5
Uncertainty
0-0.05
0.05-0.1
0.1-0.15
0.15-0.2
0.2-0.25
0.25-0.3
0.3-0.35
0.35-0.4

Figure 1.6



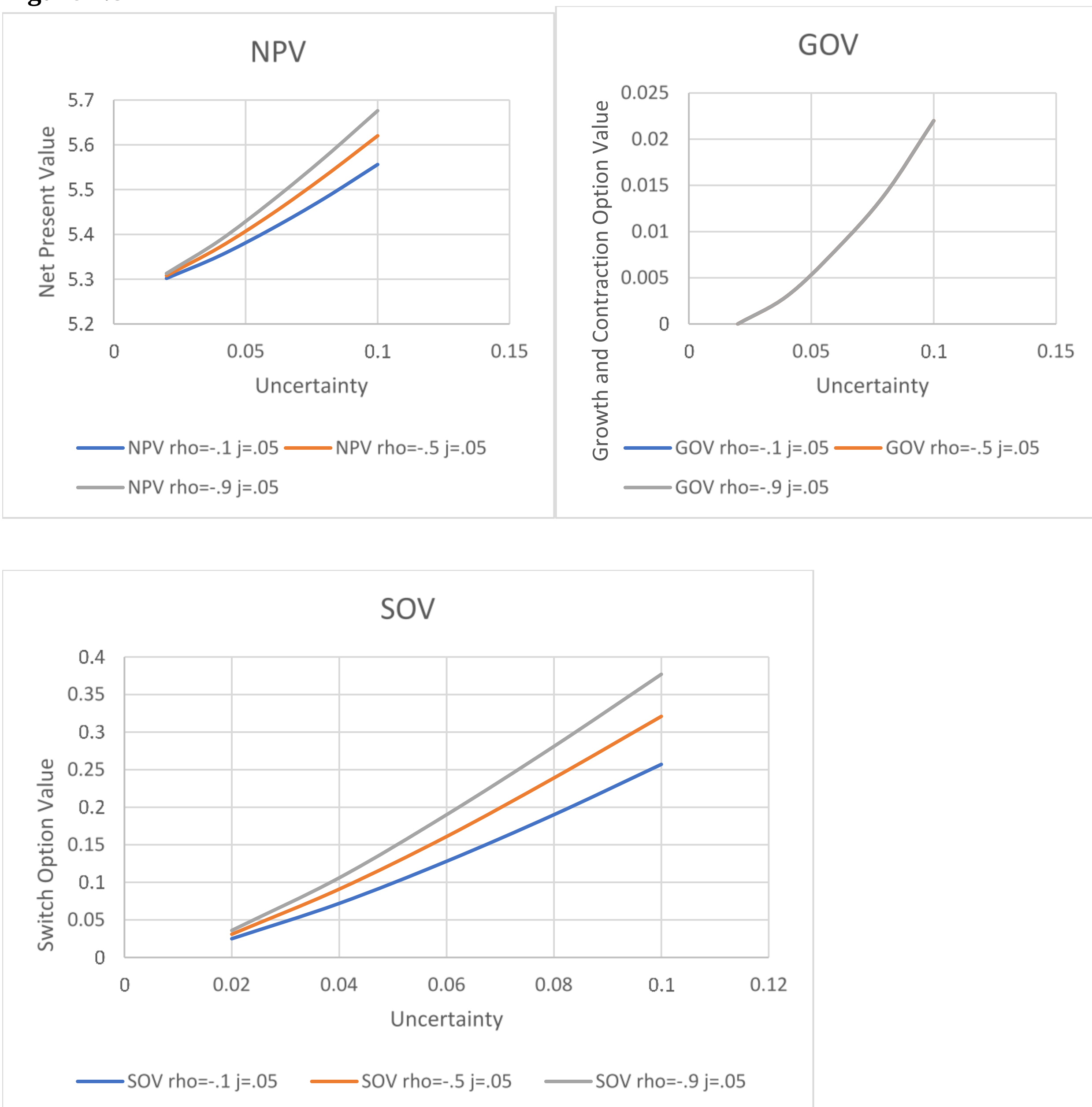
Rho=.9
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Switch Option Value
rho=.9 j=00
rho=.9 j=03
rho=.9 j=06
rho=.9 j=09
rho=.9 j=12
rho=.9 j=15
rho=.9 j=18
Capacity Cost
0
0.1
0.2
0.3
0.4
0.5
Uncertainty
0-0.02
0.02-0.04
0.04-0.06
0.06-0.08
0.08-0.1
0.1-0.12
0.12-0.14
0.14-0.16
0.16-0.18
0.18-0.2

Figure 1.7



Rho=.98
Switch Option Value
0.07
0.06
0.05
0.04
0.03
0.02
0.01
rho=.98 j=0
rho=.98 j=.03
rho=.98 j=.06
rho=.98 j=.09
Capacity Cost
rho=.98 j=.12
rho=.98 j=.15
rho=.98 j=.18
0
0.1
0.2
0.3
0.4
0.5
Uncertainty
0-0.01
0.01-0.02
0.02-0.03
0.03-0.04
0.04-0.05
0.05-0.06
0.06-0.07

Figure 1.8



NPV
Net Present Value
5.7
5.6
5.5
5.4
5.3
5.2
0
0.05
0.1
0.15
Uncertainty
NPV rho=-.1 j=.05
NPV rho=-.5 j=.05
NPV rho=-.9 j=.05
GOV
Growth and Contraction Option Value
0.025
0.02
0.015
0.01
0.005
0
0
0.05
0.1
0.15
Uncertainty
GOV rho=-.1 j=.05
GOV rho=-.5 j=.05
GOV rho=-.9 j=.05
SOV
Switch Option Value
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.02
0.04
0.06
0.08
0.1
0.12
Uncertainty
SOV rho=-.1 j=.05
SOV rho=-.5 j=.05
SOV rho=-.9 j=.05

Figure 1.9

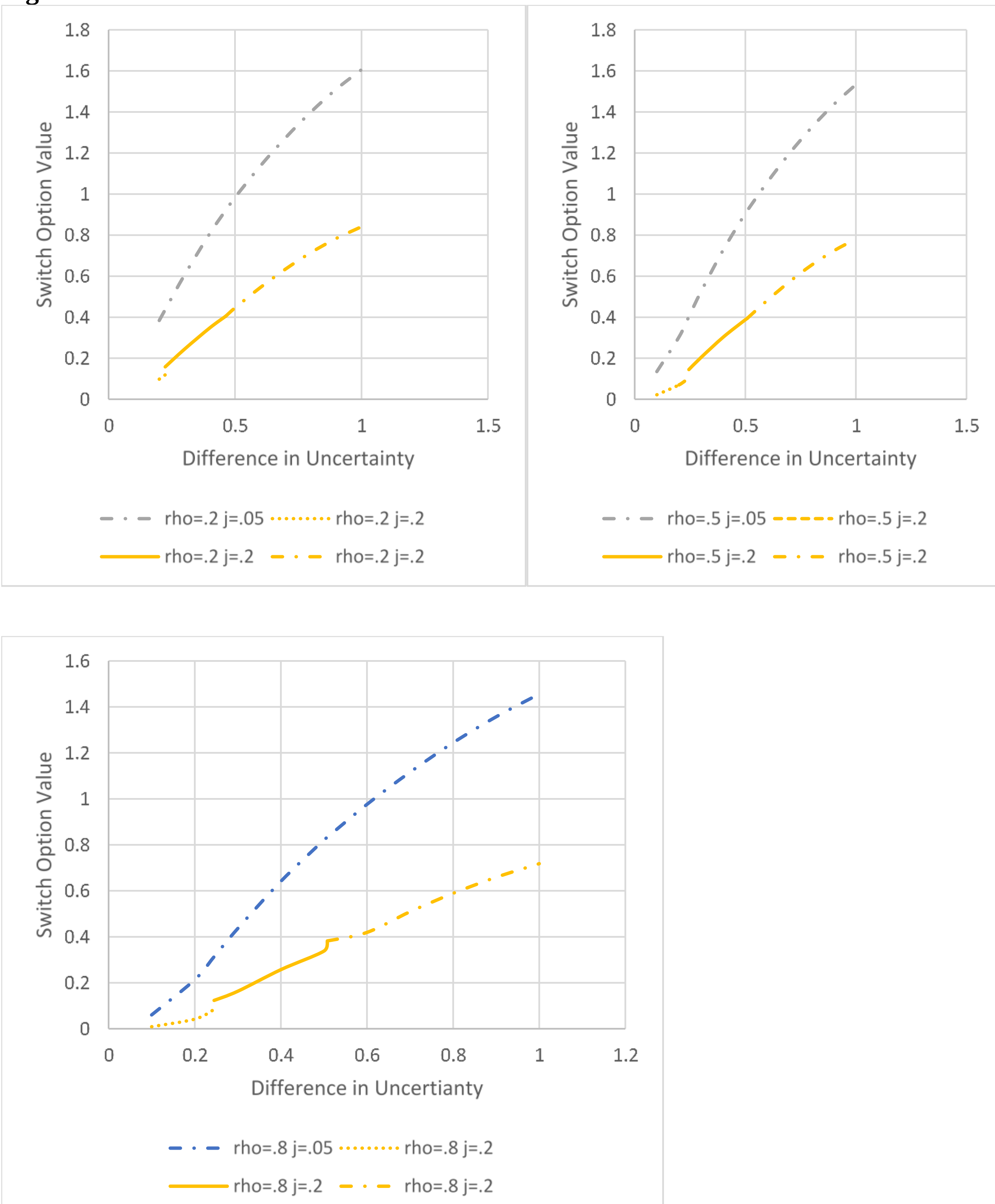
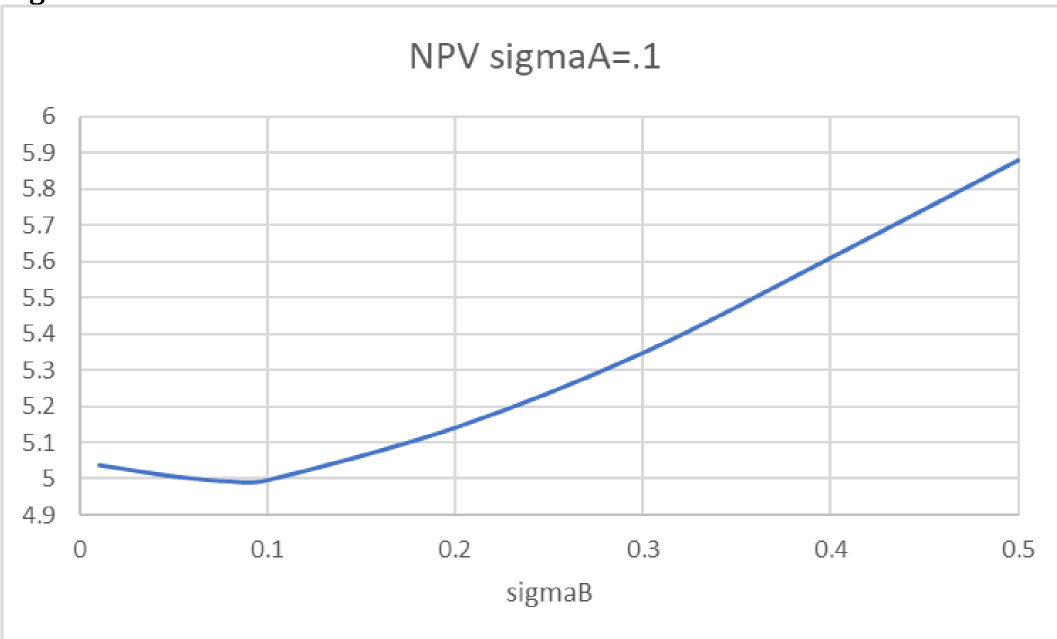

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Switch Option Value
0
0.5
1
1.5
Difference in Uncertainty
rho=.2 j=.05
rho=.2 j=.2
rho=.2 j=.2
rho=.2 j=.2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Switch Option Value
0
0.5
1
1.5
Difference in Uncertainty
rho=.5 j=.05
rho=.5 j=.2
rho=.5 j=.2
rho=.5 j=.2
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Switch Option Value
0
0.2
0.4
0.6
0.8
1
1.2
Difference in Uncertianty
rho=.8 j=.05
rho=.8 j=.2
rho=.8 j=.2
rho=.8 j=.2

Figure 1.10


NPV sigmaA=.1
6
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5
4.9
0
0.1
0.2
0.3
0.4
0.5
sigmaB

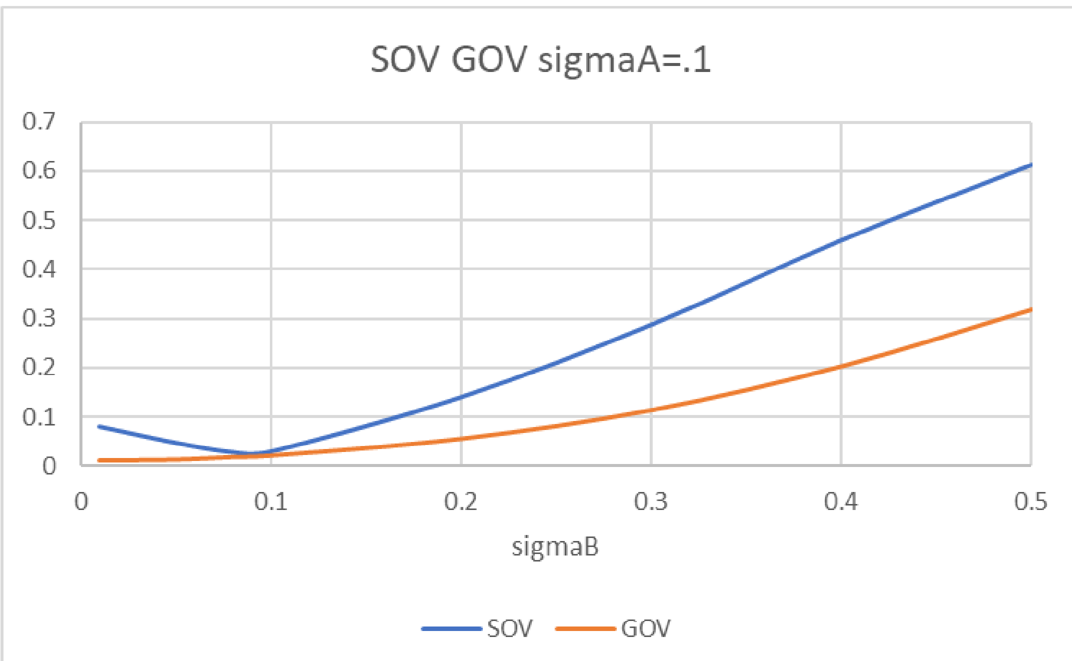
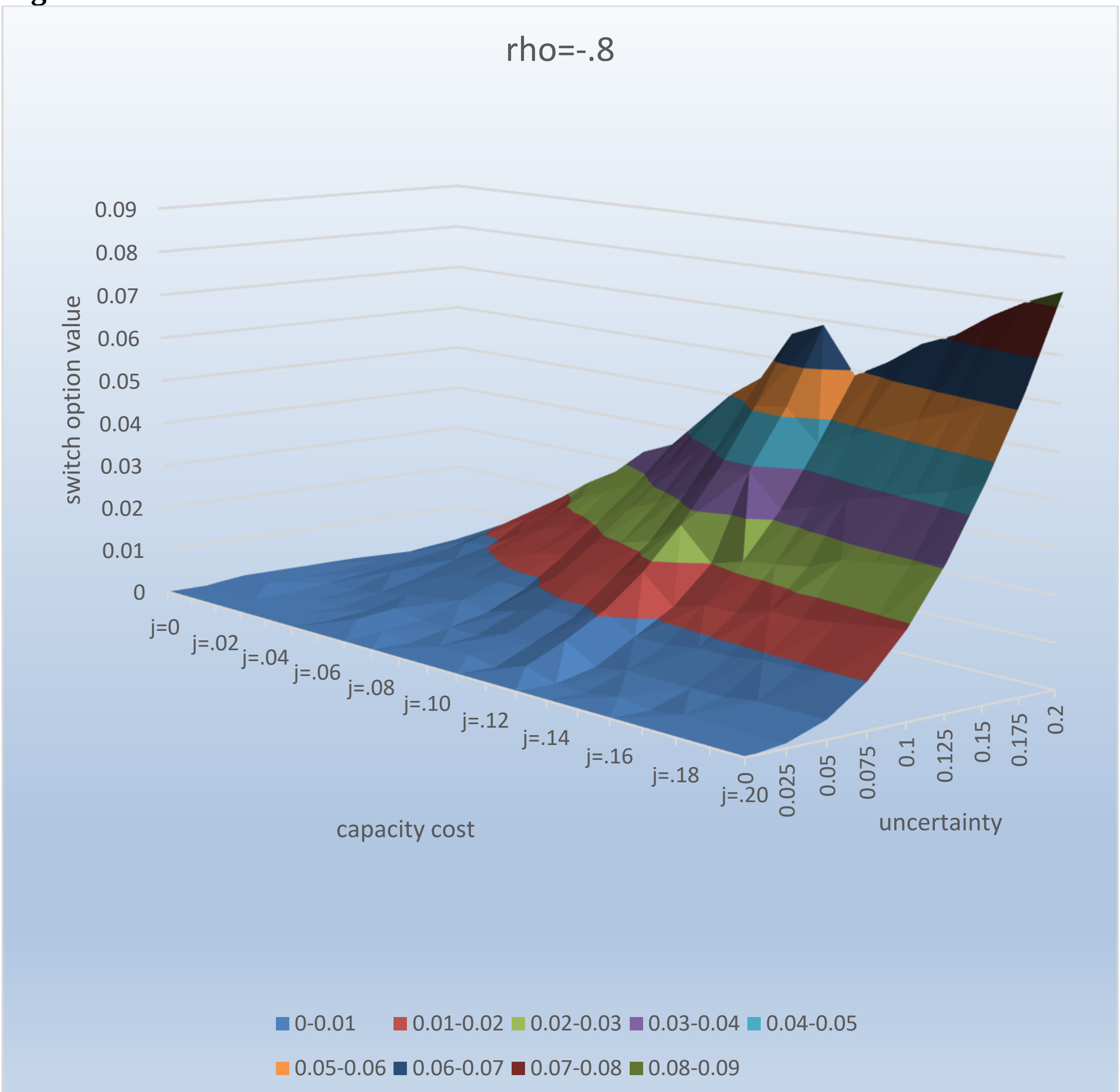

SOV GOV sigmaA=.1
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
sigmaB
SOV
GOV

Figure 2.1



rho=-.8
switch option value
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
j=0
j=.02
j=.04
j=.06
j=.08
j=.10
j=.12
j=.14
j=.16
j=.18
j=.20
capacity cost
0
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
uncertainty
0-0.01
0.01-0.02
0.02-0.03
0.03-0.04
0.04-0.05
0.05-0.06
0.06-0.07
0.07-0.08
0.08-0.09

Figure 2.2

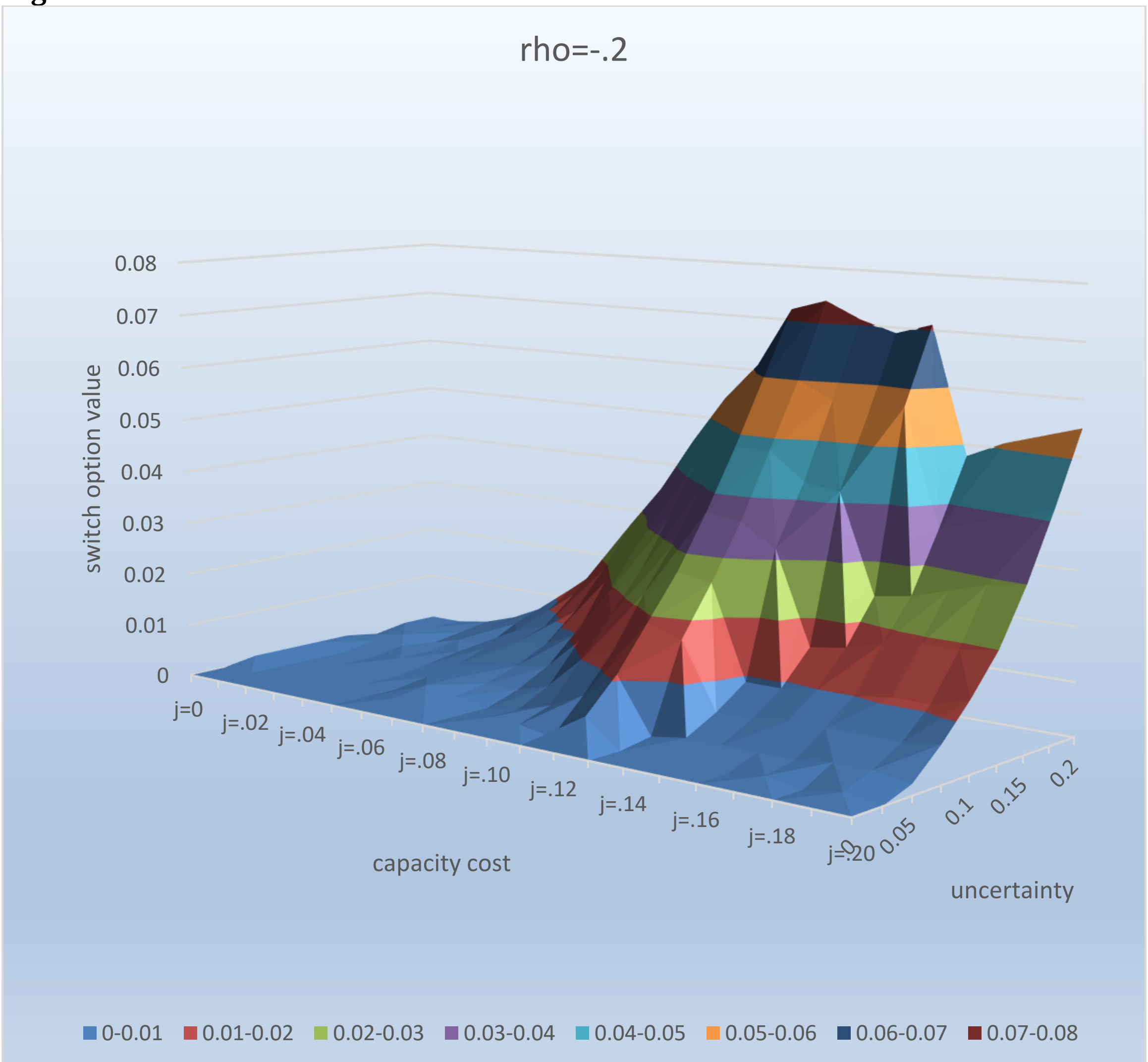

rho=-.2
switch option value
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
j=0
j=.02
j=.04
j=.06
j=.08
j=.10
j=.12
j=.14
j=.16
j=.18
j=.20
capacity cost
0
0.05
0.1
0.15
0.2
uncertainty
0-0.01
0.01-0.02
0.02-0.03
0.03-0.04
0.04-0.05
0.05-0.06
0.06-0.07
0.07-0.08

Figure 2.3

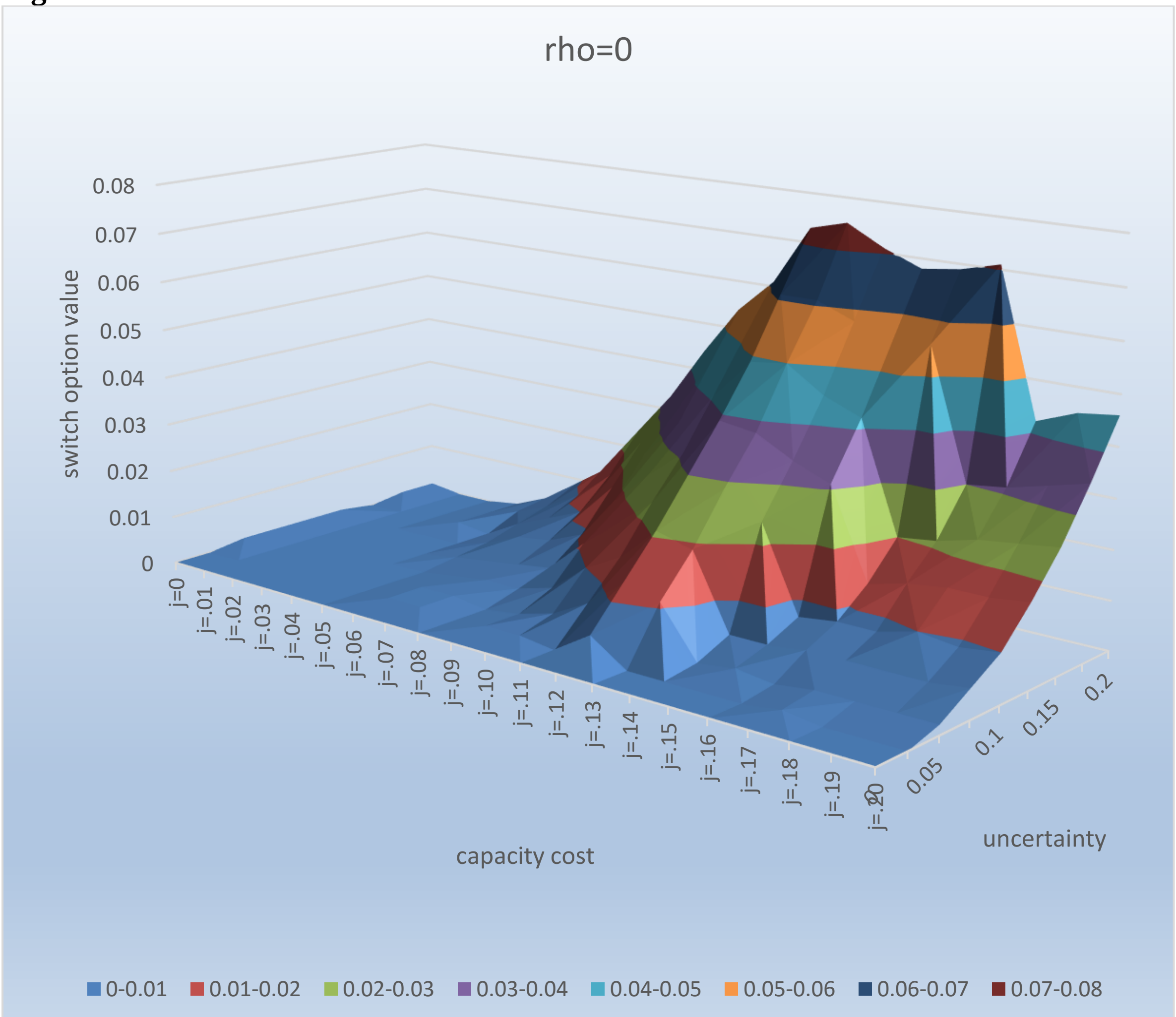

rho=0
switch option value
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
j=0
j=.01
j=.02
j=.03
j=.04
j=.05
j=.06
j=.07
j=.08
j=.09
j=.10
j=.11
j=.12
j=.13
j=.14
j=.15
j=.16
j=.17
j=.18
j=.19
j=.20
capacity cost
0
0.05
0.1
0.15
0.2
uncertainty
0-0.01
0.01-0.02
0.02-0.03
0.03-0.04
0.04-0.05
0.05-0.06
0.06-0.07
0.07-0.08

Figure 2.4

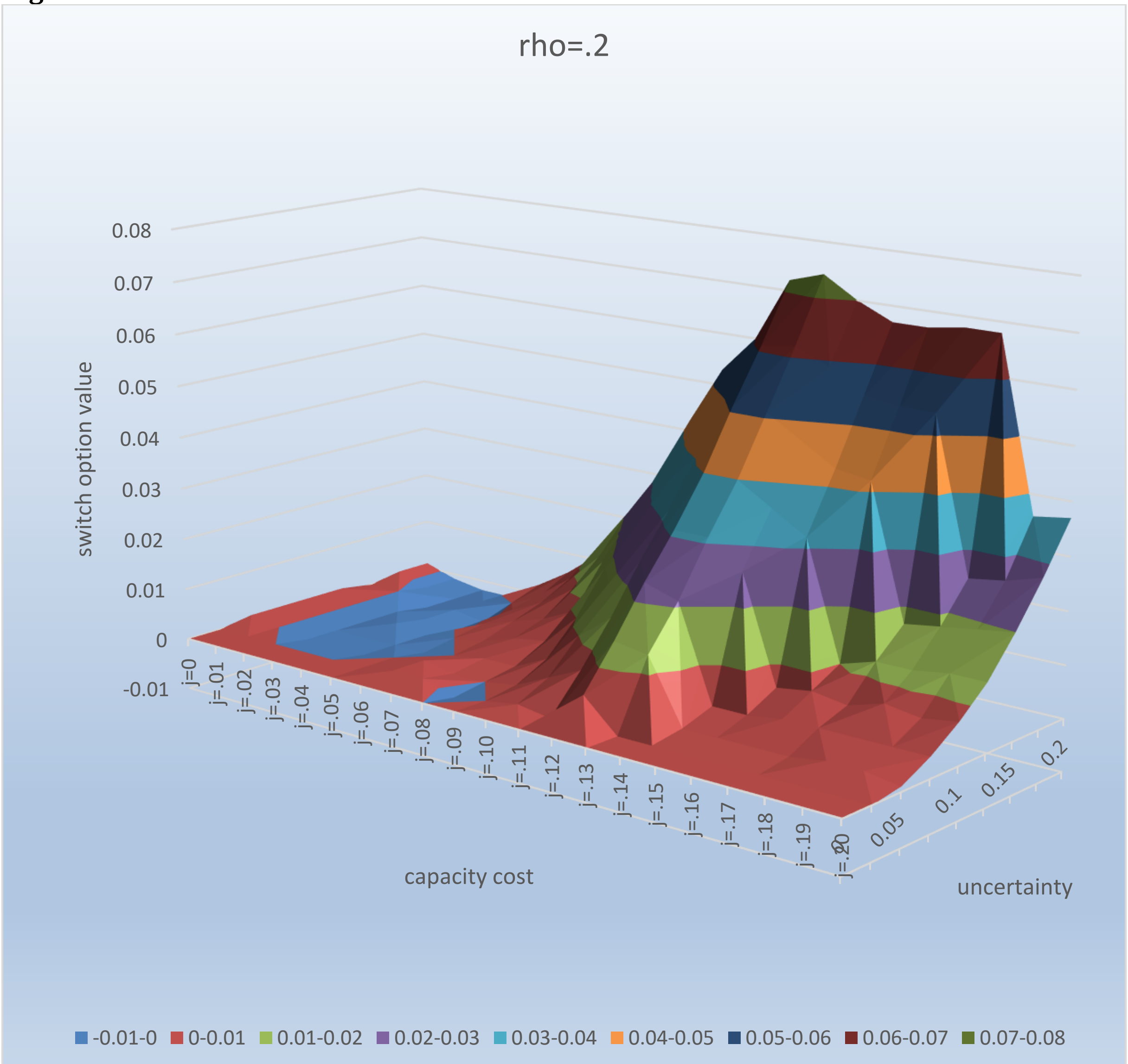

rho=.2
switch option value
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
j=0
j=.01
j=.02
j=.03
j=.04
j=.05
j=.06
j=.07
j=.08
j=.09
j=.10
j=.11
j=.12
j=.13
j=.14
j=.15
j=.16
j=.17
j=.18
j=.19
j=.20
capacity cost
0
0.05
0.1
0.15
0.2
uncertainty
-0.01-0
0-0.01
0.01-0.02
0.02-0.03
0.03-0.04
0.04-0.05
0.05-0.06
0.06-0.07
0.07-0.08

Figure 2.5

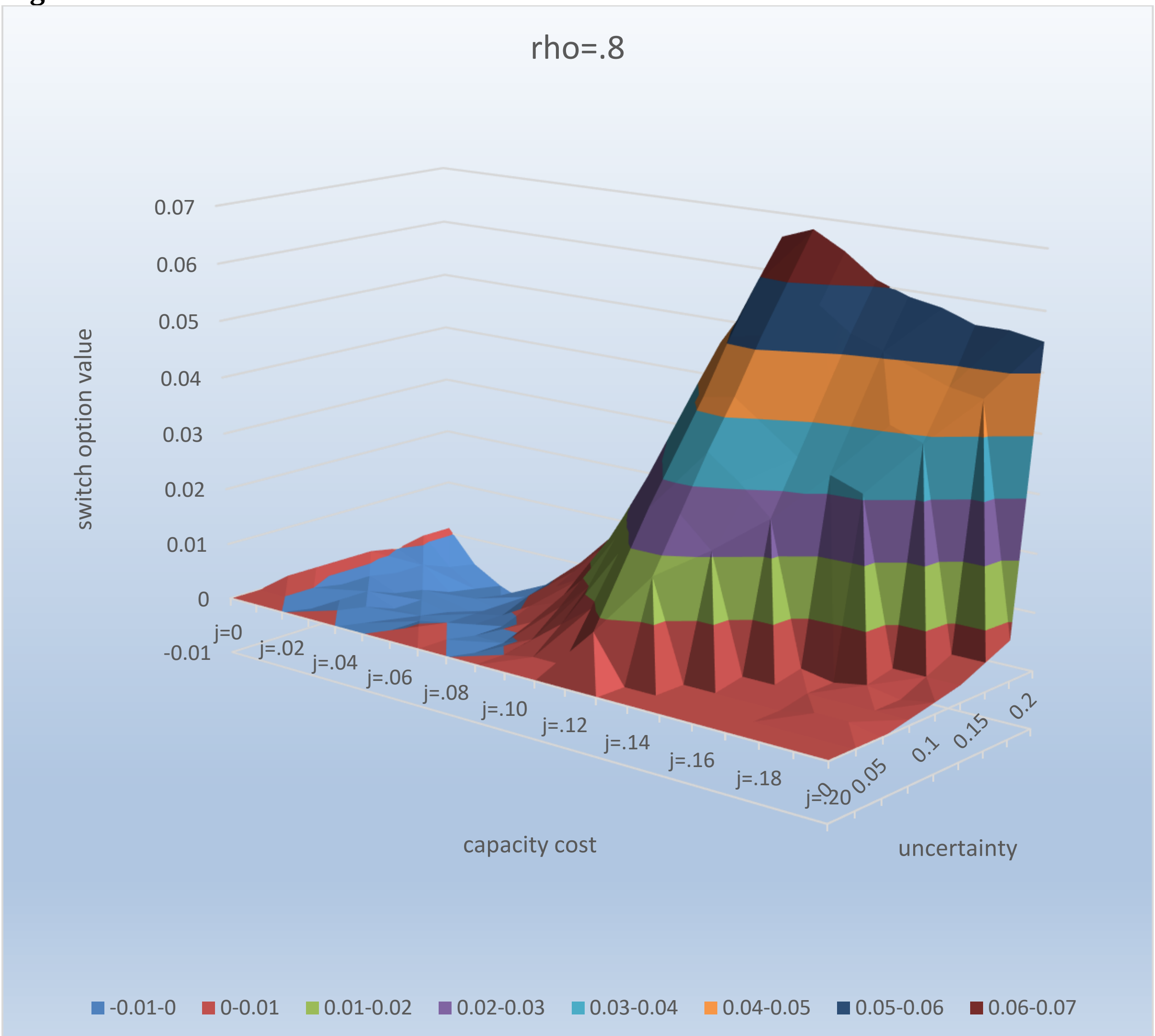

rho=.8
switch option value
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
j=0
j=.02
j=.04
j=.06
j=.08
j=.10
j=.12
j=.14
j=.16
j=.18
j=.20
capacity cost
0
0.05
0.1
0.15
0.2
uncertainty
-0.01-0
0-0.01
0.01-0.02
0.02-0.03
0.03-0.04
0.04-0.05
0.05-0.06
0.06-0.07

Figure 2.6

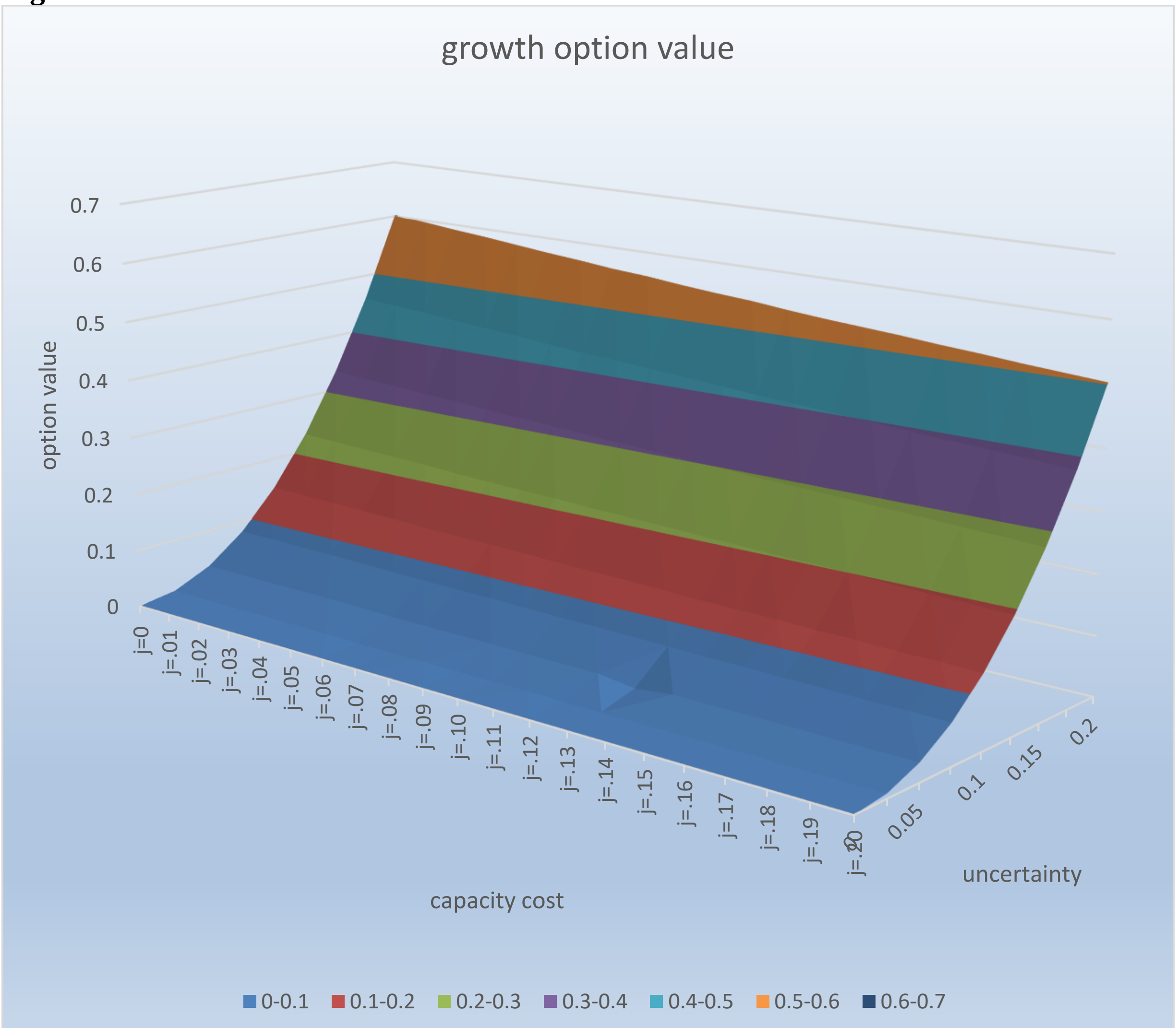
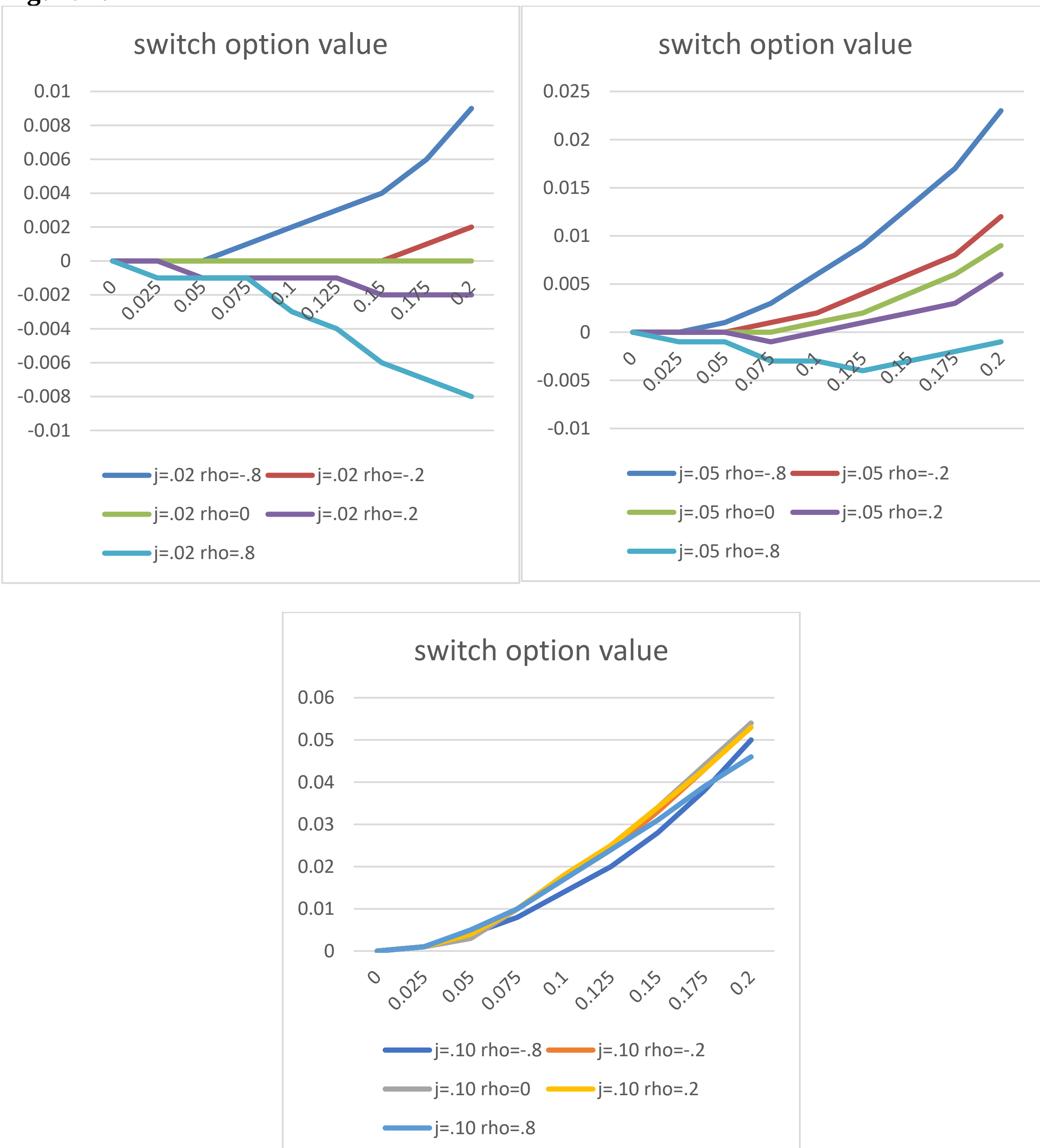

growth option value
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
option value
j=0
j=.01
j=.02
j=.03
j=.04
j=.05
j=.06
j=.07
j=.08
j=.09
j=.10
j=.11
j=.12
j=.13
j=.14
j=.15
j=.16
j=.17
j=.18
j=.19
j=.20
capacity cost
0
0.05
0.1
0.15
0.2
uncertainty
0-0.1
0.1-0.2
0.2-0.3
0.3-0.4
0.4-0.5
0.5-0.6
0.6-0.7

Figure 2.7



switch option value
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
0
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
j=.02 rho=-.8
j=.02 rho=-.2
j=.02 rho=0
j=.02 rho=.2
j=.02 rho=.8
switch option value
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
0
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
j=.05 rho=-.8
j=.05 rho=-.2
j=.05 rho=0
j=.05 rho=.2
j=.05 rho=.8
switch option value
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
j=.10 rho=-.8
j=.10 rho=-.2
j=.10 rho=0
j=.10 rho=.2
j=.10 rho=.8

Figure 3.1

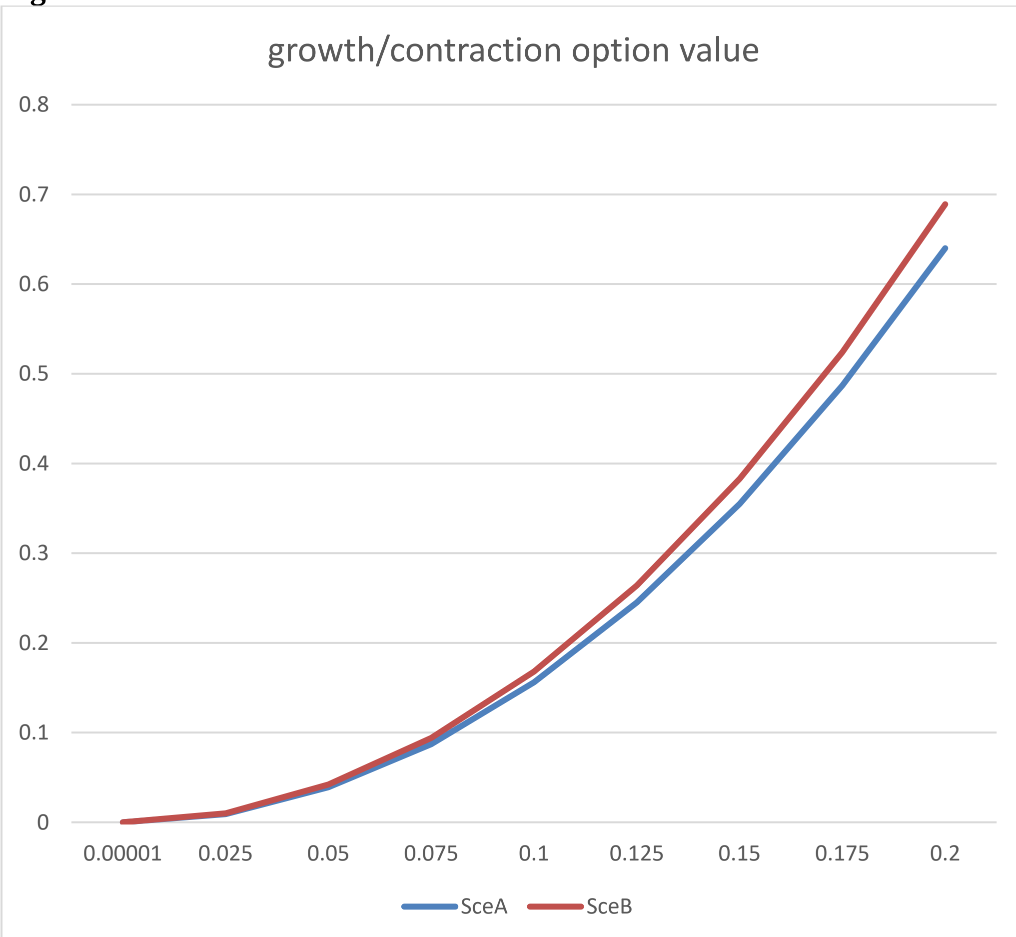
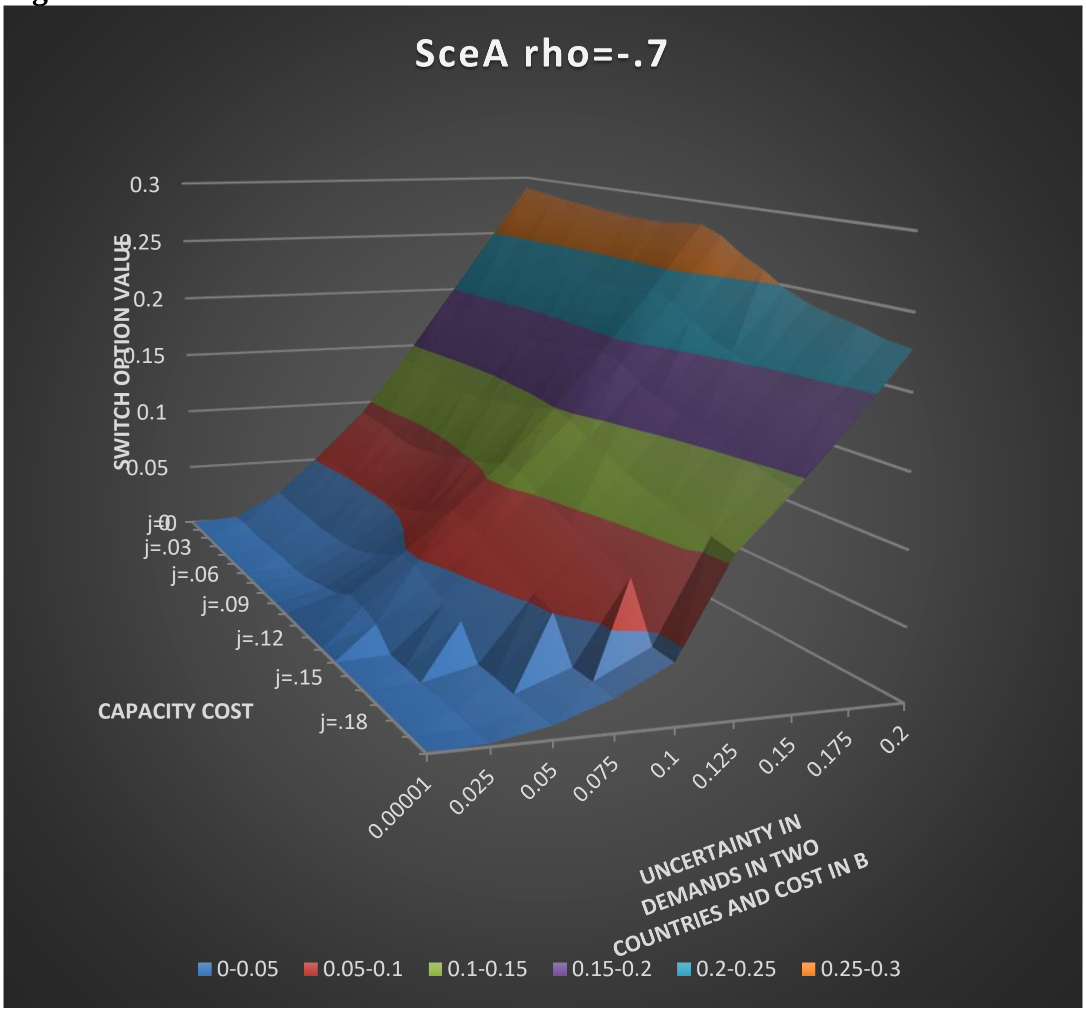

growth/contraction option value
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.00001
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
SceA
SceB

Figure 3.2



SceA rho=-.7
0.3
0.25
0.2
0.15
0.1
0.05
0
SWITCH OPTION VALUE
j=0
j=.03
j=.06
j=.09
j=.12
j=.15
j=.18
CAPACITY COST
0.00001
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
UNCERTAINTY IN DEMANDS IN TWO COUNTRIES AND COST IN B
0-0.05
0.05-0.1
0.1-0.15
0.15-0.2
0.2-0.25
0.25-0.3

Figure 3.3

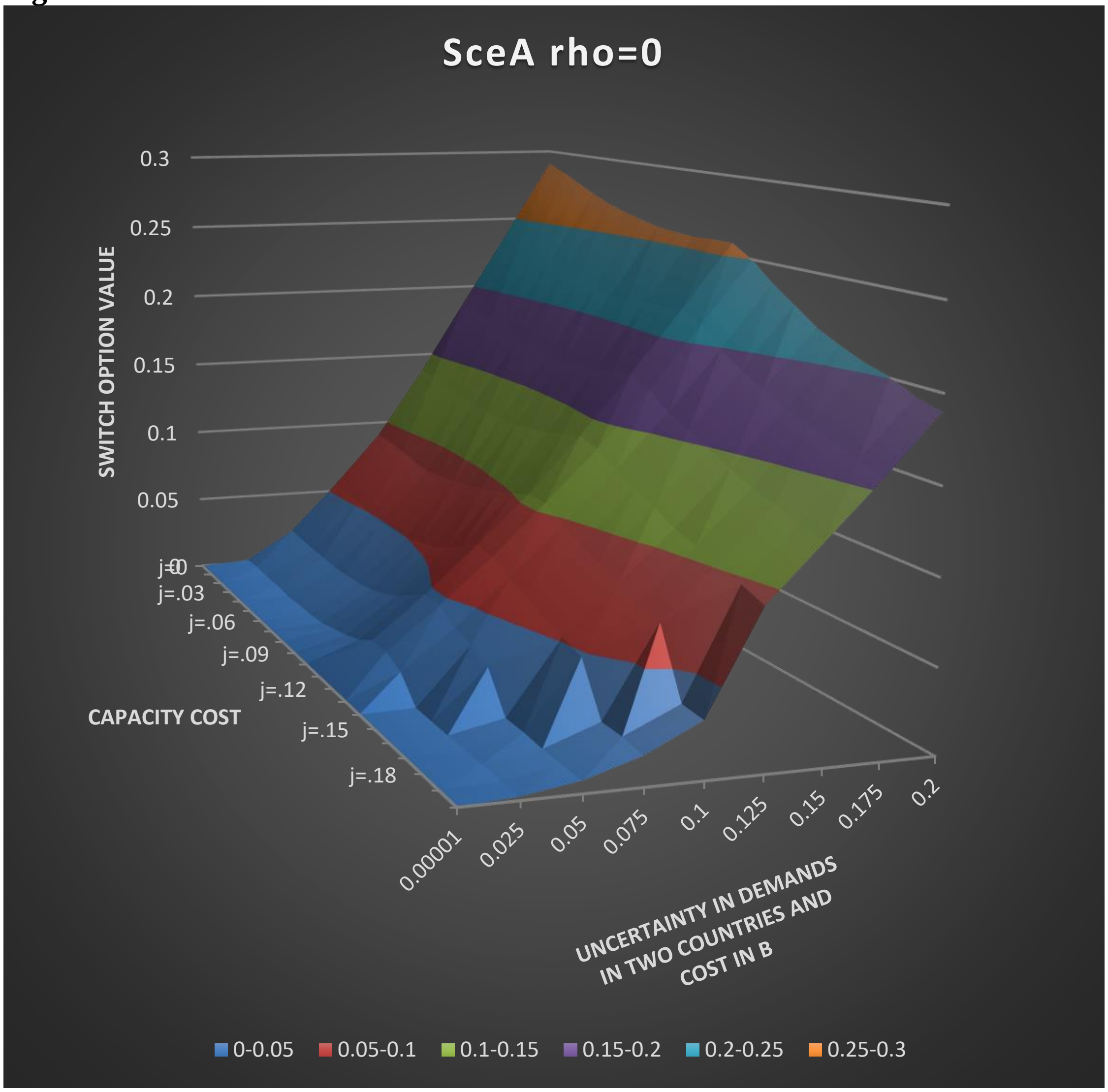

SceA rho=0
SWITCH OPTION VALUE
0.3
0.25
0.2
0.15
0.1
0.05
0
j=0
j=.03
j=.06
j=.09
j=.12
j=.15
j=.18
CAPACITY COST
0.00001
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
UNCERTAINTY IN DEMANDS IN TWO COUNTRIES AND COST IN B
0-0.05
0.05-0.1
0.1-0.15
0.15-0.2
0.2-0.25
0.25-0.3

Figure 3.4

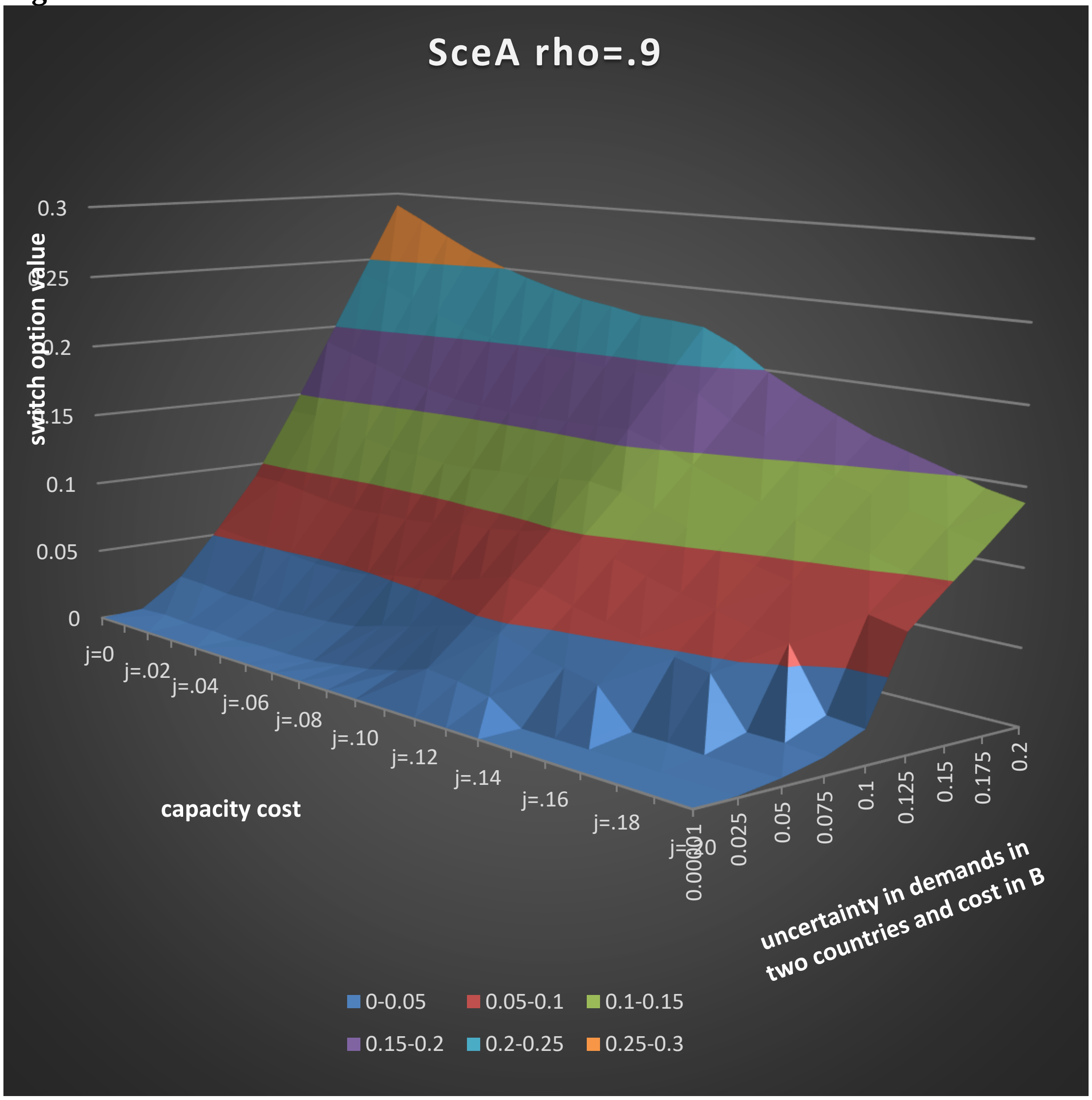

SceA rho=.9
switch option value
0.3
0.25
0.2
0.15
0.1
0.05
0
j=0
j=.02
j=.04
j=.06
j=.08
j=.10
j=.12
j=.14
j=.16
j=.18
j=.20
capacity cost
0.00001
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
uncertainty in demands in two countries and cost in B
0-0.05
0.05-0.1
0.1-0.15
0.15-0.2
0.2-0.25
0.25-0.3

Figure 3.5

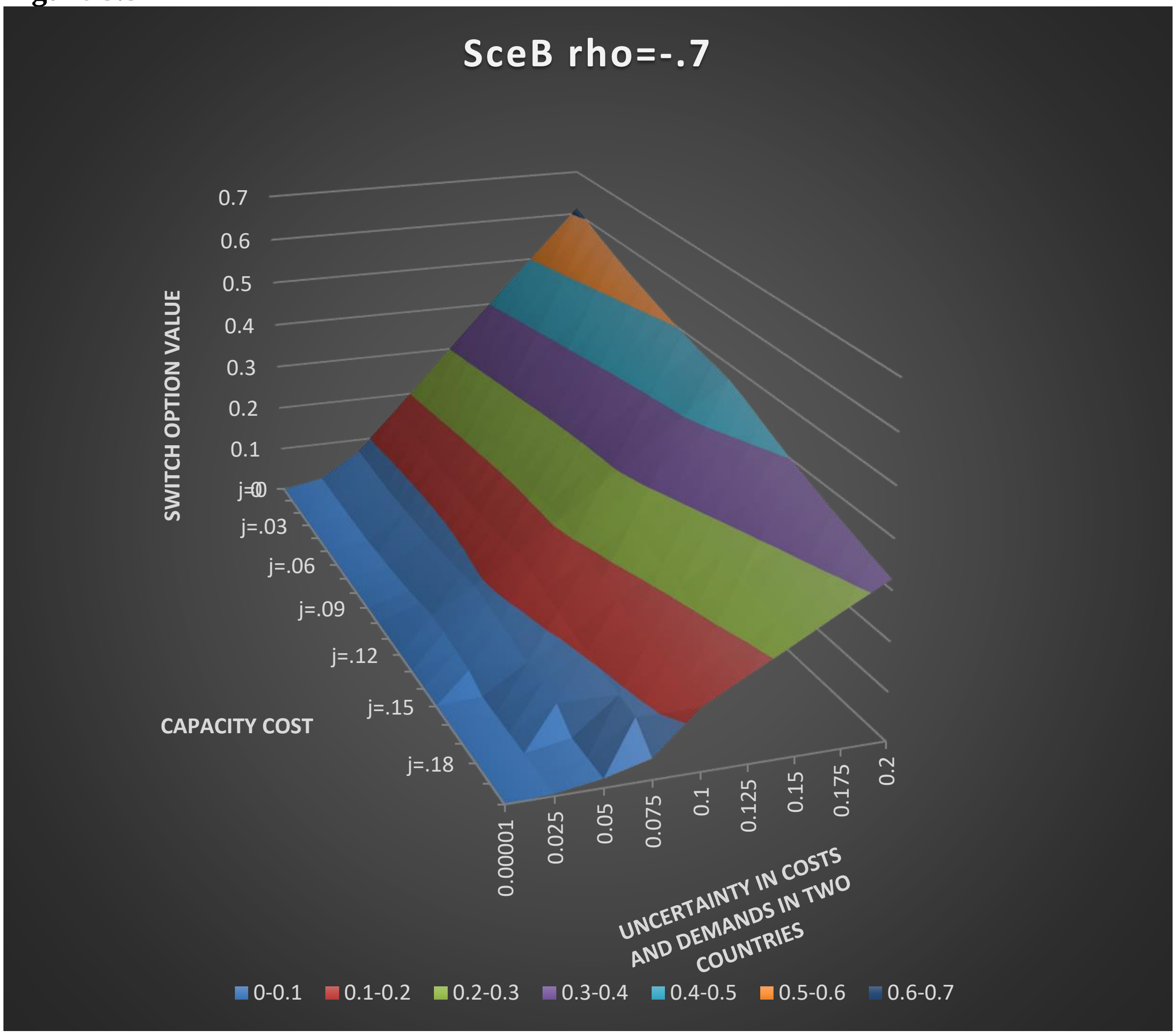

SceB rho=-.7
SWITCH OPTION VALUE
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
j=0
j=.03
j=.06
j=.09
j=.12
j=.15
j=.18
CAPACITY COST
0.00001
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
UNCERTAINTY IN COSTS AND DEMANDS IN TWO COUNTRIES
0-0.1
0.1-0.2
0.2-0.3
0.3-0.4
0.4-0.5
0.5-0.6
0.6-0.7

Figure 3.6

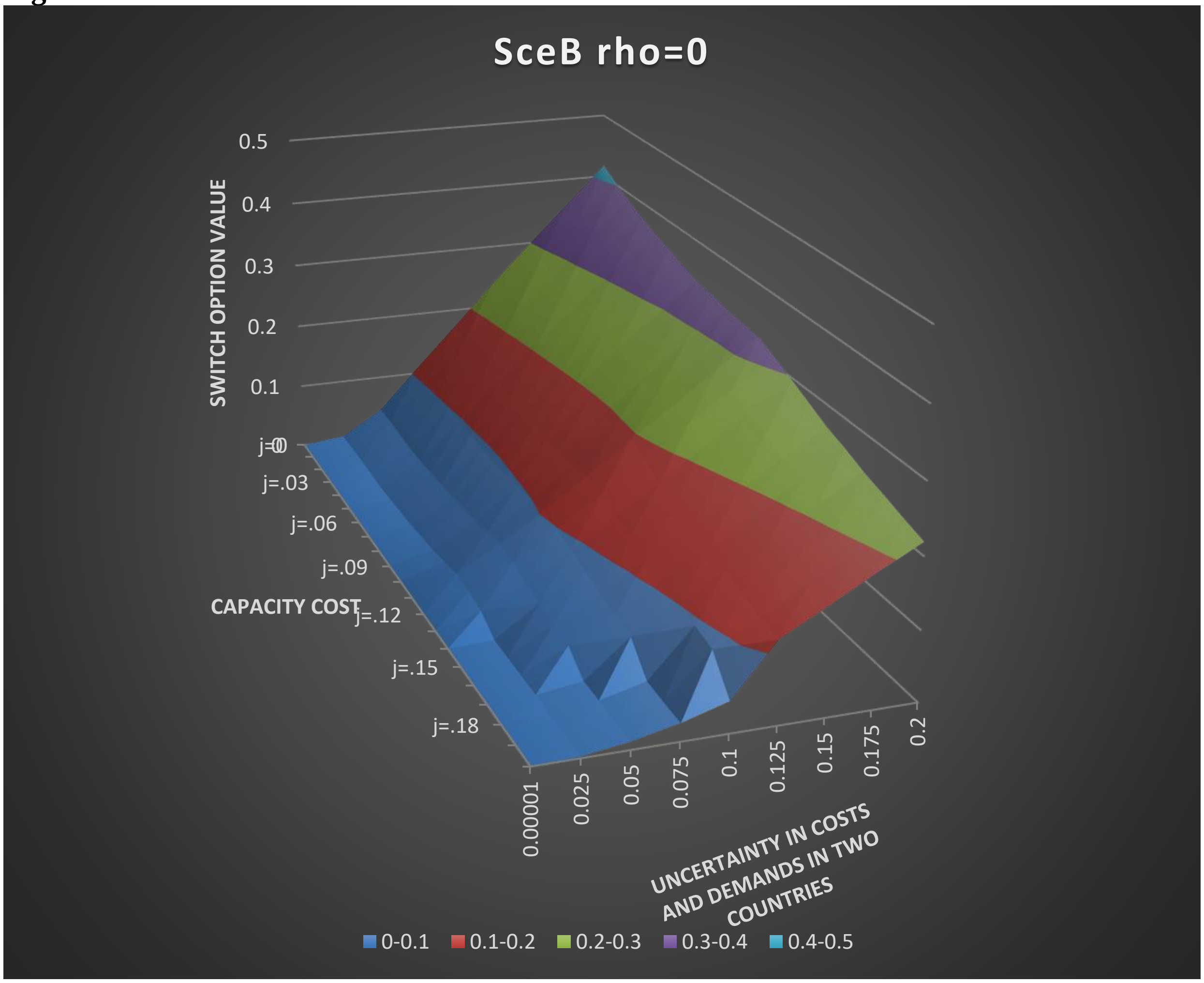
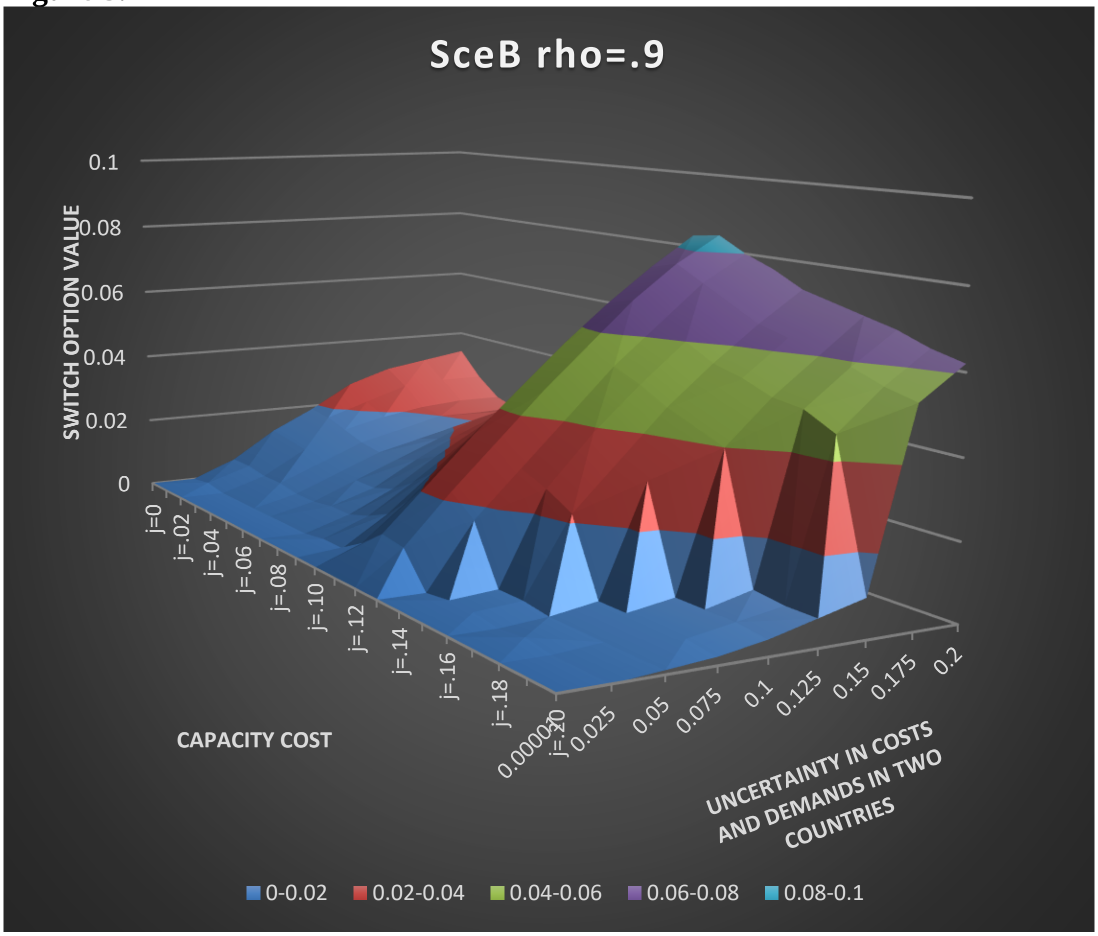
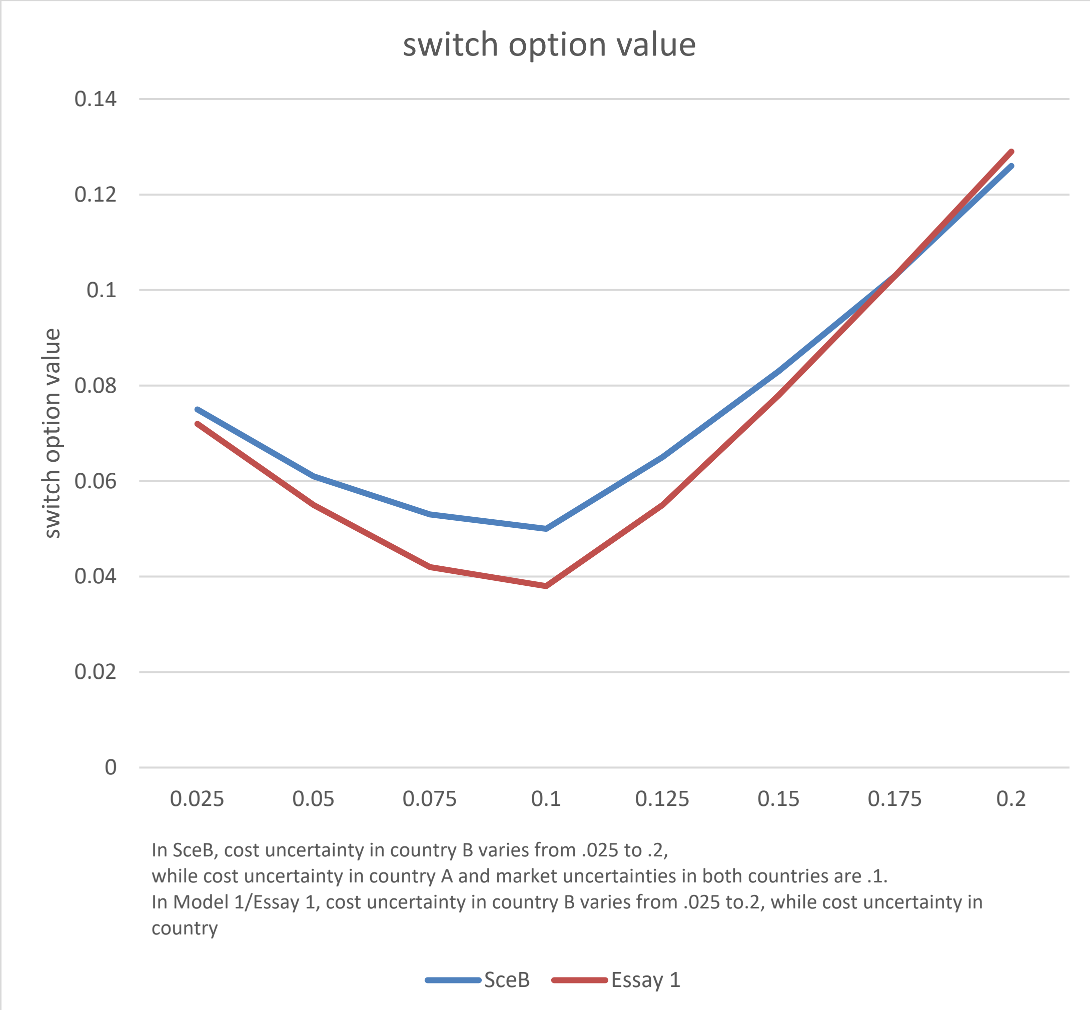

SceB rho=0
SWITCH OPTION VALUE
0.5
0.4
0.3
0.2
0.1
0
j=0
j=.03
j=.06
j=.09
CAPACITY COST
j=.12
j=.15
j=.18
0.00001
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
UNCERTAINTY IN COSTS AND DEMANDS IN TWO COUNTRIES
0-0.1
0.1-0.2
0.2-0.3
0.3-0.4
0.4-0.5

Figure 3.7



SceB rho=.9
SWITCH OPTION VALUE
0.1
0.08
0.06
0.04
0.02
0
j=0
j=.02
j=.04
j=.06
j=.08
j=.10
j=.12
j=.14
j=.16
j=.18
j=.20
CAPACITY COST
0.000001
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
UNCERTAINTY IN COSTS AND DEMANDS IN TWO COUNTRIES
0-0.02
0.02-0.04
0.04-0.06
0.06-0.08
0.08-0.1

Figure 3.8


switch option value
switch option value
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
In SceB, cost uncertainty in country B varies from .025 to .2,
while cost uncertainty in country A and market uncertainties in both countries are .1.
In Model 1/Essay 1, cost uncertainty in country B varies from .025 to.2, while cost uncertainty in country
SceB
Essay 1