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Robin Killian

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List of Abbreviations

CTH	Change in Tariff Heading
DCF	Discounted Cash Flow
FTA	Free Trade Agreement
HS	Harmonized System
IMF	International Monetary Fund
LC	Local Content
LP	Linear Programming
MIP	Mixed-Integer Programming
$NAFTA$	North American Free Trade Agreement
NPV	Net Present Value
RTA	Regional Trade Agreement
RVC	Regional Value Content
SAA	Sample Average Approximation
WTO	World Trade Organization

1 Introduction

Globalization is in force and has changed the image of today's world economy. Foreign Direct Investment has risen exponentially since the mid-1980's, which highlights the fast acceleration of this process (Jacob and Strube 2008, p.7). World-wide opportunities for production, sourcing and distribution deliver huge potential for growth. Hence, today's companies are obliged to exploit global manufacturing and sourcing options, to stay competitive in the long-run. Following this, almost all companies today either source globally, sell globally or have competitors that do, which initiates managers to configure their supply chains efficiently on a world-wide basis (Mentzer, Stank, and Myers 2007, p.1).

But modeling global supply chains is a challenging task, a variety of aspects such as duties, taxes, trade barriers, transfer prices and duty-drawbacks must be considered (Vidal and Goetschalckx 1997, p.2). A factor that comes into play is the huge rush of Regional Trade Agreements (RTA's) over the last two decades (Guerrieri and Dimon 2006, p.85). Until 15 May of 2011, 297 agreements were in force of which about 90% were Free Trade Agreements (FTA's) (WTO 2011c). FTA's have the inherent feature, that tariffs between member countries are eliminated, while external tariffs to non-members can be set individually (Krueger 1997, p.173). This would provoke large trade deflections without further regulations, since trade-flows from non-members to a FTA would enter exclusively through the country with the lowest external tariff (Ju and Krishna 2005, p.291). To avoid this effect, Rules of Origin (ROO's) are applied, which can arise in various forms. Widely-used ROO's are so-called Local Content (LC) requirements, where the local value-added (within a FTA) of a final good has to reach a certain minimum percentage during the last processing step, to ensure tariff-free shipments to other FTA-members (Plehn et al. 2010, p.4). To stay competitive in the long-run, it's crucial to take such constraints into account when designing global supply chains.

But, global supply chains are confronted in addition, with a substantial increase in the variety of risks such as exchange rate uncertainty, economic and political instability and changes in the regulatory environment (Meixell and Gargeya 2005, p.533). Especially currency fluctuations, demonstrate a significant risk for global supply chain networks. Today's financial- and economic markets cannot be considered separately, they are interconnected on a global basis. Following this, the impact of currency fluctuations can be very large, with changes of about 1-2% a day to differences of up to 20% within some months. Such fluctuations can cause heavy impacts on global operating firms (Simchi-Levi, Kaminsky, and Simchi-Levi 2008, p.317). It's advisable therefore, to consider exchange rate risk during the strategic orientation of a supply chain, to exploit arising opportunities and compensate for negative effects, if necessary.

1.1 Motivation

Following the previously stated arguments, this thesis deals with the development of a global network design model which incorporates exchange rate risk and LC regulations, that are implied by FTA's. Global production- and sourcing opportunities will be taken into account, to study the resulting trade-offs between sourcing costs advantages and LC-fulfillment in an uncertain exchange rate environment.

Special focus will be placed on the development of a stochastic program and the corresponding representation of future exchange rate scenarios. The corresponding LC-constraints will be based on the Transaction Value Method applied under the NAFTA, a quite general approach also widely used under other FTA's. The formulated model will therefore be easy applicable to other FTA's around the world. General impacts of exchange rate risk on the configuration of global supply chains shall be highlighted. However exchange rate fluctuations may also have an impact on the LC of final products, distributed within a FTA. Resulting implications on sourcing decisions in relation to RVC-compliance and there effects on product allocation decisions for a company which operates in the NAFTA are of special interest in this thesis.

1.2 Structure

The remainder of this thesis is structured in the following way. Chapter 2 states the theoretical framework regarding network design and the corresponding challenges in a global environment. Furthermore, Regional Trade Agreements will be discussed with a focus on the NAFTA and their inherent Rules of Origin. Finally, an overview of various supply chain risks will be stated, while exchange rate risk and resulting implications on LC regulations will be discussed in more detail.

Following the theoretical part, chapter 3 discusses fundamental principles regarding mathematical optimization, which are applied under the model formulation in chapter 4. General remarks on Mixed-Integer Programming (MIP) will be stated, while following sections are dedicated to stochastic programming.

In Chapter 4, the general model formulation will be presented. First of all, the relevant literature will be discussed, followed by a deterministic model formulation of the problem, which incorporates LC constraints implied by the NAFTA. The deterministic model will then be extended to a two-stage stochastic program under exchange rate uncertainty. Exchange rate risk will be constituted in binomial trees, to deliver in combination with the Sample Average Approximation (SAA) a solvable approach for the stochastic model. The resulting deterministic equivalent model is then stated in the last section.

Chapter 5 is dedicated to the appliance of the presented stochastic model in chapter 4 and highlights the optimization potential from considering exchange rate risk when configuring global supply chain networks. In addition, interrelations between exchange rate risk and LC-regulations will be pointed out in several case studies.

Finally, chapter 6 summarizes the findings of this thesis and provides an outlook for future research.

2 Supply Chain Design

The following chapter sets the theoretical framework for the remainder of this thesis. The scope ranges from general aspects of Supply Chain Management and Strategic Network Design in section 2.1, to Supply Chain Design and their requirements in today's global environment in section 2.2. Regional Trade Agreements will be discussed with a focus on the North American Free Trade Agreement (NAFTA) and their inherent Rules of Origin (ROO) in section 2.3. Finally, section 2.4 gives an overview of the various risks to which global supply chains are exposed, whereas exchange rate risk and possible interrelations with LC-requirements will be discussed in more detail.

2.1 Strategic Network Design

One of the most important planning activities of a (global) operating firm is the proper configuration of its supply chain, also referred to supply chain design or strategic network design. Generally, a supply chain includes all parties and network flows, from the supplier's supplier to the customer's customer. A huge amount of definitions can be found in the literature, which try to put these relationships into one sentence. One quite aptly phrased definition is stated in the article of Santoso, Ahmed, Goetschalckx, and Shapiro (2005, p.96), in which a supply chain is defined as *"a network of suppliers, manufacturing plants, warehouses, and distribution channels organized to acquire raw materials, convert these raw materials to finished products, and distribute these products to customers"*. In more general terms, a supply chain can be summarized by its legally separated organizations which are linked by *material*, *information* and *financial flows* (Stadtler 2008, p.9).

A supply chain's task can be considered as increasing its competitiveness, which can be reached either by a closer integration of the parties involved or through a better coordination of the material, information and financial flows (Stadtler 2008, p.11). A resulting trade-off may be the reduction of costs while ensuring a required customer service level. Following this considerations, Simchi-Levi et al. (2008, p.1) define supply chain management as *"a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and the right time, in order to minimize system-wide costs while satisfying service level requirements"*.

Depending on the planning horizon, generally three levels of planning decisions can be considered. Decisions regarding the operational level involve short-term decisions like scheduling operations to assure in-time delivery of final products to customers and range generally from hours to some days. The tactical level with a decision impact of some months to two years, prescribes material flow management policies, including production levels at all plants, assembly policy, inventory levels and lot sizes (Schmidt and Wilhelm 2000, p.1501). Supply chain planning at the strategic level may range, with respect to the nature of the company's business, from one to ten years and incorporates generally the decisions regarding network design (Shapiro 2007, p.307). The fundamental key strategic network design decisions include the following aspects:

- the location of each facility,
- the number of required manufacturing and distribution facilities,
- the allocation of products to the facility sites,
- the capacity size of each facility,
- the establishment of major manufacturing technologies,
- the selection of the target markets and their assignment to plant locations,
- the selection of the suppliers for sub-assemblies and materials and their assignment to plant locations,
- the selection of the right means of transportation (Simchi-Levi et al. 2008, p.80)

As a result of decisions like facility location or product allocation, decisions regarding the configuration of manufacturing capacity and the allocation of these capacities to products and markets are taken, which in turn defines the boundaries for the material flows on the tactical and furthermore on the operational level regarding daily business (Goetschalckx and Fleischmann 2008, p.118). Such relations and constraints can be modeled by the usage of Mixed-Integer Programming (MIP), as will be discussed in section 3.1, where decisions regarding supply chain design are often based on financial objectives. Therefore, the intention is often the maximization of the net present value (NPV) of the profits or the minimization of the respective costs, which accumulate in pre-specified time periods in the future, subject to demand and budget constraints (Goetschalckx and Fleischmann 2008, p.118). Beside costs, performance measures like reliability, responsiveness and flexibility might come into play, especially in a global environment (Meixell and Gargeya 2005, p.534). Following this, the challenge of strategic network design can be considered as the long-term optimization of the whole supply chain, to generate competitive advantages.

But in fact, the great deal of today's networks are archaic structures and only a fraction were strategically planned, which underscores the vast potential which can be captured from strategic network design (Jacob and Strube 2008, p.2). Hence, for the development of well-performing supply chains, decision makers have to recognize that they are *holistic*, *global* and *stochastic*, (Goetschalckx and Fleischmann 2008, p.118). The holistic approach of a supply chain network goes beyond conventional methods, where single aspects of the supply chain are considered separately. It observes a company's supply chain as on integrated network, from the suppliers through the manufacturing plants to the final buyer (Meyer and Jacob 2008, pp.142). Following the previously stated argument, the next sections give more detailed information on global aspects and supply chain risks.

2.2 Global Network Design

The trend toward globalization is not a new phenomenon. Companies had expanded their networks beyond their national boarders since centuries. However, the fast acceleration of this process delivers a new image of today's world economy (Jacob and Strube 2008, p.1). The world's demand for standardized products and higher-value goods can be observed in many instances. Emerging markets, in Asia, South-America or Eastern Europe have opened for these products and deliver huge potential for growth. At the same time, decreasing costs are the result of world-wide opportunities for sourcing and an increasing number of possible production, distribution and outsourcing options (Simchi-Levi et al. 2008, p.8). By taking advantage of this trend, the progress of globalization provides huge opportunities for firms to grow and to increase their competitiveness through economies of scale in relation to production, management and distribution (Jacob and Strube 2008, p.1). In this regard, almost all companies today either source globally, sell globally or have competitors that do, which forces managers to design their supply chains efficiently on a world-wide basis (Mentzer et al. 2007, p.1).

But generally, global supply chains are more difficult to manage since their material, information and financial flows are more complex and harder to coordinate (Vidal and Goetschalckx 1997, p.2). Both, domestic and global supply chains have to integrate factors such as market prices, production costs, interest rates and transportation costs. Regarding world-wide operations however, these factors are country dependent and therefore harder to predict (Schmidt and Wilhelm 2000, p.1502). Laborious transportation problems with the choice of different modes of transportation and their reliability arise, which lead to challenges in terms of coordination to insure in-time delivery on a global basis. Trade-offs like centralized production to achieve economies of scale versus decentralized production with a focus on customer service, evoke even more distinctive in respect to global production (Schmidt and Wilhelm 2000, p.1501). Apart from that, a range of additional aspects has to be considered for the design of well-performing supply chains in a global environment such as:

- duties and tariffs,
- duty drawbacks,
- non-tariff based trade-barriers such as local content requirements,
- subsidies and taxes,
- transfer prices,
- government regulations,
- exchange rates,
- a variety of additional risks (Vidal and Goetschalckx 1997, p.2)

Generally it can be said, that the successive elimination of tariff- and non-tariff based trade barriers is in progress under the force of the World Trade Organization (WTO) and their rounds of negotiation. But even in well-developed countries, custom duties are still high enough to have an influence on strategic decisions (Meyer 2008, p.80). In the case, that custom duties represent a substantial part of total landed costs, the study of complex duty-drawback regulations delivers also huge potential for supply chain optimization (Meyer 2008, p.80). Product allocation decisions to plants located in different countries can have fundamental effects on taxes paid by a company. Furthermore small differentials in transfer prices can have major effects on the tax burden of multinationals (Vidal and Goetschalcks 2001, p.135). In addition, governments usually offer different kinds of subsidies, like tax abatements to firms, which may have some implications on strategic decisions. Beside this macroeconomic issues, the availability of production technologies and infrastructural factors like supplier availability, supplier quality, skilled labor force and the existence of transportation and communication means can play an important role when designing supply chains (Chopra and Meindl 2007, pp.117-119).

Even if it's true that there was strong liberalization of world trade under the WTO and their multilateral intentions, there is a huge increase in Regional Trade Agreements (RTA's) observable. These regional alliances, bear complex non-tariff based trade barriers, like local content rules, where tariff-free distribution of goods between member countries is dependent on the local value-added within a RTA. Following this, these tasks and their implications on supply chain design are discussed in more detail in the next sections.

2.3 Regional Trade Agreements

As mentioned before, companies are more and more forced to take advantage of global sourcing and manufacturing to remain competitive in today's global environment. In contrast, governments are focused on the protection of their local industries, which can be realized through the establishment of Regional Trade Agreements (RTA). RTA's are introduced, among other things, to keep employment in domestic countries and to motivate firms to transfer their value-adding activities to the countries of the agreement (Plehn et al. 2010, p.1). These alliances are sometimes also designated to Preferential Agreements, since member countries of a RTA can allow preferential tariffs and easier market access conditions to each other, which don't hold for non-members (Pal 2004, p.1). A few examples of RTA's are the European Union (EU), the North American Free Trade Agreement (NAFTA), the Southern Common Market (MERCOSUR), the Association of Southeast Asian Nations (ASEAN) and the Common Market of Eastern and Southern Africa (COMESA), to mention the most active ones (WTO 2011b). Today's world economy is characterized by a huge increase of Regional Trade Agreements since the early 1990's, also known as *New Regionalism* (Guerrieri and Dimon 2006, p.85). Until 15 May of 2011, 297 agreements were in force of which about 90% were Free Tarde Agreements (FTA's) (WTO 2011c).

The reasons for this rush are extensively discussed in the literature, since the acceleration started. Bhagwati (1993, p.29) points out, that the conversion of the USA from a multilateral player to regionalism, especially with the negotiations about the North American Free Trade Agreement (NAFTA) at that time, had a major impact on the whole process. Baldwin (1995, p.13) talks about the *Domino Effect* of regionalism, meaning that major trading parties (like the USA and Europe) created regional trade blocks which initiated other countries to follow, for the most part with the motive of avoiding costs from staying apart. Guerrieri and Dimon (2006, p.88) state that foreign policy and security considerations rank among the driving forces of regionalism, which especially may be true for the development of the European Union (EU). Another trend is the increasing number of alliances between developed ("North") and undeveloped countries ("South"), also designated to "North-South" agreements. The main advantage for the "South" of such an alliance may be the attraction of Foreign Direct Investment (FDI) (Pal 2004, p.9), whereas for the "North", a way to dictate trade reforms and cheap manufacturing options may be the main focus (Heetkamp and Tusveld 2011, p.41). Further considerations of RTA's in this thesis are limited to Free Trade Agreements, and their inherent Rules of Origin (ROO) which are explained in the next section.

2.3.1 Free Trade Agreements and Rules of Origin

Rules of Origin (ROO) demonstrate the required criteria to determine the country of origin of a good and can be partitioned into preferential and non-preferential Rules of Origin (Heetkamp and Tusveld 2011, p.71). Non-preferential ROO's are used, among others things, to implement measures and instruments of commercial policy, such as anti-dumping duties and safeguard measures, for the purpose of trade statistics, for the application of labeling and marking requirements and for government procurement (WTO 2011d). On the other hand, preferential ROO's are used to determine whether a product originates in a FTA-member country and is therefore able to obtain preferential treatment (WTO 2011d).

The necessity for preferential ROO's arises from the legal shape of Free Trade Agreements. A FTA is generally characterized by a full elimination of all tariffs among member countries, while external tariffs of each member country to third parties, also known as Rest of the World countries (ROW), don't have to be necessarily identical (Krueger 1997, p.173). Without further regulations and ignoring transportation costs, this would lead to large trade deflections, since the trade flows from non-member countries to a FTA would enter exclusively through the country with the lowest external tariffs (Ju and Krishna 2005, p.291). The result would be the transshipment of goods through a low-tariff member country to a high-tariff one, without additional tariff costs (Estevadeordal, Harris, and Suominen 2007, p.2).

To avoid this effect, generally preferential ROO's are established, which means that a good qualifies for preferential treatment only if it originates in a member-country of a FTA (Ju and Krishna 2005, p.291). Their are generally two conditions which qualify a good as originating under preferential ROO's. The first one is that the good is *"wholly obtained"*, which means that the good has been produced, grown, harvested or extracted completely in a member country (Plehn et al. 2010, p.4). In that case, it's clear that the good originates in the country where it was wholly obtained, which leads to no further implications regarding network design. The second condition refers to the case, where two or more countries are involved in the production of a good. Generally, a product originates in the country where it was exposed to its last *"substantial transformation"*, which is of special interest for companies which manufacture their goods locally (within a FTA) but source parts on a global basis to benefit from lower input costs (Plehn et al. 2010, p.4). Hence, tariff free distribution of the final goods to other member of a FTA is only granted if the inputs have been substantial processed, which can generally be determined under three criteria:

1) A **Change in Tariff Heading (CTH)**, which is fulfilled if the processing of the imported parts will lead to a product with a tariff heading, that is different from its inputs (Falvey and Reed 2002, p.394). The tariff headings are normed by the Harmonized System (HS), which constitutes an international nomenclature developed by the World Customs Organization, which is arranged in six-digit codes. The HS allows all participating countries to classify traded goods on a common basis. Beyond the six-digit level, countries are free to introduce national distinctions for tariffs and many other purposes (WTO 2011e).

2) **Technical Requirements (TECH)**, which define certain criteria for the processing of a good to grant originating status (positive test) or not (negative test) (Falvey and Reed 2002, p.394).

3) The **Value Content Criterion (VC)**, specifies the minimum amount of local value required to treat a product as originating. In general, this criterion can appear in three different legal shapes. The first one is, that the difference of the value of the final good and the imported inputs has to reach a minimum threshold, which is also known as *Import Content (IC)*. Another method is, that a given *Value of Parts (VP)*, which is defined by the minimum amount of originating parts out of all components used, has to be fulfilled. The third method states, that a certain *Regional Value Content (RVC)* or *Local Content (LC)* has to be achieved. Hence, the RVC is defined as the minimum percentage of local value which has to be added during the last processing step (Plehn et al. 2010, p.4).

Depending on the agreement, all three criteria (CTH, TECH and VC) can be applied individually or in combination (Li, Lim, and Rodrigues 2007, p.425). The next section gives an overview of the legal framework adopted under the NAFTA. Special focus is tended to the Transaction Value Method, which is a form of the Regional Value Content or Local Content Criterion and demonstrates a quite general approach, also widely applied in similar ways under other FTA's.

2.3.2 The North American Free Trade Agreement

The North American Free Trade Agreement (NAFTA) is a FTA between the United States, Canada and Mexico which was established on January 1, 1994. It was generally based on a former agreement between Canada and the United States and created through the integration of Mexico one of the first big "North-South" agreements (Pethke 2007, 13). The general goal was the elimination of trade-barriers to boost the cross-boarder movement of goods and services between the parties of the trilateral trade bloc. A great deal of trade-barriers was repealed immediately, whereas others for more sensitive goods were eliminated over a period of 5-15 years. Since external tariffs of the parties are set individually, as usual under FTA's, a detailed framework of ROO's was established to avoid trade deflection (Pethke 2007, 13). The majority of ROO's are defined in Chapter 4 (NAFTA 2011a), supplemented by Annex 401 (NAFTA 2011a), which states a list of product specific ROO's in reference to Chapters 1-99 of the Harmonized System (HS). Chapter 5 (NAFTA 2011a) treats in addition the norms for the verification and the administrative accomplishment of the ROO's.

2.3.2.1 The Regional Value Content

The ROO's under the legal framework of the NAFTA are generally based on the so-called Change in Tariff Heading Criterion (CTH) (Stephan et al. 2010, p.5). However, a range of specific ROO's, basically set out in Annex 401 (NAFTA 2011a), may require a sufficient Regional Value Content (RVC) to qualify a good as originating. This means that a certain percentage of the value of the good has to be added within the NAFTA territory to justify preferential status. Except for some special cases, the exporter or producer has generally an option between two RVC calculation methods, the Transaction Value- and the Net Cost Method (NAFTA 2011a, Article 402 §1). The RVC regarding the Transaction Value Method is expressed as a percentage and defined in respect to Article 402 §2 (NAFTA 2011a) as:

$$RVC = \frac{TV - VNM}{TV} \cdot 100 \tag{2.1}$$

, where TV is defined as the transaction value of the good adjusted to a F.O.B. basis and VNM denotes the value of the non-originating materials used by the producer in the production of the good.

The term transaction value for a good or material is specified in Article 415 (NAFTA 2011a) as the price actually paid or payable for a good or material, which may be adjusted in accordance with the principles of §1, 3 and 4 of Article 8 of the Customs Valuation Code (WTO 2011a). The term transaction value specified under Article 415 (NAFTA 2011a) coincides generally with the definition of the customs value under Article 1 of the Customs Valuation Code (WTO 2011a). F.O.B means Free On Board, regardless of the mode of transportation, at the point of direct shipment by the seller to the buyer, according to Article 415 (NAFTA 2011a). Following this, Section 2 of the Rules of Origin Regulations (NAFTA 2011b) gives a more precise definition of the F.O.B. adjustment. Hence, the costs of transportation, loading, packaging and insurance from the point of direct shipment, shall be deducted from the transaction value (if included), when calculating the RVC under the Transaction Value Method. However the same costs shall be added until the point of direct shipment.

Additional regulations, regarding the materials used in the production of good are important for further considerations. A material shall be defined as a good, that is used in the production of another good (e.g. a part, component or ingredient) for the remainder of this thesis, in accordance with Article 415 (NAFTA 2011a). Following this, Article 402 §4 (NAFTA 2011a) states that the non-originating fraction of an originating material is generally not considered when calculating the RVC for a good under the Transaction Value Method. An originating material can therefore be processed with an inherent RVC of 100 %, which is also known as *"roll-up"*[1]. The same holds in the opposite direction. A non-originating material has therefore an inherent RVC of 0 %, even if it contains a certain originating fraction (*"roll-down"*) (Pethke 2007, p.112).

The value of the materials used in the production of a good is defined in Article 402 §9 (NAFTA 2011a) as the transaction value (the price actually paid or payable for a good or material) in reference to Article 1 of the Customs Valuation Code (WTO 2011a). In the case that no transaction value is available under this condition, the evaluation has to follow Article 2-7 of the Customs Valuation Code (applied in an hierarchical order), which lay down five other methods for the determination of the transaction value. However, the transaction value of the materials used has to include in either case the costs of freight, insurance, packaging and all other costs incurred in transporting the material to the location of the producer plus duties, taxes and custom brokerage fees (NAFTA 2011a, Article 402 §9c). Following this, the value of the non-originating parts must therefore include the transportation costs which incur for delivery to the producer. Further considerations regarding this thesis, are taken with respect to the Transaction Value Method, the Net Cost Method is therefore just stated in brief for completion and defined under Article 402 §3 (NAFTA 2011a) as:

$$RVC = \frac{NC - VNM}{NC} \cdot 100 \tag{2.2}$$

, where NC depicts the net costs of the good. The net costs are specified under Article 415 (NAFTA 2011a) as total cost minus sales promotion, marketing and after-sales service costs, royalties, shipping costs, packing costs, and non-allowable interest costs. The required RVC under the transaction value method is generally higher than that under the net cost method and set to at least 60%. This comes from the fact, that the TV includes all costs and the profit margin in contrary to the net costs. Hence, the required RVC under the net cost method is set to a minimum of 50% for a specific product (Pethke 2007, p.111). Exceptions from this general setting are settled in Annex 401 (NAFTA 2011a).

[1] This is not valid for sequences of production steps (*"cascading roll-up"*) in all cases, see (Pethke 2007, p.113) for further information on these special cases.

2.4 Supply Chain Risks

Strategic decisions incorporate significant investments and are hard to reverse in the short-run. Once they are made, they stay in place over several years to decades and define the boundaries within the supply chain must compete. The challenging task is, that during the time in which a supply chain operates, the environment may change substantially. Therefore, a company will experience fluctuations in demand, prices, production- and transportation costs, exchange rates and the competitive environment over the life of a supply chain network. Decisions that are compatible with the conditions today may work quite poor in the future (Chopra and Meindl 2007, p.152). As a result, it is essential to incorporate uncertainties in network design decisions to ensure competitive strength in the long-run.

Supply chain risks can have a variety of shapes and sources such as disruptions, forecast errors, system breakdowns, intellectual property infringements, procurement risks, inventory issues and capacity problems, whereas each risk class has its own drivers and mitigation strategy (Chopra and Sodhi 2004, p.53). Dealing with supply chain risks can be challenging, since single risks are often connected with each other. For example, the trend towards lean manufacturing and just-in time production may lower the risk from over-forecasting demand but in the case that anything goes wrong in the supply chain, e.g. a supply chain disruption, the impact might be huge (Chopra and Sodhi 2004, p.54).

Global supply chains are generally confronted with similar risks than domestic ones but additionally to other risks since they are geographically more diverse (Simchi-Levi et al. 2008, p.315). On the other hand, global operations in procurement, production and sales can also reduce the risk exposure of a company through diversification and arbitrage effects. Figure 2.1 gives an short overview of relevant supply chain risks, relevant from a global perspective. Risks such as natural disasters or geopolitical risks, are relative hard to quantify. In other words, it is quite impossible to identify the likelihood of occurrence for such scenarios in the long-run.

On the lower side of figure 2.1, are risks like supplier performance, forecasting errors and execution problems, which can be quantified to a large extent and can be

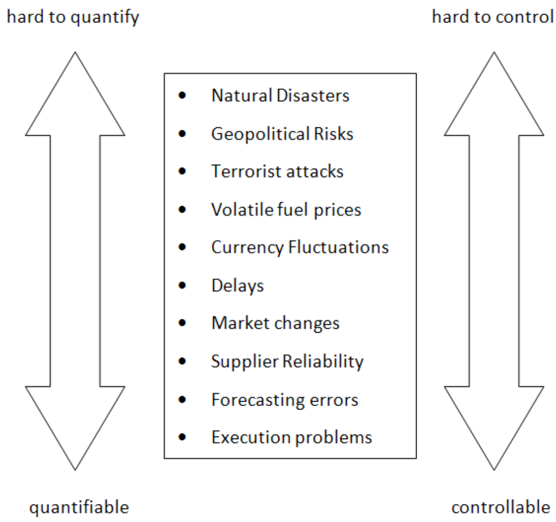

Figure 2.1: Supply Chain Risks
(Adapted from Simchi-Levi et al. (2008, p.316))

seen therefore as relative controllable. For example, forecasting errors and supplier performance can be analyzed by using historical data (Simchi-Levi et al. 2008, p.316). Risks which lie in between these two extremes, e.g. currency fluctuations, can be controlled to some extent, as will be stated in further sections of this thesis.

Meyer (2008, p.84) points out, that risks which become especially relevant for companies once when they start to globalize their operations are: Exchange rate risk, stochastic transportation costs and time, changes in tariffs and non-tariff based trade barriers, changes in legal regulations and uncertainties in the supply chain resulting from the length and complexity of transportation routes and communication hurdles. Following this, the next section gives more details on exchange rate risk in reference to the topic of this thesis.

2.4.1 Exchange Rate Risk

Currency fluctuations demonstrate a significant risk for global operating companies for a variety of reasons. First of all, the value of world-wide dispersed assets and liabilities is generally reported in the currency of the country where the headquarter of a company is located. This leads to changes in book values resulting from volatile exchange rates. While changes of book values may have some effect, it is generally the operating exposure which can have the most crucial impact on annual operating profit (Simchi-Levi et al. 2008, p.317).

The operating exposure may result from a variety of different channels: A firm may produce domestically to export products, a firm may buy components from foreign countries for domestic production or retail, or a firm may produce a product abroad (Bodnar and Marston 2003, p.110). Generally it can be said, that a depreciation of a currency stimulates exports and a appreciation makes imports more attractive. A US-based company for example, which produces its products domestically to export their products in further steps to foreign markets, is able to price its products competitively, in the case that the dollar is weak in contrast to foreign currencies (Lowe, Wendell, and Hu 2002, p.573). On the other hand, a company located in the US which sources components from a foreign supplier for domestic production, may suffer huge losses under a depreciation of the Dollar, if it relies only on this supplier. The impact of currency fluctuations can be very large, with changes of about 1-2% a day to differences of up to 20% within some months. Consider for example, the huge appreciation[2] of the Dollar versus the Euro, in the environment of the financial crisis (2007-2010) of about 22% from July to November 2008, as represented in figure 2.2. Such fluctuations can change operations from being extremely profitable to a complete loss.

But operating exposure, cannot be simplified to the fractions of revenues and costs generated in different currencies and their relative fluctuations. In fact, there can be essential differences between real exposure and nominal exposure. This comes from the fact, that shifts in exchange rates do not necessarily reflect inflation rates changes in the short-run (Simchi-Levi et al. 2008, p.317). The argument, that fluctuations in exchange rates are be balanced out by changes in purchasing power, may therefore hold for some products but not for all (Meyer 2008, p.87). Two extreme examples are diary products and crude oil. Where the market prices for diary products seem to be relative uncorrelated with the movement of exchange rates, the difference between the crude oil prices in different countries and their

[2] An appreciation of the Dollar is represented as a downturn in figure 2.2, since the Dollar is expressed in terms of one Euro. Generally, the USD is the quote currency and the EUR is the base currency in respect to the market conventions of exchange rate quotation.

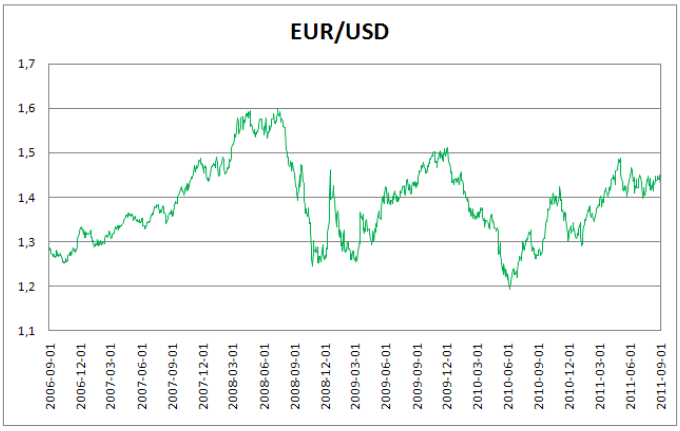

Figure 2.2: EUR/USD 5 year chart
(Data Source: IMF (2011))

respective exchange rate is almost balanced out immediately (Meyer 2008, p.89). Determining the real impact of exchange rate fluctuations ex-ante is therefore often a difficult task, since price levels of intermediate products and end products may adjust in different ways (Meyer 2008, p.87).

Hedging against exchange rate risk is often associated with financial instruments, like forwards, futures, swaps or currency options. But in most cases, financial derivatives are not very efficient in reducing the long-term exchange rate risk exposure of a firm's cash flows. Huchzermaier and Cohen (1996, p.107) state that financial hedging can even increase the risk of foreign market entry in the long-run, because it makes the cost structure predictable for competitors, while it hinders at the same time that global comparative cost differentials can be exploited. But the main problem originates from the fact that companies usually can't predict the exact structure of revenues and costs accumulating in the future. The complex relationships between market prices of intermediate/end products and currency fluctuations makes it hard to determine which imbalance demands hedging and over which time-frame in the most cases (Meyer 2008, p.85).

One way to hedge against volatile exchange rates is the adjustment of the effective cost and sales "footprint" to the exposure prevailing in different countries (Meyer 2008, p.90). In addition, several authors such as (Kogut and Kulatilaka 1994), (Huchzermaier and Cohen 1996) or (Kouvelis 1999, p.633) point out, that flexibility in terms of sourcing, production and distribution, defined as real options can mitigate against exchange rate risk exposure through operational hedging. Production and sourcing can therefore be relocated to countries with devalued currencies, where the respective costs are lower compared to other countries. At the same time, sales may be increased in markets where the value of the currency has appreciated, to gain an competitive advantage over rivals, while in markets with devalued currencies prices should be increased to avoid declining profit margins (Meyer 2008, p.90).

In summary it can be said, that exchange rate fluctuations can have a huge impact on the profit of global operating firms. As a result, the effects of volatile exchange rates should be considered seriously during the strategic configuration of a company's supply chain network, to exploit arising opportunities and compensate for negative effects, if necessary.

2.4.2 Exchange Rate Risk and Local Content

However exchange rate fluctuations can, besides the previously described effects, also have an impact on the Local Content of a final product. Consider the following simple network illustrated in figure 2.3, which operates in the territory of the NAFTA. A plant located in the US produces one final product, consisting of two parts, whereas one part can be sourced from a local supplier (US, within the NAFTA) and another one from a global supplier, located in the EURO-Zone. The final product is shipped in further steps to two sales markets (US, MX) within the NAFTA.

The LC of a final product will be calculated in reference to the Transaction Value Method illustrated in equation (2.2), in the following. It will be assumed therefore, that the transaction values of the final product, are consistent with the corresponding market prices, prevailing at the two sales markets (US, MX), while the non-originating costs coincide with the costs for the parts sourced from the EU-based supplier. Following this, tariff-free cross-boarder deliveries (plant-US $\rightarrow$ market-MX) are satisfied if the required Local Content of 60% is fulfilled. However, in the case of LC non-compliance, high punitive duties have to be paid for such shipments.

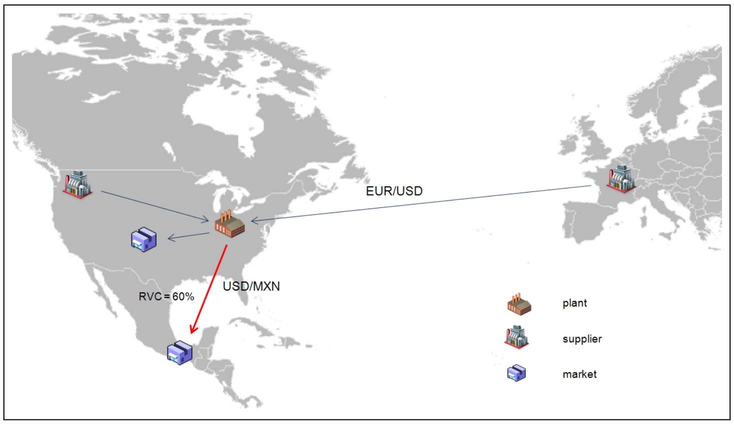

Figure 2.3: Exchange Rate Risk and Local Content: Network

In accordance with NAFTA's Transaction Value Method, the LC-value relevant for cross-boarder deliveries of the final product (plant-US → market-MX) has to be calculated on a per product basis in terms of USD-values, since the production plant of the company is located in the US (NAFTA 2011b, Currency Conversion). As obvious from figure 2.3, the transaction value for cross-boarder deliveries (market price MX) is therefore influenced by the USD/MXN exchange rate. On the other hand, fluctuations of the EUR/USD might have implications on the value of the non-originating sourced components (supplier-EU).

Following the example, the values of the two exchange rates are assumed to be 1.4 (EUR/USD) and 14 (USD/MXN) today (t=0). The sourcing costs for the non-originating parts (EU-based supplier) are set to 2.8 EURO/Unit, while the corresponding market price of the final product, prevailing at the Mexican market, shall be 140 Pesos by assumption. This leads finally to the following RVC calculation, valid for cross-boarder shipments today:

$$RVC_{t=0} = \frac{TV - VNM}{TV} \cdot 100 = \frac{140/14 - 2.8 \cdot 1.4}{140/14} \cdot 100 = 60.8\% > 60\% \qquad (2.3)$$

As obvious from equation (2.3), the LC-value is just 0.8 percentage points over the required RVC-threshold of 60%. Underachieving the requested LC, would lead to high punitive duty payments of 25% of the corresponding transaction value (customs value). Following this, two states of the respective exchange rates (EUR/USD = 1.4 or 1.2, USD/MXN = 14 or 17) will be assumed at t=1, to highlight the effects of currency fluctuations on the LC of a final product. Under the assumption of independently distributed exchange rates, a simple scenario tree is constructed, while each future state of the world (scenario) occurs with the same probability (0.25), as illustrated in figure 2.4.

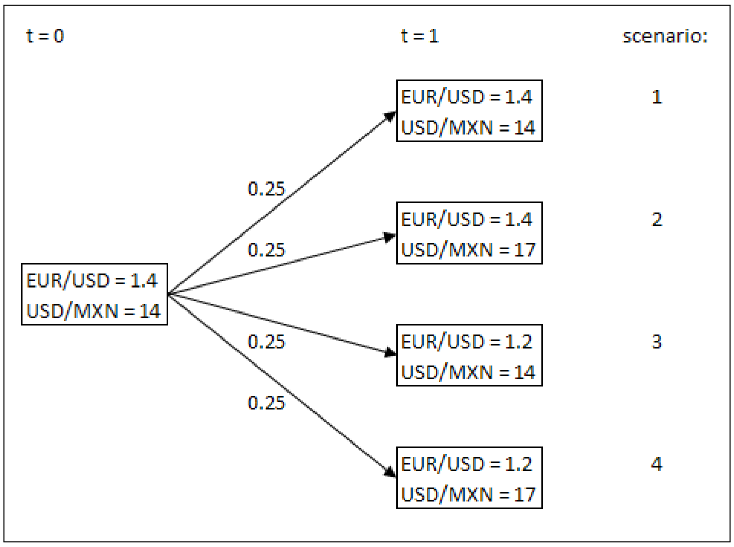

Figure 2.4: Exchange Rate Risk and Local Content: Scenario Tree

Following the proposed tree, scenario 1 expresses the case where the two exchange rates remain unchanged. The resulting LC-value is therefore the same as the value at t=0.

$$RVC_{scen.\,1} = RVC_{t=0} = 60.8\% > 60\% \tag{2.4}$$

Scenario 2 however, refers to an acceleration of the USD against the Mexican Peso (14 →17), while the EUR/USD exchange rate remains unchanged. This results in a lower transaction value in terms of USD-values, which finally leads to a decline of the corresponding RVC under the required threshold, as illustrated in equation (2.5). Hence, scenario 2 would result in unprofitable punitive duty payments, under the assumption that the demand at the Mexican market has to be fulfilled.

$$RVC_{scen.\,2} = \frac{TV - VNM}{TV} \cdot 100 = \frac{140/17 - 2.8 \cdot 1.4}{140/17} \cdot 100 = 52.4\% < 60\% \quad (2.5)$$

In contrast, scenario 3 refers to a devaluation of the EURO against the USD (1.4 →1.2), while the USD/MXN exchange rate remains constant. The result is a descent of the non-originating sourcing costs in relation to the USD, which leads to a higher LC-value for cross-boarder deliveries to the Mexican market (see equation (2.6)).

$$RVC_{scen.\,3} = \frac{TV - VNM}{TV} \cdot 100 = \frac{140/14 - 2.8 \cdot 1.2}{140/14} \cdot 100 = 66.4\% > 60\% \quad (2.6)$$

Scenario 4 refers to a state of the world, where both exchange rates change their values. The positive implication on the non-originating sourcing costs, provoked by the devaluation of the EURO against the USD (1.4 →1.2) however, are more than offset by the resulting negative effect on the transaction value, resulting from the acceleration of the USD against the Peso (14 →17). The result is a decline of the LC under the RVC-threshold of 60%, which leads to punitive duties as under scenario 2.

$$RVC_{scen.\,4} = \frac{TV - VNM}{TV} \cdot 100 = \frac{140/17 - 2.8 \cdot 1.2}{140/17} \cdot 100 = 59.2\% < 60\% \quad (2.7)$$

The previously stated example illustrates, how currency fluctuations can alter both, the transaction value and the value of the non-origination parts, which implies fluctuations of the corresponding RVC-value of a final good in accordance with equation (2.2). Hence, exchange rate fluctuations might have an impact on sourcing decision in relation to RVC-compliance, which in turn may have an influence on the network design of a global operating company. Following this, a strategic network design model which incorporates exchange rate risk and local content regulations will be developed in chapter 4 of this thesis. Several case studies, presented in chapter 5, highlight then the effects of exchange rate risk on the configuration of a global supply chain and their interdependencies with LC-regulations, implied by FTA's.

3 Mathematical Programming

The following chapter discusses principles regarding mathematical programming, used under the model formulation in chapter 4. First of all the idea of mixed-integer programming will be highlighted, while further sections are designated to stochastic programming.

3.1 Mixed-Integer Programming

Linear programming (LP) models include decision variables, defined as continuous variables which can take on any nonnegative values. The concept of mixed-integer programming (MIP) is based on a generalization of LP-models. Beside the definition of continuous variables, some of the variables are defined as integer variables, which are restricted to take on any nonnegative integer value. The majority of integer variables used in network design models are defined as binary variables, which can take on values of 0 or 1. Binary variables demonstrate powerful tools for supply chain analysis and are able to model important decision options that cannot be comprised by LP-models. For strategic network design problems, binary variables can be used to capture the timing, sizing and location of investment options such as the opening or closing of facilities or product allocation decisions (Shapiro 2007, p. 117).

Solution approaches for MIP-models like the branch-and bound method provide good solutions to the problems by optimizing MIP as a sequence of LP approximations. Optimal solutions can be achieved if decision makers are willing to wait long enough for the algorithms to identify them. However, the modeling power of MIP doesn't come without a cost, since the number of approximations that have to be solved to optimize a given problem can increase exponentially with the number of binary variables used in the model. Following this, MIP-models should be designed by using binary variables economically, to decrease computational effort (Shapiro 2007, p. 118). In the following, the Capacitated Warehouse Location Problem (CWLP), which incorporates the basic ideas of most network design models, is presented as a mixed-integer program. The CWLP is used as an example to explain the method of stochastic programming in the following sections.

$$min\ \ Z = \sum_{j \in J} f_j \cdot x_j + \sum_{j \in J} \sum_{m \in M} c_{jm} \cdot y_{jm} \tag{3.1}$$

The basic idea of this simple network design model is to find an optimal solution with respect to plant locations under a set of possible facility sites ($j \in J$), to meet the demand defined for a given set of demand points or markets ($m \in M$). Decisions regarding plant locations are modeled by the use of the binary decision variable $x_j \in \{0, 1\}$, which activate the fixed costs f_j for the opened plants ($x_j = 1$). The decision variables $y_{jm} \geq 0$ model the network flows with their corresponding unit variable transportation costs c_{jm}, which incur from plant j to market m.[1]

$$\sum_{j \in J} y_{jm} = D_m \qquad \forall m \tag{3.2}$$

$$\sum_{m \in M} y_{jm} \leq K_j \cdot x_j \qquad \forall j \tag{3.3}$$

$$x_j \in \{0, 1\}; \ \ y_{jm} \geq 0 \tag{3.4}$$

The problem in this simplified form, represents basically a trade-off between investment costs (fixed costs f_j) and the costs from the resulting transportation problem. The objective function (3.1) therefore, minimizes the total costs of setting up

[1] In real-world problems, decisions regarding network flows are integer decisions, since it is not possible to produce a fraction of a product. However, this integer constraint is often relaxed to reduce computational effort, especially for large problems.

and operating the network. Constraint (3.2) ensures, that the demands D_m occurring at the different markets m are always satisfied, whereas constraint (3.3) models the restrictions regarding plant capacities K_j for the opened plants ($x_j = 1$).

3.2 Stochastic Programming

Stochastic Programming provides the tools for solving optimization problems where some input data involve uncertainty. Deterministic optimization problems, like program (3.1), are designed under the assumption that all parameters are known with certainty. This seems to be a strong assumption since almost all real world problems include some uncertainty. To consider uncertainty, stochastic programming models are designed under the assumption that probability distributions of the respective data are known or can be estimated. The most widely studied and applied stochastic programming models are two-stage stochastic programs with recourse, which will be explained next in the following section.

3.2.1 Two-Stage Stochastic Programming with Recourse

As mentioned before, stochastic linear programs can be considered as linear programs where some input data involve uncertainty. Data uncertainty means, that the respective parameters are represented by random events $\omega \in \Omega$, where Ω defines the set of random events which can be described by known probability distributions, densities or more generally, probability measures (Birge and Louveaux 1997, p.52). Recourse programs can be defined as programs where so-called recourse or compensation actions can be conducted after the random events ω have presented themselves.

From this it follows, that under the two-stage stochastic programming approach, the decisions can be partitioned into two sets:

- Decisions which have to be taken before the actual realizations of the random events are known, are defined as *first-stage decisions*. The corresponding period in which these decisions have to be taken is called *first-stage* (Birge and Louveaux 1997, p.52).

- Decisions which can be conducted after the uncertain data is known (recourse decisions), under a given set of first-stage decisions, are defined as *second-stage decisions*. Whereas the *second-stage* is defined as the period in which these decisions have to be taken (Birge and Louveaux 1997, p.52).

The method of two-stage stochastic programming, achieves the requirements of strategic network design models under uncertainty in a good manner. This will be illustrated next by the extension of the deterministic program (3.1) to a two-stage stochastic program (3.5), assuming uncertainty about transportation costs.

$$\begin{aligned} min\ \ Z = & \sum_{j \in J} f_j \cdot x_j \\ & + min\, E_\Omega \left[\sum_{j \in J} \sum_{m \in M} c_{jm}(\omega) \cdot y_{jm}(x_j, \omega) \right] \end{aligned} \tag{3.5}$$

In the context of the simple Network Design Model, the first-stage decisions (plant locations x_j) on the strategic level have to be decided before the uncertain events $\omega \in \Omega$ (which influence the transportation costs $c_{jm}(\omega)$ through a functional dependence) have presented themselves. Once the uncertain information, represented by a single random event ω becomes available, further improvements on the tactical (operational) level can be made by choosing at a certain cost the second-stage decision variables (production quantities $y_{jm}(x_j, \omega)$) (Shabbir and Shapiro 2002, p. 118). Following this considerations, the sequence of actions is presented in figure 3.1, as illustrated below.

$$\begin{array}{|lclclc|} \hline decision\ \ x_j & \longrightarrow & observations\ \ \omega & & & \\ & \longrightarrow & realizations\ \ c_{jm}(\omega) & \longrightarrow & compensations\ \ y_{jm}(x_j, \omega) & \\ \hline \end{array}$$

Figure 3.1: Decision sequence of a two-stage stochastic program

The independence of the first-stage decisions x_j on a single random event ω, is a basic feature of stochastic programs, which is also known as *nonanticipativity* (Shapiro, Dentcheva, and Ruszczynski 2009, p. 52). As defined before, after the realization of a single state of the world ω, the information on the random variable

$c_{jm}(\omega)$ becomes available. However, the dependence of y_{jm} on ω is of a different kind of nature as the dependence of c_{jm} on ω. This dependence is not functional but demonstrates that the decision about y_{jm} are basically not the same under different realizations of the random events (Birge and Louveaux 1997, p.54). In fact they are chosen in a way that constraints (3.6) - (3.8) hold.

$$\sum_{j \in J} y_{jm}(x_j, \omega) = D_m \qquad \forall m, \omega \qquad (3.6)$$

$$\sum_{m \in M} y_{jm}(x_j, \omega) \leq K_j \cdot x_j \qquad \forall j, \omega \qquad (3.7)$$

$$x_j \in \{0,1\} \quad \forall j; \;\; y_{jm}(x_j, \omega) \geq 0 \quad \forall j, m, \omega \qquad (3.8)$$

Objective (3.5) therefore is composed of a deterministic first-stage and the expectation of the second-stage objective, designated by the expectation operator E_{Ω}, in respect to all possible realization of the random events $\omega \in \Omega$. The second-stage is the more challenging one, and represents the main difference to a deterministic problem, since for every realization of ω the value of $y_{jm}(x_j, \omega)$ is the solution of a linear program (Birge and Louveaux 1997, p.54). In summary it can be said, that the objective of the two- stage stochastic program is to select the first-stage decision variables in a way, that the sum of the first-stage costs and the expected value of the second-stage costs is minimized.

The optimal policy from such a program gives useful information to decision makers, consisting of the optimal solution for single first-stage decisions and a range of second-stage decisions, defining which recourse decisions should be taken under the realization of the single random events.

3.2.2 Stages vs. Periods; Two-Stage vs. Multi-Stage

This section gives some remarks on the difference between periods and stages and their impact on stochastic programming. Starting point is the two-stage stochastic program (3.5), with the difference that the problem will be considered over multiple periods. Hence, the uncertain information is disclosed gradually over time and represented by a stochastic process. Generally, a stochastic process can be defined by a sequence of random events $\omega_t \in \Omega_t$ over time $(t = 1 \ldots T)$ with a specified probability distribution (Shapiro et al. 2009, p. 63). The program can then be defined as:

$$\begin{aligned} min\ Z = & \sum_{j \in J} f_j \cdot x_j \\ & + min \sum_{t \in T} E_{\Omega_t} \left[\sum_{j \in J} \sum_{m \in M} c_{jmt}(\omega_t) \cdot y_{jmt}(x_j, \omega_t) \right] \end{aligned} \tag{3.9}$$

Under this setup, all decisions which are independent on single random events (plant locations x_j, nonanticipativity), have to be taken before the realizations of the stochastic process ($\omega_t \in \Omega_t$ over $t = 1 \ldots T$) have presented themselves. The model includes therefore the deterministic first-stage, with the corresponding first-stage decision variables regarding plant locations x_j and the second-stage, represented by the expectations of the second-stage value functions $Q_t\left(x_j, y_{jmt}(x_j, \omega_t)\right)$ in reference to the uncertain variables (transportation costs $c_{jmt}(\omega_t)$). Hence, the associated second-stage compensation variables $y_{jmt}(x_j, \omega_t)$ respond to the realizations of the stochastic process over time, and are set in a way that the constraints (3.6) - (3.8) of program (3.5) hold for all specified time points t. The objective of program (3.9) is therefore to select the first stage decisions in a way, that the first stage costs and the sum of the cost of the expected value functions of the second-stage are minimized. Such a program may be defined as a two-stage stochastic program with multi-period compensation, the sequence of this setting is illustrated in figure 3.2.

Under a multi-stage setting however, the problem includes sequences of decisions over time (Birge and Louveaux 1997, p.234). This mean, that the decisions (plant locations x_{jt}) should be adjusted to defined stochastic process (Shapiro et al. 2009, p.

stage 1:		**stage 2:**		
decision x_j	$\longrightarrow$	*observations* ω_1		
	$\longrightarrow$	*realizations* $c_{jm1}(\omega_1)$	$\longrightarrow$	*comp.* $y_{jm1}(x_j, \omega_1)$
		$\vdots$		
	$\longrightarrow$	*observations* ω_T		
	$\longrightarrow$	*realizations* $c_{jmT}(\omega_T)$	$\longrightarrow$	*comp.* $y_{jmT}(x_j, \omega_T)$

Figure 3.2: Decision sequence of a multi-period two-stage stochastic program

63). The history of the stochastic process can then be defined by $\Omega_{[t]} := (\Omega_1, \cdots, \Omega_t)$. Hence, the decisions x_{jt} at stage t may therefore depend on the information available up to time t ($\Omega_{[t]}$) but not on future information, which reflects the basic requirements of *nonanticipativity* Shapiro et al. (2009, p. 63). A result of such a program is, that the expected value functions are nested and not independent of each other like before in program 3.9. The nested sequence of decisions of the multi-stage stochastic program is illustrated in figure 3.3, for a better understanding.

stage 1:		**stage 2:**		**stage 3:**	$\cdots$	**stage T:**
dec. x_{j0}	$\longrightarrow$	*obs.* ω_1				
	$\longrightarrow$	*real.* $c_{jm1}(\omega_1)$				
	$\longrightarrow$	*comp.* $y_{jm1}(x_{j0}, \omega_1)$				
	$\longrightarrow$	*dec.* x_{j1}	$\longrightarrow$	*obs.* ω_2		
			$\longrightarrow$	*real.* $c_{jm2}(\omega_2)$		
			$\longrightarrow$	*comp.* $y_{jm2}(x_{j1}, \omega_2)$		
			$\longrightarrow$	*dec.* x_{j2}	$\longrightarrow$	$\cdots$
					$\vdots$	
					$\longrightarrow$	*obs.* ω_T
					$\longrightarrow$	*real.* $c_{jmT}(\omega_T)$
					$\longrightarrow$	*comp.* $y_{jmT}(x_{j(T-1)}, \omega_T)$

Figure 3.3: Decision sequence of a multi-stage stochastic program

Generally, there are two ways of implementing multi-stage stochastic programs. The first one is to define the decision variables x_{jt} as a function of the stochastic process up to time t, designated by $x_{jt}(\Omega_{[t]})$ under consideration of so-called nonanticipativity constraints. Another possibility is to write a corresponding dynamic program, with the basic idea to calculate the value function recursively, starting at the last stage and going backward in time (Shapiro et al. 2009, p. 64). Further considerations in this thesis are designated to programs as illustrated in equation (3.9). However, the interested reader can find a full mathematical representation of a T-stage stochastic program in the book of Shapiro et al. (2009, p.64) and the definition of a corresponding dynamic programming representation in Shapiro et al. (2009, p. 65).

3.2.3 The Sample Average Approximation

Generally, a discretization of the uncertain events is necessary to convert a stochastic program into a solvable approach. Hence, the stochastic components of a problem have to be replaced by discrete scenarios. In a multi-period environment, a scenario can generally be defined as the sequence of the discrete realizations, prevailing at the defined time points t, in accordance with the underlying stochastic process. The idea behind this approach is, that all scenarios together are able to describe the defined distributions of the uncertain variables in a good manner.

Following this, S discrete scenarios have to be generated for the observed stochastic variables, with $\omega_{s1} \ldots \omega_{sT}$ realizations over the specified time frame ($t = 1 \ldots T$). The corresponding probabilities of occurrence of each realization at a specific point in time shall be designated by $p(\omega_{st})$ with $\sum_{s \in S} p(\omega_{st}) = 1, \forall t$. Following the proposed example, the stochastic transportation costs $c_{jmt}(\omega_t)$ are replaced by its discrete realizations c_{jmst}, which describe their underlying distribution in reference to time. In accordance to program (3.9), the expected value functions of the second-stage can then be approximated by the Sample Average Function $\sum_{s \in S} p_{st} \cdot Q_t \left(x_j, y_{jmt}(x_j, \omega_t) \right)$ for each time period ($t = 1 \ldots T$) (Shabbir and Shapiro 2002, p.3). A stochastic program can therefore be converted into a solvable approach through the appliance of the Sample Average Function, as depicted in program (3.10).

$$
\begin{aligned}
min\ \ Z = & \sum_{j \in J} f_j \cdot x_j \\
& + \sum_{t \in T} \sum_{s \in S} p_{st} \cdot \left[\sum_{j \in J} \sum_{m \in M} c_{jmst} \cdot y_{jmst} \right]
\end{aligned}
\tag{3.10}
$$

The corresponding constraints (3.11) - (3.13) of the reference example can then be formulated as illustrated below.

$$\sum_{j \in J} y_{jmst} = D_m \qquad \forall m, t, s \tag{3.11}$$

$$\sum_{m \in M} y_{jmst}(x_j, \omega) \leq K_j \cdot x_j \qquad \forall j, t, s \tag{3.12}$$

$$x_j \in \{0, 1\} \quad \forall j; \ \ y_{jmst} \geq 0 \quad \forall j, m, t, s \tag{3.13}$$

The result of such an approach is, that decisions like plant locations or product allocations can be configured in a way that they are optimal under the sum of all considered scenarios, while the network design may be suboptimal under the realization of single scenarios.

4 Model Formulation

The following chapter is designated to the development of a strategic network design model in reference to a company with manufacturing plants, located in the territory of the NAFTA. The company produces several products consisting of parts, which can be sourced either from local suppliers (within the NAFTA territory) or from global ones. First of all, the relevant literature will be discussed, followed by a more detailed problem statement. In a next step a deterministic model formulation will be presented, tailored to the specific RVC requirements under the NAFTA. The deterministic model will then be extended to a stochastic model formulation which incorporates exchange rate risk. The stochastic behaviour of the uncertain variables will be constituted in binomial tree models to deliver in connection with the Sample Average Approximation a solvable approach for the stochastic model in the last section.

4.1 Literature Review

The following literature review presents papers, related to the topic of this thesis. General terminology regarding FTA's, supply chain risks and stochastic programming can be found in previous sections. The review is sub-divided into two parts, the first one discusses papers concerning global aspects, especially LC requirements and the second part is designated to supply chain risks with a focus on exchange rate risk and stochastic network design models. The categorization of the literature comes from the fact, that most relevant papers don't include both subject areas.

Arntzen et al. (1995) presented on of the first big Global Supply Chain Models (GSCM) which was developed for the Digital Equipment Corporation to optimize their world-wide manufacturing and distribution strategy. The proposed model is formulated as a mixed-integer problem (MIP) with the objective of minimizing total costs and weighted activity time (the time needed to perform an operation). Decisions concerning multiple products consisting of multiple parts, facility locations, different production stages and technologies, time periods and transportation modes are included. The proposed model considers global aspects such as taxes, duty payments, duty drawbacks and local content requirements. The authors delivered a quit general but large deterministic model.

One of the early papers with a focus on local content rules and supply chain design is presented by Munson and Rosenblatt (1997). They state a single plant and a multi plant mixed-integer model to study the impact of local content rules on global sourcing, both from a value- and quantity-based perspective. Moreover, economic questions such as negative effects of to restrictive RVC requirements are discussed. Under this approach, local content requirements are modeled as binding constraints with the assumption, that the resulting penalties from a violation are too high to demonstrate an option.

Kouvelis, Rosenblatt, and Munson (2004) present a multi-period mixed-integer program formulation which maximizes the discounted after-tax cash-flows of a global operating firm. The proposed model explicitly considers government subsidies in facility financing, taxes, trade tariffs and regional trade rules such as local content requirements and describes their influences on the shape of global manufacturing and distribution networks. In contrary to the approach stated by Munson and Rosenblatt (1997), the proposed model allows for an optional fulfillment of LC requirements, under the condition that a tariff-penalty has to be paid for non-compliance of the required RVC. The authors presented in addition various case studies, which give useful insights in the nature of several global aspects in connection with supply chain deign. Concerning LC requirements, they proposed a sensitivity analysis regarding RVC values, with the result that reasonable RVC values are able to transfer the value-added activities to the member-countries of a FTA, while inappropriate settings might have the opposite effect.

On the basis of the insights proposed by Kouvelis et al. (2004), Li, Lim, and Rodrigues (2007) defined a non-linear MIP-program with an appliance to the Japan-Singapore Economic Partnership (JSEPA). They proposed an algorithmic approach for linearization, using dynamic programming for the uncapacitated sourcing problem and a column generation approach for the capacitated case, which allows to solve realistic large scale problems within reasonable time. The defined LC constraints, which allow for optional RVC compliance, are tailored to the specific legal requirements of the JSEPA. Hence, the proposed RVC constraints are based on the transaction value method, applied for each product unit exported. In addition, numerical studies are presented which describe the effects of ROO's on sourcing strategies to highlight their strategic optimization potential.

The paper presented by Guo et al. (2008) is dedicated to the multi-stage Production Line Design Problem (PLD) in which a global operating company makes decisions on where to source and locate its manufacturing plants under consideration of world-wide production cost differentials and different tariff concessions, arising from FTA's. The problem is modeled as a mixed-integer problem with the objective to find an assignment of production stages to countries with the goal of minimizing total costs. Costs under consideration are, production-, transportation-, and tariff costs under consideration of FTA tariff exemptions regarding RVC requirements. Since the problem is NP-hard, they proposed a multi-exchange heuristic which embeds a Very Large Scale Neighborhood (VSLN) search in a Simulated Annealing (SA) framework. Numerical studies, based on a fictive test design highlighted the speed of the proposed metaheuristic and showed its ability to solve large scale realistic problems.

Stephan et al. (2010) modeled explicitly the legal framework regarding local content for a truck manufacturer located in the NAFTA, for which the Net Cost Method is obligatory. The authors presented a non-linear mixed-integer network design model which enables for optional RVC-compliance. Further, an accurate allocation of the fixed costs was proposed, which allows for an exact calculation of possible duty payments. The resulting non-linearity of the problem was solved by a nested linear approximation method. In addition, two case studies in reference to the automotive industry were presented. The first one highlighted the impact of different RVC calculation methods on production and sourcing strategies, while the second one was dedicated to study the implications of NAFTA's LC-regulations on strategic network design decisions.

An additional overview of global supply chain models can be found in Schmidt and Wilhelm (2000), Goetschalckx et al. (2002), Meixell and Gargeya (2005) or Melo et al. (2009) while the review papers of Snyder (2006), Vanany et al. (2009) or Peidro et al. (2009) give an overview of stochastic models, which will be discussed in the following.

The paper presented by Huchzermaier and Cohen (1996) is one of the basic reference articles concerning exchange rate risk. They stated a stochastic dynamic program for the valuation of global manufacturing strategy options (real options). The presented model is formulated as a discounted cash flow model (DFC) which maximizes the global after-tax value of a firm through the exercise of real options regarding sourcing, production and distribution with the aim of hedging against global exchange rate exposure (operational hedging). Exchange rates are modeled as stochastic diffusion processes (Geometric Brownian Motion) under consideration of inter-country correlations. Further, a multi-nominal approximation model in form of a tractable lattice tree model is proposed to develop a solvable solution approach for the stated compound option valuation model. The advantage of flexibility and operational hedging in contrast to financial derivatives as well as trade-offs between globalization and localization are demonstrated on the basis of a fictive test design.

Kouvelis (1999) studied the effects of exchange rate risk and price uncertainty on sourcing decisions. Volatile exchange rates are modeled in a similar way as in the paper presented by Huchzermaier and Cohen (1996) and represented by correlated stochastic diffusion processes. The author proposed a valuation model based on sourcing options, to study the impact of multi-supplier sourcing on global operating networks. One of the main findings was, that firms are willing to source from more expensive suppliers in the case that switching costs are more costly than the gains from lower sourcing costs. This effect of inaction was defined as hysteresis band.

In the article of Lowe et al. (2002), a two-phase screening approach for possible network design options under exchange rate risk is discussed. Phase 1 of the approach consists of a one-year-ahead analysis of preselected network configurations under utilization of methods such as Pareto optimality, maximum regret, Markowitz mean-variance efficiency and pairwise stochastic comparison in reference to plant locations and the value of over-capacities in an uncertain exchange rate environment.

Extensive data sets can be simplified through the appliance of phase 1, which in turn leads to less complex and easier solvable problem settings for an in-deep analysis in phase 2, if required. The authors presented a quite practical approach and applied their screening methods to the Applichem case, a popular Harvard Business School case study.

Kazaz et al. (2005) studied the effects of exchange rate uncertainty on a network, inspired by an aggregate production planning problem of a global electronics manufacturer. The authors proposed a two-stage stochastic program based on profit maximization, tailored to a company with a single plant which serves two markets with one product. Exchange rates were modeled as correlated nonnegative random variables. Following this, the corresponding first-stage of the problem refers to the setting of the total production quantity, while the second-stage decision variables define the allocation of the produced quantity to the considered markets. The implied flexibility of the model on the first-stage was dedicated to production hedging, in reference to the option of producing less than the total quantity demanded. Furthermore, the possibility of not serving some of the markets under unfavorable exchange rates on the second-stage was designated to allocation hedging. The basic model was then extended to a multi-period setting, while further sections were dedicated to the inclusion of demand uncertainty, monopolistic pricing and price setting under demand uncertainty. To sum up, the authors pointed out, that the two modeled forms of operational hedging (production- and allocation hedging) are able to create robust production planning solutions in an uncertain exchange rate environment.

Goh et al. (2007) extended an earlier two-stage stochastic program presented by Cohen and Huchzermaier (1999), which deals with demand-, price- and exchange rate uncertainty, to a multi-stage stochastic program based on after-tax profit maximization. They included also import and export tariffs in their costs structure. The multi-stage model considers a global plant location problem in reference to a one product distribution company. Demands, exchange rates, taxes and import tariffs are defined as one multi-dimensional random variable associated with the network flows. Further, an algorithmic approach was developed to solve the defined multi-stage setting of the global supply chain network problem. However, specific applications to the problem were not stated.

A recently published paper by Liu and Nagurney (2011) deals with the impacts of exchange rate risk and competition on global supply chain networks under consideration of offshore-outsourcing activities. The proposed model is based on a variational inequality formulation, which allows for large scale empirical research. The model includes decisions regarding product prices, in-house production quantities, material procurement and offshore-outsourced quantities. Exchange rate risk, provoked by possible outsourcing options, is considered through the appliance of a Markowitz mean-variance framework, under which the risk-behaviour of decision makers can be considered. Following this, the presented numerical studies were designated to how competition an exchange rate risk affect outsourcing decisions, pricing strategies and profits under the comparison of risk-neutral and risk-avers supply chains. One of the main finding of the article was, that risk-averse supply chain managers should differentiate their products from competitors, since strong competition would reduce their profitability and increase their risk. On the other hand, supply chain managers which are less sensitive to high exchange rate risk should focus on competition with more risk-averse firms to gain market shares through outsourcing operations.

The discussion of the following papers is not directly related to exchange rate risk but refers to articles which served as additional inspiration, in terms of stochastic programming and network design, for the model formulation presented below.

Hence, a modeling framework for strategic network design under uncertainty is discussed in the article of Alonso-Ayuso et al. (2003). The proposed multi-period two-stage stochastic programming model refers to profit maximization and considers uncertainty about product net prices, demands, raw material prices and production costs. The first-stage includes strategic decisions like plant locations and sizes, product allocation and supplier selection, while on the second-stage tactical decisions such as production volumes, capacity expansions, inventory decisions, raw material flows and transportation quantities are taken. Uncertainty was expressed in scenario trees, in which the different stochastic variables were combined. The model was solved by a branch and fix algorithm and applied to a fictive test design under consideration of 23 scenarios.

While the model presented by Alonso-Ayuso et al. (2003) is quite restricted in the number of scenarios solvable, Santoso et al. (2005) proposed a two-stage stochastic supply chain design program for realistic scales. The first-stage decisions include facility location, capacity planing and product allocation decisions, while the second-stage problem considers the material flows. Demands, supply quantities, capacities as well as production- and transportation cost were treated as stochastic variables under the assumption of log-normal distributions. The model was applied to two test instances, a US soft-drink manufacturer which serves the domestic market and a global network which includes the US and Latin American market. The problem was solved by the appliance of the Sample Average Approximation (SAA) combined with an accelerated Benders Decomposition, which led to qualitative solutions for large scale network design problems.

In the article of Bihlmaier et al. (2009), the model of Santoso et al. (2005) is extended to deal with the requirements of strategic network design in the automotive industry. A two-stage stochastic program was defined, with decisions on plant openings and capacity levels on the first-stage and the corresponding network flows on the second-stage. In addition, an extension of the model which deals with tactical workforce planning was presented. Uncertainty about demand was modeled by a scenario-based approach assuming log-normal distributions. Scenarios were generated by a Monte-Carlo Simulation approach under consideration of the correlations of different product demands. Further an algorithm was proposed based on Benders Decomposition related to the paper of Santoso et al. (2005). The presented numerical studies showed, that the demonstrated method decreases computational effort, which enables the handling of large-scale problems in reasonable run-times.

Nickel et al. (2012) proposed a multi-stage stochastic program which considers uncertain demands and interest rates. The objective is based on profit maximization and includes service level considerations and the downside risk for the Return on Investment (ROI). Decisions regarding plant locations, investments and loans are taken into account at each stage, while the corresponding recourse decisions are represented by the network flows from the established plants to the final customers. Stochastic demands and interest rates are represented by a scenario tree, where the two random variables are combined. Furthermore, a simplified model formulation (path-based approach) is proposed, which leads to an easier handling of the stochastic multi-period setting in terms of implementation and solvability. Based on this approach, a case study was presented which highlights the value-added of a stochastic solution in contrast to a deterministic network design problem setting.

An overview of the discussed literature is illustrated in figure 4.1. As obvious, the great part of the literature published so far, has either a focus on global aspects like LC requirements or deals with supply chain risks. Hence, in the following section a network design model will be presented which includes both, exchange rate risk and the requests regarding local content of global operating firms.

	Arntzen et. al (1995)	Munson et. al (1997)	Kouvelis et. al (2004)	Li et. al (2007)	Guo et. al. (2008)	Stephan et. al (2010)	Huchzermaier et. al (1996)	Kouvelis (1999)	Lowe et. al (2002)	Alonso-Ayuso et. al (2003)	Kazaz et. al (2005)	Santoso et. al (2005)	Goh et. al (2007)	Bihlmaier et. al (2009)	Liu et. al (2011)	Nickel et. al (2012)
model	**focus LC**						**focus stochastic models**									
deterministic	x	x	x	x	x	x	-	-	-	-	-	-	-	-	-	-
stochatsic	-	-	-	-	-	-	x	x	x	x	x	x	x	x	x	x
type	MIP	MIP	MIP, DCF	MIP	MIP	MIP, DCF	MIP, DCF	DCF	screen. app	two-st. MIP	two-st. MIP	two-st. MIP	multi-st. MIP	two-st. MIP	mean-var.	multi-st. MIP
function	min. cost,	min. costs	max. profit	min. costs	min. costs	min. costs	max. profit	opt. val.	min. costs	min. max.	max. profit	min. costs	max. profit	min. costs	max. profit	max. profit
(strat.) decisions																
facility location	x	x	x	-	x	-	x	-	x	x	-	x	x	-	-	x
supplier selection	-	x	-	x	x	x	x	x		x	-	-	-	-	-	-
product allocation	x	x	x	-	x	x	-	-		x	x	x	-	x	x	-
capacity planning	x	-	-	-	-	-	-	x	x	x	-	x	-	x	-	-
inventory planning	x	-	-	-	-	-	-	-		x	-	-	-	-	-	-
global aspects																
LC binding	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LC optional	-	-	x	x	x	x	-	-	-	-	-	-	-	-	-	-
tariffs/duties	x	-	x	x	x	x	-	-	-	-	-	-	x	-	-	-
duty drawback	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
taxes	-	-	x	-	-	-	x	-	-	-	-	x	x	-	-	-
stoch. variables																
exchange rates	-	-	-	-	-	-	x	x	x	-	x	-	x	-	x	-
demand	-	-	-	-	-	-	-	-	-	x	x	x	x	x	-	x
others	-	-	-	-	-	-	-	price risk	-	price risk, procur. costs, prod. costs,	-	supply quant., plant cap.	taxes, tariffs	-	-	interest rates

Figure 4.1: Literature Review

4.2 Problem Statement and General Assumptions

The model presented in the following sections refers to strategic network design and is tailored to a company which manufactures different products in the territory of the NAFTA. It is assumed, that the plants are already established but strategic decisions concerning product allocation have to be taken for multiple periods in the future. The products which have to be assigned to the plants consist of several parts or subassemblies which can be sourced from local suppliers (within the NAFTA) and global ones. A final product can therefore be assembled from a variety of different product configurations, which represent the enumeration of possible sourcing strategies in accordance with its bill of material. A simple bill of material is illustrated in table 4.1, for a better understanding.

		A			B		
config. v / comp. c		a1	a2l	a2g	b1	b2l	b2g
A	1	1	1	0	0	0	0
	2	1	0	1	0	0	0
B	3	0	0	0	1	1	0
	4	0	0	0	1	0	1

Table 4.1: Example: Bill of Material

Following the simple example, each product (A, B) can be assembled under consideration of two sourcing strategies, represented by its product configurations. One, consisting of just locally sourced parts (e.g., a1l, a2l) and a mixture of locally and globally sourced components (e.g., a1l, a2g). The assembled products are shipped in further steps to markets within the NAFTA. As stated in section 2.3.2, tariff-free shipments to member-countries are justified if the assembled products contain sufficient Regional Value Content (RVC), which is considered by the appliance of the Transaction Value Method in Reference to Article 402 §2 (NAFTA 2011a).

Generally it will be assumed, that globally sourced parts are cheaper than domestic ones. In addition, locally sourced parts (within the NAFTA) have an inherent RVC of 100 % while globally sourced parts have an RVC of 0 %. As mentioned in section 2.3.2.1, even if originating materials would contain non-originating fractions, they would be treated generally as 100% originating ("rolled-up materials") under NAFTA's legal definition (NAFTA 2011a, Article 402 §4). Correspondingly, non-originating materials have an inherent RVC of 0% even if they contain some originating fractions ("rolled-down materials"). The company has therefore to select from a variety of sourcing options or product configurations. As a result, configurations with more globally sourced parts are cheaper while containing less RVC than configurations with more locally sourced parts. Underachieving the required RVC would result in punitive duty payments for cross-boarder deliveries, while global sourcing cost advantages could be exploited. The fulfillment of the local content threshold will therefore be modeled as an option to consider the resulting trade-offs between duty payments and cheaper sourcing costs.

As discussed in sections 2.4.1, currency fluctuations demonstrate a significant risk for global operating firms and may therefore influence strategic decisions. However, a far reaching dynamic adjustment of decisions like product allocations to the behaviour of exchange rates may not be reasonable in today's highly volatile currency markets, since the adjustment costs would overwhelm the gains. In reference to this argument, product allocations have to be decided at the beginning of the considered time frame and are not subject to dynamic adjustments.

However of special interest in further considerations, is the influence of exchange rates on sourcing decisions in relation to RVC compliance and their effects on strategic product allocation decisions. As discussed in section 2.4.2, currency fluctuations can alter both, the transaction value of the final goods and the non-originating value of the sourced components, which may have an impact on the RVC fulfillment of a final product. The presented model will therefore be tailored to study such effects under the legal framework of the NAFTA. The notation of the proposed model will be introduced in the next section, for a better overview.

4.3 Notation

The Notation stated below refers to the deterministic equivalent model presented in section 4.6. The Notation for the deterministic model (section 4.4) and the stochastic model (section 4.5) can be read without the index set $k \in K(t)$.

Indices

$j \in J$	index set of plants
$m \in M$	index set of markets
$a \in A$	index set of currency areas
$c \in C, c \in C(a)$	index set of components, index set of components in currency area a
$p \in P$	index set of products
$v \in V, v \in V(p)$	index set of product configurations, index set of product configurations of product p
$t \in T$	index set of time periods
$k \in K(t)$	index set of nodes in time period t

Parameters

C_{jt}^{fix}	fixed costs of plant j, in time period t, in currency where plant j is located
C_{jp}^{inv}	initial investment costs to allocate product p to plant j, in numeraire currency, at time t = 0
C_{jct}^{source}	unit variable sourcing costs of component c at plant j, in time period t, in currency of currency area a where component c comes from

C^{prod}_{jpt}	unit variable production costs of product p at plant j, in time period t, in currency where plant p is located
C^{ship}_{jpmt}	unit variable shipping costs of product p, from plant j (the point of direct shipment) to market m, in time period t, in currency where plant j is located
C^{ship}_{jct}	unit variable shipping costs of component c to plant j, in time period t, in currency where component c comes from
L_{jc}	regional value content percentage of component c at plant j based on C^{source}_{jc}
B_{vc}	bill of material, amount of component c needed in producing one unit of product configuration v
D_{pmt}	demand for product p, at market m, in time period t
P_{pmt}	price of product p at market m, including the costs for final delivery C^{ship}_{jpmkt}, in currency of market m in time period t
K_{jt}	per period production capacity of plant j [*units*], in time period t
R_t	discount factor in period t, for calculating the discounted cash flow at t = 0
T_{jpm}	duty rate for shipping the non-originating product p from plant j to market m
α	regional value content requirement
M	sufficiently large number

(Decision) Variables

$z_{jmvkt} \geq 0$	production quantity of product configuration v at plant j, shipped to market m, at node k in time period t

$d_{jmpkt} \geq 0$	total duty costs, that are caused by the production of product p at plant j, shipped to market m, in currency where plant j is located, at node k in time period t
$V^{trans}_{jmvkt} \geq 0$	transaction value (customs value) of product configuration v, in currency where plant j is located, at node k in time period t
$V^{trans(F.O.B.)}_{jmvkt} \geq 0$	transaction value of product configuration v, adjusted to a F.O.B basis in currency where plant j is located, at node k in time period t
$V^{nor}_{jmvkt} \geq 0$	non-originating value of product configuration v, in currency where plant j is located, including the non-originating value of the sourced components, at node k in time period t
$x_{jp} \in \{0, 1\}$	if set to 1, product p is allocated to plant j; else not
$y_{jmvkt} \in \{0, 1\}$	if set to 1, product configuration v produced at plant j, shipped to market m, fulfills not the required local content, at node k in time period t; else true

(Stochastic) Variables

e_{mkt}	exchange rate of currency c, where market m is located, with the numeraire currency, at node k in time period t
e_{jkt}	exchange rate of currency c, where plant j is located, with the numeraire currency, at node k in time period t
e_{jmkt}	exchange rate of currency c, where plant j is located, with the currency at market m, at node k in time period t
e_{jakt}	exchange rate of currency c, in currency area a, where component c comes from, with the currency where plant j is located, at node k in time period t

4.4 The Deterministic Model

First of all, a deterministic version of the strategic network design model is presented as a mixed-integer program (MIP). The deterministic model is inspired by the article of Stephan et al. (2010) and will be extended in further steps to a stochastic program which considers uncertainty about exchange rates. The data regarding exchange rates are therefore assumed to be known, or represented by its expected values in a first attempt. Generally, all cash flows are transformed into a specified numeraire currency, which constitutes the currency of the country where the headquarter of the firm is located. Hence, the model is defined as a maximization function, to consider beside the effects of volatile exchange rates on the cost structure, also their impacts on prices. It will be assumed therefore, that nominal prices do adjust through a perfect exchange rate elasticity of prices, the same holds for the costs involved.

$$
\begin{aligned}
max\, DCF = \\
& -\sum_{j\in J}\sum_{p\in P} x_{jp} \cdot C^{inv}_{jp} \\
& +\sum_{t\in T} R_t \cdot \Bigg[-\sum_{j\in J} e_{jt} \cdot C^{fix}_{jt} \\
& \qquad + \sum_{j\in J}\sum_{m\in M}\sum_{p\in P}\sum_{v\in V(p)} z_{jmvt} \cdot \left(e_{mt} \cdot P_{pmt} - e_{jt} \cdot \left(C^{prod}_{jpt} + C^{ship}_{jpmt} \right) \right) \\
& \qquad - \sum_{a\in A}\sum_{c\in C(a)}\sum_{j\in j}\sum_{m\in M}\sum_{v\in V} z_{jmvt} \cdot e_{jt} \cdot e_{jat} \cdot \left(C^{source}_{jct} + C^{ship}_{jct} \right) \cdot B_{vc} \\
& \qquad - \sum_{j\in J}\sum_{m\in M}\sum_{p\in P} e_{jt} \cdot d_{jmpt} \Bigg]
\end{aligned}
\tag{4.1}
$$

As a result, the objective function represented by equation (4.1) maximizes the net present value (NPV) of the discounted cash flows. The cash flows which incur at the specific time periods in the future, are therefore discounted to the present with the corresponding discount rate, represented by R_t in the objective function. Following this, the first term of the objective (4.1) demonstrates the strategic part of the program and consist of the initial investment costs C_{jp}^{inv} which accumulate if a product p is assigned to a specific plant j, represented by the binary variable $x_{jp} = 1$. The decisions regarding product allocation have to be decided today for a specified time frame in the future. Hence, the strategic costs C_{jp}^{inv} are not exposed to any currency fluctuations which justifies the assumption, that these costs directly accumulate in the numeraire currency. The second term of program (4.1) considers the annual fixed costs C_{jt}^{fix} for the operation of the plants, which are converted into the numeraire currency through the exchange rate e_{jt}.

The last three terms of the objective function (4.1), sum up the revenues, the production costs C_{jp}^{prod}, the transportation costs for final delivery C_{jpmt}^{ship}, the sourcing costs C_{jc}^{source}, the transportation costs affiliated with the sourced components C_{jct}^{ship} and the duty costs d_{jmpt}. Generally, these costs result from the network flows designated by the continuous decision variable z_{jmvt}, which represents the production quantity of a possible product configuration v at plant j shipped to market m at a specified time point t in the future. The conversion of the market prices into the numeraire currency is implemented through e_{mt}, while production and final delivery costs are translated by the exchange rate e_{jt}. The resulting sourcing and associated shipping costs are first of all converted into the currency where a specific plant j is located, by e_{jat}, and in a second step into the numeraire currency through the exchange rate e_{jt}. In addition, the program is subject to a variety of constraints.

$$\sum_{j \in J} \sum_{v \in V(p)} z_{jmvt} \leq D_{pmt} \qquad \forall m, p, t \tag{4.2}$$

$$\sum_{m \in M} \sum_{p \in p} \sum_{v \in V(p)} z_{jmvt} \leq K_{jt} \qquad \forall j, t \tag{4.3}$$

$$\sum_{m \in M} \sum_{v \in V(p)} z_{jmvt} \leq K_{jt} \cdot x_{jp} \qquad \forall j, p, t \tag{4.4}$$

The first three constraints (4.2) - (4.4) define the tactical (operational) production planning level and are involved in most network design models. Constraint (4.2) ensures, that the production of the plants j doesn't exceed the demand for the products p at the specified markets m. Since the problem is defined as a maximization function, demands don't have to be fulfilled if it turns out to be more profitable for the company. Constraint (4.3) models the capacity limits of the production plants and constraint (4.4) refers to the product allocation flexibility. As a result of this constraint, a specific product p can only be produced at plant j if it is allocated to that plant, indicated by the binary decision variable $x_{jp} = 1$.

The following constraints, model the NAFTA specific requirements regarding local content. Constraints (4.6) - (4.10) are based on the Transaction Value Method specified in Article 402 §2 (NAFTA 2011a), which will be stated once more for a better understanding:

$$RVC = \frac{TV - VNM}{TV} \cdot 100 \tag{4.5}$$

, where TV is defined as the transaction value of a product adjusted to a F.O.B basis, VNM denotes the value of the non-originating parts and RVC designates the required regional value content. The transaction value is defined in Article 415 (NAFTA 2011a) as the price actually paid or payable for a good or material which coincides generally with the customs value stated in Article 1 of the Customs Valuation Code (WTO 2011a). In reference to equation (4.5), the RVC values have to be calculated on a product basis. As stated before, a product can be assembled under different sourcing strategies, represented by its product configurations v. In accordance with this definition, the customs value of a possible product configuration V_{jmvt}^{trans}, which is assigned to a product p, is calculated in equation (4.6) from the price of the product, prevailing at market m and converted into the currency where plant j is located by e_{jmt}. In reference to Article 415 (NAFTA 2011a), F.O.B is defined as Free On Board, regardless of the mode of transportation, at the point of direct shipment by the seller to the buyer. For simplification it will be assumed, that the point of direct shipment is a plant j. In addition, the shipping cost for final delivery C_{jpmt}^{ship} are included in the prices P_{pmt}, since they are part of the companies costs. Adjusted to a F.O.B basis means, that the costs of transportation, loading, packaging and insurance from the point of direct shipment, shall be deducted from the transaction value (if included), when calculating the RVC under the Transaction Value Method (NAFTA 2011b, Section 2 of the Rules of Origin Regulations). Following this, the adjusted transaction value $V_{jmvt}^{trans(F.O.B.)}$ is calculated in equation (4.7) from the customs value V_{jmvt}^{trans} minus the transportation costs for final delivery C_{jpmt}^{ship}, which accumulate in the currency where plant j is located; as a result no further conversion is required.

$$V_{jmvt}^{trans} = z_{jmvt} \cdot e_{jmt} \cdot P_{pmt} \qquad \forall j, m, p, v \in V_{(p)}, t \tag{4.6}$$

$$V_{jmvt}^{trans(F.O.B.)} = z_{jmvt} \cdot \left(e_{jmt} \cdot P_{pmt} - C_{jpmt}^{ship} \right) \qquad \forall j, m, p, v \in V_{(p)}, t \tag{4.7}$$

$$\begin{aligned} V_{jmvt}^{nor} = \sum_{a \in A} \sum_{c \in C(a)} z_{jmvt} \cdot e_{jat} \cdot & \\ B_{vc} \cdot \left(C_{jct}^{source} + C_{jct}^{ship} \right) \cdot (1 - L_{jc}) & \qquad \forall j, m, v, t \end{aligned} \tag{4.8}$$

The value of the materials used in the production of a good is defined in Article 402 §9 (NAFTA 2011a) as the transaction value (the price actually paid or payable for a good or material) represented by C_{jc}^{source}, which shall include the costs of freight, insurance, packaging and all other costs incurred in transporting the material to the location of the producer (NAFTA 2011a, Article 402 §9c). As mentioned in section (4.2), originating materials have an inherent RVC (L_{jc}) of 100% ("rolled-up materials") while non-originating materials have an inherent RVC of 0% ("rolled-down materials") under NAFTA's Transaction Value Method. The non-originating value of a configuration, designated by V_{jmvt}^{nor} in equation (4.7), consists therefore of the value of the non-originating sourced components plus the corresponding non-originating transportation costs, which are both converted into the currency where a plant j is located by e_{jat}.

$$V_{jmvt}^{trans(F.O.B.)} - V_{jmvt}^{nor} \geq \alpha \cdot V_{jmvt}^{trans(F.O.B.)} - y_{jmvt} \cdot M \qquad \forall j, m, v, t \qquad (4.9)$$

$$d_{jmpt} \geq \sum_{v \in V(p)} \left[V_{jmvt}^{trans} \cdot T_{jpm} - M \cdot (1 - y_{jmvt}) \right] \qquad \forall j, m, p, t \qquad (4.10)$$

The RVC constraint (4.9) replicates the Transaction Value Method illustrated in equation (4.5). From this it follows, that the originating value of a configuration v ($V_{jmvt}^{trans(F.O.B.)} - V_{jmvt}^{nor}$) divided by the corresponding transaction value $V_{jmvt}^{trans(F.O.B.)}$, has to reach the required RVC threshold, designated by α, to qualify a configuration as originating. The optional fulfillment of the RVC target is modeled through the binary decision variable y_{jmvt}, which indicates whether the Local Content is achieved ($y_{jmvt} = 0$) or not ($y_{jmvt} = 1$) for a single configuration. In the case of RVC non-compliance, duties have to be paid for shipments to other NAFTA-members. The duty payments are defined by constraint (4.9) and are calculated on a product basis from the customs value V_{jmvt}^{trans} under consideration of the corresponding duty rate T_{jpm}, if the RVC target is not met ($y_{jmvt} = 1$). The duty payments accumulate in the currency where a plant j is located, since the the values of V_{jmvt}^{trans} incur in the same currency. Hence, possible duty payments are converted into the numeraire currency by e_{jt} in the objective function (4.1).

4.5 The Stochastic Model

The deterministic model presented in section (4.4) will be transformed in a next step into a two-stage stochastic program under exchange rate uncertainty. The techniques of stochastic programming were introduced in detail in section (3.2) and will therefore be applied straightforward to the proposed model. Hence, the first term of the objective function (4.11) defines the deterministic first-stage, with the strategic first-stage decisions regarding product allocations $x_{jp} \in \{0, 1\}$, at the beginning of the considered time-frame. The second-stage is represented by the last four terms, defined by the expectations E_{Ω_t} of the second-stage value functions $Q_t\left(x_{jp}, z_{jmvt}(x_{jp}, \omega_t), y_{jmvt}(x_{jp}, \omega_t)\right)$ in respect to the uncertain variables of the exchange rates ($e_{mt}(\omega_t)$, $e_{jt}(\omega_t)$, $e_{jmt}(\omega_t)$, $e_{jat}(\omega_t)$).

$$
\begin{aligned}
& max\, DCF = \\
& \quad - \sum_{j \in J} \sum_{p \in P} x_{jp} \cdot C^{inv}_{jp} + \\
& \quad\quad max \sum_{t \in T} R_t \cdot E_{\Omega_t} \Bigg[- \sum_{j \in J} e_{jt}(\omega_t) \cdot C^{fix}_{jt} \\
& \quad\quad\quad + \sum_{j \in J} \sum_{m \in M} \sum_{p \in P} \sum_{v \in V(p)} z_{jmvt}(x_{jp}, \omega_t) \cdot \\
& \quad\quad\quad\quad \left(e_{mt}(\omega_t) \cdot P_{pmt} - e_{jt}(\omega_t) \cdot \left(C^{prod}_{jpt} + C^{ship}_{jpmt} \right) \right) \\
& \quad\quad\quad - \sum_{a \in A} \sum_{c \in C(a)} \sum_{j \in j} \sum_{m \in M} \sum_{v \in V} z_{jmvt}(x_{jp}, \omega_t) \\
& \quad\quad\quad\quad e_{jt}(\omega_t) \cdot e_{jat}(\omega_t) \cdot \left(C^{source}_{jct} + C^{ship}_{jct} \right) \cdot B_{vc} \\
& \quad\quad\quad - \sum_{j \in J} \sum_{m \in M} \sum_{p \in P} e_{jt}(\omega_t) \cdot d_{jmpt}(z_{jmvt}(x_{jp}, \omega_t)) \Bigg]
\end{aligned} \tag{4.11}
$$

The greek letter ω_t marks the stochastic behaviour of the uncertain variables, in a set of possible realizations $\omega_t \in \Omega_t$ at a specific time point t in the future. The behaviour of the random variables might be different, however ω_t can be considered under this formulation as one state of the world under which the variables may realize. Since the compensation variables $z_{jmvt}(x_{jp}, \omega_t)$ depend on the realizations of the stochastic variables ($e_{mt}(\omega_t)$, $e_{jt}(\omega_t)$, $e_{jmt}(\omega_t)$, $e_{jat}(\omega_t)$) under a given state of the world, they are themselves random variables and set in a way that constraints (4.2)-(4.10) hold for all $\omega_t \in \Omega_t$, under a given set of first-stage decisions $x_{jp} \in \{0, 1\}$. The variables V_{jmvt}^{trans}, $V_{jmvt}^{trans(F.O.B.)}$, V_{jmvt}^{nor}, the duty payments d_{jmpt} and the binary variables $y_{jmvt}(\omega_t) \in \{0, 1\}$ depend on the recourse variable $z_{jmvt}(x_{jp}, \omega_t)$ and are therefore as well random.

The objective of program (4.11) is therefore to select the first-stage decisions $x_{jp} \in \{0, 1\}$ in a way that the profit, resulting from the sum of the first-stage costs and the sum of the discounted expected values of the second-stage value functions $Q_t(x_{jp}, z_{jmvt}(x_{jp}, \omega_t), y_{jmvt}(x_{jp}, \omega_t))$, which accumulate at the specified time-points t, is maximized. The constraints of program (4.11) are consistent with the constraints of program 4.1 for all $\omega_t \in \Omega_t$ at the defined time points ($t = 1 \ldots T$) and are therefore not stated again.

4.5.1 The underlying Stochastic Process

Generally it can be said, that future changes in exchange rates are not exactly predictable. Therefore it will be assumed, that statements about future exchange rates can only be made in reference to their mean change per time unit (drift) and their corresponding volatility (Huchzermaier 2001, p.6). As a result, the future behaviour of the uncertain variables can be described by stochastic diffusion processes[1], which define the probabilistic evolution of the variables through time (Hull 2007, p.275). The proposed stochastic diffusion process, also known as Geometric Brownian Motion or Generalized Wiener Process, for a variable X is illustrated in equation (4.12):

$$dX = \mu \cdot X \cdot dt + \sigma \cdot X \cdot dz \tag{4.12}$$

, where μ and σ are known constants and dX designates the change of the random variable during an infinitesimal time unit ($\Delta t \to 0$). Dividing through by X,

[1] Similar approaches for the description of the behaviour of exchange rates can be found in Huchzermaier and Cohen (1996), Kogut and Kulatilaka (1994), Kouvelis (1999), Cohen and Huchzermaier (1999) or Hull (2007).

equation (4.12) can be illustrated in the following form:

$$\frac{dX}{X} = \mu \cdot dt + \sigma \cdot dz \tag{4.13}$$

Equation (4.13) shows, that the percentage change of the variable dX/X can be partitioned into two components. The first component declares, that the mean change of the variable X during a small period of time is $\mu \cdot dt$, which is deterministic and the known parameter μ is defined as the drift. Added to the drift term is a stochastic component, which consists of the change of a random variable dz and the known parameter σ, which defines the volatility of the variable X (Clewlow and Strickland 1998, p.4). The change of the random variable dz during a short period of time is defined as a Wiener or Brownian Motion Process. A basic Wiener Process, can be defined as a particular type of Markov stochastic process, with a mean change per time unit of 0 and a variance rate of 1 per year. Generally, a variable z follows a Wiener Process if it fulfills two properties. The first one is, that any change over a small period of time is equal to:

$$dz = \epsilon \cdot \sqrt{dt} \tag{4.14}$$

, whereas ϵ has a standardized normal distribution $\phi(0, 1)$. The second property states, that the values of dz for any two different short intervals of time are independent, which implies that z follows a Markov Process. From the first property (4.14) follows, that dz itself has a normal distribution with $\phi(0, \sqrt{dt})$. The standard deviation is therefore proportional to the square root of time and bigger as far as we are looking ahead. This is a result of the Markov Property, since the means and variances of the changes of successive time periods are additive, but their standard deviations not (Hull 2007, p.265).

With a look at equation (4.13) and the information of previous remarks, it follows therefore, that a variable with a value of X_0 at time $t = 0$ which follows a Geometric Brownian Motion is normally distributed at any time point t in the future with:

$$X_t - X_0 \sim \phi \left[\ \mu \cdot t, \ \ \sigma \cdot \sqrt{t} \ \right] \tag{4.15}$$

$$X_t \sim \phi\Big[\ X_0 + \mu \cdot t,\ \ \sigma \cdot \sqrt{t}\ \Big] \tag{4.16}$$

However, a log-normal distribution describes the behaviour of uncertain variables, like demands, exchange rates or transportation costs in a better way, since their values cannot drop below zero (Chopra and Meindl 2007, p.156). Let's assume that $G = \ln$ X and the process of G can be defined as[2]:

$$dG = \left(\mu - \frac{\sigma^2}{2}\right) \cdot dt + \sigma \cdot dz \tag{4.17}$$

, where μ and σ are known constants. Equation (4.17) specifies therefore, that $G = \ln X$ follows a Geometric Brownian Motion, with a constant drift rate of $\mu - \frac{\sigma^2}{2}$ and a constant variance rate of σ^2. Hence, the change in $\ln X$ between time $t = 0$ and any time point t in the future is normally distributed with (Hull 2007, p.275):

$$\ln X_t - \ln X_0 \sim \phi\Big[\ \left(\mu - \frac{\sigma^2}{2}\right) \cdot t,\ \ \sigma \cdot \sqrt{t}\ \Big] \tag{4.18}$$

$$\ln X_t \sim \phi\Big[\ \ln X_0 + \left(\mu - \frac{\sigma^2}{2}\right) \cdot t,\ \ \sigma \cdot \sqrt{t}\ \Big] \tag{4.19}$$

, where X_0 is the value of the variable at time point t and X_t is the value of the variable at any time point t in the future. As the natural logarithm of the variable X is normally distributed, it follows that the variable itself has a log-normal distribution. The proposed model implies therefore, that the value of the variable X_t at time point t, given its value today X_0, is log-normal distributed (Hull 2007, p.275). The process derived in equation (4.17) and its probability distribution are stated to get a better understanding of the proposed binomial-tree model, which is illustrated in the next section.

[2]The specification of the function G, their properties and the stochastic process defined in equation (4.17) are derived in Appendix A.

4.5.2 Binomial Trees

To continue with numerical studies, it is useful to make a discretization of the underlying stochastic process, i.e. that the underlying stochastic process has a finite number of realizations. A good manner to illustrate discrete stochastic processes deliver scenario trees. A scenario tree is a diagram representing the possible paths that might be followed by the random variable over the considered time-frame. The following assumption is, that the variable follows a *random walk*, which can be represented by a binomial tree. In each time step therefore, the variable has a certain probability (p) of moving up by a certain factor ($u > 1$) and a certain probability ($1 - p$) of moving down by a certain factor ($d < 1$) (Hull 2007, p.241). These kind of trees are also known a multiplicative binomial trees. In contrast, under a additive binomial tree, the underlying factor increases by (u) with probability (p) and decreases by (d) with a probability ($p - 1$). However, multiplicative binomial trees have the advantage, that the considered variables cannot take on negative values, which is especially relevant for uncertain variables such as demands, prices or exchange rates. A further advantage is, that the factors (u, d) are proportional to the current value of the variable (Chopra and Meindl 2007, p.155).

The binomial model used to generate scenarios in the remainder of this thesis, is based on an approach which was first introduced by Sharpe (1978) for the valuation of American Style Options. Generally, the probability (p) and the rates for an up and down movement (u, d) are chosen in a way, that in the limit, as the time steps become smaller ($\Delta t \to 0$), the binomial tree model converges to a Geometric Brownian Motion (illustrated in equation (4.17)), which leads to the log-normal assumption depicted in equation (4.18) and (4.19) (Hull 2007, p.241). However, since there are three parameters (p, u, d) and we have only to match two (μ and σ in reference to equation 4.17), there is a free choice for one of the parameters (Clewlow and Strickland 1998, p.18). Cox, Ross, and Rubinstein (1979) set the jump sizes to be equal, which leads to unequal probabilities. Rendleman and Bartter (1979) restated this formulation, which leads to equal probabilities and different jump sizes. This has the advantage, that the probabilities are always 0.5 and independent of the value of σ or the number of time steps (Hull 2007, p.406). Following the approach of Rendleman and Bartter (1979), the up and down movements can be represented as:

$$u = e^{(\mu - \frac{1}{2}\sigma^2)\Delta t + \sigma\sqrt{\Delta t}} \tag{4.20}$$

$$d = e^{(\mu - \frac{1}{2}\sigma^2)\Delta t - \sigma\sqrt{\Delta t}} \tag{4.21}$$

$$p = \frac{1}{2} \tag{4.22}$$

The input parameters for the calculation of the up and down movements can be illustrated as:

T	number of considered years in the future
N	number of time steps with $\Delta t = \frac{T}{N}$
$\mu - \frac{1}{2}\sigma^2$	constant drift rate
σ^2	constant variance rate

A Descriptive Example

A scenario tree, with the input parameters $T = 1$, $N = 4$, $\mu = 0.1$ ($\mu - \frac{1}{2}\sigma^2 = 0.95$) and $\sigma = 0.1$ is illustrated in figure (4.2). With $T = 1$ and $N = 4$ the realizations of the stochastic process are sampled quarterly over one year. The presented binomial tree consists of nodes organized in levels $t = 0 \ldots T$ in accordance to the number of time steps $n = 0 \ldots N$. In the following, Ω_t is defined as the set of all nodes $k = 0 \ldots K$, numbered from top to bottom, at time level t. The corresponding elements of Ω_t, which represent the discrete realization of the stochastic process, are designated to ω_{tk}. At time level $t = 0$, there is only one root node, which represents the known value ω_{00} (defined by 1 for illustration purposes).

The set of realizations at time level t=0.25 is depicted by two nodes, whereby each of them is connected with the root node by an arc. The arcs illustrate the relationship between the root node and the two *children nodes*, $\omega_{10} = \omega_{00} \cdot u$ and ω_{11}

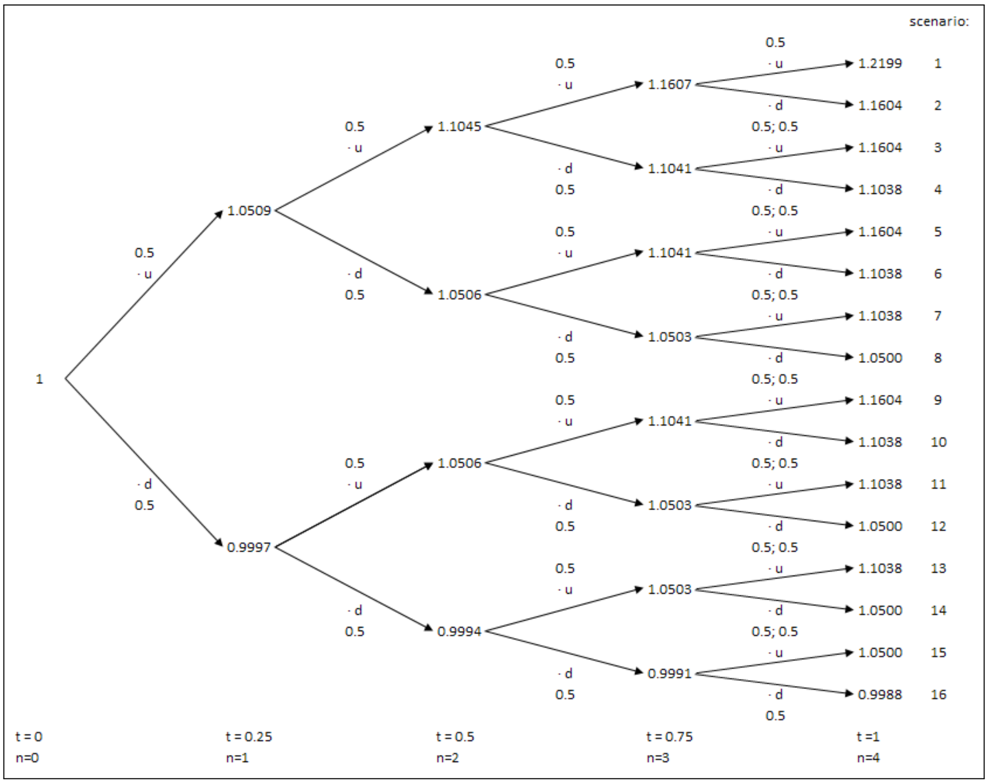

Figure 4.2: Scenario Tree

$= \omega_{00} \cdot d$, with their corresponding conditional probabilities, $p = 0.5$ and $1-p = 0.5$. In general, each node at time level t is connected to a single node at the previous time level, defined as the *ancestor node* and is also connected to two nodes at the next time level, *called children* nodes, which represent possible continuations of the process (Shapiro et al. 2009, p. 69). The probability of occurrence of a single realization, represented by a node at a specific time level t, is then the product of the conditional probabilities following the path up to node k at time level t. This can be expressed mathematically by $P(\omega_{tk}) = p^n$ with $\sum_{k \in K} P(\omega_{tk}) = 1, \forall t$. A *scenario* is defined by a path from the root node to a node a the last time level, which leads to $16 = (2^N)$ different scenarios (see figure (4.2)) each with probability p^N (Shapiro et al. 2009, p. 69).

It is obvious, that some realizations at a given time level in figure (4.2) are equal to each other, which can be explained as follows. With a look at time level $t = 0.5$ of the binomial tree, we have four realizations, $\omega_{20} = \omega_{00} \cdot u \cdot u$, $\omega_{21} = \omega_{00} \cdot u \cdot d$, ω_{22}

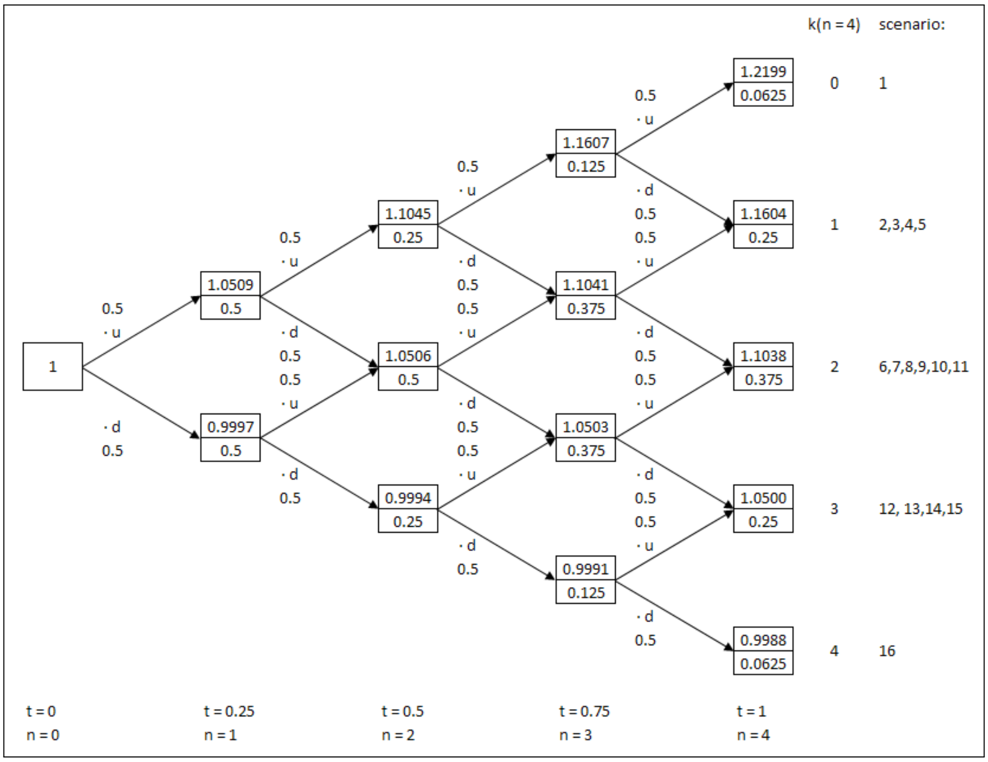

Figure 4.3: Recombining Tree

$= \omega_{00} \cdot d \cdot u$ and $\omega_{23} = \omega_{00} \cdot d \cdot d$, whereby $\omega_{21} = \omega_{22}$. This means that $\omega_{00} \cdot u \cdot d = \omega_{00} \cdot d \cdot u$. It is said, that the tree is recombinable, which leads to the simplified representation of the binomial tree in figure 4.3, with a reduced number of nodes.

The number of possible paths passing through a node in the tree (figure (4.3)), is then equal to the binomial coefficient, defined in equation (4.24). Hence, the probability of occurrence of a single realization at time level t can be calculated from the probability mass function of the binomial distribution, as illustrated in equation (4.23), with $\sum_{k \in K} P(\omega_{tk}) = 1, \forall t$ (Brannath and Futschik 2001, p. 95):

$$P(\omega_{tk}) = \binom{n}{k} \cdot p^k \cdot (1-p)^{n-k} \tag{4.23}$$

$$\binom{n}{k} = \frac{n!}{k! \cdot (n-k)!} \tag{4.24}$$

4.5.3 Data Structure and Combination of Trees

First of all, the test design which is stated in section 5.1 has to be explained in brief, to describe the data structure of the considered stochastic variables. The examined network consists of two plant, one located in the US and another in Mexico. The parts, which are required for the production of a final good can be sourced from a local US-supplier and a global one located in the EU. The assembled products are shipped in further steps to the US and the Mexican market. It follows therefore, that three exchange rates (EUR/USD, USD/MXN, EUR/MXN) and their corresponding reciprocals are relevant for the realizations of the stochastic variables (e_{mkt}, e_{jkt}, e_{jmkt}, e_{jakt}). The exchange rates are stated in the remainder of this thesis in accordance with the general applied market conventions, which define how the currency pairs are quoted. In reference to the EUR/USD exchange rate, the EURO is defined as the base or unit currency, whereas the US Dollar is specified as the quote or price currency. However just two of the three exchange rate have to be simulated, the third one can be derived from the corresponding cross-rate. For example, the EUR/MXN exchange rate can be deduced from the relationship:

$$EUR/MXN = \frac{EUR/USD}{\frac{1}{USD/MXN}} \tag{4.25}$$

Hence, we have two data drivers which determine the realizations of the uncertain variables (e_{mkt}, e_{jkt}, e_{jmkt}, e_{jakt}). Under the assumption, that the stochastic variables are independently distributed, two binomial trees can be sampled, one for each data driver in accordance to figure 4.3. In a further step, the two trees can be combined as illustrated in figure 4.4. The values of X and Y in figure 4.4 may therefore refer to two exchange rates, e.g. the EUR/USD and the USD/MXN rate.

One node $k \in K(t)$ at time t contains therefore all the information needed to describe on state of the world $\omega_t \in \Omega_t$ in accordance with program (4.11). The corresponding probability of a node k at time level t, is then the product of the two probabilities of the single nodes and will be designated by p_{kt}, with $\sum_{k \in K(t)} p_{kt} = 1$, $\forall t$.

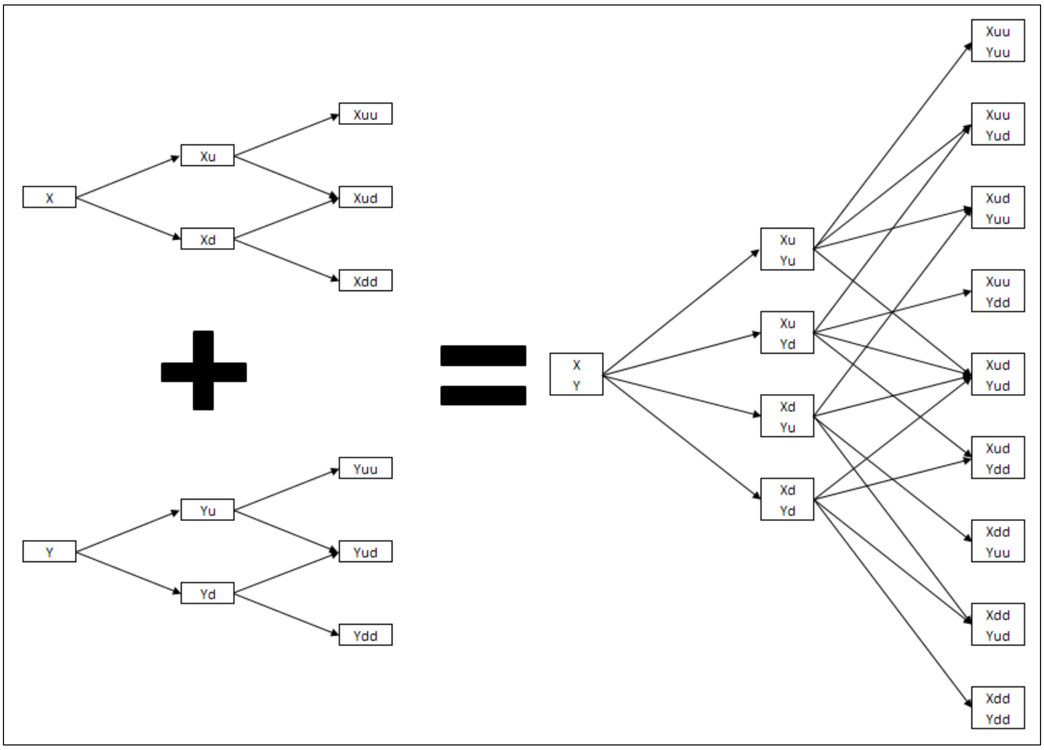

Figure 4.4: Scenario Tree Combination

The two trees, will be sampled with $T = 5$ and $N = 20$ ($\Delta t = \frac{T}{N} = 0.25$), i.e quarterly over five years, which leads to a combined tree with a set of specified nodes $k \in K(t) = (25(1), 81(2), 169(3), 289(4), 441(5))$ for the considered time points $t = 1 \ldots T$.

4.6 The Deterministic Equivalent Model

On the basis of the previously described approach to generate discrete scenarios for the considered stochastic variables, a deterministic equivalent of the stochastic model will be presented in a next step. In the following, all stochastic variables are replaced by its discrete realizations (e_{mkt}, e_{jkt}, e_{jmkt}, e_{jakt}) at node $k \in K(t)$ at time level t. The corresponding probability of a single node is designated by p_{kt}, with $\sum_{k \in K(t)} p_{kt} = 1, \forall t$. Hence, the expected values of the second-stage value functions can be approximated by the Sample Average Function $\sum_{k \in K(t)} p_{kt} \cdot Q_t \left(x_{jp}, z_{jmvt}(x_{jp}, \omega_t), y_{jmvt}(x_{jp}, \omega_t) \right)$ (Shabbir and Shapiro 2002, p.3). It follows therefore, that the stochastic model presented in section 4.5, can be reformulated into a solvable program under the appliance of the Sample Average Approximation (SAA), as illustrated in the objective function below.

$$
\begin{aligned}
max\, DCF = & \\
& - \sum_{j \in J} \sum_{p \in P} x_{jp} \cdot C_{jp}^{inv} + \\
& \quad \sum_{t \in T} R_t \cdot \sum_{k \in K(t)} p_{kt} \cdot \Bigg[- \sum_{j \in J} e_{jkt} \cdot C_{jt}^{fix} \\
& \qquad + \sum_{j \in J} \sum_{m \in M} \sum_{p \in P} \sum_{v \in V(p)} z_{jmvkt} \cdot \\
& \qquad \quad \left(e_{mkt} \cdot P_{pmt} - e_{jkt} \cdot \left(C_{jpt}^{prod} + C_{jpmt}^{ship} \right) \right) \\
& \qquad - \sum_{a \in A} \sum_{c \in C(a)} \sum_{j \in j} \sum_{m \in M} \sum_{v \in V} z_{jmvkt} \\
& \qquad \quad e_{jt} \cdot e_{jat} \cdot \left(C_{jct}^{source} + C_{jct}^{ship} \right) \cdot B_{vc} \\
& \qquad - \sum_{j \in J} \sum_{m \in M} \sum_{p \in P} e_{jkt} \cdot d_{jmpkt} \Bigg]
\end{aligned}
\tag{4.26}
$$

The corresponding constraints (4.27) - (4.34) of the program (4.26) have then to hold for all nodes $k \in K(t)$ of the considered time frame $t = 1 \ldots T$, as illustrated below.

Basic tactical (operational) constraints:

$$\sum_{j \in J} \sum_{v \in V(p)} z_{jmvkt} \leq D_{pmt} \qquad \forall m, p, t, k \tag{4.27}$$

$$\sum_{m \in M} \sum_{p \in p} \sum_{v \in V(p)} z_{jmvkt} \leq K_{jt} \qquad \forall j, t, k \tag{4.28}$$

$$\sum_{m \in M} \sum_{v \in V(p)} z_{jmvkt} \leq K_{jt} \cdot x_{jp} \qquad \forall j, p, t, k \tag{4.29}$$

Variables for RVC calculation:

$$V_{jmvkt}^{trans} \leq z_{jmvkt} \cdot e_{jmkt} \cdot P_{pmt} \qquad \forall j, m, p, v \in V_{(p)}, t, k \tag{4.30}$$

$$V_{jmvkt}^{trans(F.O.B.)} = z_{jmvkt} \cdot \left(e_{jmkt} \cdot P_{pmt} - C_{jpmt}^{ship} \right) \qquad \forall j, m, p, v \in V_{(p)}, t, k \tag{4.31}$$

$$V_{jmvkt}^{nor} = \sum_{a \in A} \sum_{c \in C(a)} z_{jmvkt} \cdot e_{jakt} \cdot B_{vc} \cdot \left(C_{jct}^{source} + C_{jct}^{ship} \right) \cdot (1 - L_{jc}) \qquad \forall j, m, v, t, k \tag{4.32}$$

RVC constraint and possible duty payments:

$$V_{jmvkt}^{trans(F.O.B.)} - V_{jmvkt}^{nor} \geq \alpha \cdot V_{jmvkt}^{trans(F.O.B.)} - y_{jmvkt} \cdot M \qquad \forall j, m, v, t, k \tag{4.33}$$

$$d_{jmpkt} \geq \sum_{v \in V(p)} \left[V_{jmvkt}^{trans} \cdot T_{jpm} - M \cdot (1 - y_{jmvkt}) \right] \qquad \forall j, m, p, t, k \tag{4.34}$$

5 Numerical Studies

The following Numerical Studies are broadly categorized into two parts, a deterministic and a stochastic study. The deterministic study refers to program (4.1) and is dedicated to the analysis of single exchange rate scenarios to study their general impact on strategic decisions (product allocations) and on sourcing decisions in relation to RVC compliance. The stochastic study is based on program (4.26) and highlights the advantages of considering exchange rate risk when designing supply chains under LC-considerations.

5.1 Test Design

The data presented in the following are generally based on a test design published in the article of Stephan et al. (2010), which refers to a truck manufacturer operating in the NAFTA. However, the test instance was generalized with some modifications, to justify the appliance of the more general Transaction Value Method.

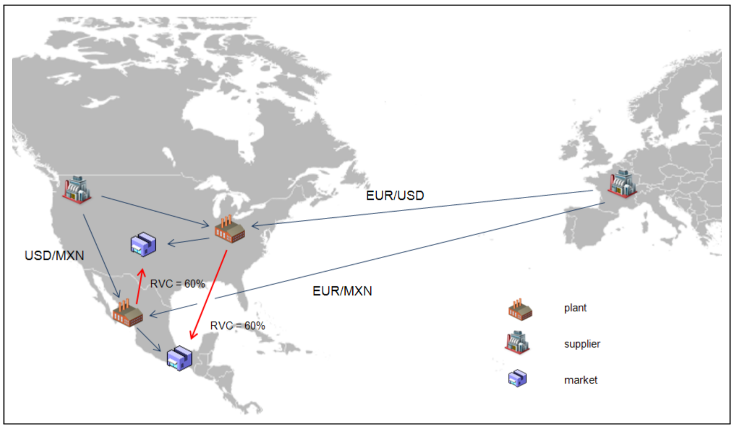

Figure 5.1: Numerical Studies: Network

The considered network is illustrated in figure 5.1 and consists of two plants located in the territory of the NAFTA, one in the USA and another one in Mexico. Two products (A, B), each consisting of five parts (sub-assemblies, components) have to be assigned for five periods (years, $t = 1 \dots 5$) in the future to the existing plants (P-US, P-MX).

The components are labeled by a 3 digit code in the following. Hence, the first digit (a, b) specifies the affiliation of a sub-assembly to a specific product (A, B), the second digit numbers the components from 1 to 5, sorted by their corresponding values and the last digit dedicates whether the part is sourced locally "l" or globally "g". Furthermore, components 1 to 4 of each final product can be sourced from a local US-based supplier and a global one, located in the EURO-Zone, whereas component 5 is only available on a global basis. Table 5.1 depicts the sourcing- and related transportation cost of the sub-assemblies and their corresponding RVC values at $t = 0$. Further it will be assumed, that the specified costs are the same for both plants at the beginning of the considered time-frame ($t = 0$). Total sourcing costs of each component (sourcing- + transportation cost) are transformed into the specified numeraire currency (USD), for a better comparison. For simplicity, all costs will be stated in thousands of their true values in the following.

product	component	sourc. costs	transp. costs	sourc. + transp.	RVC
A	a1l	1.9 USD	0.15 USD	2.05 USD	100%
	a1g	0.6 EUR	0.37 EUR	1.33 USD	0%
	a2l	5.5 USD	0.25 USD	5.75 USD	100%
	a2g	2.1 EUR	0.74 EUR	3.85 USD	0%
	a3l	8.2 USD	0.25 USD	8.45 USD	100%
	a3g	3.5 EUR	0.74 EUR	5.74 USD	0%
	a4l	10.3 USD	0.25 USD	10.55 USD	100%
	a4g	4.6 EUR	0.74 EUR	7.21 USD	0%
	a5g	6.2 EUR	0.74 EUR	9.50 USD	0%
B	b1l	1.5 USD	0.15 USD	1.67 USD	100%
	b1g	0.4 EUR	0.37 EUR	1.06 USD	0%
	b2l	4.4 USD	0.25 USD	4.65 USD	100%
	b2g	1.5 EUR	0.74 EUR	3.08 USD	0%
	b3l	6.6 USD	0.25 USD	6.81 USD	100%
	b3g	2.6 EUR	0.74 EUR	4.59 USD	0%
	b4l	8.2 USD	0.25 USD	8.49 USD	100%
	b4g	3.5 EUR	0.74 EUR	5.77 USD	0%
	b5g	4.9 USD	0.74 EUR	7.60 USD	0%

Table 5.1: Sourcing Costs, Transportation Costs, RVC

Hence, globally sourced parts (supplier EU) are cheaper than locally sourced parts (supplier US). Furthermore, locally sourced parts have an inherent RVC of 100% (*"rolled-up materials"*), while globally sourced parts have an RVC of 0% (*"rolled-down materials"*), as mentioned in section 2.3.2.1. Generally, the company has to select from a variety of sourcing options (product configurations v), in which configurations with more globally sourced parts (value) are cheaper while containing less RVC than locally sourced parts. In further steps, it will be assumed that 6 configurations are taken into account for each product (A, B), as illustrated in table 5.2. The sourcing strategies of a product are sorted in a descending order with respect to costs and RVC values. Hence configuration 1(7) of product A(B) is most expensive while containing the highest RVC value, whereas configuration 6(12) is the cheapest sourcing strategy but possesses the lowest RVC value.

	A						B					
comp./conf.	1	2	3	4	5	6	7	8	9	10	11	12
a1l	1	0	0	1	1	1	0	0	0	0	0	0
a1g	0	1	1	0	0	0	0	0	0	0	0	0
a2l	1	0	1	0	0	1	0	0	0	0	0	0
a2g	0	1	0	1	1	0	0	0	0	0	0	0
a3l	1	1	1	0	1	0	0	0	0	0	0	0
a3g	0	0	0	1	0	1	0	0	0	0	0	0
a4l	1	1	0	1	0	0	0	0	0	0	0	0
a4g	0	0	1	0	1	1	0	0	0	0	0	0
a5g	1	1	1	1	1	1	0	0	0	0	0	0
b1l	0	0	0	0	0	0	1	0	0	1	1	1
b1g	0	0	0	0	0	0	0	1	1	0	0	0
b2l	0	0	0	0	0	0	1	0	1	0	0	1
b2g	0	0	0	0	0	0	0	1	0	1	1	0
b3l	0	0	0	0	0	0	1	1	1	0	1	0
b3g	0	0	0	0	0	0	0	0	0	1	0	1
b4l	0	0	0	0	0	0	1	1	0	1	0	0
b4g	0	0	0	0	0	0	0	0	1	0	1	1
b5g	0	0	0	0	0	0	1	1	1	1	1	1
RVC (t = 0)	80%	68%	61%	58%	55%	51%	79%	67%	60%	57%	54%	50%

Table 5.2: Bill of Material

The final products (A, B) are send in further steps to two markets, the US-market and the Mexican-market, both located in the territory of the NAFTA. Duty-free cross-boarder deliveries are satisfied if a final product fulfills the required RVC of 60% under NAFTA's Transaction Value Method. The product configurations are set in a way, that 3 sourcing strategies of a product (A={1,2,3}; B={7,8,9}) fulfill the requested RVC, while the other 3 configurations (A={4,5,6}; B={10,11,12}) range below the claimed 60% at the beginning of the considered time-frame, as illustrated at the bottom of table 5.2.

In the case of RVC non-compliance, a duty rate of 25 % of the products custom values has to be paid for cross-boarder deliveries. The customs value coincides generally with the transaction value of a product, i.e. the price paid or payable for a good, as specified in section 2.3.2.1. Table 5.3 illustrates the transfer prices of the two products (A,B), prevailing at the two sales markets (M-US, M-MX). The transfer price of a product is based on the sum of the average variable costs (sourcing, production, transportation) plus a margin of 10 %. The Demand for the two products is assumed to be constant over the next five periods and is stated as well in table 5.3.

	Transfer Price		Demand [Units]	
market	A	B	A	B
US	47.9 USD	38.3 USD	10000	5000
MX	648.4 MXN	518.7 MXN	10000	5000

Table 5.3: Transfer Prices and Demand

The annual fixed costs for the operation of the plants and the variable production costs of the products are specified in table 5.4. The initial investment costs for the product allocations accumulate at $t = 0$, therefore they are not exposed to any currency fluctuations. The assumption is therefore, that these costs directly accrue in the numeraire currency (USD) and are set to 45 Mio. USD for each plant and product. Additionally it will be assumed, that the plants have no capacity limits but each plant has to produce at least 6000 units per period in the future, as illustrated in table 5.4.

			Prod. Costs	
plant	Fixed Costs	Min. Prod. Cap. [Units]	A	B
US	25000 USD	6000	10 USD	8 USD
MX	338377.5 MXN	6000	135.4 MXN	108.3 MXN

Table 5.4: Fixed Costs, Min. Production Capacity and Production Costs

Table 5.5 specifies the final transportation costs for inland- and cross-boarder deliveries from the two plants (P-US, P-MX) to the two sales markets (M-US, M-MX). Further, the discount rates for the implied DCF approach of the proposed model, will be based on an assumed WACC of 10 % and refer to discrete compounding.

from/to	US	MX
US	1 USD	2 USD
MX	27.1 MXN	13.5 MXN

Table 5.5: Final Transportation Costs

Generally all cash flows of the company will be transformed into a specified numeraire currency (USD). As obvious from figure 5.1, three exchange rates (EUR/USD,

USD/MXN, EUR/MXN) may have an impact on the firms network, the relevant exchange rates prevailing at $t = 0$ are illustrated in table 5.6.

EUR/USD	USD/MXN	EUR/MXN
1.3601	13.5351	18.4092

Table 5.6: Exchange Rates at the Beginning of the Considered Time-Frame (Data Source: Bloomberg (2011))

The presented data are set in a way, that they are the same for both plants and markets today ($t = 0$). However both, the variable- and fixed costs of the two plants (P-US, P-MX) and the transfer prices of the two products (A, B), prevailing at the two sales markets (M-US, M-MX), change their values in respond to exchange rate fluctuations over the specified time-frame ($t = 1 \ldots 5$). All following studies were conducted on an Intel 2.66 Core 2 Duo processor under the usage of Xpress-IVE 7.1.

5.2 A Deterministic Study

As mentioned in section 2.3.1 of this thesis, LC-regulations implied by FTA's, constrain the opportunity to benefit from global sourcing cost advantages, which in turn may have an influence on strategic decisions, like product allocations, for companies which operate within a FTA. On the other hand, generally the whole cost structure and the revenues of global operating firms are influenced by the realization of future exchange rates. Additionally, currency fluctuations can alter both, the transaction value of a final product and the value of the non-originating parts, which in turn results in fluctuating RVC-values for considered product configurations (sourcing strategies). The deterministic study is therefore designated to the analysis of single exchange rate scenarios to study:

- their impact on the firm's cash flows
- their interrelation with RVC-compliance under the assumed sourcing flexibility (Bill of Material, figure 5.2)
- and the resulting impacts on the strategic configuration (product allocations) of the proposed network

The Transaction Value Method in respect to Article 402 §2 (NAFTA 2011a) will be stated once more, for a better understanding of the following studies:

$$RVC = \frac{TV - VNM}{TV} \cdot 100 \tag{5.1}$$

, where TV is defined as the transaction value of the good adjusted to a F.O.B. basis and VNM denotes the value of the non-originating materials used by the producer in the production of the good.

The following scenarios are based on a linear up- or downward movement of a single exchange rate, while the other two rates are assumed to remain constant over time. Moreover, the value of a specific exchange rate at the beginning of the considered time-frame ($t = 0$) refers to table 5.6, while the respective final value ($t = 5$) refers to the minimum or maximum value which was observable over the last 5 years, rounded to the next full digit. The history of the past closing values (EUR/USD, USD/MXN, EUR/MXN) is illustrated in Appendix B, for comparison.

5.2.1 Devaluation of the EURO against the USD

The first scenario refers to a linear downward movement of the EUR/USD, from the actual value (1.3601, table 5.6) to a value of 1.1 at $t = 5$. Further it will be assumed, that the other two exchange rates (USD/MXN, EUR/MXN) remain constant over the next five periods.

The devaluation of the EURO against the USD leads to a decline of the non-originating sourcing- and related transportation costs (supplier-EU) in respect to the US-plant over time ($t = 1 \dots 5$), while all other costs of the two plants (US, MX) and the transfer prices of the two products (A, B), which prevail at the two sales-markets (M-US, M-MX) remain unaffected under this scenario. The result is a general sourcing cost advantage of the plant-US in respect to the non-originating parts, in contrast to the Mexican plant. Following this, two products (A, B) are allocated to the US-plant, while only product A is assigned to the Mexican-plant, as can be deduced from the production plan illustrated in figure 5.3.

The production plan can be read in the following way. A colored bar defines the production quantity of a specified product configuration (sourcing strategy) at a plant j (P-US, P-MX) which is shipped to a defined market m (M-US, M-MX) at a specific time period $t = 1 \dots 5$. The configuration index ($1 \dots 12$) is illustrated on the right-hand side of the chart, while the assignment of the configurations to the two products (A, B) is depicted below the chart. The presented chart allows therefore an illustration of the optimal production program of each product (A, B), the associated optimal sourcing strategy (configuration) and the corresponding

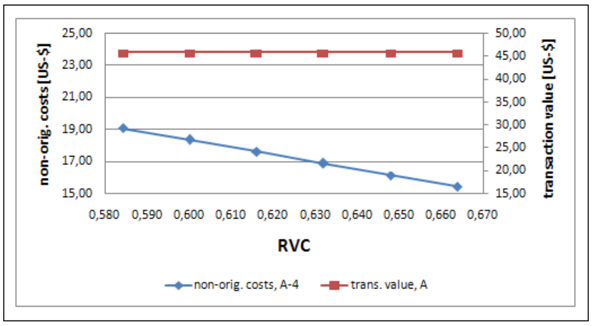

Figure 5.2: Plant US, Conf. 4, EUR/USD 1.3601 → 1.1

product allocation decisions.

However, the product allocation decisions cannot only be traced back to the favorable exchange rate realizations for the US-plant. In fact, they result from the interrelations between exchange rate fluctuations and the LC-constraints for US cross-boarder deliveries, which can be explained as follows. The steady devaluation of the EURO against the USD leads to rising RVC values for cross-boarder deliveries (P-US → M-MX), since their non-originating values decline (parts sourced from EU-supplier), while the transaction values of the final products (A, B) remain constant. This effect can be derived with a look at equation (5.1) and is illustrated in figure 5.2 for configuration 4 (product A) produced at the US-plant.

The production plan illustrated in figure 5.3, demonstrates the previously described effects. At $t = 1$, plant-US serves its domestic demand (market-US) for product A and B with the cheapest configurations (6, 12) and delivers the whole demand for product B (conf. 9) to the Mexican-market. In contrast, plant-MX satisfies only its own market demand for product A (conf. 6). As mentioned in section 5.1, conf. 9 of product B fulfills the required local content at the beginning of the considered time-frame ($t = 0$). However, with a further decline of the EUR/USD exchange rate over time, cheaper configurations of product B (10 at $t = 2, 3$ and 11 at $t = 4, 5$) can be shipped duty-free from the plant-US to the Mexican-market,

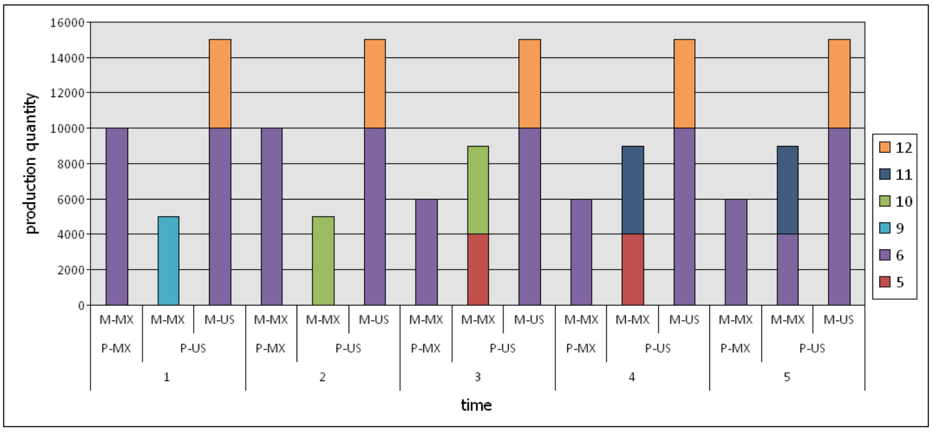

Figure 5.3: Production Plan: EUR/USD 1.3601 → 1.1
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

because the requested RVC value of 60% becomes fulfilled for these shipments. In addition, it comes to a production shift of 4000 units (product A) from plant-MX to plant-US at $t = 3$, while plant-MX produces only at the min. production level (6000 units). This comes from the fact, that US cross-boarder deliveries of product A (conf. 5 at $t = 3, 4$ and conf. 6 at $t = 5$) get even cheaper than Mexican domestic deliveries (plant-MX $\rightarrow$ market-MX) with the cheapest sourcing strategy 6 of product A.

Figure 5.4 depicts the gains which can be captured from the assumed sourcing flexibility in a graphical manner and refers to US cross-boarder shipments of product A (conf. 3-6). Hence, the ongoing devaluation of the EUR against the USD leads to a steady decline of the related non-originating sourcing costs (supplier-EU $\rightarrow$ plant-US), which in turn rises the corresponding RVC values of single configurations produced at the plant-US. The result is a stepwise decreasing sourcing cost function

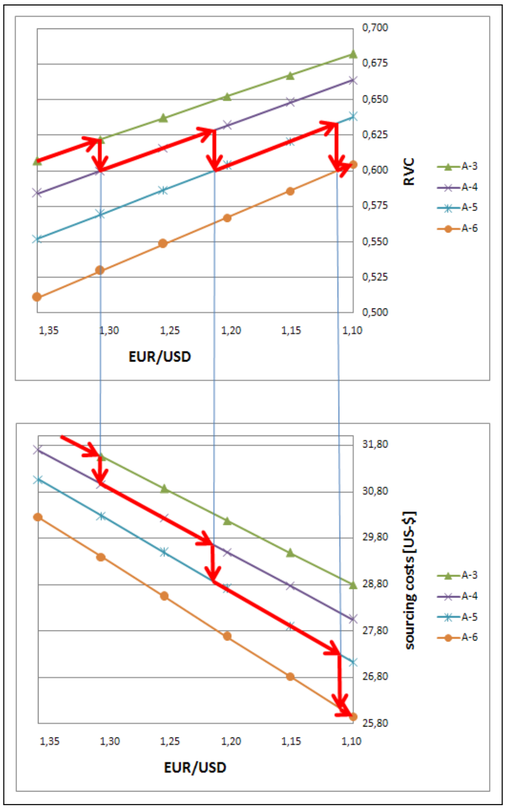

Figure 5.4: P-US $\rightarrow$ M-MX: RVC, Sourcing Costs, EUR/USD 1.3601 $\rightarrow$ 1.1

in respect to US cross-boarder deliveries, consisting of the general sourcing cost decline plus a jump to a next cheaper configuration, as soon as the required RVC level of 60% is reached.

The implications on the costs, the revenues and the profits of the network, under the assumed exchange rate scenario, are depicted in table 5.7. As obvious, the sourcing- (Source) and related transportation costs (TP Source) decline over the specified time-frame caused by the positive impact of the EUR/USD exchange rate on the US-plant. The production shift of product A to the US-plant at $t = 3$ leads to more cross-boarder deliveries to the Mexican-market, which results in higher final transportation costs (TP Final). To sum up, total costs decline while revenues remain constant, which finally leads to higher profits over time.

		↓	↓	↑				↓		↑
time	**Prod.**	**Source**	**TP Source**	**TP Final**	**Duty**	**Fix**	**Inv.**	**Total**	**Rev.**	**Profit**
1	280	744	98	35	0	50	0	1207	1341	135
2	280	727	98	35	0	50	0	1189	1341	152
3	280	709	94	39	0	50	0	1172	1341	169
4	280	690	91	39	0	50	0	1151	1341	191
5	280	670	89	39	0	50	0	1128	1341	214
DCF	1061	2697	359	141	0	190	135	4582	5085	503
%	23.2%	58.9%	7.8%	3.1%	0.0%	4.1%	2.9%	100%	-----	-----

Table 5.7: Costs, Revenue, Profit in Mio. USD: EUR/USD 1.3601 → 1.1

5.2.2 Acceleration of the EURO against the USD

The following scenario refers to a linear upward movement of the EUR/USD from the actual value (1.3601 table 5.6) to a value of 1.7 at the end of the considered time-frame ($t = 5$).

In contrast to the previous scenario, the acceleration of the Euro against the USD leads to an increase of the non-originating sourcing costs over time in reference to the US-plant. Furthermore, the transaction values at the Mexican-market remain constant (USD/MXN constant) which leads to an increase of the RVC-values for US cross-boarder deliveries in accordance with equation 5.1. Hence, more expensive configurations had to be shipped from the US-plant to the Mexican-market to fulfill the required RVC-level of 60% in combination with a general ascent of the non-originating sourcing costs. However, this is avoided and it comes to a reallocation of the production to the Mexican-plant, where the costs for the parts sourced from the EU-supplier remain constant.

It follows therefore, that both products (A, B) are allocated to the Mexican-plant while only one product (A) is manufactured at the US-plant, as illustrated in figure 5.5. Further, plant-MX serves the whole local demand (market-MX) of both products (A, B) with the cheapest configurations (6, 12) at each time period, while plant-US delivers the total demand of product A to the US-market (conf. 6) at t = 1 and 2. As mentioned in section 5.1, configuration 3 (product A) and 9 (product B) fulfill the required local content of 60% for cross-boarder deliveries in a constant exchange rate environment. Hence, plant-MX serves the US-market with 5000 units of product B (conf. 3) at each time period and from t = 3 with 4000 units of product A (conf. 9). The production shift of product A (4000 units) results from the fact, that Mexican cross-boarder deliveries with configuration 3 get cheaper than US local deliveries (plant-US → market-US) with the cheapest configuration 6 under the steady ascent of the EUR/USD exchange rate.

The respective costs, the revenues and the profits of the network are illustrated in table 5.8. The sourcing- (Source) and related transportation costs (TP Source) increase over the specified time-frame through the negative implications of the

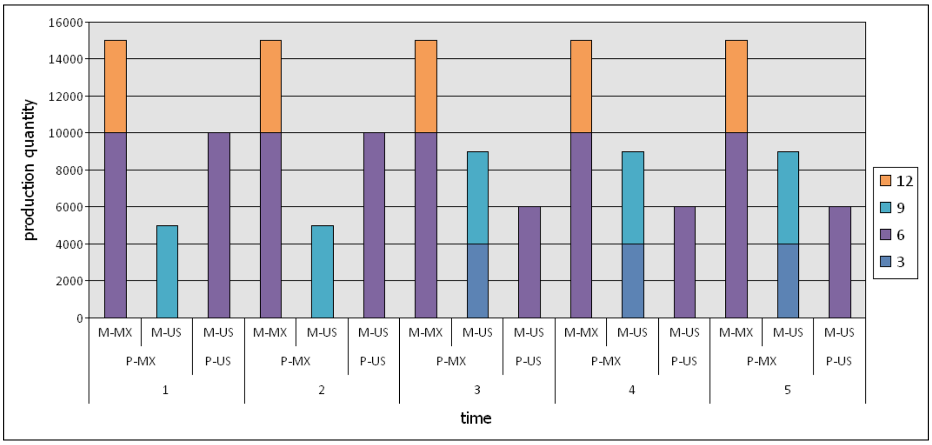

Figure 5.5: Production Plan: EUR/USD 1.3601 → 1.7
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

EUR/USD exchange rate on plant-US. Furthermore, final transportation costs (TP Final) rise at $t = 3$, provoked by the production shift of product A to the US-plant, which in turn leads to a greater amount of more expensive cross-boarder deliveries. As a result total costs increase, while revenues remain constant which leads to decreasing profits over time.

time	Prod.	Source	TP Source	TP Final	Duty	Fix	Inv.	Total	Rev.	Profit
1	280	766	102	35	0	50	0	1233	1341	108
2	280	776	104	35	0	50	0	1244	1341	97
3	280	783	102	39	0	50	0	1254	1341	88
4	280	789	103	39	0	50	0	1261	1341	81
5	280	795	103	39	0	50	0	1267	1341	74
DCF	1061	2958	389	141	0	190	135	4874	5085	211
%	21.8%	60.7%	8.0%	2.9%	0.0%	3.9%	2.8%	100%	-----	-----

Table 5.8: Costs, Revenue, Profit in Mio. USD: EUR/USD 1.3601 → 1.7

5.2.3 Devaluation of the USD against the PESO

The following scenario refers to a devaluation of the USD against the Mexican Peso, reflected by a linear downward movement of the USD/MXN exchange rate from the actual value (13.5351, table 5.6) to value of 10 at $t = 5$, while the other two exchange rates (EUR/USD, EUR/MXN) remain constant.

The transaction values (market prices) for cross-boarder deliveries accumulate in foreign currency, i.e. for plant-US in Mexican Pesos and for the Mexican-plant in USD. However, the RVC calculation for single configurations has to be carried out in the currency where a plant or producer is located, in consistency with Section 3 of the Rules of Origin Regulations (NAFTA 2011b, Currency Conversion). Following this, the transaction values for configurations produced at the plant-US rise for deliveries to the Mexican-market, in connection with the steady acceleration of the Peso against the USD. Further, the values of the non-originating parts remain constant (EUR/USD constant), which results in higher RVC-values for such shipments. An example for product configuration 4 (product A) produced at the US-plant and shipped to market-MX is illustrated in figure 5.6.

The opposite effect is observable for the Mexican-plant. The transaction values for Mexican cross-boarder deliveries (US-market), prevail in USD and have to be

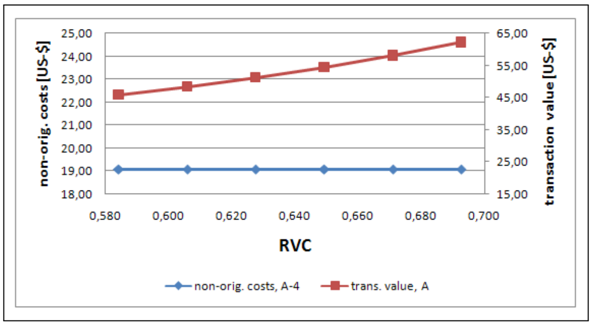

Figure 5.6: P-US → M-MX, Conf. 4, USD/MXN 13.5351 → 10

converted in Pesos for the RVC calculation of single product configurations. The result is a steady decline of the transaction values over the considered time-frame ($t = 1 \dots 5$) in correspondence with the devaluation of the USD against the Peso. Furthermore, the non-originating costs for parts sourced from the EURO-Zone remain constant (EUR/MXN constant), from the perspective of the Mexican-plant, which finally leads to a decline of the RVC-values for configurations shipped from plant-MX to the US-market. This effect is illustrated in figure 5.7 for configuration 9 (product B) delivered to the US-market.

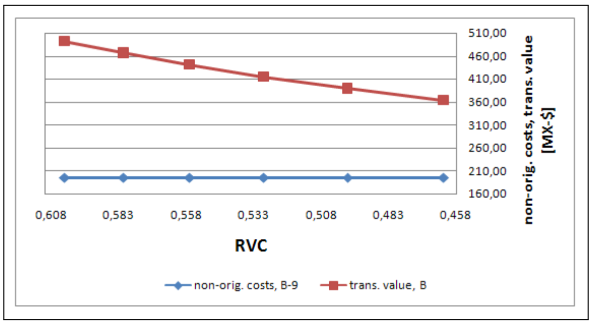

Figure 5.7: P-MX → M-US, Conf. 9, USD/MXN 13.5351 → 10

The general implications on the network provoked by this scenario, can be explained as follows. In respect to the US-plant, generally all costs remain unaffected by the steady decline of the USD/MXN exchange rate, since they already have been accumulate in the numeraire currency (USD) or have been converted into USD (non-originating sourcing- + transportation cost) by the EUR/USD exchange rate. The same holds for the transaction values of the two products (A, B), prevailing at the US-market (USD), which leads to constant market prices for US local deliveries (plant-US → market-US) and Mexican cross-boarder deliveries (plant-MX → market-US), in terms of USD-values.

However, with the steady acceleration of the Peso against the USD all costs of the Mexican-plant, which accumulate in Pesos (fixed-, production-, final-transportation costs), rise over the considered time-frame in relation to the numeraire currency (USD). The sourcing costs for the originating parts (US-supplier, USD) remain constant, since they are first of all converted into Pesos and converted back into the numeraire currency (USD) at each time point t. As previously mentioned, the sourcing costs of the non-originating parts (EU-supplier, EUR) remain constant in reference to RVC calculation (in local currency, MXN), they rise however from the perspective of the US-based headquarter through the final conversion into the numeraire currency (USD). While the costs for the Mexican-plant rise, the transaction values for the two products (A, B), prevailing at the Mexican-market rise too, in relation to the USD. This results in rising market prices for US cross-boarder deliveries (plant-US → market-MX) and for Mexican local deliveries (plant-MX → market-MX), in reference to Dollar values.

The production plan for the next five periods is illustrated in figure 5.8 and

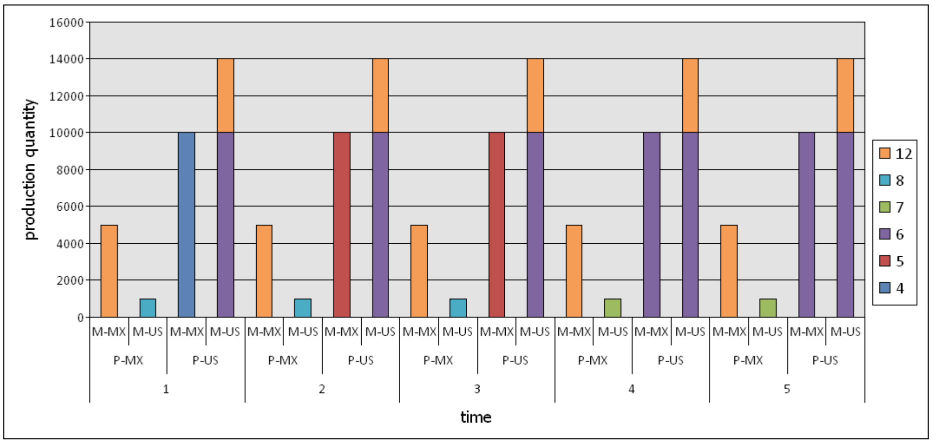

Figure 5.8: Production Plan: USD/MXN 13.5351 → 10
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

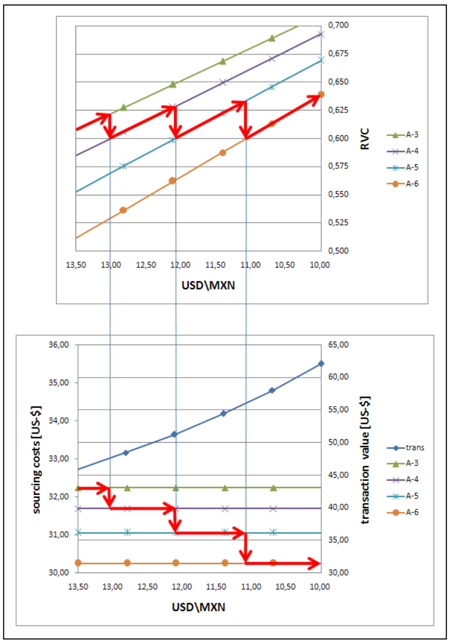

Figure 5.9: P-US → M-MX: RVC, Sourcing Costs, USD/MXN 13.5351 → 10

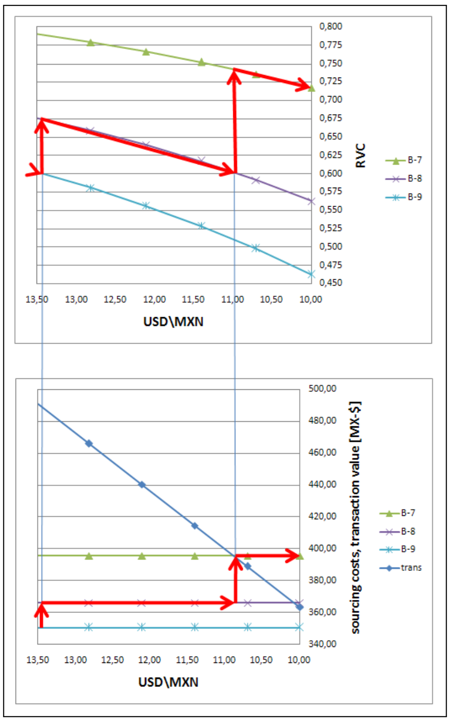

Figure 5.10: P-MX → M-US: RVC, Sourcing Costs, USD/MXN 13.5351 → 10

confirms the previously described relations. As obvious, both products (A, B) are allocated to the plant-US, which serves the whole domestic and foreign demand of product A and 4000 units of the domestic demand for product B. In contrary, plant-MX produces only product B at the minimum production level (6000 units) and serves its own market demand (5000 units) and the remaining 1000 units of the US-market for product B. Hence, maximum production is allocated to the US-plant in each time period, which can be explained as follows. The first reason is the general cost advantage of the US-plant, which increases over time with the steady devaluation of the Dollar against the Peso. The second reason can be traced back to the positive implication on RVC-values for US cross-boarder deliveries. As obvious from the production plan, cheaper configurations of product A (4 at $t = 1$, 5 at $t = 2, 3$ and 6 at $t = 4, 5$) can be sent to the Mexican-market over the considered periods, as soon as the required RVC of 60% becomes fulfilled. Additionally, increasing revenues can be realized for such shipments with the steady acceleration of the corresponding transaction values (market-MX). A graphical illustration for product A, produced at the US-plant and shipped to the Mexican-market is depicted in figure 5.9.

In reference to the production plan (figure 5.8) more expensive configurations (8 at $t = 1, 2, 3$ and 7 at $t = 4, 5$) of product B have to be shipped from the Mexican-plant to the US-market as a result of the negative implications on the RVC for these shipments. The assumed sourcing flexibility can therefore be used to counterbalance RVC-non-compliance. However, the graphical illustration in figure 5.10 demonstrates, that the enforced Mexican cross-boarder deliveries of product B (min. production requirement) seem to be quite unprofitable as a result of the declining transaction value of product B, in terms of Mexican Pesos.

The costs, revenues and profits for each plant and the whole network are depicted in figure 5.9. As previously mentioned, the cost structure of the US-plant remains unaffected from the devaluations of the USD against the Peso. The sourcing costs decline, a result of the shipment of cheaper configurations to the Mexican-market, while increasing revenues can be realized for these deliveries, which leads finally to rising profits of the US-plant. In contrary all costs of the Mexican plant rise in reference to USD-values. Moreover, some of the negative implications might be

	time	Prod.	Source ↓	TP Source	TP Final	Duty	Fix	Inv.	Total ↓	Rev. ↑	Profit ↑
plant US	1	232	635	82	34	0	25	0	1008	1138	130
	2	232	629	82	34	0	25	0	1002	1167	165
	3	232	629	82	34	0	25	0	1002	1200	198
	4	232	621	82	34	0	25	0	994	1238	244
	5	232	621	82	34	0	25	0	994	1281	287
	DCF	879	2379	311	129	0	95	90	3883	4542	658

	time	Prod. ↑	Source ↑	TP Source ↑	TP Final ↑	Duty	Fix ↑	Inv.	Total ↑	Rev. ↑	Profit ↑
plant MX	1	51	133	21	7	0	26	0	239	241	2
	2	54	138	22	8	0	28	0	250	252	3
	3	57	144	23	8	0	30	0	262	266	3
	4	61	153	23	9	0	32	0	278	281	3
	5	65	160	25	9	0	34	0	293	298	4
	DCF	215	548	86	31	0	112	45	1037	1003	-34

	time	Prod. ↑	Source ↑	TP Source ↑	TP Final ↑	Duty	Fix ↑	Inv.	Total ↑	Rev. ↑	Profit ↑
Network	1	283	768	103	41	0	51	0	1247	1378	132
	2	286	767	104	42	0	53	0	1252	1420	168
	3	289	773	105	42	0	55	0	1264	1466	202
	4	293	774	105	43	0	57	0	1271	1519	247
	5	297	781	107	43	0	59	0	1287	1578	291
	DCF	1094	2927	397	160	0	207	135	4920	5545	624
	%	22.2%	59.5%	8.1%	3.3%	0.0%	4.2%	2.7%	100%	-----	-----

Table 5.9: Costs, Revenue, Profit in Mio. USD: USD/MXN 13.5351 → 10

offset through the realization of higher revenues for local deliveries (market-MX). However, in reference to the DFC-value, rising profits are not able to amortize the investment costs for product B over the specified five periods, which finally results in a loss for the Mexican-plant.

Additionally, three further scenarios could be analyzed. However, the effects of the first two studies (5.2.1 and 5.2.2) can be devolved to the Mexican-plant under an acceleration or devaluation of the EURO against the Mexican-Peso. Additionally, an acceleration of the USD against the Pesos leads generally to the opposite effects on the corresponding plants as stated under study 5.2.3. The production plans for these studies are illustrated in Appendix C, for completion.

5.3 A Stochastic Study

The previously stated deterministic cases demonstrated how strategic product allocation decisions might be influenced by taking exchange rate fluctuations and LC-regulations into account. However, deterministic assumptions about future exchange rates might lead to suboptimal network configurations. The first stochastic study 5.3.2.1 is therefore designated to a comparison of the solution from a deterministic approach with the result from the stochastic program, developed in section 4.6 of this thesis. Additionally, it was pointed out in detail how currency fluctuations can alter both, the transaction value and the value of the non-originating parts, which in turn leads to fluctuating RVC values. Following this it was shown, that the assumed sourcing flexibility allows for an additional exploitation of global sourcing cost advantages under favorable exchange rate scenarios, while RVC non-compliance can be counterbalanced under unfavorable realizations. The second study 5.3.2.2 is therefore designated to the risk of underachieving the required RVC, when exchange rate risk is not taken into account. The third study 5.3.3 states then a general valuation of the proposed sourcing flexibility in relation to RVC-compliance and exchange rate risk. The fourth stochastic study 5.3.4 is designated to the comparison of different LC-considerations under exchange rate uncertainty, while the last study 5.3.5 compares the solution quality of the SAA-function under increasing sample sizes. However, first of all adequate approximations for the input parameters (drift, volatility) of the proposed binomial tree model have to be derived, which will be presented in the next section.

5.3.1 Parameter Setting

In reference to the proposed binomial tree model in section 4.5.2, the stochastic behaviour of the uncertain variables can be specified by the mean change per time unit μ or more precise $(\mu - \frac{1}{2}\sigma^2)$ and their corresponding variance rate σ^2. The drift for an exchange rate can be set to the difference between the risk-free interest rates of the corresponding countries. This balance condition is based on interest rate parity and has to hold in the long-run, because otherwise financial arbitrage possibilities would arise, i.e. investors could realize profits over the risk-free rates through the exchange of local currencies in foreign currencies without any risk (Huchzermaier 2001, p.6). Hence, the up and down movements for the exchange rates, specified in section 4.5.2, can then be defined as follows:

$$u = e^{(r_{quote} - r_{base} - \frac{1}{2}\sigma^2)\Delta t + \sigma\sqrt{\Delta t}} \tag{5.2}$$

$$d = e^{(r_{quote} - r_{base} - \frac{1}{2}\sigma^2)\Delta t - \sigma\sqrt{\Delta t}} \tag{5.3}$$

$$p = \frac{1}{2} \tag{5.4}$$

, with the corresponding input parameters:

T	number of considered years in the future
N	number of time steps with $\Delta t = \frac{T}{N}$
$r_{quote} - r_{base} - \frac{1}{2}\sigma^2$	constant drift rate
σ^2	constant variance rate

A good approximation for the risk-free rate of a country can be obtained by subtracting the corresponding country risk premium from the government bond yield, as illustrated in table 5.11 for the USA, Europe (Germany) and Mexico. Ten year government bond yields are easily available for most of the countries and are therefore selected for the calculation of the exchange rate drifts, as depicted in table 5.12.

	US Gov. Bond	German Gov. Bond	Mexican Gov. Bond
10y treasury	1.86%	1.77%	6.38%
- country risk premium	0.75%	0.00%	2.25%
= risk-free rate	1.11%	1.77%	4.13%

Table 5.11: Risk-Free Rates: USA, Europe, Mexico
(Data Source Gov. Bonds: Bloomberg (2012))
(Data Source Country Risk: Damodaran (2012))

EUR/USD	-0.66%	$= r_{US} - r_{EU}$
USD/MXN	3.02%	$= r_{MX} - r_{US}$
EUR/MXN	2.36%	$= r_{MX} - r_{EU}$

Table 5.12: Drift Rates: EUR/USD, USD/MXN, EUR/MXN

The volatility of an exchange rate can be determined by analysing risk structures of the past or through the calculation of so-called implied volatilities of currency options, which represent the expected volatility of an exchange rate by the market participants. The first approach is selected for the following studies, hence table 5.13 illustrates the annualized volatilities for the EUR/USD, the USD/MXN and the EUR/MXN exchange rate, calculated from the data of the past five years [1].

EUR/USD	USD/MXN	EUR/MXN
11.49%	13.18%	16.11%

Table 5.13: Annualized Volatilities: EUR/USD, USD/MXN, EUR/MXN (Data Source: IMF (2011))

As explained in section 4.5.3, the realizations of two exchange rates (EUR/USD, USD/MXN) will be simulated quarterly over 5 years in accordance with the proposed binomial tree model and the previously defined input parameters. Under the assumption of independently distributed exchange rates, the two trees are combined as illustrated in figure 4.4, while the realizations of the third exchange rate are calculated from the corresponding cross-rate (equation (4.25)).

[1] The corresponding historical data of the EUR/USD, USD/MXN, EUR/MXN are depicted in Appendix B, for comparison.

5.3.2 Considering vs. Disregarding Exchange Rate Risk

5.3.2.1 The Effects on the Network Design

The first stochastic study is designated to highlight the importance of considering exchange rate risk when designing supply chain networks. Two different approaches will be compared, the first one (stoch) refers to the stochastic program (det. eq. program) illustrated in section 4.6, where exchange rate risk is taken into account under the appliance of the described binomial tree model depicted in section 4.5.2. The previously stated approximations for the drift rates and the volatilities (for the EUR/USD and the USD/MXN) in table 5.12 and 5.13 serve as input parameters for the binomial tree model. The second approach (det) refers to the deterministic program illustrated in section 4.4. Under this approach, the derived drift rates are taken into account for future exchange rate realizations, but any associated risk is disregarded. This approach (det) can be considered as taking the expected values of the three exchange rates into account when configuring the network, the corresponding realizations over time are depicted in table 5.14[2]. Additionally it will be assumed, that the demand for the two products (A, B) at the two sales markets (M-MX, M-US), illustrated in table 5.3, must not be fulfilled as assumed under the model formulation, stated in section 4.6.

ex. rate/time	0	1	2	3	4	5
EUR/USD	1.3601	1.3512	1.3423	1.3334	1.3247	1.3159
USD/MXN	13.5351	13.9504	14.3784	14.8195	15.2742	15.7429
EUR/MXN	18.4092	18.8491	19.2996	19.7609	20.2332	20.7168

Table 5.14: Exchange Rate Realizations: det

Table 5.15 gives an overview of the corresponding objective values (profits) of the two approaches (stoch, det) under different investment cost levels. As obvious (see $\Delta_{det-stoch}$ for inv = 25 Mio. USD $\rightarrow$ 150 Mio. USD), not taking exchange rate risk into account leads to an underestimation of the corresponding future cash flows and the consequential NPV under the proposed assumptions. This cannot be generalized, an overestimation is also possible under different settings. However,

[2]The realizations of the EUR/MXN rate were calculated by the cross-rate, stated in equation (4.25), to get a better comparison to the stochastic approach.

both is disadvantageous and leads to wrong implications regarding investments, like product allocation decisions.

obj./inv. costs	25	50	75	100	125	150
stoch	477	402	333	283	233	183
det	297	212	137	62	56	-44
$\Delta_{det-stoch}$	-180	-190	-197	-222	-228	-228

Table 5.15: Objective Values [Mio. USD]: Stochastic vs. Deterministic

Following this, table 5.16 summarizes the product allocation decisions for the stochastic and deterministic approach (stoch, det) and underscores the previously stated argument. Hence, the product allocation decisions under the deterministic approach are generally all different from the stochastic solution, even when investment costs carry more weight (higher investment cost levels). Just taking expected values into account without considering any variability might therefore lead to sub-optimal network configurations.

	plant	product	25	50	75	100	125	150
stoch	US	A	1	1	1	1	1	1
		B	1	1	0	0	0	0
	MX	A	1	1	0	0	0	0
		B	0	0	1	1	1	1
det	US	A	1	1	1	1	0	0
		B	1	0	0	0	1	1
	MX	A	1	1	1	1	1	1
		B	1	1	1	1	0	0

Table 5.16: Product Allocations: Stochastic vs. Deterministic

To illustrate this effect, the network configurations of the deterministic approach will therefore be fixed and are tested in the stochastic environment. The objective functions under this setting are designated by stoch(det) and depicted in table 5.17. Following this, the improvement of the stochastic solution (stoch) over the deterministic one ranges between 0.25% and 16.25%. The delta is highest at inv. = 100 Mio. USD, where the allocation decisions are also different regarding the number of the allocations. However, this is just a small network, the delta would be much larger under the consideration of networks where more product allocation decisions are taken into account.

obj./inv. costs	25	50	75	100	125	150
stoch	477	402	333	283	233	183
stoch(det)	476	393	318	243	208	158
$\Delta_{rel.}$	0.25%	2.20%	4.76%	16.52%	12.18%	16.04%

Table 5.17: Improvement: Stochastic vs. Deterministic

5.3.2.2 The Effects on RVC-Compliance

The previously stated study highlighted, that disregarding exchange rate risk might lead to suboptimal network configurations. However as stated before exchange rates have also an impact on the RVC of a final product since they can alter both, the transaction value and the non-originating costs of a final product. Another risk associated with exchange rate uncertainty, is therefore the risk of underachieving the required RVC of a final product for cross-boarder deliveries within a FTA. The following study is therefore designated to highlight this effect through the comparison of the stochastic approach (stoch) with an approach where the behaviour of future exchange rates (EUR/USD, USD/MXN, EUR/MXN) is disregarded completely (no drift, no volatility) when designing the network. This approach will be designated to "no fluc" in the following. In contrary to the last study, it will be assumed that the demand for the two products at the two sales markets have to be fulfilled, settled by long-term contracts over the specified time-frame[3]. Additionally, the initial investment costs are set to 125 Mio. USD per plant and product under this case.

Following this, figure 5.11, illustrates the production plan for the approach where the future behaviour of the exchange rates is disregarded completely (no fluc). Under this approach, the product allocation decisions are generally configured with respect to the investment costs. As these costs are quite high (125 Mio. USD) only one product (B) is allocated to the US-plant while the other one (A) is assigned to the Mexican-plant. Local deliveries of product A (P-MX → M-MX) and product B (P-US → M-US) are conducted with the cheapest configurations (6, 12), since no LC-constraints have to be considered for these shipments. Additionally, plant-MX serves the whole demand for product A at the US-market with configuration 3 while

[3]The results for the stochastic approach under this study are therefore different from the previously stated one, where demand fulfillment was not obligatory.

plant-US delivers the required quantity of product B with configuration 9 to the Mexican-market. These configurations are more expensive but fulfill the required RVC of 60% for cross-boarder deliveries (see table 5.2), taking no exchange rate fluctuations into account.

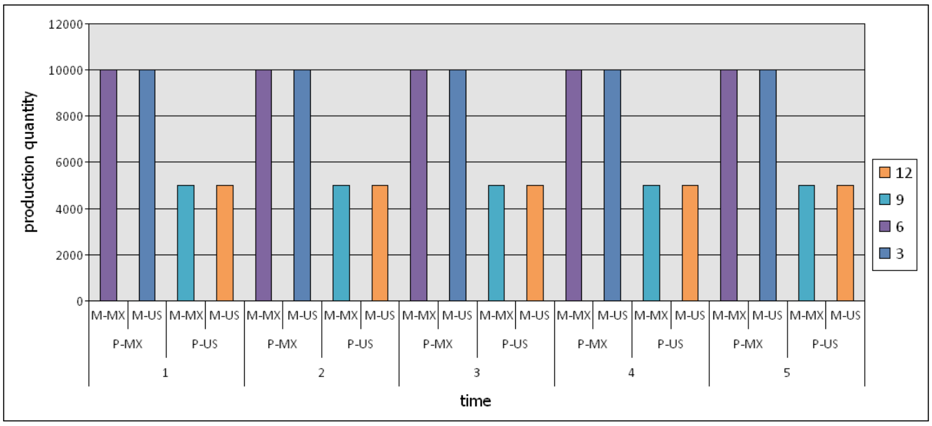

Figure 5.11: Production Plan: no fluc
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

The production plan for the stochastic approach is illustrated in figure 5.12. The corresponding shipments of the two plants (P-US, P-MX) to the sales markets (M-US, M-MX) are weighted by their corresponding probability of occurrence for a better overview. As obvious, two products (A, B) are allocated to the Mexican plant while only one product (A) is assigned to the US-plant. The high investment costs are therefore secondary when considering exchange rate risk, in contrary to the previously stated approach (no fluc). The resulting product allocation decisions can be explained with a look at the derived drift rates and volatilities in table 5.12 and 5.13[4]. As obvious the USD/MXN exhibits the highest drift and reflects a general ascent of this exchange rate. An ascent of the USD/MXN results in a shift of the main production to the Mexican-plant, as can be seen from the opposite scenario of deterministic study 5.2.3, illustrated in figure .4 in Appendix C. Further, the volatilities of the USD/MXN and the EUR/MXN, which affect the Mexican-plant

[4]As mentioned in section 5.3.1, the realizations of the EUR/MXN exchange rate are derived from the EUR/USD and USD/MXN through the corresponding cross-rate and are therefore slightly different from the values illustrated in table 5.12 and 5.13.

are higher than the volatility of the EUR/USD, which additionally contributes to the allocation of both products to the Mexican-plant, under the assumption that the demand has to be fulfilled.

As obvious from the production plan, the cost optimal sourcing strategies of the two products (6 for product A (light-brown) and 12 for product B (dark-brown)) are used for local deliveries, since no LC-constraints have to be taken into account for these shipments[5]. In contrast, for resulting cross-boarder deliveries from the Mexican-plant to the US-market, generally the whole range of possible product configurations is used. Cheaper configurations (lower RVC at $t = 0$) are shipped under favorable exchange rate realizations, which contributes to additional sourcing cost gains, while more expensive configurations are used to counterbalance RVC non-compliance.

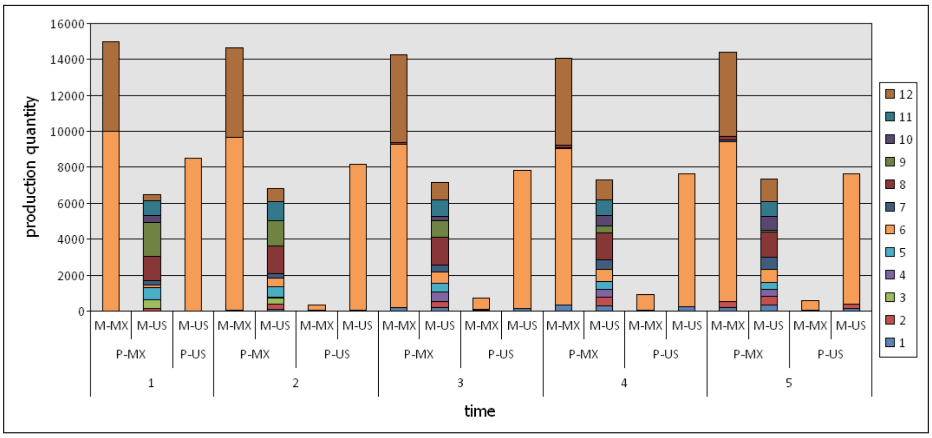

Figure 5.12: Production Plan: stoch
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

The resulting product allocation decisions of the two approaches (stoch, no fluc) are summarized in table 5.18. To highlight the importance of flexibility in respect

[5] Additionally a small range of initially (t=0) most expensive configurations (1, 2 of product A; 7, 8 of product B) are used for local deliveries in periods farther away in the future. This occurs (in reference to the Mexican plant), when the acceleration of the EUR against the USD is high enough to offset the initial sourcing cost advantage for parts sourced from the EU-based supplier, i.e. locally sourced parts (supplier US) get cheaper than globally sourced ones. The same holds for the US-plant under a corresponding acceleration of the EUR against the Mexican Peso.

to sourcing and RCV-compliance under exchange rate risk, the following will be assumed. The network structure of the approach, where the behaviour of future exchange rates is disregarded completely (no fluc), will be fixed and tested in the stochastic environment, as before under the previous study. Moreover it will be assumed, that the company enters into long term sourcing contracts for their strategic parts[6]. Changes to other sourcing options, as these taken previously into account, are therefore not possible. The available sourcing opportunities for the first approach (no fluc), based on the previous results, are illustrated in table 5.19.

plant	product	stoch	no fluc
US	A	1	0
	B	0	1
MX	A	1	1
	B	1	0

Table 5.18: Product Allocations: stoch, no fluc

product	stoch	no fluc	RVC (t = 0)
A	1	-	80%
	2	-	68%
	3	3	61%
	4	-	58%
	5	-	55%
	6	6	51%
B	7	-	79%
	8	-	67%
	9	9	60%
	10	-	57%
	11	-	54%
	12	12	50%

Table 5.19: Sourcing Options: stoch, no fluc

The objective value of the approach where the future behaviour of the exchange rates was disregarded completely (no fluc), solved in the stochastic exchange rate environment, is designated by stoch(no fluc) and illustrated in figure 5.20. To sum up, under the first approach (no fluc), product allocation decisions were based only on investment costs which led to the allocation of one product to each plant. In addition, the production mix was settled under long-term contracts under the obligation to fulfill the required demand at the two sales markets, while taking no exchange rate risk into account. The results are high duty costs (252 Mio. USD), related to

[6]Resulting sourcing cost advantages from entering into long-term contracts are not considered for simplicity.

obligated cross-boarder deliveries while underachieving the required RVC provoked by exchange rate fluctuations. This can be traced back to the fixed sourcing strategy under suboptimal product allocation decisions which finally leads to a complete loss of -116 Mio. USD. Under the stochastic approach however, product allocation decisions were not primarily based on investment costs. In fact they were configured by taking the assumed distributions for the three exchange rates into account. Additionally, the production mix was adjusted under unfavorable exchange rate realizations to counterbalance against RVC non-compliance. As a result only a small amount of duty payments (0.07 Mio. USD) were taken into account, as illustrated in table 5.20. Furthermore, favorable exchange rate scenarios could be exploited under the proposed sourcing flexibility, which contributed to additional gains and finally to a profit of 91 Mio. USD.

	stoch	stoch(no fluc)
objective	91	-116
duties	0.07	252

Table 5.20: Difference to Stochastic Solution

5.3.3 The Value of the Assumed Sourcing Flexibility

The previously stated study pointed out, among others, that a fixed sourcing strategy might lead to high duty payments provoked by RVC non-compliance under unfavorable exchange rate realizations. Following this, a general valuation of the proposed sourcing flexibility will be stated next through a comparison of three different approaches. The first one is designated by opt 6 and considers 6 product configurations per product as under the stochastic approach in previous studies. As mentioned in section 5.1, configuration 1(7) of product A(B) is most expensive while containing the highest RVC value, in contrary configuration 6(12) is the cheapest sourcing strategy but possesses the lowest RVC value at $t = 0$. Under opt 3, only the sourcing strategies above the required RVC are taken into account, while opt 1 refers to a completely fixed sourcing strategy and considers just one configuration above the requested LC for each product (A, B). The available sourcing options and their corresponding RVC-values at $t = 0$ are illustrated in table 5.21 for each approach (opt 6, opt 3, opt 1). Additionally, the investment costs for the product allocations are set to 75 Mio. USD for each product and plant, while the demand has to be fulfilled.

product	opt 6	opt 3	opt 1	RVC ($t = 0$)
A	1	1	-	80%
	2	2	-	68%
	3	3	3	61%
	4	-	-	58%
	5	-	-	55%
	6	-	-	51%
B	7	7	-	79%
	8	8	-	67%
	9	9	9	60%
	10	-	-	57%
	11	-	-	54%
	12	-	-	50%

Table 5.21: Sourcing Options: opt 6, opt 3, opt 1

The corresponding objective values of the three approaches (opt 6, opt 3, opt 1) are illustrated in table 5.22 for different volatility levels[7]. Following this, $\Delta_{opt\,6-opt\,3}$ can be considered as the value added of considering product allocations below the required RVC at $t = 0$. As illustrated in figure 5.4 and 5.9 of the deterministic study, these configurations allow for an exploitation of additional sourcing cost advantages as soon as they fulfill the required RVC of 60% under favorable exchange rate realizations. On the other hand, configurations which range above the requested RVC can be used to counterbalance against RVC non-compliance, as pointed out under the previous study 5.3.2.2 and illustrated in a graphical way in figure 5.10 in deterministic study 5.2.3. Hence, $\Delta_{opt\,3-opt\,1}$ can be considered as the value added of taking sourcing strategies above the requested RVC (at $t = 0$) into account. A consequent result is, that these options generally rise under higher volatility as obvious from table 5.22[8].

[7]E.g. 1 σ refers to the estimated volatilities depicted in table 5.13, 2 σ refers to twice the volatility and 0 σ means that just the drift rates were considered, taking no volatility into account.

[8]Additionally, it can be observed that profits rise with increasing volatility. This effect will be explained in Appendix D of this thesis.

volatility	0 σ	0.5 σ	1 σ	1.5 σ	2 σ
opt 6	137	157	241	394	616
opt 3	-29	-24	45	188	403
opt 1	-48	-91	-10	132	344
$\Delta_{opt\,6-opt\,3}$	166	181	196	206	213
$\Delta_{opt\,3-opt\,1}$	19	67	55	56	59
$\Delta_{opt\,6-opt\,1}$	185	248	251	262	272

Table 5.22: Profits [Mio. USD], Increasing Volatility: opt 6, opt 3, opt 1

5.3.4 Comparison of Different LC-considerations

The following stochastic study refers to a comparison of the output resulting from program (4.26), where duty payments were modeled as an option (optional), with an approach were RVC-fulfillment is obligatory (binding), i.e. the required RVC of 60% has to be fulfilled for all cross-boarder deliveries, and an approach where LC-regulations are disregarded completely (no-lc). This study was conducted for different investment cost levels (25 Mio. USD → 150 Mio. USD) under the assumption that the demand has to be fulfilled.

As obvious from figure 5.13, the solutions of the profit functions for the optional- and the binding approach are generally the same for Inv. = 25 Mio. USD, both products (A, B) are allocated to both plants (US, MX), as depicted in table 5.23. However, with increasing investment costs, the value of optional duty payments for cross-boarder deliveries rises, which can be explained as follows. In reference to the proposed test design, four out of five parts of each product can be either sourced locally (supplier-US) or globally (supplier-EU), while one component is only available on a global basis. This leads to a maximum RVC of approximately 80% for the most expensive configurations (1, 7) of each product (A, B) at $t = 0$ (see table 5.21, opt 6). However, as pointed out in previous studies, currency fluctuations alter the transaction value and the non-originating costs of a final product, which results in fluctuating RVC-values. It might therefore come to exchange rate scenarios where the required LC for cross-boarder deliveries cannot be fulfilled, especially in time periods farther away in the future (higher volatility). The binding LC approach implies therefore, that each product (A, B) has to be allocated to each plant (US, MX) for all investment cost levels (see table 5.23, binding). Under the optional-

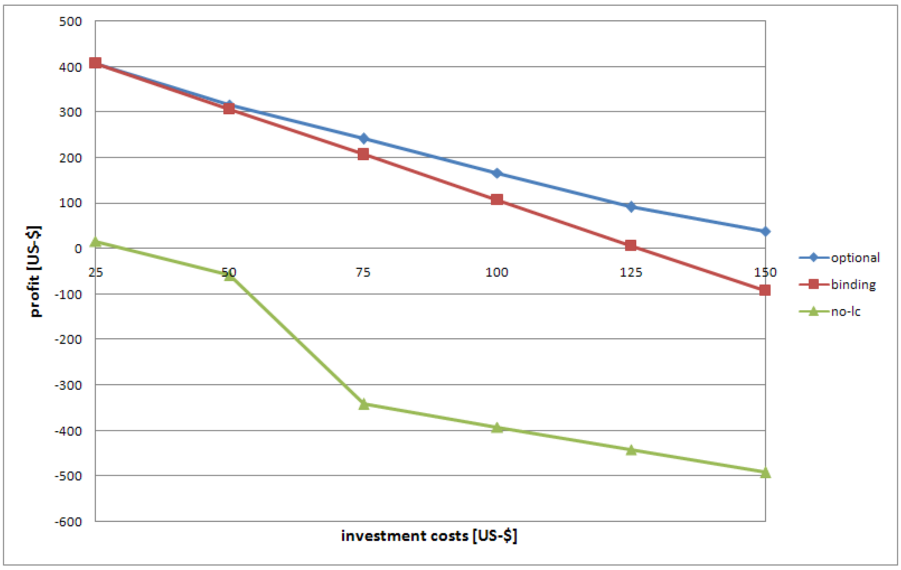

Figure 5.13: Profits [Mio. USD] over Increasing Investment Costs [Mio. USD]: Optional-LC, Binding-LC, No-LC

approach however, the network can be configured in a way that duty payments are taken into account for a small range of scenarios (see table 5.24), which finally leads to savings on investment costs, in contrast to the binding approach. The steady divergence of the optional- and binding solution under rising investment costs can therefore be traced back to the resulting product allocation flexibility of the optional approach.

Under the approach with no LC-consideration only the cost optimal product configurations are manufactured, also for cross-boarder deliveries, which finally leads to high duty payments in contrast to the binding and optional approach (see table 5.24). Under rising investment costs, even more punitive duties have to be paid, since savings on product allocations lead unavoidable to more cross-boarder deliveries necessary to satisfy the demand at the two sales-markets (US, MX). The result are increasing losses in correspondence with less product allocations provoked by rising investment costs, as illustrated in figure 5.13.

The necessity for the incorporation of LC-regulations in global network design models can be underscored with a look at table 5.23. At Inv. = 150 Mio. USD, the product allocation decisions for the optional- and the approach without LC-

	plant	product	25	50	75	100	125	150
optional	US	A	1	1	1	1	1	0
		B	1	0	0	0	0	1
	MX	A	1	1	1	1	1	1
		B	1	1	1	1	1	0
binding	US	A	1	1	1	1	1	1
		B	1	1	1	1	1	1
	MX	A	1	1	1	1	1	1
		B	1	1	1	1	1	1
no-lc	US	A	1	1	0	0	0	0
		B	0	0	1	1	1	1
	MX	A	1	1	1	1	1	1
		B	1	1	0	0	0	0

Table 5.23: Product Allocations, Increasing Investment Costs [Mio. USD]: Optional-LC, Binding-LC, No-LC

duties/*inv. costs*	25	50	75	100	125	150
optional	4.22E-05	0.067	0.067	0.067	0.067	6.082
binding	0	0	0	0	0	0
$no - lc$	407	407	629	629	629	629

Table 5.24: Duty Payments [Mio. USD], Increasing Investment Costs [Mio. USD]: Optional-LC, Binding-LC, No-LC

consideration are the same. However, disregarding LC leads to a high loss, since savings on sourcing costs are more than offset by high punitive duties. In contrast, under the optional approach duties are only taken into account for a small range of scenarios. Furthermore, positive and negative implications on RVC-values provoked by exchange rate fluctuations could be exploited or compensated to some extent through the right adjustment of the production mix, which finally leads to a high improvement over disregarding LC.

5.3.5 The Sample Size and the SAA-Solution

In respect to the proposed binomial tree model, stated in section 4.5.2 of this thesis, the probability (p) and the rates for an up- and down movement (u, d) are chosen in a way, that in the limit, as the time steps become smaller ($\Delta t \to 0$), the binomial tree model converges to a Geometric Brownian Motion (illustrated in equation (4.17)), which leads to the log-normal assumption depicted in equation (4.18) and (4.19). Following this, as $\Delta t = \frac{T}{N}$ gets smaller, the approximation of the assumed log-normal distribution gets better. The following study refers therefore to a comparison of the solution quality under increasing N (the number of time steps). The problem is considered over one year (T = 1) to reduce computational effort, further the investment cost are set to 25 Mio. USD under this study. The stochastic program (4.6) was conducted for N = 4, 8, 12, 16, 20 and 40 which leads to a maximum of 1681 nodes (K) for the approach with N = 40. The solution for N = 40 is defined as the reference value, i. e. the solution with the best known approximation of the SAA-function of program (4.26). The product allocation decisions under N = 40 are depicted in table 5.25. As obvious from table 5.26, all sample sizes lead to the same solution depicted by $\Delta_{binary(40)} = 0$. The objective value for N = 4 to 20 converge generally to the solution with N = 40, as can be seen from $\Delta_{obj.(40)}$ illustrated in table 5.26.

plant	product	N = 40
US	A	1
	B	0
MX	A	0
	B	1

Table 5.25: Product Allocations: N = 40

N	Δt	K	$time\,[sec.]$	$objective$	$\Delta_{obj.(40)}$	$\Delta_{binary(40)}$
4	0.25	25	0.562	47616.4	4.51%	0
8	0.13	81	1.656	46317.2	1.66%	0
12	0.08	169	3.203	46781.6	2.68%	0
16	0.06	289	6.376	46268.6	1.55%	0
20	0.05	441	9.375	46019.3	1.01%	0
40	0.03	1681	37.766	45561.1	-	-

Table 5.26: The Sample Size and the SAA-Solution

The conclusion which can be drawn from this study is that tree sampling is quite efficient. Good results can be obtained with small sample sizes and reasonable run-times. Even the solution with N = 4 ($\Delta t = 0.25$) delivered quite good results with $\Delta_{obj.(40)} = 4.51\%$ and the same set of product allocations as under N = 40. The previously stated studies were conducted with N = 20 and T = 5 ($\Delta t = 0.25$), i.e the realizations of the two trees were sampled quarterly over five years, which led to a combined tree with a set of specified nodes $k \in K(t) = (25(1), 81(2), 169(3), 289(4), 441(5))$ for the considered time points $t = 1 \ldots 5$ (see section 4.5.3). The solutions of this study conducted with T = 1, cannot be directly compared to the approach with T = 5. However, the results depicted in table 5.26 suggest, that the sampled trees with N = 20 and T = 5, deliver a sufficient approximation and reliable results within reasonable run-time (about 1 minute) for the previously stated studies.

6 Conclusion

Summary

A variety of challenges must be considered for the design of well-performing supply chains in today's global environment. This thesis was dedicated to the development of a global network design model which considers two of them, exchange rate risk and LC regulations, implied by FTA's. Following this, chapter 2 was dedicated to the theoretical disquisition of Regional Trade Agreements and their inherent Rules of Origins. Special focus was laid on the Transaction Value Method applied under the NAFTA. Additionally, exchange rate risk, its effects on global operating networks and interdependencies with LC-regulations regarding global sourcing were drawn down. Chapter 3, exposed the principals of mixed-integer programming, while stochastic programming was discussed in detail. Under the following chapter 4, a deterministic MIP-model was presented, which incorporates standard network design features and the constraints regarding NAFTA's Transaction Value Method. The applied Transaction Value Method is a quite general approach, which makes the presented model easy applicable to other FTA's. The model was then extended in a further step to a two-stage stochastic program under exchange rate uncertainty. Furthermore, a binomial tree approach was discussed, which approximates the assumed time-dependent log-normal distribution for exchange rates by a binomial distribution, to deliver in combination with the Sample Average Approximation a solvable approach for the stochastic program..

In addition, several case studies were presented in chapter 5. The deterministic study 5.2 demonstrated how product allocation decisions might be influenced by taking deterministic exchange rate scenarios and LC-regulations into account. Furthermore it was pointed out in detail, that currency fluctuations can alter both, the transaction value of a final product and the corresponding value of the the non-originating parts, which in turn leads to fluctuating RVC-values. Following this it was shown, that flexibility in terms of local and global sourcing, allows an additional exploitation of global sourcing cost advantages, while RVC non-compliance can be counterbalanced. The first stochastic study 5.3.2.1 was then dedicated to a comparison of a deterministic approach with the results of the developed stochastic program (4.26). The main conclusion from this study was, that deterministic assumptions about future exchange rates lead to wrong implications regarding future cash flows which in turn might results in suboptimal network configurations. Study 5.3.2.2 pointed out, that disregarding exchange rate risk in combination with fixed sourcing strategies for final products provokes heavy risk in relation to RVC non-compliance, which in turn might lead to a complete loss resulting from high punitive duty payments. Study 5.3.3 was dedicated to a general valuation of the proposed sourcing flexibility in an uncertain exchange rate environment. It was shown, that taking sourcing strategies below and above the requested RVC for cross-boarder deliveries into account, can contribute to a substantial value added for companies which operate within a FTA. Further study 5.3.4 demonstrated that taking optional duty payments into account might be valuable in a stochastic exchange rate environment. Under such an approach, a network which operates within a FTA can be configured in a way, that a small range of duty payments is taken into account, which finally leads to more efficient network configurations as under the binding approach (i.e. RVC-fulfillment for cross-boarder deliveries is obligatory). Disregarding LC-regulations leads to high duty payments, the constraints implied by FTA's should therefore be considered seriously for the design of well-performing and competitive supply chains. Finally study 5.3.5 gave some remarks on the solution quality of the developed stochastic program 5 in reference to the sample size. It was pointed out, that the proposed binomial tree model is quite efficient, reliable results can be obtained with small sample-sizes and reasonable run-times.

Outlook

The presented model formulation can be extended in many ways. Further research could focus on the extension of the presented binomial tree model. In this thesis, exchange rates were modeled under the assumption, that they are independent from each other. In a next step, correlations between currency pairs could be considered, to improve the presented approach. References for the development of such a model can be found in articles like Huchzermaier and Cohen (1996) or Kouvelis (1999), were multinomial approximation models for correlated exchange rates are presented. Additionally, the impact of real exchange rates in contrary to nominal exchange rates could be considered in an advanced model.

Furthermore, transportation costs demonstrate by far the largest cost component of a firms logistic costs, especially in a global environment (Simchi-Levi et al. 2008, p.8). While there was a steady decline of sea and air freight rates over the last decades as a result of the technological progress, they have begun to rise again in connection with the drastic increase of the crude oil prices, starting around the year 2003 (Meyer 2008, p.73). Only a few published articles consider transportation costs uncertainty in global supply chain models seriously. Their consideration might however gain importance in accordance with the previously stated argument. However, transportation costs might also have an impact on the Local Content of a final product. The presented model was tailored to study such effects, as obvious from constraints (4.7)-(4.7). Hence a rise of the corresponding transportation costs would result in a lower RVC of a final good, in accordance with the F.O.B. adjustment of the Transaction Value and the consideration of sourcing related transportation costs, when calculating the value of the non-originating parts. Hence, transportation cost fluctuations can have an impact on sourcing decisions in relation to RVC-compliance too. Resulting implications on a company's network could be pointed out in further studies.

A further aspect, which could be considered in future research is uncertainty about LC regulations itself. While tariff-oriented supply chains take costly long-term investments in respect to consisting legal frameworks of FTA's, the requirements regarding Local Content can change overnight (Plehn et al. 2010, p.2). Following this, the study of such effects and their implications on network design could be part of further studies.

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Appendix

Appendix A

The following derivations are based on Clewlow and Strickland (1998, pp.4-5) and Hull (2007, pp.273-275). The general stochastic diffusion process was presented in equations 4.12 and 4.13 , in section 4.5.1 as follows:

$$dX = \mu \cdot X \cdot dt + \sigma \cdot X \cdot dz \tag{.1}$$

The process illustrated above is an example of an Itó process, since the drift μ and the volatility σ (or variance rate σ^2) only depend on the current value of the variable X and time t. Generally, the stochastic differential equation for a variable X which follows an Itó process can be defined as follows:

$$dX = \mu\left(X,t\right) \cdot dt + \sigma\left(X,t\right) dz \tag{.2}$$

, where dz is a standard Wiener process and the functions $\mu\left(X,t\right)$ and $\sigma\left(X,t\right) dz$ represent general functions for the drift and volatility. In reference to Itó's Lemma[1], a function G of X and t follows the process:

$$dG = \left(\frac{\partial G}{\partial X}\mu + \frac{\partial G}{\partial t} + \frac{1}{2}\frac{\partial^2 G}{\partial X^2}\sigma^2\right) dt + \frac{\partial G}{\partial X}\sigma dz \tag{.3}$$

However, with a look at equation .1, we have an expected drift rate of $\mu \cdot X$ and a variance rate of $\sigma^2 \cdot X^2$. This was not mentioned explicitly in section 4.5.1 but has the implication, that the expected drift divided by the value of X is constant.

[1] Itó's Lemma is an extension of well known results in differential calculus, however a proof of the Lemma is beyond the scope of this thesis. The interested reader can find a derivation of Itó's Lemma in Hull (2007, p.297) or in the original paper of Ito (1951).

The same holds for the variance rate under the assumption that μ and σ are known constants and expressed in decimal form. The drift and the volatility are therefore proportional to the actual value of X at time t. Hence equation .3 can be stated as:

$$dG = \left(\frac{\partial G}{\partial X}\mu X + \frac{\partial G}{\partial t} + \frac{1}{2}\frac{\partial^2 G}{\partial X^2}\sigma^2 X^2 \right) dt + \frac{\partial G}{\partial X}\sigma dz \tag{.4}$$

, where dz is the same Wiener process as in equation .1. As a result G follows as well an Itó process, with a drift of:

$$\frac{\partial G}{\partial X}\mu X + \frac{\partial G}{\partial t} + \frac{1}{2}\frac{\partial^2 G}{\partial X^2}\sigma^2 X^2 \tag{.5}$$

and a resulting variance rate of:

$$\left(\frac{\partial G}{\partial X} \right)^2 \sigma^2 X^2 \tag{.6}$$

In further steps, Itó's Lemma is used to derive the process which is followed by $\ln X$, in the case that X follows a process like defined in equation .1. As a result $G = \ln X$ and

$$\frac{\partial G}{\partial X} = \frac{1}{X}, \qquad \frac{\partial G}{\partial t} = 0, \qquad \frac{\partial^2 G}{\partial X^2} = -\frac{1}{X^2} \tag{.7}$$

The process followed by G in reference to .4 is then:

$$dG = \left(\mu - \frac{\sigma^2}{2} \right) \cdot dt + \sigma \cdot dz \tag{.8}$$

, which finally leads to the distribution as illustrated in section 4.5.1:

$$\ln X_t - \ln X_0 \sim \phi \left[\ \left(\mu - \frac{\sigma^2}{2} \right) \cdot t, \ \ \sigma \cdot \sqrt{t} \ \right] \tag{.9}$$

$$\ln X_t \sim \phi \left[\ \ln X_0 + \left(\mu - \frac{\sigma^2}{2} \right) \cdot t, \ \ \sigma \cdot \sqrt{t} \ \right] \tag{.10}$$

Appendix B

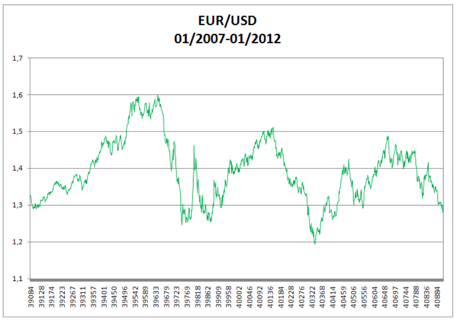

Figure .1: EUR/USD 5 year chart
(Data Source: IMF (2011))

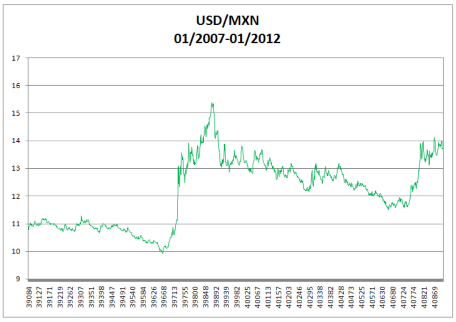

Figure .2: USD/MXN 5 year chart
(Data Source: IMF (2011))

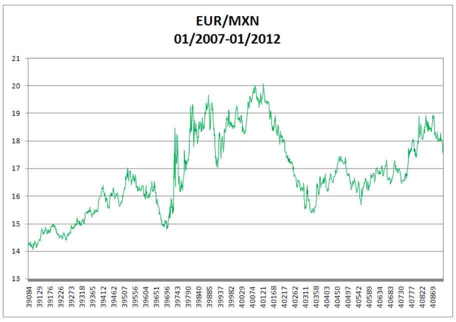

Figure .3: EUR/MXN 5 year chart
(Data Source: IMF (2011))

Appendix C

Acceleration of the USD against the PESO

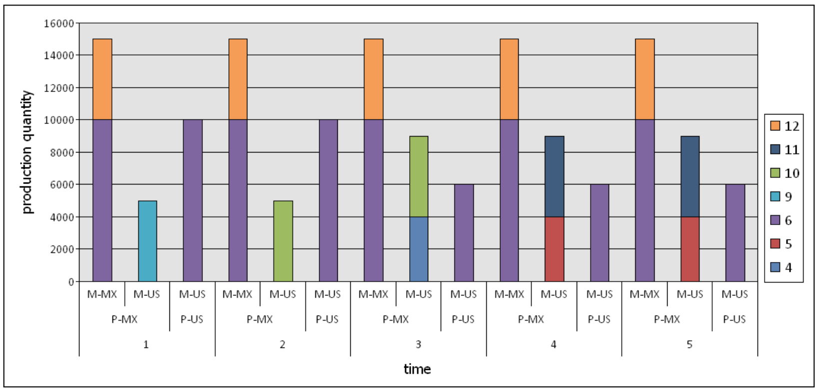

Figure .4: Production Plan: USD/MXN 13.5351 → 16
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

Devaluation of the EURO against the PESO

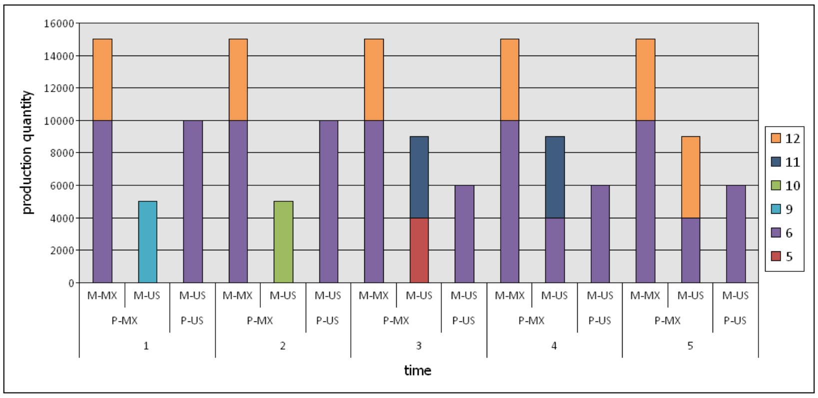

Figure .5: Production Plan: EUR/MXN 18.4092 → 14
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

Acceleration of the EURO against the PESO

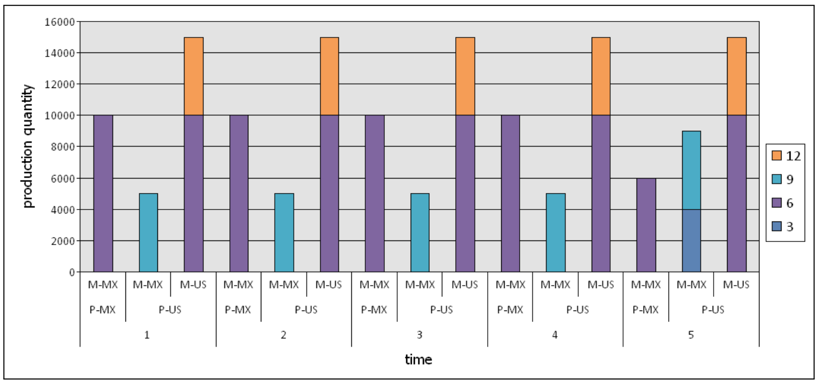

Figure .6: Production Plan: EUR/MXN 18.4092 → 21
(Product A: Conf. 1 . . . 6; Product B: Conf. 7 . . . 12
Conf. 1,7 . . . most expensive, highest RVC
Conf. 6, 12 . . . cheapest, lowest RVC)

Appendix D

Explanation for Rising Profits under Rising Volatility

As obvious from table 5.22 illustrated in study 5.3.3 of this thesis, profits rise under rising volatility. One could argue, that the corresponding drift rates are the reason for the rising profits, however this is not the case. Figure .1 depicted below, illustrates the objective values for all considered approaches in this thesis (optional (opt 6), binding, no-lc, opt 3, and opt 1), taking the volatilities of the exchange rates into account but no drifts. The investment costs were set to 75 Mio. USD under the assumption that demands have to be fulfilled, for the results in table .1.

volatility	0 σ	0.5 σ	1 σ	1.5 σ	2 σ
optional (*opt* 6)	229	254	352	533	788
binding	229	253	331	516	787
$no - lc$	-339	-319	-253	93	303
opt 3	85	81	164	333	586
opt 1	85	24	121	282	519

Table .1: Profits [Mio. USD], Increasing Volatility, No Drifts: Optional-LC (opt 6), Binding-LC, No-LC, opt 3, opt 1

As obvious, the objective values increase generally under all approaches under rising volatility, which can be explained as follows. The proposed two-stage stochastic program (4.26) in section 4.6 of this thesis includes the first stage decision regarding product allocations and the corresponding recourse variables at the second stage, defined by the network flows. The product allocations are configured in a way, that they are optimal under the whole range of considered scenarios. Additionally, the compensation variables on the second stage enable for an exploitation of favorable exchange rate realizations, while negative effects can be compensated to some extent, e.g. through production shifts, under a given set of first-stage decision variables. These possibilities (product allocation flexibility and compensations) can therefore be defined as options, more accurately as real options, which limit the associated downside risk, while they enable to benefit from the corresponding upside potential. It follows therefore, that the value of financial options and their real option complements, rise under higher volatility (Hull 2007, p.207). This thesis was not dedicated to the valuation of real options, however the previously stated arguments explain the rising NPV's under increasing volatility. Adding more options, e.g. the assumed sourcing flexibility and the possibility of optional duty payments, creates more value, however the general upside movement of the profits under higher volatility can be observed for all approaches. However, the previously stated arguments are just a broad explanation for this effect. The valuation of real options and their inherent features are generally more complicated as previously described. The interested reader can find more information on this topic in Huchzermaier and Cohen (1996), Kouvelis (1999), Cohen and Huchzermaier (1999), Huchzermaier2001 or Hull (2007).

Abstract

Globalization is in force and changes the image of today's world economy. Worldwide opportunities for production and sourcing deliver huge potential for growth and should be exploited to stay competitive in the long-run. However, these opportunities might be strongly constricted by non-tariff based trade barriers, like Local Content regulations which come with Free Trade Agreements (FTA's). Additionally, global supply chains are confronted with a substantial increase in the variety of risks. Especially currency fluctuations, demonstrate a significant risk and have to be considered for the design of well-performing global supply chains. As a result, this thesis is dedicated to the development of a two-stage stochastic program which considers exchange rate risk and the constraints regarding Local Content (LC) implied by FTA's. Under the assumption, that future exchange rate realizations can be described by stochastic diffusion processes (Geometric Brownian Motion), a binomial tree model is proposed to deliver a solvable approach for the stochastic model in connection with the Sample Average Approximation (SAA). Several case studies, based on a network which operates in the territory of the North American Free Trade Agreement (NAFTA) are presented. The studies highlight general effects of exchange rate risk on a global operating company. However of special interest is the influence of exchange rate fluctuations on sourcing decisions in relation to LC compliance and resulting implications on the network design.

Keywords: Strategic Network Design, Free Trade Agreements, NAFTA, Local Content, Two-Stage Stochastic Programming, Exchange Rate Risk, Binomial Trees, Sample Average Approximation

Zusammenfassung

Die ständig fortschreitende Globalisierung bietet eine Reihe von Herausforderungen für global operierende Unternehmen. Weltweite Produktions- und Materialbeschaffungsmöglichkeiten liefern großes Potenzial für Wachstum und sollten daher in der strategischen Planung von global operierenden Netzwerken ausgenutzt werden. Diese Möglichkeiten können jedoch stark durch nicht-tarifäre Handelsbarrieren, wie Local Content Bestimmungen von Freihandelszonen beschränkt sein um die lokale Wirtschaft zu schützen. Zusätzlich sind globale Wertschöpfungsketten einer Vielzahl von Risiken ausgesetzt, wobei speziell Wechselkursschwankungen eine signifikante Rolle spielen können. Die vorliegende Diplomarbeit beschäftigt sich daher mit der Entwicklung eines Zweistufig-Stochastischen Programms, welches Wechselkursrisiko und Local Content Bestimmungen von Freihandelszonen miteinbezieht. Die Unsicherheit bezüglich zukünftiger Wechselkursrealisierungen wird in Binomialbäumen dargestellt, um in Verbindung mit der Sample Average Approximation (SAA) einen lösbaren Ansatz für das stochastische Modell zu liefern. In Anlehnung an das entwickelte Modell werden Fallstudien präsentiert, die sich auf ein in der NAFTA operierendes Unternehmen beziehen. Von den Studien können generelle Effekte von Wechselkursrisiken auf die strategische Orientierung eines global operierenden Netzwerkes abgeleitet werden. Von besonderem Interesse ist jedoch der Einfluss von Wechselkursschwankungen auf Materialbeschaffungsentscheidungen in Verbindung mit der geforderten LC-Erfüllung von Freihandelszonen und daraus resultierende Auswirkungen auf die Konfiguration des Netzwerks.

Stichwörter: Strategische Netzwerk Planung, Freihandelszonen, NAFTA, Local Content, Zweistufige-Stochastische Programmierung, Wechselkursrisiko, Binomialbäume, Sample Average Approximation

Curriculum Vitae

Personal Data:

Name:	Robin Killian
Date of Birth:	April 9, 1983, Zurich
Citizenship:	Austria, Switzerland

Education:

since 2005	University of Vienna International Business Administration Specializations: Supply Chain Management, Investments Diploma Thesis: “Strategic Network Design under Exchange Rate Risk and Local Content”
02/2010 - 09/2010	University of Granada, Spain Exchange Semester, Erasmus
09/1998 - 10/2003	Higher Technical College of Eisenstadt Specialization: Aeronautical Engineering

Languages:

German:	Native
English:	Fluent
Spanish:	Good