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| Saint-Petersburg State University  Master in Management Program  **MODELLING PRICE COORDINATION IN THE SUPPLY CHAIN: THE EXAMPLE OF RUSSIAN FORESTRY INDUSTRY COMPANY**  Master’s Thesis by the 2nd year student  Concentration - General Management  Zenkevich Ekaterina  Research advisor:  Konstantin V. Krotov, Associate Professor  St. Petersburg  2017 |

ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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**АННОТАЦИЯ**

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| **Описание цели, задач и основных результатов**  Цель: модификация модели мульти-эшелонной цепочки поставок, которая функционирует в режиме конкуренции как мера ценовой координации для цепочки поставок российской компании лесной промышленности.  Основные задачи: проанализировать подходы к эволюции основных концепций управления цепочкой поставок. Математически формализовать координацию в мульти-эшелонной цепочке поставок для компании лесной промышленности и уточнить критерии оптимальности. Просчитать улучшенную модель и выявить подход, который принесет наиболее значительную прибавку к прибыли в случае ценовой координации компании лесной промышленности. Основываясь на практических выводах, составить рекомендации для улучшения деятельности среди компаний лесной промышленности.  Основные результаты:   1. Анализ основных теоретических концепций выявил область для изучения среди переменных в области цепочки поставок, минимизации размытых практических результатов и чрезмерного сужения данных исследований. 2. Формализация мульти-эшелонной модели указала на существование зависимости между узлами в цепочке поставок лесной промышленности, где один узел сообщает возможную выручку другому 3. Произведенные расчеты привели к выбору взвешенного равновесного решения по Нэшу, так как оно гарантирует выигрыш не только для всех членов цепи поставок, но и для всех цепи 4. Рекомендации указали на целесообразности использования инструмента в планировании ценообразования для минимизации оппортунистического поведения, отсутствия затоваривания и увеличения прибыли для рыночного игрока | |
| **Ключевые слова** | Ценовая координация, лесная промышленность, мульти-эшелонная модель, улучшение модели в области управления цепочкой поставок |

**ABSTRACT**

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| **Master Student's Name** | Ekaterina N. Zenkevich |
| **Master Thesis Title** | Modelling Price Coordination in the Supply Chain: the Example of Russian Forestry Company |
| **Faculty** | Graduate School of Management |
| **Program** | General Management |
| **Year** | 2017 |
| **Academic Advisor's Name** | Konstantin V. Krotov |
| **Description of the goal, tasks and main results**  Goal: modify the model for the multi-echelon supply chain that is acting in competition as a measure of price coordination in the supply chain for the Russian forestry industry market player.  Main tasks: To analyse the approaches to the evolution of the key concepts in the field of supply chain management. To mathematically formalize coordinated multi-echelon supply chain for the case of forestry industry companies and define its optimality criteria accordingly. To perform calculations for the modified model and find out which approach gains the most substantial price increase for the forestry industry company. Based on the practical outcome, to conduct recommendations for the performance improvement among the forestry industry players.  Main results:   1. The key concepts’ analysis has found out the research gap in terms of the supply chain variables, robustness of the empirical results and too narrow focus of the current research 2. The formulization of the multi-echelon model has resulted in foundation of the dependence sequence within the supply chain flow where the revenue from the previous juncture is transferred to the next juncture within the hierarchy 3. The preformed calculations have resulted in the choice of the Nash weighted equilibrium solution as the main instrument that allows the not only every operator within the supply chain, but also to the supply chain on the whole 4. Recommendations have focused on the tool application to the process of pricing updates as it helps obsolescence minimization, increases the revenue for the market player and prevents from opportunistic behavior in the market | |
| **Keywords** | Price coordination, forestry industry, multi-echelon models, Modification of the supply chain management model |

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# 1. Introduction

## 1.1 Justification of the Study.

The field of supply chain management (SCM) has developed as an academic discipline in the last 30 years, as can be observed by the growing number of academic journals and articles that focus on it. During this period of time the very processes in this management sphere have become significantly more complex.

However, in the following timeframe it was not only practice, but also theory that has been significantly evolved. The following academic discipline revolves around coordination among several business partners that are linked through flows of material, money and information. These partners include suppliers of basic raw materials and component parts, manufacturers, wholesalers, distributors, transporters, retailers, banks and financial institutions. In general, the materials, component parts and finished goods flow downstream although the returned merchandise flows upstream. For an effective supply chain system, the management of upstream flow of money is as important as the management of downstream flow of goods (Gupta and Dutta, 2011). Nevertheless, the research work on supply chain management has primarily focused on the study of materials flow and very little work has been done on the study of upstream flow of money.

Apart from the example above, there is a substantial number of different complex concepts that have become an essential part of the modern supply chain: to name a few, complex coordination, globalization, lean logistics, increasing number of actions from logistics’ providers and multichannel deliveries. Previously, these concepts were applicable only to the industries that produce innovative products (according to the Fischer’s classification) that were forced to the constant innovation in order to keep one step ahead of competitors. Nowadays, the practical applications of the cutting-edge practices’ have become so widespread that even those industries that were used to be more not significantly affected by the technological and business innovation, currently tend to apply them. The two most widespread reasons are the revenue increase and/or cost cutting.

In the spotlight of the following work are Russian forestry industry companies. In the period of modern history, they have been through certain significant changes, for instance, increase of the strong export orientation for the certain types of products (i.e., pulp) and centralization of the market players. Due to the specific coordination mechanism for the supply chain structure of every industry, in the following work forestry industry is being solely discussed. Among the specific traits of the supply chain in this analysed industry are: its hierarchical structure and the fact that all the final products are produced from the same raw material. It is important to specify that every product that is a result of the raw material processing’s stage could act as the final product for the one type of customers and by-product for another at the same time.

The maximization of the gain for all of the players in the supply chain is a very crucial topic in the research world of the countries that are the leading producers of the products from wood and pulp. The majority of the companies in the industry are vertically integrated and use multi-echelon supply chains. In other words, they depend heavily on the coherent mechanism of the coordination between its components. However, due to the long cycles of innovative features’ implementation forestry industry companies are used to rely on a little safety stock on the one hand and are unable to operate without any delays on the other. Thus, the problem of coordination is crucial for these companies to remain competitive in both the quality of demand and costs optimization.

## 1.2. Research Questions and Objectives.

The goal of this research is to modify the model for the multi-echelon supply chain that is acting in competition as a measure of price coordination in the supply chain for the Russian forestry industry market player. According to the goal of the research there are two research questions stated:

1) How traditional model for multi-echelon chains with linear demand can be changed for the forestry industry company?

2) To what amount could the final revenue for the supply chain increase if the coordination mechanism in the supply chain is implemented to the forestry industry company?

To achieve the above formulated goal the following objectives are to be fulfilled:

1. To analyse the approaches to the evolution of the key concepts in the field of supply chain management.
2. To mathematically formalize coordinated multi-echelon supply chain for the case of forestry industry companies and define its optimality criteria accordingly.
3. To perform calculations for the modified model and find out which approach gains the most substantial price increase for the forestry industry company.
4. Based on the practical outcome, to conduct recommendations for the performance improvement among the forestry industry players.

## 1.3. Methodology of the Research.

The following work is based on the logical concept, from general to the specific, of an empirical study. First of all, the theoretical framework and literature review are presented (about their design it would be told in the next paragraph). That is how the most recent problems and understudied parts in the theoretical concept are defined. After that, the empirical study itself was conducted. As the main goal of the paper is closely connected with the revenue increase that a forestry industry company might get from its supply chain coordination, the empirical data was a crucial thing to collect. The close to real prices were received from the largest Russian pulp & paper producer that differ according to the destination areas of the final products. Then centralized, decentralized and weighted Nash solutions were mathematically formalized for the forestry industry supply chain. Finally, via the program, created in the MATLAB application, the three solutions were compared, the optimization problem for all the 3 cases was solved and the one that has given the highest results in terms of final gains for all the supply chain participants, was chosen. Finally, these results were analysed and the practical recommendations for the following tool’s usage were performed.

It is important to understand how the literature review was designed as well. Having faced up the non-existence of the extensive and recent literature review on the topic, the goal of that chapter was formulated as to provide a snapshot of the diversity of the recent pieces of research being conducted in the field of supply chain management coordination and in it’s the most recent parts as financial supply chain management. In order to outline further research paths on the basis of theoretical and methodological gap identification, only the journals ranked 4\* or 4 (top journals in the field) in the Chartered Association of Business Schools Academic Journal Guide 2015 research were used for the initial search, namely: Journal of Operations Management, International Journal of Operations and Production Management, Production and Operations Management (in the field of Operations and Technology Management). It has been suggested that top-ranked journals should communicate, diffuse and archive scholarly knowledge more effectively than other journals.

The period of search was set from 2010 till 2015 year. An initial keyword search for articles containing any of the terms of the phrase supply chain management coordination (limited to citations and abstracts of periodicals) was then subsequently limited to the exact phrase, supply chain management coordination.

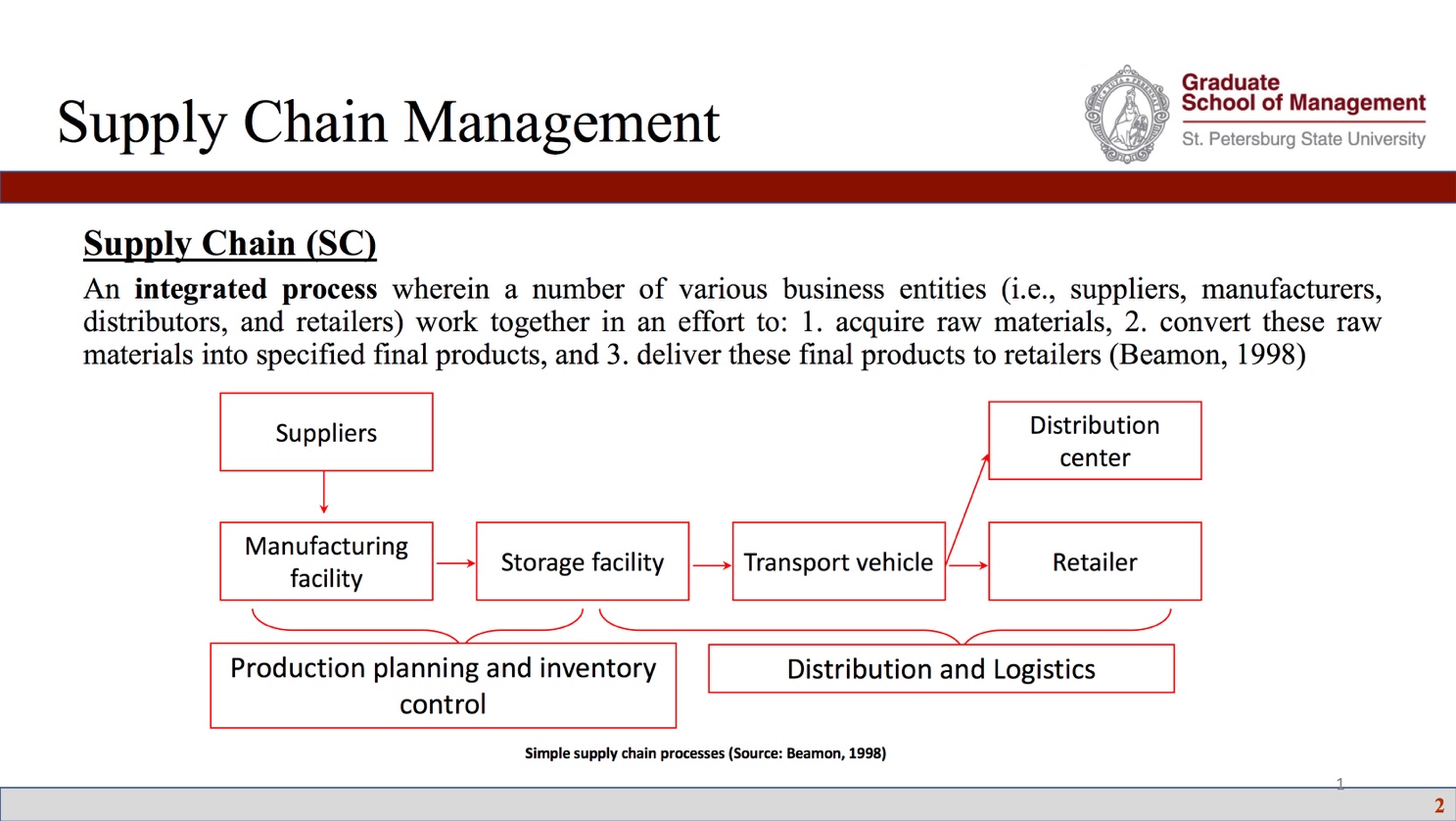
# 2. Modelling Price Coordination in the Supply Chain: Theoretical Background

## 2.1. Concept of Supply Chain Management.

While interest in SCM is immense, it is clear that much of the knowledge about SCM resides in narrow fields such as purchasing, logistics, IT and marketing. At least partly as a result of this, there appears to be little consensus on the conceptual and research methodological bases of SCM. This has contributed to the existence of a number of gaps in the knowledge base of the field. Thus, from a conceptualization perspective, the definition of the term is unclear.

According to Beamon (1998), “a simple supply chain (SC) may be defined as an integrated process wherein a number of various business entities (i.e., suppliers, manufacturers, distributors, and retailers) work together in an effort to: 1. acquire raw materials, 2. convert these raw materials into specified final products, and 3. deliver these final products to retailers. This chain is traditionally characterized by a forward flow of materials and a backward flow of information.

At its highest level, a SC can be decomposed to two basic, integrated processes: 1. the Production Planning and Inventory Control Process, and 2. the Distribution and Logistics Process. These processes, illustrated in Fig. 1 provide the basic framework for the conversion and movement of raw materials into final products.

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*Figure 1 Simple supply chain processes (adopted from Beamon 1998)*

The Production Planning and Inventory Control Process comprises of the manufacturing and storage sub-processes, and their interfaces. More specifically, production planning describes the design and management of the entire manufacturing process (including raw material scheduling and acquisition, manufacturing process design and scheduling, and material handling design and control). Inventory control describes the design and management of the storage policies and procedures for raw materials, work-in-process inventories, and usually, final products (Confessore, Rismondo 2004).

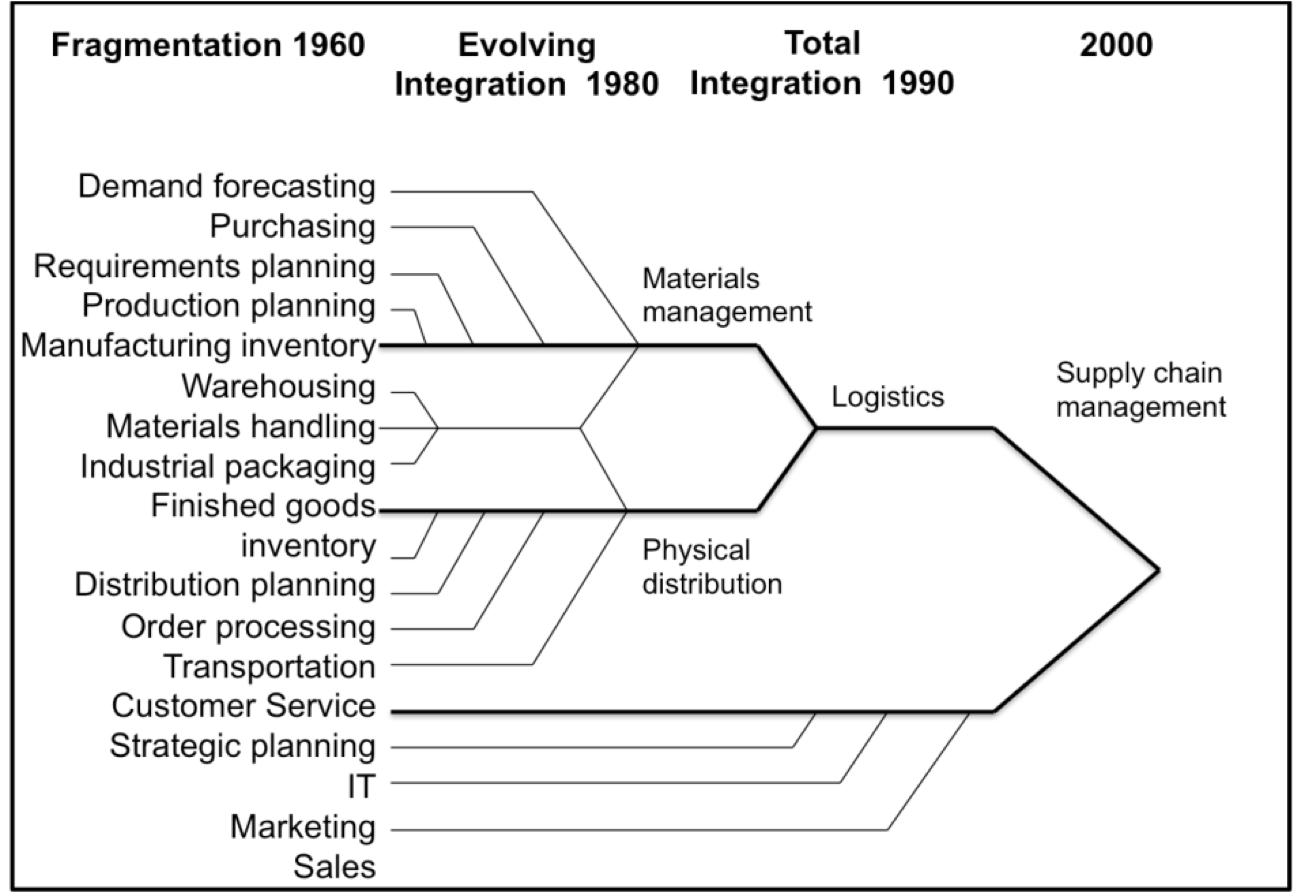
The Distribution and Logistics Process determines how products are retrieved and transported from the warehouse to retailers. These products may be transported to retailers directly, or may first be moved to distribution facilities, which, in turn, transport products to the retailers. This process includes the management of inventory retrieval, transportation, and final product delivery (Ljuingberg 2002).

These processes interact with one another to produce an integrated SC. The design and management of these processes determine the extent to which it works as a unit to meet the required performance objectives.

Definition of an integrated SC was affirmed by Akkermans (2003). He stated that “SC is a network that consists of suppliers, manufacturers, distributors, retailers, and customers. This network is supported by three types of flows (material, information and financial) and requires more careful planning and closer coordination”.

The evolution of the concept of SC took 30 years. Internal supply chain integration transitioned to external supply chain integration as there was a limited amount of performance improvement that could be achieved without involving suppliers and customers. External supply chain integration transitioned to goal directed network supply chains as firms understood that supply chains were non-linear networks and that there would be benefit for non-strategic (or non-integrated) suppliers to have visibility of demand. It is generally supposed, that by now the process of undergoing a transition to devolved is being faced, collaborative supply chain clusters. It is suggested that this transition is occurring due to the increased complexity, risk and costs that are being borne by focal firms who are attempting to manage large networks. By effectively outsourcing elements of this management to lead suppliers, there is devolvement of the collaboration into clusters.

The evolution of SC concept displayed in the previous paragraph can be used further and implemented to the concept of supply chain management, namely the evolution of SCM shown in Fig. 2.



*Figure 2 Evolution of SCM concept (adopted from Langley, et al., 2009)*

Today one of the most widespread definitions of SCM is one produced the Council of by Supply Chain Management Professionals (CSCMP): “SCM encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers”. (CSCMP official website 2017).

Mentzer et al. (2001) define SCM as “the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole”.

Given that the aim of this chapter is not to review the numerous definitions of SCM in extent literature, it simply adopts one that of Mentzer et al. (2001) since it contains all the key elements (strategic coordination, collaboration across the whole supply chain and long-term performance), while dealing not only with material and information flows, but also with financial ones.

Thus, it might be concluded that supply chain is a very complex and essential part of every organisation with the problem of the resources coordination as one of the most crucial in the present time. To solve it, market player should take into consideration the necessity to plan all its actions on a long-term perspective and be willing to maximize its gain in the first place. That is how the maximum gain to all the members of the supply chain will be guaranteed.

## 2.2. Cooperation, Coordination and Collaboration in Supply Chain

A good indication of the maturity level of a field is the attitude of researchers to the definition of key concepts. In a mature field, most researchers would use existing standard definitions. In our case, there is no clear convergence among the authors on a single definition (although most were based on themes associated with operations research). Though, there are efforts in literature regarding collaboration of different functions of the SC, the study of coordinating functions in isolation may not help to coordinate the whole SC. It appears that the study of SC collaboration (SCC) is still in its infancy. Though, the need for collaboration is realized, a little effort has been reported in the literature to develop a holistic view of coordination.

Supply chains are generally complex and are characterized by numerous activities spread over multiple functions and organizations, which pose interesting challenges for effective SC collaboration. To meet these challenges, SC members must work towards a unified system and cooperate with each other. It is proved that collaboration of the supply chain is a very broad term that has not been found the finite interpretations. What is more, so far the concept of collaboration is believed to be difficult to implement. It is suggested that many of the problems related to SC collaboration are due to a lack of understanding of what collaboration actually implies. It is believed that the reason lays behind the attractiveness of the e-business integration for the wide range of the modern organisations. However, together with modernisation of the sales processes in the company it is generally believed that the collaboration will be the tool to improve the organisational operational performance. It might be concluded that the concept itself is yet very new, thus, it might be improved through time and development of the SCM field itself.

It is argued that SCM developed from a baseline of functional (independent) silos and the first level of integration was across functions (akin to process integration). This then moved to full internal integration involving a seamless flow through the internal supply chain, and finally to external integration embracing suppliers and customers. The primary benefits were identified as improved customer service and reduced inventory and operating costs. What has changed since the introduction of the concept of SCM is the context within which supply chains operate, and the enablers of change and performance improvement. As a result the relevance of narrow, linear-based supply chain models has been challenged as firms have looked more and more toward networked and collaborative supply chain strategies to deliver superior performance.

SCM as a discipline has evolved rapidly. The early focus of SCM began when organizations began to improve their inventory management and production planning and control. The aim of these practices was to improve production efficiencies and ensure that the capacity of capital assets and machinery was utilized efficiently. This extended upstream to include the management of transport of raw materials at a time when firms were relatively vertically integrated.

The early definition of integration is provided by Frohlich and Westbrook: “At the tactical level, there are two interrelated forms of integration that manufacturers regularly employ. The first type of integration involves coordinating and integrating the forward physical flow of deliveries between suppliers, manufacturers, and customers. The other prevalent type of integration involves the backward coordination of information technologies and the flow of data from customers to suppliers” (Frohlich and Westbrook 2001)

The next phase in the evolution of SCM was the systematization of materials, production, and transport management. This began with materials requirement planning (MRP) focusing on inventory control. MRP expanded to become MRPII by incorporating the planning and scheduling of resources involved in manufacturing. Both MRP and MRPII were conceived in the 1960s but did not gain prominence until the 1980s. MRP and MRPII evolved to become ERP, in an attempt to gain greater visibility over the entire enterprise (Stevens and Johnson, 2016).

The mid to late 1980s brought intense retrospection from western firms concerning the threat of Japanese firms that were perceived to be more competitive due to higher productivity. This period led to the implementation of “Japanese” practices such as total quality management (TQM) and lean by firms. These practices focused on reducing inventory through improving quality and flow and involving suppliers in product and process design. At this point, one can say, that cooperation is a substantial prerequisite for further coordination and collaboration.

The next phase in the evolution of SCM included the introduction of other process improvement practices (e.g. six sigma) that sought to provide a more concrete improvement method compared to TQM or lean. As process improvement, and the standardization of products and processes that facilitated it, took place, there was increasing awareness that end customers were requiring ever increasing levels of choice and differentiation. This led firms to consider that they had become too lean and rigid and should be focusing on creating agile supply chains to adapt to changing demand. The agile approach was blended with lean as demand could be decoupled into push and pull to create greater choice for the customer while still retaining some control (Stevens and Johnson 2016).

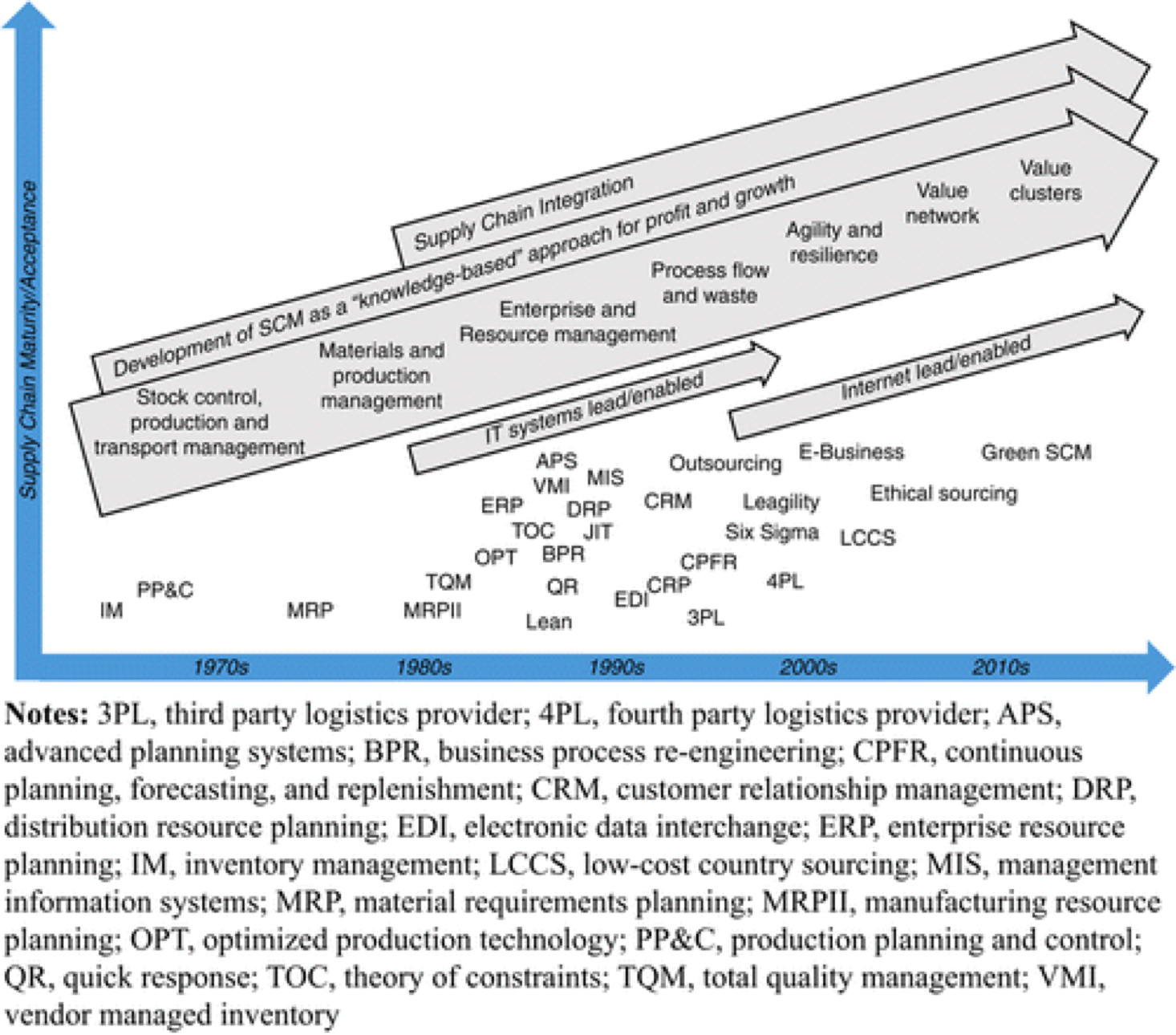
There is no single definition of supply chain coordination which everyone is agreed with. The most commonly accepted definition of coordination in the literature is “the act of managing dependencies between entities and the joint effort of entities working together towards mutually defined goals” (Malone and Crowston 1994). In this thesis, I will use this one as it reveals the very essence of the term: coordination is aimed for the companies to reach common goals by aligning some of their interests. Along with that, one of the most widespread coordination mechanism is Buyer-Vendor coordination with Procurement-Inventory-Production-Distribution scheme (Arshinder, Kanda and Deshmukh 2011).

Another coordination type is buyer-supplier. Its prerequisites are: firm’s transactional cost, resource-based view and strategy structure theory. The main difference from the type that was described in the paragraph above was in the coordination mechanisms that are common. Here these are either connected with price (quantity-based discounts, changes of prices themselves) or with the resource sharing (information sharing, partial deliveries, coordination of decision-making, joint polices’ establishment).

The 1990s also saw a focus upon core competences within firms. This led to a rise in increased outsourcing of non-core activities to lower cost economies. Political factors such as unilateral liberalization measures and the removal of formal free trade barriers have contributed to the growth of developing countries exporting to high wage economies, encouraging firms to source from lower cost economies. This, in turn, fuels both demand for products from developed economies and the competition to supply. This changed the topology of the supply chain as well as the magnitude, profile and direction of material, and information flows. Significant changes have also taken place around the understanding of how a firm secures a competitive position. Traditionally, superior competitive advantage was seen to be a function of how a firm organized its resources to differentiate itself from the competition and its ability to operate at a lower cost. The prevailing tendency was to control as much of its upstream and downstream activities as possible, often leading to high levels of vertical integration (i.e. within a firm rather than with suppliers). Thus, firms focused more on managing, in-house, core competences, i.e. those competencies or capabilities that deliver value (as perceived by the customer) and outsourcing non-core activities to specialist – often lower cost – third parties. This resulted in the advent of 3PL providers and supply chain integrators.

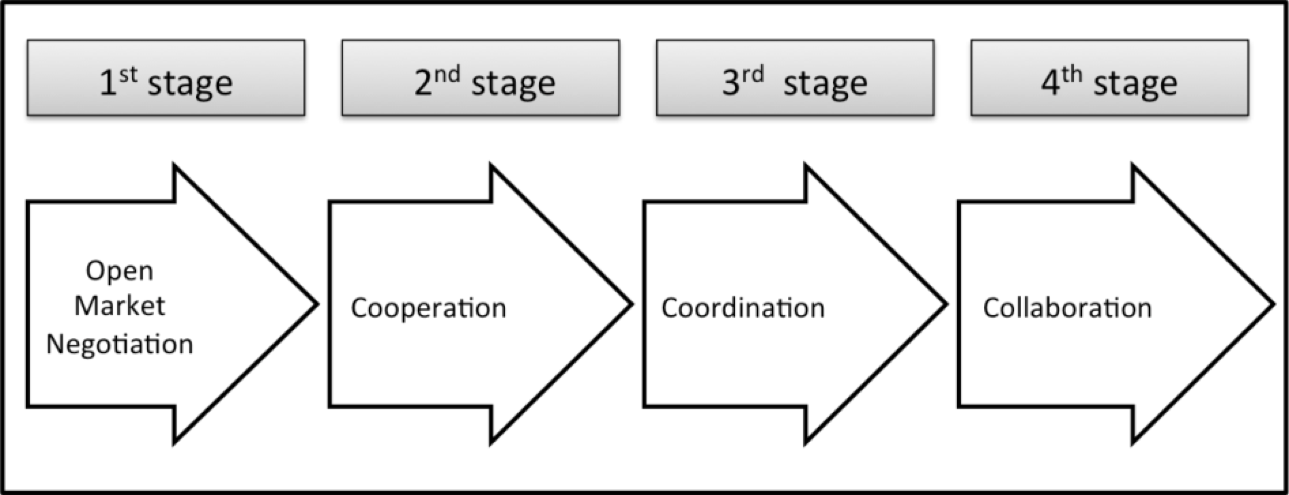
Supply chains are inherently unstable in terms of inevitable challenges of forecasting and data integrity. Technology has been used to good effect to improve information flows. However, the increased remoteness of a global market and supply base, together with the need to manage an increasingly complex network has exacerbated the challenge. In addition to the issues caused by information distortion and a global supply base, the twenty-first century is a time when organizations are facing pressure – from consumers and other stakeholders – to have green and ethical supply chains. This requires organizations to become more transparent in terms of disclosing their sources of supply, which increases costs and may place pressure on moving away from the lowest cost economies where labor rights can be poor. At this period of time the concept of collaboration evolved.

M. Simatupang and R. Sridharan introduced one of the most cited definitions of SC collaboration in 2002. According to authors: “A collaborative supply chain simply means that two or more independent companies work jointly to plan and execute supply chain operations with greater success than when acting in isolation” (Simatupang and Sridharan 2002). But this definition is limited by the boundaries of the inter-organizational processes. To overcome this problem B. Flynn reflected more spread definition of Supply Chain Collaboration (SCC): “as the degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra- and inter-organization processes. The goal is to achieve effective and efficient flows of products and services, information, money and decisions, to provide maximum value to the customer at low cost and high speed” (Flynn, Hou and Zhao 2010). This definition more precisely outlined that collaboration in supply chain can happen not only between several companies but also at the level of one company.



*Figure 3 A timeline of SCM strategies, tools, and techniques (adopted from Stevens and Johnson 2016)*

This all points toward an explosion in SCM thinking over the last 25 years. Fig. 3 presents a timeline of SCM strategies, tools, and techniques. The dates in the figure are based upon when these practices were popularized, not introduced (Stevens and Johnson, 2016). Fig. 4 outlines the transition of collaboration.



*Figure 4 Transition of the forms in integrated supply chains (adopted from Spekman et. al. 1998)*

As in the following work numerous entities with different aims and planning mechanisms were analysed, but which are experiencing problems with alignment of their efforts to reach the common benefits by information sharing, it is logical to choose coordination mechanism as the most suitable one for the supply chain of the pulp and paper industry.

In fact, the problem of coordination might lead to deteriorating consequences in every industry. The consequences of lack of coordination may result in poor performance of SC as a whole, particularly in inaccurate forecasts, low capacity utilization, excessive inventory, inadequate customer service, inventory turns, inventory costs, time to market, order fulfilment response, quality, customer focus and customer satisfaction (Arshinder, Kanda and Deshmukh 2011). These problems are solved by implementing some mechanisms in SC activities, which may result in the improvement of some performance measures. These mechanisms include: joint decision making, information sharing, resource sharing, implementing IT, joint promotional activities, etc. The other motivation seems to be the ability of SC members to share the risks and subsequently share the benefits. Further these mechanisms are discussed in detail.

*SC Contracts.* SC members coordinate by using contracts for better management of supplier–buyer relationship and risk management. The objectives of SC contracts are:

· to increase the total SC profit,

· to reduce overstock/understock costs, and

· to share the risks among the SC partners.

In buyback contract, the buyer is allowed to return the unsold inventory to some fixed amount at agreed upon prices. The manufacturers accept the returns from the retailers when the production costs are sufficiently low and demand uncertainty is not too great (Cachon and Lariviere 2005).

In the revenue-sharing contracts, the supplier offers the buyer a low wholesale price when the retailer shares fraction of his revenue with supplier, which helps partners in selecting order quantities that are optimal for the whole SC (Cachon and Lariviere 2005).

In the quantity flexibility contracts, the supplier and the buyer accepts some of the inventory and stock out cost burden. The supplier allows the buyer to change the quantity ordered after observing actual demand. The buyer commits to a minimum purchase and the supplier guarantees a maximum coverage (Tsay 1999). The coordination achieved by the contracts provides incentives to all SC members and improves the service level.

There are a number of extensions to buy back contracts are presented in the literature like two period supply contract model for decentralized assembly system (Zou et al. 2008) and flexible returns policies in three-level SC (Ding and Chen 2008) to fully coordinate SC members.

*Information technology.* IT is used to improve inter-organizational coordination and in turn, inter-organizational coordination has been shown to have a positive impact on select firm performance measures, such as customer service, lead time and production costs.

IT helps to link the point of production seamlessly with the point of delivery or purchase. It allows planning, tracking and estimating the lead times based on the real-time data. Advances in IT (e.g. internet, EDI (electronic data interchange), ERP (enterprise resource planning), e-business and many more) enable firms to rapidly exchange products, information, and funds and utilize collaborative methods to optimize SC operations.

The various coordination problems handled by information systems are:

· little value to the supplier because of competitive bidding,

· forced implementation of IT,

· incompatible information system at different levels of SC,

· greater lead times,

· inefficient purchase order and

· misaligned e-business strategies and coordination mechanisms (Arshinder, Kanda and Deshmukh 2011).

*Information sharing.* The SC members coordinate by sharing information regarding demand, orders, inventory, POS data, etc. Timely demand information or advanced commitments from downstream customers helps in reducing the inventory costs by offering price discounts and this information can be a substitute for lead time and inventory (Reddy and Rajendran 2005). The value of information sharing increases as the service level at the supplier, supplier-holding costs, demand variability and offset time increase, and as the length of the order cycle decrease.

There are many factors involved in achieving coordination like human, technology, strategies, relationship, rewards, sharing of knowledge, sharing benefits, aligning goals, scheduling of frequent meetings of stakeholders for conflict resolution, understanding of nature of intermediates and knowledge of SC concepts, status or power difference and resistance in following the instructions of other organizations.

Even though SCC improves the performance of the SC, it may not always be beneficial to coordinate all the SC members. The high adoption costs of joining inter-organizational information systems and information sharing under different operational conditions of organizations may hurt some SC members. Therefore, it is essential to investigate the conditions under which SCC is beneficial, so that it should not result in higher SC costs and imprecise information.

*Supply Chain Cooperation Performance.* There is a growing recognition among company executives that today's business competition is no longer between individual firms, but between SCs. If a SC is properly managed, its whole value can be greater than the sum of its parts. Not surprisingly, there is an increasing demand for both scholars and business practitioners to make SCM more financially accountable. Optimizing financial performance along the SCs should be the ultimate goal of any SCM strategy. The existing literature has shown SCM's great potential to enhance a firm's key financial outcomes. To demonstrate the financial accountability of SCM activities a number of SCM drivers for firm-level financial performance are identified (Min and Wei 2013).

On the basis of collaborative management of relationships between the organizations that constitute the value chain and integrated coordination of processes from the ultimate supplier to the ultimate customer, SCM aims to create more value for customers, as well as for the supply chain partners, thus improving performance not only within each organization, but also across the whole chain (Min and Wei 2013). A SCM system entails the implementation of a set of practices that can be defined as activities deployed in an organization in order to enhance the effective management of its supply chain. Despite the constantly growing attention to SCM, contributions to the link between supply chain management practices (SCMPs) and performance are very diverse in scope and nature, and most often remain dispersed and incomplete.

The existing studies on the financial impacts of SCM have enabled the researchers to formulate some empirical patterns, with which a number of performance drivers contributing to firm financial performance was identified, in particular: sourcing strategy, information technology (IT), system integration, and external relationship.

*Sourcing strategy.* When a firm develops its sourcing strategy in the SCM context, it constantly weighs the total costs associated with the make-or-buy decisions. A well-developed SC sourcing strategy allows SC partners to focus on their key competitive advantages, thus resulting in a win-win situation for all involving parties. According to TCE, successful SC sourcing strategy should be able to reduce production costs and increase process flexibility since firms no longer need to commit to asset specificity (Williamson, 1981).

According to Min and Wei (2013), the performance implications of SC sourcing strategy are widely debated in the literature. On one hand, several empirical studies have shown its positive contributions to firms' financial performance. It was discussed, how purchasing and supply management affect financial performance such as business growth, profitability, cash flow, and asset utilization. On the other hand, not all the studies are able to establish positive relationship between sourcing strategy and financial performance. It was previously found, that firms performing more aggressive outsourcing practices do not experience significant and direct performance improvements. In addition, firm strategy and environmental dynamism are found to moderate the relationships between outsourcing intensity and financial performance. (Shi and Wei, 2013). Overall, SC sourcing strategy generate positive contributions to financial performance. However, an optimal level of ability to outsource may exist to maximize the benefits.

*Information technology.* According to transaction cost economics (TCE), the main purpose of IT in SCM is to enhance SC collaboration and reduce coordination costs along SC by increasing SC visibility and transparency. Meanwhile, there is a debate on whether the IT capability can really serve as a catalyst in improving firms' performance. The sceptics’ major argument is that particular SC technology can be easily duplicated by competitors, making it difficult for the investing firms to gain competitive advantages over their competitors. According to resource based view (RBV), therefore, the increasing investments in IT capability do not guarantee performance improvements. Blankley (2008) provides a comprehensive literature review relevant to the impacts of IT on the financial performance. He proposes a conceptual model to demonstrate how an effect chain is extended from SCM technology to a firm's financial performance. Therefore, the following empirical finding regarding the financial impacts of IT can be derived: Information technology in SCM makes positive contributions to financial performance, but IT alignments and implementations could affect financial outcomes.

*System integration.* An integrated SCM system enhances a firm's capability to coordinate all business processes within and beyond the firm's boundary. Enterprise resource planning (ERP) system, which integrates internal and external information flows and management functions within and across involving SC participants, is a typical example.

By collecting survey results from Korean and Japanese firms, Kim (2009) uses SEM approach to examine the causal relationship among SC activities, competitive strategy, SC integration, and firm performance. For both Korean and Japanese samples, there exists a significant relationship between SCM activities and competition capability. However, the mechanism of how SC integration impacts firm performance is different in Korean and Japanese samples due to firm sizes and levels of SC integration. In Korean firms, the interrelationship between SCM practices and competition capability enhances SC integration, which in turn has a direct effect on firm performance. On the other hand, some studies are not able to establish positive relationship between SCM integration and firms' performance. Hendricks et al. (2007) report mixed results concerning the impacts of ERP, SCM, and customer relationship management (CRM) on firms' long-term financial performance. Specifically, they find some improvements in firms' financial metrics (ROA and ROS) for the ERP and SCM adopters, but not for the CRM adopters. To partly explain this performance puzzle, some studies suggest that the SCM systems be integrated with other IT infrastructures to achieve the best performance. An integrated SCM system represents a firm's general capability to coordinate all business processes within and beyond the firm's boundary and improve overall financial performance. Summing up, system integration in SCM achieves optimal financial performance when it is implemented together and aligned with IT infrastructures and overall business strategies.

*External relationships.* As a firm's unique resource and valuable asset, external relationships in SCM, including supplier and customer management, is expected to be highly associated with financial performance. As a matter of fact, it can be argued that the quality of external relationships with upstream and downstream partners is one of the most important drivers of financial performance. The association between external and internal contextual SCM factors and various performance measures in the information industry was earlier investigated in Taiwan. Several studies focus on the specific components of external relationships in SCM. For example, Flynn et al. (2010) especially investigate the impact of supplier-customer-internal (SCI) relationship on firms' performance in China. Empirical analysis shows that the SCI relationship is positively associated with both operational and financial performance.

SC collaboration and mutual trust are especially important to manage external relationships with suppliers and customers. Cao and Zhang (2011) investigate SC collaboration and its impact on firm performance. The empirical results indicate that SC collaboration considerably improve collaborative advantage, which in turn, has significant positive effect on firms' financial performance. In particular, the mediator role of collaborative advantage is stronger for small firms than medium and large firms. Therefore, there is the following empirical finding: as a firm's unique resource and valuable assets, SC external relationships are highly associated with financial performance.

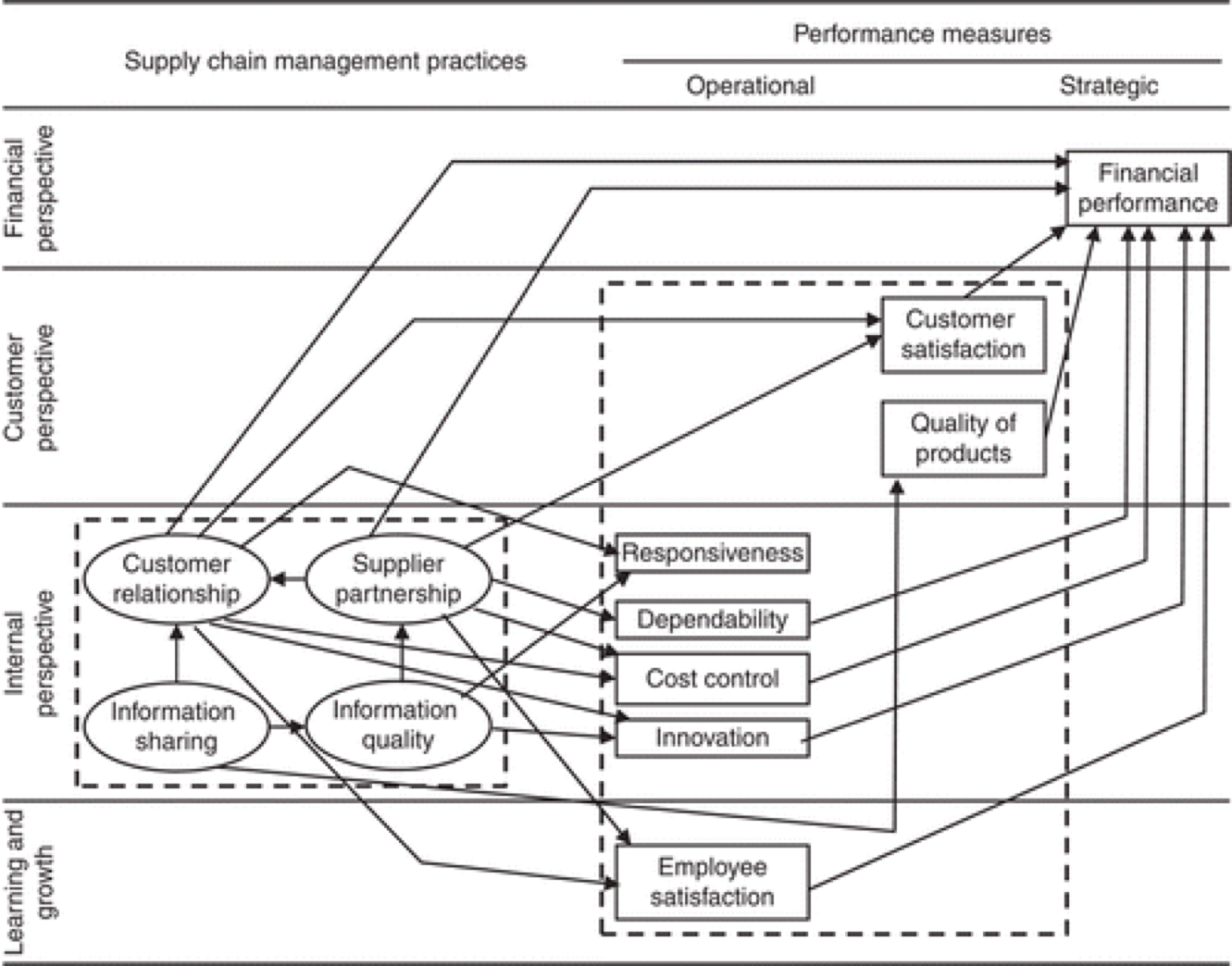
Over the past few decades, more and more executives have realized the strategic importance of SCM and recognized the distinctive competitive advantages that a well-managed SC can bring to the company. SCM has therefore attracted substantial investments across various industries recently and company executives not only need to know whether SCM is able to make positive contributions to firm-level financial performance, but also want to know how to direct their SC investments to enhance competitive advantages and optimize financial outcomes. SCM managers, therefore, are obliged to demonstrate SCM's positive financial contributions and justify relevant expenses.

As this study is constrained on the financial impacts of SCM practices, only accounting- and market-based financial measures are discussed in this section.

The accounting-based financial measures are direct indicators of a firm's financial conditions from different perspectives. For example, return on assets (ROA), return on equity (ROE), and return on investment (ROI) are usually used to examine a firm's asset and capital utilization, while profit margin, cost of goods sold (COGS), and economic value added (EVA) are common measures of a firm's capability to make profits. Some accrual measures, such as ROA, ROI, and profit margin, are particularly popular in the SCM literature. However, it is worth noting that the accrual measures are not always appropriate in performance measurement due to their own limitations. First, most accrual measures are not able to catch intangible or non-cash benefits associated with SCM practices, such as market share, market reputation, and company goodwill. Second, they are used to measure the past performance but are not forward-looking indicators. Third, they are relatively easy to be manipulated by accounting frauds and illegal practices. A few studies, therefore, propose financial measures based on cash flow to directly evaluate a firm's profits and liquidity. To better catch the company-wide effects of SCM practices, several studies develop comprehensive financial measures by combining multiple corporate income and balance sheet values together.

As an essential complement to accounting-based financial measures, market-based measures focus on shareholder value. Min and Wei (2013) state, that in one of the early studies investigating the impacts of SC strategy on shareholder value, Christopher and Ryals (1999) define the shareholder value as “the financial value created for shareholders by the companies in which they invest”. Since SCM activities are strongly associated with revenue growth, operating cost reduction, fixed and working capital efficiency, they are expected to impose significant effects on shareholder values. It is consistent with studies in other disciplines. Swink et al. (2010) employ Sharpe ratio to characterize how well the excess return of SCM excellence compensates the stockholder for the risk taken. As the most popular market-based measure, abnormal stock return documents the difference between the expected stock return and the actual stock return, which is often triggered by special SCM events (see event study in research method section for details). In a widely-cited study, Hendricks and Singhal (2003) propose a framework to link SC performance to shareholder value through operational metrics and intangible assets. In an efficient financial market, the improved SC performance eventually will be reflected on shareholder values. Johnson and Templar (2011) develop a unified performance proxy composing of different elements in profitability, liquidity, and productivity. Since a significant proportion of firm value today lies in intangible assets, market-based measures provide a more objective approach than the accounting-based measures. In the absence of deep understanding of SCM's contributions to shareholder value, SCM professionals have great impediments to assess the true value of SCM activities and justify the continuous SCM investments.

Fig. 5 summarises all the paths that link learning and growth perspective and internal process perspective (SCMPs and some operational non-financial performance measures) to the customer and financial perspectives (customer satisfaction, product quality and financial performance), which constitute a firm’s strategic objectives.



*Figure 5. Linkage of SCM practices on performance (adopted from Okongwu, Brulhart and Moncef, 2015)*

*Theoretical Gaps in Supply Chain Coordination.* Despite research confirming the positive benefits of supply chain integration, and its importance to a firm’s success (Flynn et al. 2010), ambiguity remains as to what constitutes supply chain collaboration (Fabbe-Costes et al. 2014).

The gap between the theoretical concepts of the SCC and their implementation to the practical side has always been an important issue in this research field. There were attempts of numerous researchers to bond the current practical concepts with such theory as agency, institutional, network, game, and strategic choice ones (Chatha and Butt 2015). However, there were not found any feasible evidence of support within the papers that are presenting empirical findings. Thus, the following points can become starting points for further research:

1. *More diverse theoretical foundations*. Nowadays in the majority of the academic papers one can find the development of only few empirical concepts: principal-agent, agency and network theory are often discussed in the peer reviewed journals. However, the further development of other empirical propositions might result in deeper learning of the multifaceted nature in the sphere of SCM.

2. *Narrow focus.* Regarding the fundamental question of which SCM practices impact individually or collectively on which performance measures, most studies often focus on only one or few aspects (or parts) of the supply chain such as the upstream network (Eltantawy et al. 2015) or the internal relationships (Williams et al. 2013). In this field, two research streams can be distinguished: first, studies that aim to establish a link between two variables (a SCM practice and a performance measure) based on a unique construct of SCM and performance, Second, studies focusing on the impact of two or more SCM practices (considered separately or collectively) on one or several performance variables. What is more, in the forestry industry studies researchers are focusing only on the parts of the whole production choice that is available on the market (for instance, sawlog), without discussing the impact that SCM measures have on the company in particular and on the SC on the whole.

3. *Under-researched SC variables.* Apart from the variables that have been already discussed, one should develop their quantity. Namely, what are the variables that measure the level of price coordination between the companies? Is there any variable that can measure the revenue increase as the consequence of the successful price coordination in the supply chain?

4. *Robustness of empirical results*. As stated in the previous section, this is an emerging research area and most studies reviewed in this paper are published recently. Therefore, the robustness of the empirical findings should be tested under different environmental settings. For example, what is the role of SCM under different macroeconomic climates? Are the financial contributions from effective SCM enhanced or weakened during economic recessions? What are the SC variables attributable to the performance change?

5. *More balanced performance measurement*. Accounting- and market-based financial measures have their own merits and should be monitored simultaneously. Creative efforts are needed to design more direct measures (such as cash flows) and develop balanced systems for assessing the financial performance of the whole SC as well as each SC participant. Then, how such a comprehensive system that may have potential conflicts between different performance measures and various stakeholders can be developed? Is it possible to integrate both accounting- and market-based financial measures?

# 3. Research Methodology of coordination in the supply chain of forestry industry companies

## 3.1 Research approach and method

The following research presented in the work was considered to be done in accordance with the research paradigm of positivism. What is more, the study in the following thesis was conducted in accordance with the exploratory study principles, namely, it was aimed to answer research questions only, but not to present the very final solutions to the all problems that were introduced earlier.

The research approach chosen was the design-science one. This still relatively modern type was popularized by an American scientist Herbert Simon. It was constructed to find the applicable structure for the solutions to the existing practical problems (Simon 1969). Later on, others considered the goal of that approach as the development of a model or theory that can serve to the solutions of the problems either within the organization or in the industry on the whole. After the application of the following research concept, the final output is believed to be a modified, implemented or designed model or a theory. Was is more, there are 3 prerequisites for the following scientific approach: the work itself should be driven to the solution of the practice-oriented problem, research questions were designed in accordance with the problems of the industry/company and the final results of the research are aimed to be explained through the practical implementation (Motto 2013).

Based on the goal for the current research as long as for the present imperfections of the existing multi-echelon problems, namely, the inability to measure the impact of the price coordination in the supply chains, the design-science approach was chosen. Viskari (2012) in his article presents 4 the most widespread steps for every study that uses such an approach:

1. To justify the current problem;
2. To improve the up-to-date stated design;
3. To formulate the solution;
4. To evaluate it.

Then the research methods were initialized. According to the concept of business-related research methods (Lewis, Thornhill 2009), there are seven the following: grounded theory, action research, ethnography, archival research, experiment, survey and case study. The case study approach was chosen because of the goal of the work, its systematic literature review and the practical problem that is needed to be solved. Modified model is tested within the algorithm that was created and the solution that guarantees the highest gain not only to the participants of the supply chain, but also to the whole chain itself was chosen.

Let us examine the choice of the case study method in a bit deeper way. As the following research has used close to real data, it was crucial to bond the data with the current problem that exists in the industry on the whole and within the company – market leader in particular. In general, Yin (2003) defines four main types of case studies: single, multiple, holistic, embedded. In the following research the primary data is based on the close to real sources from the single company in the forestry industry. Judging from the academic authors’ assumptions that if the final result is the modified model, the work might have been considered as the single case study one. However, taken into the consideration the leading position of the examined company in the whole industry as well as the same supply chain pattern that is used by the majority of the market players in the industry and the impacts that incoordination of prices has on the whole industry, one might assume that the whole work could be defined as the one used multiple holistic case study method.

### 3.1.1 Supply Chain in Forestry Industry Company Overview

Russian pulp & paper market has demonstrated its remarkable growth since 2005. The main reasons are the increased production of pulp (up to 15%), packaging materials (almost doubled) as well as the development of export sales.

The main current trends in the internal market are:

* Increase of raw material prices due to the Russian Ruble’s growth
* Low amount of fiber available for recycling due to the insufficiency of current recycling technologies
* The lowest pulpwood costa among all leading pulp producers due to the exchange rate’s growth
* Sharp profitability increase for the Russian-based pulp production companies due to the extreme change in the Russian Ruble-US Dollar FX rate

One might state that the last macroeconomic trend mentioned in the list above has played the key role in the Russian pulp & paper producing companies’ reinforcement on the worldwide stage (Food Agriculture Organisation of the United Nations website 2017).

The largest players in the Russian pulp & paper market according to the pulp production facilities are: JSC Ilim Group, JSC Arkhangelsk Pulp & Paper Mill, JSC Mondi SLPK (RISI World & Recovered Paper Outlook 2016).

The typical supply chain of the company operating in the industry can be characterised by the vertically integrated structure (because of the necessity to operate with the minimal safely stock and comply with the short production idle times), several production facilities that are owned by the same legal entity and hierarchical flow of production (multi-echelon model of the supply chain), namely, the next operator can proceed with the production only after the previous one has accomplished its task and all the final goods are produced out of the one resource solely.

In the following work the pulp supply chain process was analysed. The worldwide consumption of this good has risen in 2015 up to the 169 million tones annually (RISI World Pulp & Paper Outlook 2016). The majority of the growth was associated with China. In total, the market pulp can be produced either from the Bleached Softwood Kraft Pulp (BSK) or from Bleached Hardwood Kraft Pulp (BHK), depending on clients’ needs. Within the country, the typical supply chain has the following sequence of operators:

*Owner of the natural resource->Producer->Counterparty->Client->Final consumer*

Source: created by author

It is important to mention here, that the owner of the natural resource (wood) and the producer (owner of the plant) is usually the same legal entity. Counterparty could be characterized as an independent distributor of the company’s products. Normally the producer sells the market pulp to them where later on it is distributed for the sake of its clients. In the foreign markets this supply chain flow is developed with the broker that is also the party of the vertically integrated pulp & paper company. It operates all the transactional activities with the foreign counterparties. Later on, from pulp there could be several other products produced: white paper, corrugated packaging, containerboard, wood chemicals and biochemical products.

To sum up, in the following work the prices coordination for the pulp production process were analyzed.

### 3.1.2 Data Collection

In the discussed research the chosen research approach and methods required the information gathering through the several different types of data. In the following work two their types were used – namely, secondary and primary. Out of the three typical secondary data types (multiple source, survey, documentary) for the following thesis documentary was chosen. This type has been revealed in all the trustworthy materials that have been published in the written form. Namely, industry overviews, official industry forecasts that have been issued by world renowned industrial professional services companies.

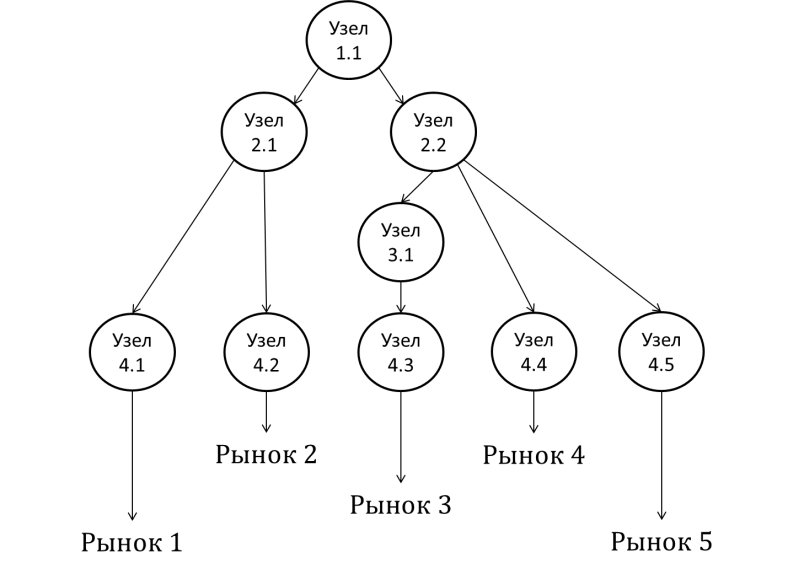
Concerning the primary data, there were the two its main sources included in the thesis: raw data based on prices and quantities of goods depending on the final destination points for the delivery. All the number only resemble being close to real, however, they reveal the real situation in the industry. The assumptions and main prerequisites for research were gathered with the help of the unstructured face-to-face interviews with the Strategy department personnel in one of the market leader’s in the industry. What is more, due to the low amount of the disclosed information about the industry prospective, documentation that dealt with the company’s and industry’s strategy was in the author’s disposal as well.

## 3.2 Theoretical Foundation of Price Coordination in the Supply Chain

Modern world is closely connected with trade and business, which supply chain is the indispensable part of. The necessity of firms to sell their goods after being produced make them develop their trading activities by systems of trade flows and trade connections organization. Every year because of the progress and globalization pressure there is a growth of not only the number of these systems, but also of the difficulty, namely their structure and scale. In addition, there are appearing problems of optimization in the already organized supply chains, however the importance of their solution might be sometimes underestimated. As a result, badly organized operational performance leads to the loss and nonnetted gain. Therefore, not only the supply chains’ wide incidence, but also importance of the optimization solutions under the revenue criteria makes the problem of coordination among the players in the supply chain could not more up-to-date. In terms of this, the goal of the current article is the elaboration of the participants’ coordination way that is aimed to optimize supply chain under the revenue criteria.

In the following case one of the most omni-purpose and widespread kind of supply chains is examined, namely, the multilevel supply chains with the tree-like structure (the example of such a chain is depicted on the Pic. 1). The problem for these chains’ coordination is not well studied, because the supply chains’ modeling of that particular structure has just recently begun. This problem was examined in the works by Corbett C., Karmarkar U. S. (2001) and Carr M. S., Karmarkar U. S. (2005) for the first time. However, later on modeling of the multilevel supply chains was continued in the direction of pricing contracts and horizontal competition (Kaya M. (2012), Cho S.-H. (2014)). Only recently scientists have returned back to the optimization of the multilevel supply chains (Zhou D., Karmarkar U. S., Jiang B. 2015)).

In the following work, there are three approaches to the coordination of participants, that are based on the different models of interaction or on the optimization criteria. For each of the approaches the process of the participants’ interaction is described, based on that the optimization criteria is formulated and satisfying way of solution is designed (Figure 6).



*Figure 6 The example of the multilevel supply chain with tree-like distribution structure*

The further structure of the article will be organized in the following way: Section 2 is devoted to the mathematical formalization of multilevel supply chains with the tree-like distribution structure; in the Sections 3, 4, and 5 there are decentralized, centralized and weighted Nash solutions that are analysed; in the Section 6 there is an example stated and the delivered results compared; in the final, 7th, section there is a summary and the results of the research presented.

## 3.3 Mathematical formalization of the price coordination in the supply chain

Let us look at the tree-like graph with a mutual peaks of and a mutual verges of The root peak of this tree can be named as In the set of peaks let us define the sets of , … , , in the following way:

=

(1)

*if*

*Comment 1.* The inserted multitudes are setting the division of multitude X, such as

*Definition 1.* Subset of junctures will be named as *the set of peaks (junctures) of the Level i.* The junctures from the set of will be named *the final* or *the finite.*

The junctures *x* from the multitude *X* were denotedas , where the upper index is equal to the number of the level , where this peak is situated and the lower index – to the order number of this peak in the multitude . For the uniformity, the root juncture will be denoted as . What is more by we will understand the number of the junctures of the level of I, i.e. =, where - the power of the multitude

*Definition 2.* One said that dissection of , … , the multitude of *X* peaks, that was defined under the rule of (1), is defining *the supply chain with the tree-like control (distributive) structure.*

*Definition 3. The sector* of the peak is the name of the multitude .

*Comment 2.* The multitude of the sectors together with the root peak are controlling the dissection on the multitudes of peaks *X.*

Under the multitude would be understood the multitude of pairs of indexes of these tech junctures that are included in the sector of the juncture , so as = Let us notice that under the generation

Assume that every peak , of supply chain consists of finite plurality of elements , for which the set of lattice points is defined , where any positive integer that is not less than 1. This plurality of elements is a context-wise a group of competitive firms that are producing and consuming the homogeneous product as well as having the different production costs (the production power is meant to be unrestricted). For each firm let us work in the variable that is characterizing the running production volume of this firm as well as the integrated volume of the homogeneous product that was produced by all firms from the juncture let us call as =Then for the sector of each juncture supply chain the following condition is considered to be fulfilled:

(2)

meaning that there is no deficit or surplus of production in the supply chain.

For every juncture let us work in the variable that is equivalent sense wise the price according to that firms from the juncture are selling the unit of the good produced. It is considered that for the every of the final peaks there is the following linear function prescribed

(3)

where . In fact, it means that the final peaks are realizing their product in the non-competitive consumer markets that are functioning according to the Cournot model with the linear correspondence that could be expressed by the formula (3).

*Definition 4.* The set of definitions ({ is defining *the trading flow d* in the supply chain.

*Definition 5.* Flow d will be named *feasible,* if

>0, j=.

Let the set D be the multitude for all the feasible flows in the supply chain. For each of the firms for j= let us define the function the revenue function that is set on the multitude D among all the feasible trading flows in the following way:

where

Let us arrange the multitude of peaks *X* supply chain:in the first place is a root peak, then the junctures of the second level in the ascending order, then – of the third, fourth levels and up to the final inclusively, i.e. the arranged system was received , , , …, This arranged multitude of all the junctures (let us denote it with N) of supply chain will be considered as the multitude of players.

The multitude of in the strategy of the player will be considered as the multitude of all the possible vectors where is created out of the arranged order of variables that are defined for all the firms and are situated within the area defining the feasible flow, namely:

Within this chapter three ways of the objectives’ formulation and optimality criteria were examined. Let us consider the case when each of the supply chain’s participants is acting independently from each other and exclusively in favor of his own interests, then such model and corresponding to it solution will be named decentralized. If all the supply chain participants are cooperating and predefining to act concordantly in order to maximize the total revenue of the supply chain, then such problem will be called centralized. The third variant – weighted Nash solution – is the result of the optimization problem solution, in which as a matter of the objective function the weighted Nash solution is stated whereas as a “status quo” point it is the solution of the decentralized model in the same supply chain that is used.

## 3.4 Formalization and the optimality criteria for a game-theoretic model of the multilevel decentralized supply chain

First of all, let us describe the procedure of the decision-making in the decentralized model:

*Step 1.* The root juncture is denoting the selling price for the junctures of its sector.

*Step 2.* The peaks of the second level in the supply chain having received the information from the root juncture, are defining the price for a good to the peaks of their sectors. Then the procedure is repeating up to the junctures of the next to last level inclusively.

*Step 3.* The final peaks based on the prices having received from their suppliers, and supply functions are defining the volumes of production of the good to the market.

*Step 4.* The procedure of volumes’ disposal is happening between firms on the each of the peaks of the final level.

*Step 5.* Information about the volumes is arriving to all the upper-situated levels and within each juncture is happening the procedure of volumes’ disposal between firms.

*Step 6.* Calculation of revenue from each participant in the supply chain.

The decision-making process that is described above characterizes the decentralized multilevel tree-like supply chain as the conflict-managed system, with the hierarchical structure, therefore these systems specifically are defined by the order of the managerial levels that are followed one by one in the order of the denoted priority.

*Definition 6.* The feasible flow d\* will be called optimal if it is fulfilled:

|  |  |
| --- | --- |
|  | (5) |

where is the flow that was created by the deviation of the strategy of the player .

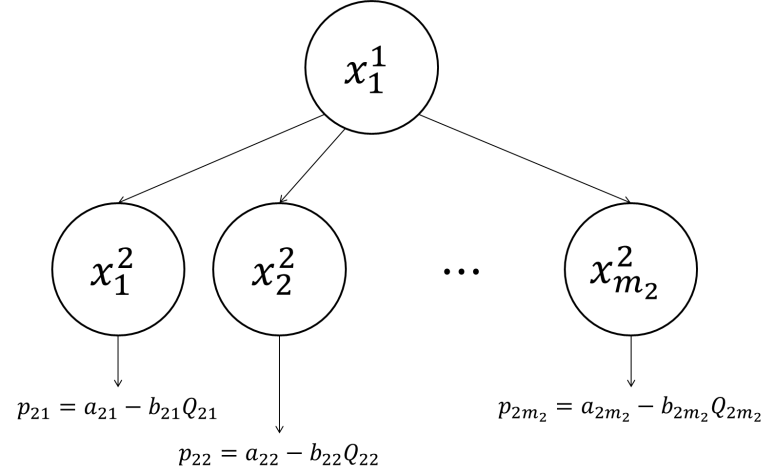
Let us look into the plus-sum multistage game with hierarchical structure that is revealed in a plurality where is the multitude of players with dissection into the subsets according to the priority, is the multitude of managing stimulus of the player to the players that are subject to him, is the payoff functional of the player that was set in the Cartesian product of sets leading the players . Control vector is forming the situation in the game At the present time let’s take the arranged multitude of supply chain junctures as the multitude of the players , as the multitude of the controlling actions – multitude of players’ strategies . Each of the player will be assigned in the correspondence the vector . Then as the payoff functions of the players let us take accordingly the arranged set of vectors : . Then the plurality is defined as the plus-sum multistage game with the hierarchical structure, and the task of decentralized model coordination of the multilevel supply chain is the process of finding the Nash equilibrium in the multilevel hierarchical game with the complete information.

In the following chapter the research approach, methods were defined as well as the peculiarities of the supply chain in the forestry industry were stated. For the following work the design-science approach was chosen thanks to its orientation for the focus on the practical results’ interpretation and for the modification of the existing model. As for the methods, holistic multiple case study was defined because the analysis introduced in the thesis is applicable to all the largest Russian pulp & paper companies as it takes into consideration its peculiarities in the supply chain. Moreover, the logic of the prerequisites to the algorithm for the model was explained: the companies in the forestry industry tend to use multi-echelon models, namely, to produce the all the final goods with the minimum safety stock and from the same raw material. However, without the coordination of the prices between the producers the following approach has its drawbacks. For instance, its consistency and sustainability under the change of the environment is under the question. What is more, for the market players opportunistic behavior could become more and more common fact due to the imperfect system of the governmental economical control. Thus, in order to solve the prices’ coordination problem, the raw data of the prices, points of delivery and quantity of goods (close to real one) was chosen and the initial multi-echelon model in the industrial leader’s case was improved to the sustainable level; new definitions were introduced and mathematically formulized. What is more, the sequence of algorithmic steps in the supply chain was formalized: each root juncture states the selling price for the next ones and to the sector.

# Empirical study

## 4.1 Construction of the two-level decentralized supply chain solution

Let us begin the coordination task with the particular example when , namely there are only 2 levels in the supply chain and it has the form of vector (see the Figure 7).



*Figure 7. Two level supply chain*

Let us look at the firm in the finite juncture , where , For it the revenue formula equation looks like:

|  |  |
| --- | --- |
|  | (4.1.1) |

Let us apply in this formula the equation for , taking into the consideration the supply function (3), namely:

Then the following equation will be got:

|  |  |
| --- | --- |
|  | (4.1.2) |

For the conforming of the assumption (5) let us apply to the revenue function (4.1.2) the condition of necessity for the maximum

and express the

(4.1.3)

Let us perform (3.2.1) – (3.2.3) for all and one will come up to the system:

|  |  |
| --- | --- |
|  | (4.1.4) |

Matrix of the system (4.1.4) is a non-degenerate due to the linear connection of the series (columns), thus, this system may be solved in a one-valued way relatively to the all .

Let us find the opposite matrix for the matrix of the system (4.1.4):

and let us multiply on the left-hand side both of the sides (3.2.4) by this matrix:

|  |  |
| --- | --- |
| . | (4.1.5) |

Having accomplished the multiplication in the par (4.1.5) the following equation would be got for :

|  |  |
| --- | --- |
|  | (4.1.6) |

The found value of the variables is in reality the point of maximum to the revenue function, i.e.:

The equation was to be for

|  |  |
| --- | --- |
|  | (4.1.7) |

Let us have a look into the root sector. For the firm from the root peak 1.1 the function of revenue has the following form:

|  |  |
| --- | --- |
|  | (4.1.8) |

The condition of surplus elimination and deficit (2) is expressed in the formula

from that one can express the value from variables :

|  |  |
| --- | --- |
|  | (4.1.9) |

Let us plug received equation (4.1.9) in the revenue formula (4.1.8):

|  |  |
| --- | --- |
|  | (4.1.10) |

and then let us use the maximum condition of necessity to the equation for the revenue functions (3.2.10):

Having leaved the variables in the left side and having transferred other parameters to the right side, we will receive the system (4.1.11):

|  |  |
| --- | --- |
|  | (4.1.11) |

Matrix of the system (4.1.11) is a non-degenerate due to the linear independence of its columns (rows). That is why in a one-valued way the meanings of the variables can be expressed in a clear way, having multiplied this system to the opposite matrix that has the form:

|  |  |
| --- | --- |
|  |  |

The equations for would be received:

|  |  |
| --- | --- |
|  | (4.1.12) |

After simplification (4.1.12) it would be come up to the pars (4.1.13):

|  |  |
| --- | --- |
|  | (4.1.13) |

The values found (4.1.13) are in reality the points of maximum, because

due to the fact that ;

In the formula (3.2.13) all the parameters are known, because they are the predefined ones in the supply chain. As a consequence, the meanings of the variables are known as well. Thus, further we can consequently find the meanings of the variables , , и . That is how the optimal flow for the two-level decentralized supply chain was found and the problem of coordination was solved.

Analytical equations of the meanings of values in equilibrium are stated in the Table 1.

*Тable 1 Analytical equations for the meanings of variables in equilibrium*

|  |  |
| --- | --- |
| *Variable* | *Equation* |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

## 4.2 Nash equilibrium in the multilevel decentralized game

Let the decentralized tree-like supply chain be set with the certain number of levels. Analogous to the previous section the solution of the coordination problem we will begin with the analysis of the final junctures proceeding to the direction of the final peak.

Let us analyze the revenue function of the firm from the juncture :

|  |  |
| --- | --- |
|  | (4.2.1) |

Let us substitute in the revenue formula (4.2.1) the formula for the variable , using the supply function (3):

|  |  |
| --- | --- |
|  | (4.2.2) |

Having done (4.2.1) – (4.2.2) for all and having applied the maximum condition of necessity (4.2.3):

|  |  |
| --- | --- |
|  | (4.2.3) |

we will result in the system (4.2.4):

|  |  |
| --- | --- |
|  | (4.2.4) |
|  |  |

System (4.2.4) has the matrix that is non-degenerate due to the linear dependence of columns (rows). That is why system (4.2.4) can be solved in a one-valued way in correspondence to the variables and the unambiguous solution has the form:

or after the multiplication of the solution has the form (4.2.5):

|  |  |
| --- | --- |
|  | (4.2.5) |

For the juncture the following par (4.2.6) is valid as well

|  |  |
| --- | --- |
|  | (4.2.6) |

Let us fulfill the same analogical operations (4.2.1) – (4.2.6) for all the final peaks .

Now let us analyze the firm from . Its revenue function has the following form:

|  |  |
| --- | --- |
| where . | (4.2.7) |

Taking into consideration that the juncture composes a sector, then from the condition of the deficit and surplus elimination (2) let us have the formula

from that it is possible to express the variable in one-valued terms:

|  |  |
| --- | --- |
|  | (4.2.8) |

Let us substitute (4.2.8) in the revenue formulas (4.2.7)

|  |  |
| --- | --- |
|  | (4.2.9) |

and let us apply the maximum condition of necessity to the formulas (3.3.9):

or in the matrix form:

|  |  |
| --- | --- |
|  | (4.2.10) |

To the matrix of the system (4.2.10) -   
(as it is non-degenerate due to having linear independence of the columns (rows)) exists the opposite matrix:

As a result of that, (4.2.10) could be solved in a one-valued way in relation to the variables :

There are could be further calculated the value of :

|  |  |
| --- | --- |
|  | (4.2.11) |

Let us repeat the process (4.2.7) – (4.2.11) for all the remained junctures from the same level: .

Then by the similar way the peaks from multitudes would be analysed, peaks of the level , , will solve the twolevel subgame in each of the sectors that were created by these junctures, having received the solution depending on the supplier price of the juncture and express the meaning of this price in terms of the variables from the volume juncture.

Let us proceed to the analysis of the multitude in the first level peaks . The revenue function’s view for the certain firm from the juncture has the view (4.2.12):

|  |  |
| --- | --- |
|  | (4.2.12) |

Let us consider that the variable has the expression by the variables and the parameters of the production costs that can be received after the consideration of all from the condition of the deficit and surplus nonexistence:

|  |  |
| --- | --- |
|  | (4.2.13) |

where is the linear function by arguments .

Let us substitute the equation (4.2.13) in the revenue function (4.2.12)

|  |  |
| --- | --- |
|  | (4.2.14) |

and apply to the (4.2.14) the maximum condition of necessity:

|  |  |
| --- | --- |
|  | (4.2.15) |

As this takes place the meanings of all derivatives are constant due to the linearity of the function . The system (4.2.15) is the linear equations system relative to with a nondegenerate matrix (4.2.16)

|  |  |
| --- | --- |
|  | (4.2.16) |

and due to that it is uniquely solvable in relation to all where this solution depends only on the predefined supply chain parameters. Then by consequently substituting the deduced meanings to the equations for the unknown variables their equilibrium meanings would be found. Hence, the optimal flow is found and the task of coordination to the decentralized model of the multilevel supply chains is solved.

## 4.3 Coordination of the centralized multilevel supply chain

Let the certain multilevel supply chain with the tree-like distributive structure be defined. Let us assume that all its participants are joining the coalition and deciding to act in coordination having the goal of the total profit function’s maximization in the overall supply chain under the known linear supply functions in the finite junctures.

For each of the firms from this chain let us write down its revenue function , and then let us sum them by in order to find the overall supply chain revenue . Then it is necessary to find that feasible flow that can contribute to the satisfaction of the formula

leading us to the optimization problem (4.3.1) under the conditions (4.3.2) – (4.3.5):

|  |  |
| --- | --- |
|  | (4.3.1) |
|  | (4.3.2) |
|  | (4.3.3) |
|  | (4.3.4) |
|  | (4.3.5) |

From the properties of the maximizing function and view of the constraints (4.3.2) – (4.3.5) we conclude that (4.3.1) – (4.3.5) is the linear optimization problem under the linear constraints of equation and inequation types.

For the solution of the analyzed optimization problem there was a program created in the MATLAB environment. This program realized the interactive search algorithm of the maximum point search under the constraints of equation and inequation types based on the sequential quadratic programming method.

Optimization problem (4.3.1) – (4.3.5) (and, as a consequence, results received after its solution) has only one, but very substantial, drawback: it requires after the usage an additional imputation system, because under the received optimal volumes that are really minimizing the revenue on the whole supply chain, the revenue of the certain participants is pertaining to zero or negative. That is why after the optimal flow to the chain identification it is necessary to imply the contract system among all the participants which states explicitly the imputation of the total revenue received. However, it is very often difficult to implement that in real life.

Let us analyze the method using an alternative definition of the optimization problem and not requiring after it usage of any mathematical instruments.

## Formalization of coordination attitude with the weighted Nash solution usage

Let us have the game in the standard form, namely the plurality , where – nonvacuous set of players, – the set of player’s strategies, and – payoff functional of the player that is defined on the Cartesian product of sets for the strategies of players , . Simply ordered plurality for all the junctures of the supply chain we will consider as the plurality of players and pluralities , defined by formula (4) – pluralities for strategies of players . Let us for each player define in accordance the vector and in terms of players’ payoff functional let us take the mix of these vectors, simply ordered according to the ordering of the players’ plurality .

Let us call as the revenue of all the supply chain participants that is gained in decentralized solution of a coordination problem in the same supply chain. Let us create the function

where are certain numbers such as and

Then the solution of the following optimization problem with constraints is, on the one hand, the weighted Nash solution and on the other is the Pareto-optimal flow in the supply chain:

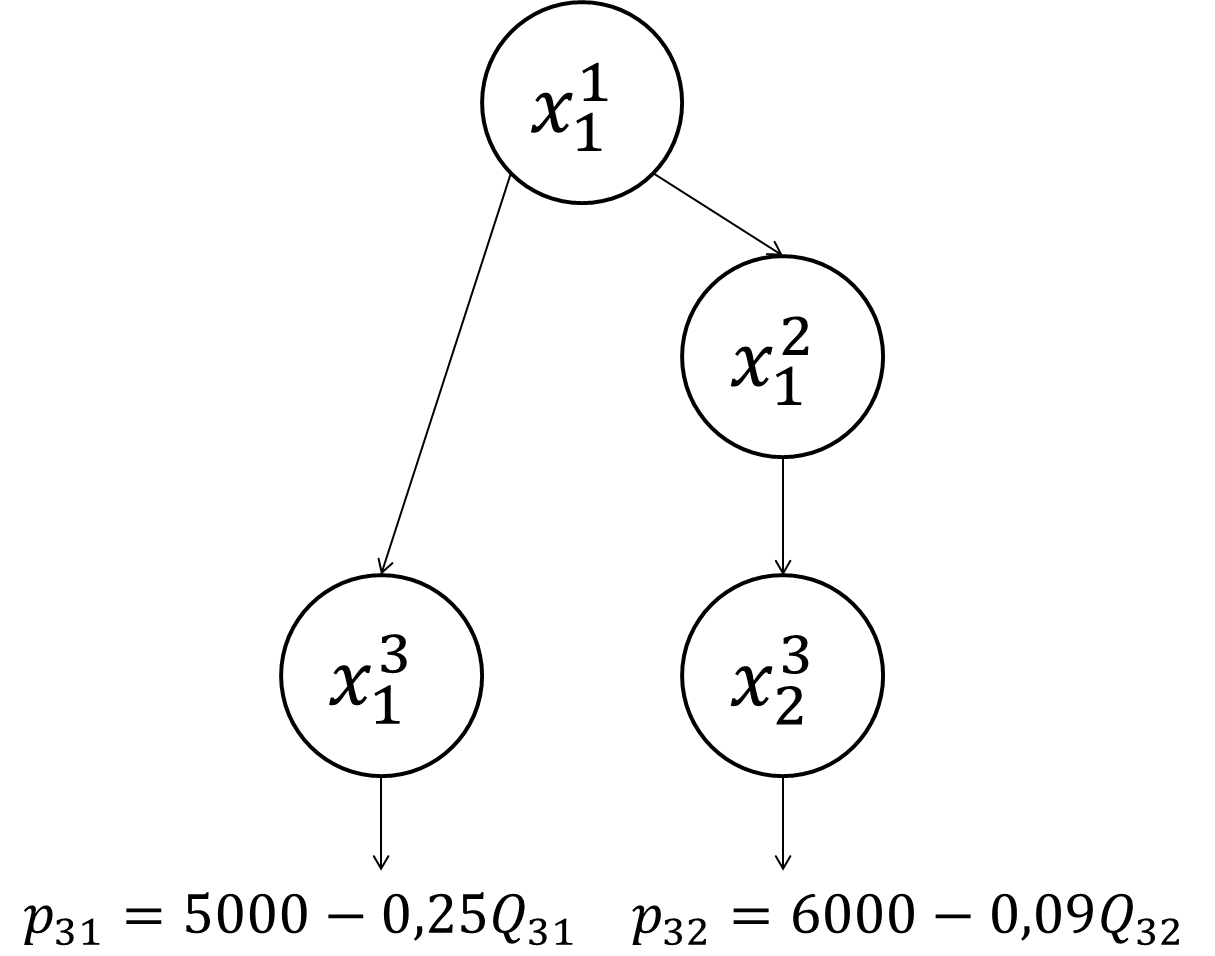
|  |  |  |
| --- | --- | --- |
|  | | 5.1) |
|  | ( 5.2) | |
|  | ((5.3) | |
|  | ((5.4) | |
|  | ((5.6) | |
|  | ((5.7) | |

For the solution of this linear optimization problem with the non-linear constraints there was a program created in MATLAB that is representing the iterative search of optimal solution with the predefined constraints in the kind of equations and inequations with the usage of the sequential quadratic programming method as the most effective method of the linear function’s constrained optimization.

## 4.5 Example and comparison of the solutions

Let us look at the specific example of the supply chain and compare the solutions that were received after each of the methods were implemented.

Let us have the supply chain depicted on the Figure 8.



*Figure 8. Supply chain*

The meaning of parameters is given in the Table 2.

*Table 2. Meanings of the supply chain parameters*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Juncture | Juncture | Juncture | Juncture |
| Number of firms in the juncture, |  |  |  |  |
| Meaning of costs to the single unit of good production, |  |  |  |  |

Let us find consequent decentralized solution for this supply chain, then centralized, and finally Nash solution in which as the weight coefficients there will be the following numbers used:

|  |  |
| --- | --- |
|  |  |

*Comment.* These numbers were received by the author’s algorithm of the number crunching in the weighted coefficients, according to which the largest weight is assigned to the root juncture, and then the weights are decreasing by the movement from the level to level.

Let us find the decentralized solution for this example. Revenue function for all the firms from the juncture of the 3rd level have the type (6.1) and (6.2):

|  |  |
| --- | --- |
|  | (6.1) |
|  |
|  |
|  |
|  | (6.2) |
|  |

Let us apply to all the functions in (6.1) and (6.2) the maximum condition of necessity and deduce the two sets of equations respectively:

|  |  |
| --- | --- |
|  | (6.3) |
|  | (6.4) |

After solving the systems (6.3) and (6.4) we have the formula for :

|  |  |
| --- | --- |
|  | (6.5) |
|  | (6.6) |

Because of the deficit and surplus mitigation condition we will receive the formula

from that one can express meaning of the variable

|  |  |
| --- | --- |
|  | (6.7) |

For the unique firm out of the juncture revenue function is written in the form of the formula:

substituting in which the equation (6.7), we will find:

Implementation of the maximum condition of necessity to this equation will be resulted in the par (6.8):

|  |  |
| --- | --- |
|  | (6.8) |

The condition of the surplus and deficit mitigation in the root peak center can be written in the form of equation

from that after having substituted (6.5) in (6.8) one can express :

|  |  |
| --- | --- |
|  | (6.9) |

Firms 1 and 2 from the root sector have revenue functions (6.10) and (6.11) respectively:

|  |  |
| --- | --- |
|  | (6.10) |
|  | (6.11) |

which after the plugging in (6.9) will have the form (6.12) and (6.13).

|  |  |
| --- | --- |
|  | (6.12) |
|  | (6.13) |

After the implementation of the maximum condition of necessity to the (6.12) and (6.13) we will receive a system:

the unique solution of which has the form (6.14)

|  |  |
| --- | --- |
|  | (6.14) |

Let us substitute the found meanings (6.14) in the equations (6.9.)

|  |  |
| --- | --- |
|  | (6.15) |

Let us substitute the meaning (6.15) in the (6.5) and (6.8) so that we will come up with the following:

|  |  |
| --- | --- |
|  | (6.16) |
|  |
|  |
|  |
|  | (6.17) |

Then, after having substituted (6.17) in the formula (6.7) we will find the meaning for :

|  |  |
| --- | --- |
|  | (6.18) |

By substituting (6.17) to the formula (6.7) let us find and from the equation (6.6):

|  |  |
| --- | --- |
|  | (6.19) |
|  |

Finally, using the calculated meanings of production volumes (6.16) and (6.19) in the finite junctures and , let us calculate the meaning of optimal prices and with the usage of the supply function:

|  |  |
| --- | --- |
|  |  |
|  |  |

Knowing the equilibrium meanings of all variables, we can calculate the revenue of every participant and then receive the overall supply chain revenue that is equal to:

|  |  |
| --- | --- |
|  | (6.20) |

Now let us find the optimal meanings by solving with the help of MATLAB platform the total revenue maximization problem in case of decentralized supply chain model and the maximization of the weighted Nash solution problem. Let us place all the received meanings in the single table (Table 3) for the intuitive comparison.

*Тable 3 Meanings of variables and revenue*

|  |  |  |  |
| --- | --- | --- | --- |
|  | Nash equilibrium | Solution of the total profit maximization in the supply chain problem | Nash weighted arbitrage solution |
| Juncture | | | |
| Volume of output |  |  |  |
| Price |  |  |  |
| Revenue of participants |  |  |  |
| Juncture | | | |
| Volume of output |  |  |  |
| Price |  |  |  |
| Revenue of participants |  |  |  |
| Juncture | | | |
| Volume of output |  |  |  |
| Price |  |  |  |
| Revenue of participants |  |  |  |
| Juncture | | | |
| Volume of output |  |  |  |
| Price |  |  |  |
| Revenue of participants |  |  |  |
| Total chain revenue: |  |  |  |

While comparing the meanings of the total chain revenue in decentralized and centralized models, let us notice that in case of centralized participants’ behavior the total revenue of chain has been increased to 1,1042\*107 or approximately to 30%. The number of analogous numerative experiments has found out that the chain centralization has on average the 25% gain in terms of total revenue in comparison with decentralized model. What is more, it is clear from the table that the Nash weighted arbitrage solution has increased the total profit of supply chain approximately to 29% from the revenue meaning in the Nash equilibrium in decentralized model. This result is a bit worse that has been received by the means of overall supply chain revenue maximization problem solution. However, the Nash weighted arbitrage solution guarantees for each of participants the positive gain and does not require an imputation procedure.

In the following chapter the practical algorithm was performed and calculated via MATLAB software: from the prices’ coordination of the decentralized solution in the supply chain to the cooperative arbitrage Nash solution. The logic that stands behind the calculations is as following: the solution itself should be aimed at the maximization of the gain to the both every juncture (operator in the supply chain) and to the root of the whole supply chain. However, only the solution with the maximum gain that complies with the criterion above could be chosen. Thus, first of all the mathematical formalization for the decentralized supply chain was executed and mathematically calculated. However, the following solution did not guarantee the maximization of the gain to the whole supply chain, so, in case of the market power change between the players it might be resulted in the unequal gain between them. Then the centralized solution was formulated and tested. The overall gain was higher because all of it was devoted to the whole supply chain. Finally, after having found the weighted arbitrage Nash solution it came out that the gain is maximum, the solution is consistent as it makes for all the market players non-profitable to devote from the price level that was coordinated. Finally, that very solution was approved and the revenue increase in case of the prices’ coordination for the company is believed to become higher to 29% in comparison with the initial prices’ level.

# Findings and conclusions

## 5.1. Main Findings and Answers to the Research Questions

The following research thesis was created in order to modify the current multi-echelon model and make it suitable for the price coordination in case of the forestry industry company.

In order to fulfil the goal stated, first of all, the systematic literature review was conducted. The absolute majority of the sources that were included there were only the recent ones within 2010-2015 years of publication. It came out that the price coordination in the supply chain is still an understudied field with the multiple diverse theoretical foundations, too narrow focus of the research (for instance, in case of forestry companies there was only sawlog production considered, without mentioning effects on the supply chain of the whole company), under-researched supply chain variables as the effects for the company or the industry have been barely studied and robustness of empirical results.

Then the peculiarities of the company that acts within the forestry industry supply chain were defined: multi-echelon chain – all finite goods are produced with little safety stock simultaneously from several production facilities and using the same raw material. According to them, the existing multi-echelon supply chain model was modified to be sustainable and decentralized. Then the algorithm of finding the most profitable to the overall supply chain solution was applied. So, one might assume that the answers to the research questions were discovered:

1. How traditional model for multi-echelon chains with linear demand can be changed for the forestry industry company?

Within this research supply chains with the tree-like distributive structure were analysed, where each juncture of this chain represents the competitive firms plurality that are producing and consuming the homogeneous product and that are having different production costs, but at the same time junctures do not compete with each other. It was assumed that the markets where the final products are realized by the finite junctures, do not compete with each other and function under the Cournot model with linear supply functions. The question of participants’ coordination was discussed, i.e. the of the problem concerning the choice of such strategies that are satisfying the predefined optimality criteria.

The mathematical formalization of the multilevel tree-like supply chains with the help of tree-like graph was conducted and the three solutions to the coordination problem were proposed: decentralized solution, centralized solution and weighted Nash solution. The search for decentralized solution has resulted in absolute Nash equilibrium being found in the multilevel hierarchical fully equipped with information game for which the algorithm of this equilibrium solution finding was created. For the case of the centralized participants’ behaviour in the supply chain with the analysed structure, the coordination problem was formulated as the problem of non-linear conditional optimization.

2. To what amount could the final revenue for the supply chain increase if the coordination mechanism in the supply chain is implemented to the forestry industry company?

Numerical simulation has found that such an approach increases the total revenue of the supply chain on average at 25%, but is does not guarantee the positive gain to all of the participants, so requires the imputation system to be implemented.

The analysis of results having received from the numerical simulation, has forced us to find an alternative approach to the supply chain coordination. Acting as such an approach the Nash weighted solution was chosen that, as it was found out experimentally, even though gives a smaller gain in terms of revenue than the one examined earlier, but guarantees the positive gain to all of the participants.

## 5.2. Theoretical Implications

First of all, the following work has systematized the most recent academic sources in the field of the supply chain price coordination. Thus, the further researchers could work on the further systematization of the approaches to the price coordination as well as elaborate on the more focused empirical results of their findings.

What is more, in the research the modified model for the price coordination was created. That is how the feasible model according to which it is possible to calculate the overall gain not only to all the operators in the chain, but also to the chain itself is now available. The logical continuation of the following stream of research might be the elaboration on the variables that might be used for these types of supply chains and industries.

Finally, according to the calculations performed, it was found out that Nash weighted solution should be considered as the most optimal instrument for the prices coordination. It came out that with the help of the prices coordination the final price that could have been defined by the pulp & paper producer might have been significantly higher because of the working capital costs as well as of the obsolescence problem minimization.

## 5.3. Managerial Implications

Besides, the presented work has made its contribution to the practical side of the impact on the business processes for all the major participants of the supply chain in the industry:

For the supplier side: the revenue is maximized due to the higher reliability of the whole supply chain. What is more, the relationships with the distributors are likely to get stronger, thus, the revenue can be better predicted and the modernization/other projects of production improvement could be performed beforehand to be one step ahead of competition.

For the distributor side: the company can buy larger batch of goods as the physical flow is coordinated, the risks of obsolescence are minimized, thus, the flow of orders can be formed in advance.

For the final consumer side: maximization of the final consumer gain makes him feel loyal to the product of the producer. Thus, in the commodity market if the condition of the same physical features occurs between the product of that very forestry industry producer and another, the customer would be likely to prefer the company that has coordinated its prices by having coordinated its flow of supply.

## 5.4. Future Research

The limitations of the following research are generally related to the market that was selected for the research. The following work is analysing solely Russian internal forestry market and, consequently, supply chains that are used for the delivery of the goods to the internal customers. What is more, the model that is selected for the following work has its own specific for forestry industry limitations, namely, hierarchy of the operators in the supply chain and the fact that all the final products should be produced from the same natural resource (raw material). Furthermore, this research took into consideration prices that were set in the macroeconomic environment where the protectionism policy towards the “Made in Russia” goods is implemented.

That is why, it might be logical, first of all, to test the universality of the modified model and apply it to the forestry industry market players in other countries. What is more, the question about the coordination of the prices in case of the goods’ delivery within the same country is still an open one. Furthermore, it might be possible to continue further modifications of the presented model to find out its implementation to other natural resource production companies that produce all the finite goods from the same raw material as well: metals & mining, oil & gas, etc. That is how its cross-industrial universality could be achieved.

# References

Arshinder, Kanda, A., & Deshmukh, S. G. (2008). Supply chain coordination: Perspectives, empirical studies and research directions. *International Journal of Production Economics*, *115*(2), 316–335. http://doi.org/10.1016/j.ijpe.2008.05.011

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal*, *9*(1), 30–42. http://doi.org/10.1108/13598540410517566

Beamon, B. M. (1998). Supply chain design and analysis: Models and methods. *International Journal of Production Economics*, *55*(3), 281–294. http://doi.org/10.1016/S0925-5273(98)00079-6

Blackman, I. D., Holland, C., & Westcott, T. (2013). Motorola’s global financial supply chain strategy. *Supply Chain Management: An International Journal*, *18*(2), 132–147. http://doi.org/10.1108/13598541311318782

Blome, C., Paulraj, A., & Schuetz, K. (2014). Supply chain collaboration and sustainability: a profile deviation analysis. *International Journal of Operations & Production Management*, *34*(5), 639–663. http://doi.org/10.1108/IJOPM-11-2012-0515

Burgess, K., Singh, P., & Koroglu, R. (2006). Supply chain management: a structured literature review and implications for future research. *International Journal of Operations and Production Management* (Vol. 26). http://doi.org/10.1108/01443570610672202

Cao, M., & Zhang, Q. (2011). Supply chain collaboration: Impact on collaborative advantage and firm performance. *Journal of Operations Management*, *29*(3), 163–180. http://doi.org/10.1016/j.jom.2010.12.008

Chata, K. a., Butt, I., & Tariq, A. (2015). Research methodologies and publication trends in manufacturing strategy A content analysis based literature review. *International Journal of Operations and Production Management*, *35*(4), 487–546. <http://doi.org/10.1108/IJOPM-07-2012-0285>

Chatha, K. A., & Butt, I. (2015). *Themes of study in manufacturing strategy literature*. *International Journal of Operations & Production Management* (Vol. 35). http://doi.org/10.1108/IJOPM-07-2013-0328

Eltantawy, R., Paulraj, A., Giunipero, L., Naslund, D., & Thute, A. A. (2015). Towards supply chain coordination and productivity in a three echelon supply chain. *International Journal of Operations & Production Management*, *35*(6), 895–924. <http://doi.org/10.1108/IJOPM-10-2013-0459> http://doi.org/10.1016/j.jom.2015.04.001

Fabbe-Costes, N., Roussat, C., Taylor, M., & Taylor, A. (2014). Sustainable supply chains: a framework for environmental scanning practices. *International Journal of Operations & Production Management*, *34*(5), 664–694. http://doi.org/10.1108/IJOPM-10-2012-0446

Fairchild, A. (2005). Intelligent matching: integrating efficiencies in the financial supply chain. *Supply Chain Management: An International Journal*, *10*(4), 244–248. http://doi.org/10.1108/13598540510612703

Flynn, B. B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance: A contingency and configuration approach. *Journal of Operations Management*, *28*(1), 58–71. http://doi.org/10.1016/j.jom.2009.06.001

Frohlich, M. T., & Westbrook, R. (2001). Arcs of integration: An international study of supply chain strategies. *Journal of Operations Management*, *19*(2), 185–200. <http://doi.org/10.1016/S0272-6963(00)00055-3>

Gunasekaran, A., Patel, C., & McGaughey, R. E. (2004). A framework for supply chain performance measurement. In *International Journal of Production Economics* (Vol. 87, pp. 333–347). http://doi.org/10.1016/j.ijpe.2003.08.003

Hadid, W., & Afshin Mansouri, S. (2014). The lean-performance relationship in services: a theoretical model. *International Journal of Operations & Production Management*, *34*(6), 750–785. <http://doi.org/10.1108/IJOPM-02-2013-0080>

Hendricks, K. B., & Singhal, V. R. (2003). The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management*, 21(5), 501–522. http://doi.org/10.1016/j.jom.2003.02.003

Hendricks, K. B., Singhal, V. R., & Stratman, J. K. (2007). The impact of enterprise systems on corporate performance: A study of ERP, SCM, and CRM system implementations. *Journal of Operations Management*, 25(1), 65–82. http://doi.org/10.1016/j.jom.2006.02.002

GSCF Forum (2016) Standard Definitions for Techniques of Supply Chain Finance. Retrieved from http://icc.academy/wp-content/uploads/2016/03/Standard\_Definitions\_for\_Techniques\_of\_Supply\_Chain\_Finance.pdf

ICC (International Chamber of Commerce), TIFA (Trade and Forfaiting Association), BAFT (Banking Commission as project facilitator), EBA (Euro Banking Association), FCI (Factors Chain International) (2016). Standard Definitions for Techniques of Supply Chain Finance. *Global Supply Chain Financial Forum*. Retrieved from <http://icc.academy/wp-content/uploads/2016/03/Standard_Definitions_for_Techniques_of_Supply_Chain_Finance.pdf>

ICC, TIFA, BAFT, EBA, FCI (2016). *Standard Definitions for Techniques of Supply Chain Finance*. *Global Supply Chain Financial Forum*. Retrieved from <http://icc.academy/wp-content/uploads/2016/03/Standard_Definitions_for_Techniques_of_Supply_Chain_Finance.pdf>

Johnson, M., & Templar, S. (2011). The relationships between supply chain and firm performance: The development and testing of a unified proxy. *International Journal of Physical Distribution & Logistics Management*, 41(2), 88–103. http://doi.org/10.1108/09600031111118512

Kim, S.W. (2009). An investigation on the direct and indirect effect of supply chain integration on firm performance. *International Journal of Production Economics*, 119(2), 328–346.

Kim, Y. H., & Henderson, D. (2015). Financial benefits and risks of dependency in triadic supply chain relationships. *Journal of Operations Management*, *36*, 115–129.

Li, X., & Wang, Q. (2007). Coordination mechanisms of supply chain systems. *European Journal of Operational Research*, *179*(1), 1–16. http://doi.org/10.1016/j.ejor.2006.06.023

Li, X., Wu, Q., & Holsapple, C. W. (2015). Best-value supply chains and firms’ competitive performance: empirical studies of their linkage. *International Journal of Operations & Production Management*, *35*(12), 1688–1709. <http://doi.org/10.1108/IJOPM-01-2014-0014>

Narayanan, S., Narasimhan, R., & Schoenherr, T. (2015). Assessing the contingent effects of collaboration on agility performance in buyer–supplier relationships. *Journal of Operations Management*, *33-34*, 140–154. <http://doi.org/10.1016/j.jom.2014.11.004>

Okongwu, U., BRULHART, F., & Moncef, B. (2015). Causal linkages between supply chain management practices and performance. *Journal of Manufacturing Technology Management*, *26*(5), 678–702. <http://doi.org/10.1108/JMTM-01-2013-0002>

Pezza, S. (2011). Supply Chain Finance: gaining control in the face of uncertainty. *Aberdeen Group*, (January), 1–23. http://doi.org/10.1080/13675560903555167

Prajogo, D., Oke, A., & Olhager, J. (2016). Supply chain processes. *International Journal of Operations & Production Management*, *36*(2), 220–238. <http://doi.org/10.1108/IJOPM-03-2014-0129>

Sazvar, Z., Mirzapour Al-E-Hashem, S. M. J., Baboli, A., & Akbari Jokar, M. R. (2014). A bi-objective stochastic programming model for a centralized green supply chain with deteriorating products. *International Journal of Production Economics*, *150*, 140–154. http://doi.org/10.1016/j.ijpe.2013.12.023

Schoenherr, T., & Swink, M. (2012). Revisiting the arcs of integration: Cross-validations and extensions. *Journal of Operations Management*, *30*(1-2), 99–115. http://doi.org/10.1016/j.jom.2011.09.001

Shi, M., & Yu, W. (2013). Supply chain management and financial performance: literature review and future directions. *International Journal of Operations & Production Management* (Vol. 33). http://doi.org/10.1108/IJOPM-03-2012-0112

Singhal, K., & Singhal, J. (2012). Opportunities for developing the science of operations and supply-chain management. *Journal of Operations Management*, *30*(3), 245–252. http://doi.org/10.1016/j.jom.2011.11.002

Srinivasa Raghavan, N. R., & Mishra, V. K. (2011). Short-term financing in a cash-constrained supply chain. *International Journal of Production Economics*. http://doi.org/10.1016/j.ijpe.2009.11.014

Stevens, G., & Johnson, M. (2006). Article information : Integrating the Supply Chain … 25 Years On. *International Journal of Physical Distribution & Logistics Management*, *46*(1), 1–30. <http://doi.org/http://dx.doi.org/10.1108/IJPDLM-07-2015-0175>

Swink, M. L., Golecha, R., & Richardson, T. (2010). Does Supply Chain Excellence Really Pay Off? *Supply Chain Management Review*, 14, 14. http://doi.org/Article

Tsinopoulos, C., & Mena, C. (2015). Supply chain integration configurations: process structure and product newness. *International Journal of Operations & Production Management*, *35*(10), 1437–1459. http://doi.org/10.1108/IJOPM-08-2013-0369

Vanpoucke, E., Vereecke, A., & Boyer, K. K. (2014). Triggers and patterns of integration initiatives in successful buyer-supplier relationships. *Journal of Operations Management*, *32*(1-2), 15–33. http://doi.org/10.1016/j.jom.2013.11.002

Walker, H., Chicksand, D., Radnor, Z., & Watson, G. (2015). Theoretical perspectives in operations management: an analysis of the literature. *International Journal of Operations & Production Management*, *35*(8), pp. 1182–1206. <http://doi.org/10.1108/IJOPM-02-2014-0089>

Wang, Z., & Sarkis, J. (2013). Investigating the relationship of sustainable supply chain management with corporate financial performance. *International Journal of Productivity and Performance Management*, *62*(8), 871–888. <http://doi.org/10.1108/IJPPM-03-2013-0033>

Weiss, J. B. (2011). How to better manage your financial supply chain. *Cash Flow Management Best Practice*, available at: www. qfinance. com/cash-flow-managementbest-practice/how-to-better-manage-your-financial-supply-chain.

Williamson, O.E. (1981). The economics of organization: the transaction cost approach. *American Journal of Sociology*, 87(3), 548 – 577, <http://doi.org/10.1086/227496>

Wong, C. W. Y., Wong, C. Y., & Boon-itt, S. (2013). The combined effects of internal and external supply chain integration on product innovation. *International Journal of Production Economics*, 146(2), 566–574. http://doi.org/10.1016/j.ijpe.2013.08.004

Wuttke, D. A., Blome, C., & Henke, M. (2013). Focusing the financial flow of supply chains: An empirical investigation of financial supply chain management. *International Journal of Production Economics*, *145*(2), 773–789. http://doi.org/10.1016/j.ijpe.2013.05.031

Xu, G., Dan, B., Zhang, X., & Liu, C. (2014). Coordinating a dual-channel supply chain with risk-averse under a two-way revenue sharing contract. *International Journal of Production Economics*, 147(PART A), 171–179. <http://doi.org/10.1016/j.ijpe.2013.09.012>

Петросян Л.А., Зенкевич Н.А., Шевкопляс Е.В. Теория игр. Изд. 2-е. СПб.: БХВ-Петербург, 2014. 432 с.

Adida E., DeMiguel V. Supply Chain competition with multiple manufacturers and retailers // Operation Research, 2011. Vol. 59, №1. P.156-172.

Cachon G.P. Supply chain coordination with contracts // Handbooks in Operations Research & Management Science, 2003. Vol. 11. P. 227-339.

Carr M.S., Karmarkar U.S. Competition in multi-echelon assembly supply chains // Management Science, 2005. Vol. 51. P. 45-59

Cho S.-H. Horizontal mergers in multi-tier decentralized chains // Management Science, 2014. Vol. 51. P. 45-59.

Corbett C., Karmarkar U.S. Competition and structure in serial supply chains with deterministic demand // Management science, 2001. № 47. P. 966-978.

Kaya M., Ozer O. Pricing in business-to-business contracts: sharing risk, profit and information // The Oxford Handbook of Pricing Management. Oxford: Oxford University Press, 2012. P. 738-783.

Laseter T., Oliver K. When will supply chain management grow up? // Strategy+business, 2003. Issue 32.

Tyagi R.K. On the effect of downstream entry // Management science, 1999. № 45. P. 59-73

Vickers J. Competition and regulation and vertically related markets // Review of economics study, 1995. № 62. P. 1-17.

Zhou D., Karmarkar U.S., Jiang B. Competition in multi-echelon distributive supply chains with linear demand // International Journal of Production Research, 2015. Vol. 53, № 22. P. 6787-6807

Ziss S. Vertical separation and horizontal mergers // Journal of industrial economics, 1995. №43. P. 63-75.

# Appendix 1. Results of the Price Coordination Calculation

