Building **R**adio frequency **ID**entification for the **G**lobal **E**nvironment

Economic Impact of RFID Report

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About the BRIDGE Project:

BRIDGE (**B**uilding **R**adio frequency **ID**entification for the **G**lobal **E**nvironment) is a 13 million Euro RFID project running over 3 years and partly funded (€7,5 million) by the European Union. The objective of the BRIDGE project is to research, develop and implement tools to enable the deployment of EPCglobal applications in Europe. Thirty interdisciplinary partners from 12 countries (Europe and Asia) are working together on : Hardware development, Serial Look-up Service, Serial-Level Supply Chain Control, Security; Anti-counterfeiting, Drug Pedigree, Supply Chain Management, Manufacturing Process, Reusable Asset Management, Products in Service, Item Level Tagging for non-food items as well as Dissemination tools, Education material and Policy recommendations.

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This document:

The focus of this report is on possible impacts RFID technology will have on the economy especially in Europe. First, in chapter 2 we give an overview of the status quo of the adoption and diffusion of RFID. Chapter 3 summarizes in brief the theory of the adoption and diffusion of new technologies - a prerequisite for an economic impact - and basic macroeconomic concepts. In chapter 4 the economic impact of IT is described and the result for the RFID technology derived. Chapter 4 discusses the analysis before chapter 5 summarizes the findings.

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Executive Summary

The Radio Frequency Identification (RFID) technology - even not a new technology - was really hyped in the recent years. Today, companies from diverse branches are hoping for solutions to a wide range of management problems through RFID, from simple increases in processing efficiency for the receipt and dispatch of goods in distribution centers through to improvements in goods availability on the shelves and on to the struggle against shrinkage and product counterfeiting and many more. RFID seems to become another revolutionary technology after the general IT wave in the 1980s/1990s. Therefore, researchers as well as practitioners are interested in being able to estimate the economic impact of the adoption and diffusion of RFID.

At present, it is almost impossible to obtain systematic and reliable data to analyze the economic impact of RFID because the adoption and diffusion process is still in an early stage. Hence, the approach chosen for this study is to derive results from studies dealing with the economic impact of IT and to transfer appropriate findings to a qualitative analysis of the potential economic impacts of RFID.

In general, RFID will have significant impacts because of three reasons: First, RFID is new in many processes and will achieve improvements in the efficiency of tasks (e.g. due to the substitution of manual labor). Second, RFID offers the possibility to completely redesign processes because of the technology's properties (e.g. increased transparency, reliability, and accuracy). Third, because RFID is a network technology significant increases in the value of using RFID can be expected by adding additional users to the network.

The results show that RFID will have impacts on the productivity due to a higher transparency in the supply chain and more accurate information, the substitution of manual labor and increased sensing and tracking capabilities. In addition to that, RFID will have effects on the employment on the one hand through a decreasing demand for manual labor (e.g. due to the overall reduction of manual scanning and data keying activities) and on the other hand by an increasing demand for qualified employees to maintain the new systems and to analyze the generated data for better decision making tools. RFID offers the possibility to develop new products and especially services which in turn opens potential new markets for companies. Altogether, these developments will contribute to a faster productivity growth, a higher per-capita income and an increasing GDP.

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1 Introduction

With the beginning of the IT revolution, many policymakers were looking for a big IT impact and could not see it. Then, in the 1990s they were told IT was transforming the world we are living in, creating the New Economy. With the implosion of the New Economy and the following recession in 2001 critiques came up that the "digital revolution" was just a creation of the media. In the case of IT the reality today exceeds the initial expectations. The digital economy is more than fulfilling the original forecasts. The integration of IT into rather all aspects of the economy and society is responsible for generating economic growth and prosperity [39].

At present, Radio Frequency Identification (RFID) enjoys an enormous interest from the standpoint of research as well as from corporate practice, public policy, and consumer issues – especially data protection and privacy issues. The technology was really hyped in the recent years (Figure 1). It is not uncommon for the computing and information technology (IT) community to hype new technologies. It happens with regularity, but it is rare when multiple industry sector leaders and government policy makers join in the hype. Enterprises from diverse branches are hoping for solutions to a wide range of management problems through RFID, from simple increases in processing efficiency for the receipt and dispatch of goods in distribution centers through to improvements in goods availability on the shelves and on to the struggle against shrinkage and product counterfeiting and many more.

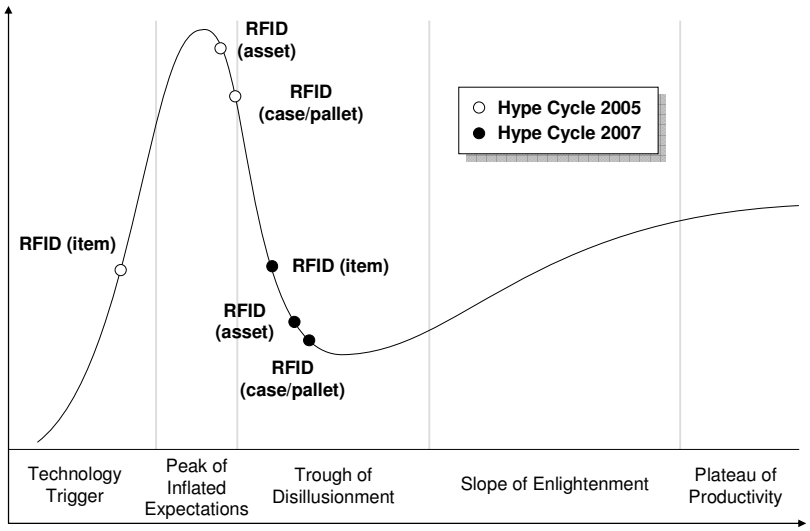

Figure 1: RFID in the 'Hype Cycle for Retail Technologies' (adapted from [27][28])

RFID and IT-networks will help to increase economic growth through the expansion of information sharing, community empowerment, and through increased sensing and tracking capabilities [37]. Therefore, the potential of a technology like RFID in new supply chain applications must be translated into measurable financial benefits. Researchers as well as practitioners have been working on challenges in establishing the value of spending on information technology [38].

The focus of this report is on possible impacts RFID technology will have on the economy especially in Europe. First, in chapter 2 we give an overview of the status quo of the adoption and diffusion of RFID. Chapter 3 summarizes in brief the theory of the adoption and diffusion of new technologies - a prerequisite for an economic impact - and basic macroeconomic concepts. In chapter 4 the economic impact of IT is described and the result for the RFID technology derived. Chapter 4 discusses the analysis before chapter 5 summarizes the findings.

2 Status Quo of the Adoption and Diffusion of RFID

The status quo of the adoption and diffusion of RFID cannot be determined exactly - it is common that prognoses are based on reported sales volumes of RFID tags, case studies, exploratory surveys, laboratory experiments, or interviews with (potential) adopters. Nevertheless, it is generally agreed that the rate of adoption of RFID has been much lower and its study more complex than anticipated – a large gap exists between the ideal vision and the current adoption and diffusion of RFID along supply chains [15][29][32]. The term ‘adoption’ is defined as the act to accept something which means in this context to deploy an innovation. The term ‘diffusion’ represents a series of individual adoption decisions [29].

For example, a study in the UK found in 2006 that only 8% of businesses were using RFID technology (including pilot studies) with a further 11% investigating its potential. A similar pattern is reported from the US were the adoption rates seemed to be modest as well. Only 9% of the retailers who responded to a survey had an implementation time line in place and most of these were at the pilot stage. The much higher figure of 44% for manufacturers was reported because of mandates by retail trading partners (e.g. Wal-Mart or Target) [29].

There are numerous studies dealing with the development of RFID applications and the resulting market growth for RFID hardware and software. For example, a study [11] in the warehousing industry predicts that the tagging of most assets should have taken place in the years 2006/2007. For the years 2008/2009 it very optimistically estimates more than 70% of assets to be equipped with RFID transponders that will reduce the operating cost by 1-3% [11]. Other studies mention a horizon until 2010 by which most transport containers will be equipped with RFID [14]. These data and other studies have to be interpreted carefully. Estimates very often depend on whose interests should be covered.

Gartner Dataquest (in [22]) predicts a strongly developing RFID market in the future (Figure 2). In the year 2004 the total RFID market was still dominated by established RFID applications: 63% are generated through RFID in security and access control (smart cards, car keys), 29% by RFID animal implants, 5% through cartons supply, and less than 1% through the tagging of consumer products (2% other). That means that the estimated growth has to be generated by upcoming applications, e.g. in supply chain management in the automotive industry, retail, and fast moving consumer goods (FMCG) [22][24].

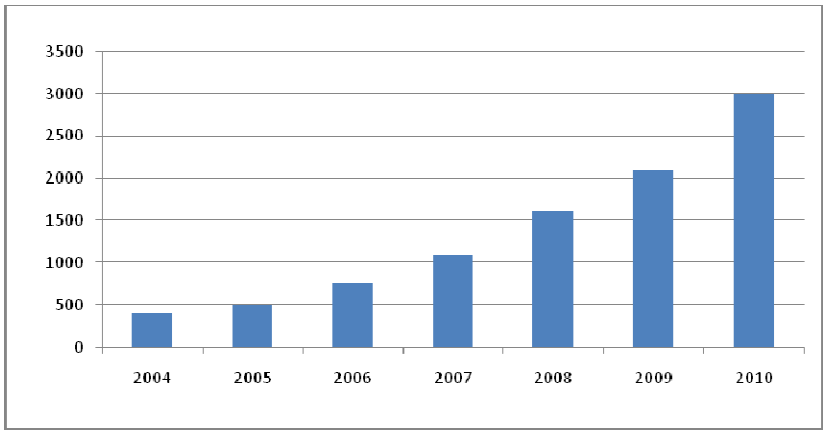

Figure 2: Total RFID market 2004-2010 in Mio. US-Dollar [22]

At the time of writing, RFID in supply chain management processes is predominantly used for closed-loop applications and the tagging of high value items respectively returnable items (e.g. reusable containers). GS1 [23] predicts that this situation will also remain the largest opportunity in the next years. Despite recent cost reductions, especially transponder prices, many business applications will only take off at much lower hardware prices. Nevertheless, implementation costs will remain prohibitive for many regularly discussed businesses cases. Furthermore, the distribution of costs and benefits between supply chain partners or companies in an open environment remains complex [23]. Table 1 shows the number of tags sold by application and the total tag value in the year 2006.

Tag location	Number of tags supplied (millions)	Value of tags (millions USD)
Drugs	15	3,5
Other Healthcare	10	5,1
Retail apparel	50	10
Consumer goods	10	2,5
Tires	0,1	0,1
Postal	0,5	0,3
Books	50	17,3
Manufacturing parts, tools	10	4
Archiving (documents/samples)	8	2,6
Military	10	200
Pallet/case	200	34
Smart cards/payment key fobs	350	770
Smart tickets/banknotes/secure docs	65	13
Air baggage	25	5
Conveyances/Other, Freight	10	10
Animals	70	140
Vehicles	2,5	23,8
People	0,5	9,5
Car clickers	46	46
Passport page	25	100
Other tag application	65	87,1
Total	1022,6	1483,8

Table 1: Number of RFID transponders (millions) sold by application in 2006 [25]

Compared to the proportions of the year 2004 there are no significant changes in the relevant applications: Still 64% of the market share are generated through RFID applications in security and access control (smart cards, car keys), 10% by RFID animal implants (discrepancy to former data), 5% through cartons supply, and, with a little increase to 3%, the tagging of consumer products.

Regarding the used frequencies, GS1 expects that UHF will be the dominant frequency for tracking purposes even if the maturity of passive UHF RFID technology is still not sufficient for many applications. It still requires significant effort to develop solutions that meet specific requirements. The HF technology will be used as well, but at the moment predominantly in specific or niche applications such as library books and already existing systems e.g. in the automotive industry [23]. However, EPCglobal plans to develop an EPC Class 1 Gen 2 for the HF band because of various reasons: On the one hand, for item level tagging purposes the HF technology showed in pilot studies with retailers and pharmaceutical companies advantages over UHF, and on the other hand, there are upcoming applications for mobile phones (NFC – Near Field Communication) that operate with HF technology [26][49]. Probably there will be a shift in strategies in the future, to tag palettes and boxes with UHF transponders and individual items with HF transponders.

Vijayaraman and Osyk [11] studied in a survey companies from the manufacturing industry, third party warehousing/logistics providers, wholesale/distributers, and retail firms whether these companies are planning or already implementing RFID and what challenges they are facing. From a total of 1.495 addressed organizations they got a total of 211 responses. Among the answering companies, 39% were manufacturing companies, 30% wholesale/distributers, 21% 3PL warehouse/logistics, 8% retail and 2% ‘others’. Within the manufacturing industry category, 44% were consumer-packaged goods, food products and apparel, 5% pharmaceutical, 5% electronics and high tech, 4% automotive, and 3% chemical companies. 15% of the survey respondents were already EPC subscribers, and 39% were planning to become an EPC member in the near future. The results are summarized in the following:

First of all, the relationship between company size and the initial RFID investment becomes obviously clear when examining Table 2. Larger companies are able to spend more money for first RFID pilots and implementations.

Initial RFID investment (USD)	Company size		
	Small	Medium	Large
Less than 100.000	9	12	6
100,000 - 500,000	3	7	5
500,000 - 1 million	0	2	2
1 - 5 million	0	0	5

Table 2: Relationship between company size and initial RFID investment [11]

All of the companies are already using various other technologies in their supply chains. The most mentioned include barcode technology, printed labels, scanners, WMS, conveyers, and MHE vehicles. 60% of the surveyed companies are already using RFID or have experiences with this technology. Even more surprisingly, only 56% of the firms are either considering or piloting/implementing RFID. Therefore, the companies were asked for their reasons to implement RFID (Figure 3) [11].

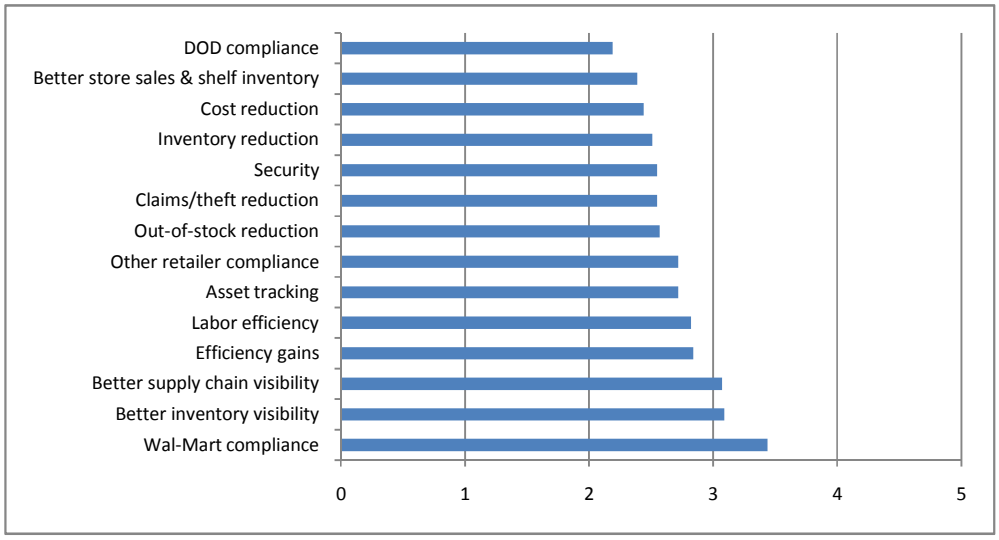

Figure 3: Reasons for implementing RFID (1-Least Applicable, 5-Most Applicable) [11]

Obviously, reasons for the use of RFID are mandates and higher supply chain visibility and hence resulting possibilities (e.g. track and trace). This group was as well asked about their biggest concerns regarding RFID technology and the development in the near future. Their answers are shown in Figure 4.

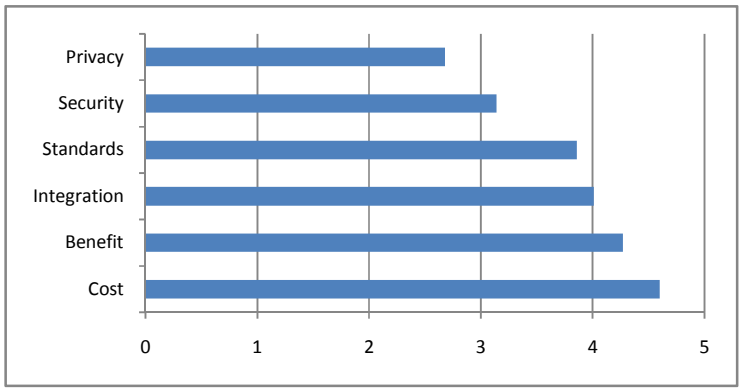

Figure 4: Concerns regarding RFID (1-Least Concerned, 5-Most Concerned) [11]

The biggest concerns are still the costs of RFID transponders, infrastructure and implementation, unclear cost/benefit sharing models, the integration in existing systems, and the lack of standards. On the other hand, 44% of the participating companies are not considering implementing or even piloting RFID in their supply chains (Figure 5). The mentioned reasons correspondent's to the concerns.

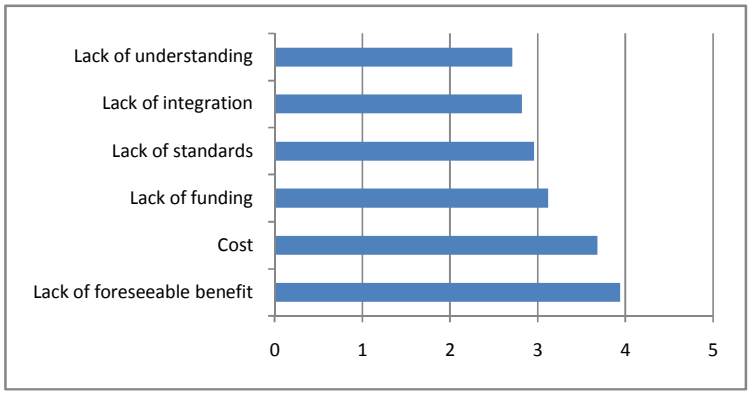

Figure 5: Reasons for not implementing RFID (1-Least Applicable, 5-Most Applicable) [11]

Another interesting result of this study comes from the question about potential cost savings of RFID implementation. The respondents were asked to rate several RFID cost saving sources on a scale of 1-5 (Figure 6).

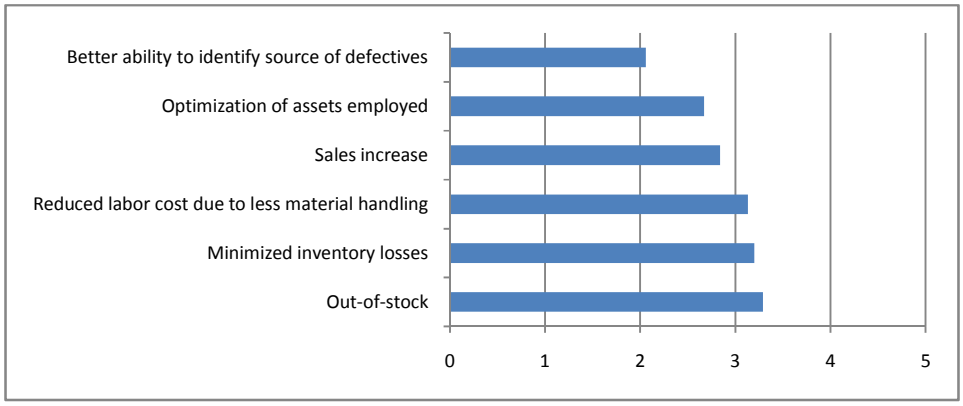

Figure 6: Sources of RFID cost savings (1-Least Likely, 5- Most Likely)[11]

Furthermore, respondents were asked about their RFID integration strategy. As shown in Figure 7 many organizations plan to integrate RFID to certain extend to warehouse applications but only a few plan to integrate RFID with supply chain management [11].

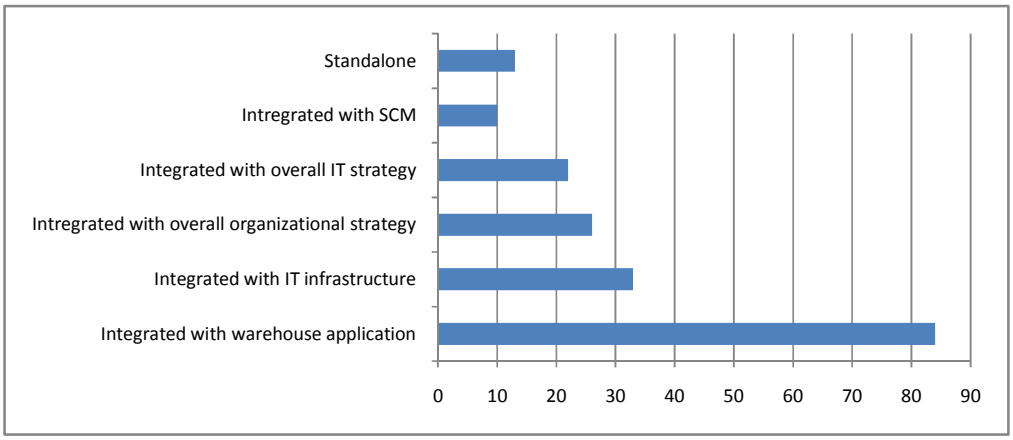

Figure 7: Integration of RFID technology [11]

In fact, one of the most important and continuously discussed issues regarding RFID is standards. Therefore, this topic will be described in detail in the following: In a global business environment, interoperability among information and communication technologies is a fundamental requirement which is essential for the use of RFID. Therefore RFID standards – e.g. the RF protocol, data-on-tag structures, etc. – are a major issue for the industry. Unfortunately though, not only different standards coexist in parallel, but different actors with divergent interests influence the standardization process to some extent as well. At the time of writing, there are two major initiatives regarding RFID standardization: ISO (International Organization for Standardization) and EPCglobal. ISO adopts a cross industry perspective with a generic approach while EPCglobal as a not-for-profit organization driven by large end users and their needs adopts a more application-specific approach [15].

EPCglobal and ISO Standards

As well as the developments in the various constituent technologies, a major trigger for the dramatically elevated interest in (passive) RFID during the late 1990s has resulted from the activities of the Auto-ID Center, a project founded in 1999 at the Massachusetts Institute of Technology (MIT). In cooperation with numerous industrial sponsors, the development of RFID standards has been promoted. The main focus of the developments at the Auto-ID Center was the definition of the "Electronic Product Code (EPC)", a worldwide unambiguous numbering scheme for the designation of arbitrary physical goods which should ensure the interoperability of the RFID technology in supply chain wide applications [16][29]. In line with the GS1 System of unique identifiers, the philosophy of the EPC concept is to save only a 64- or 96-bit long code on a passive tag which maps to information on a network to ensure the possibility to manufacture low cost RFID tags with a minimum of memory capacity. This was meant to decrease tag prices and to make RFID a technology for the mass market [16][17]. On the basis of the EPC, specifications followed for protocol standards such as communications between transponders, scanner-hardware, and information systems. Since

the termination of the Auto-ID Center according to plan in October 2003 the EPC technology is being commercialized and further developed by EPCglobal Inc., a subsidiary of GS1, the industry organization also responsible for barcode standardization [18]. In the following years, the EPC became the technical foundation for the multiple RFID initiatives (mandates) of large chain stores such as Wal-Mart, Tesco, Best Buy, Target, and Metro.

In January 2008, 1347 companies from different industries were EPCglobal subscribers[1]. With a share of 30%, solution providers of hardware, software, and RFID consulting represent the biggest group. Retail and Fast Moving Consumer Goods (FMCG) (Consumer Goods, Food & Beverage) sum up to 27% and the electronics and high tech industry to 9% of the EPCglobal community. The remaining 34% are spread over multiple other industries (Figure 8). Interestingly, within the Top 30 of the Fortune 500 one can find 13 EPCglobal subscribing companies, within the Top 100 after all 38 [19].

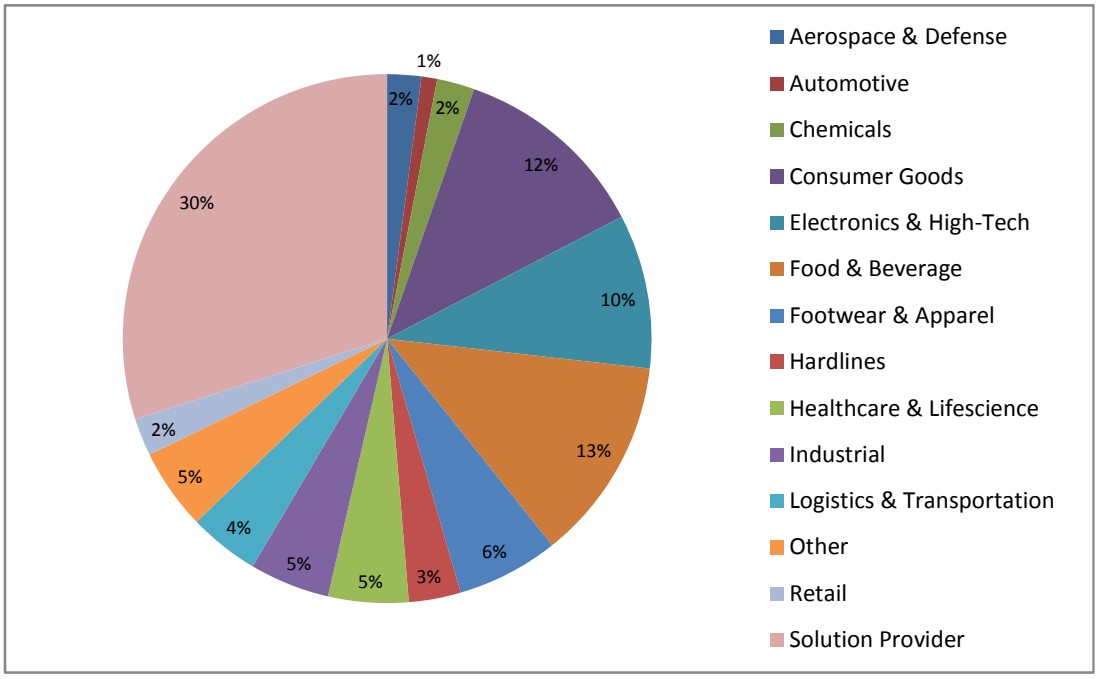

Figure 8: EPC subscribers by industry (January 2008)

Most EPCglobal subscribing companies are US based (58%) followed by European (22%) and Asian-Pacific (17%) based companies. Industries from Middle East and Africa as well as Latin America are represented with 1% resp. 2% of all EPC subscribers (Figure 9). The reason for this situation does not base on the fact that the underrepresented regions do not have any companies that want or already use RFID/EPC, but EPCglobal gradually escalates the sales and distribution activities from region to region. Furthermore, merely the headquarter of a company has to become a member to use the EPC worldwide in all of its subsidiaries e.g. in Latin America.

[1] Calculations based on original data provided by courtesy of EPCglobal Inc.

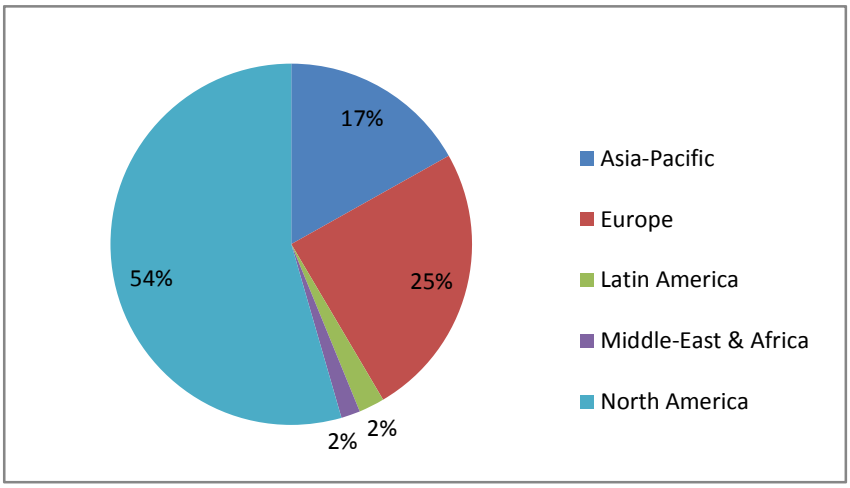

Figure 9: EPC subscriber by region (January 2008)

Figure 10 shows the overall development of the number of EPCglobal subscribing companies from 2004 to 2008.

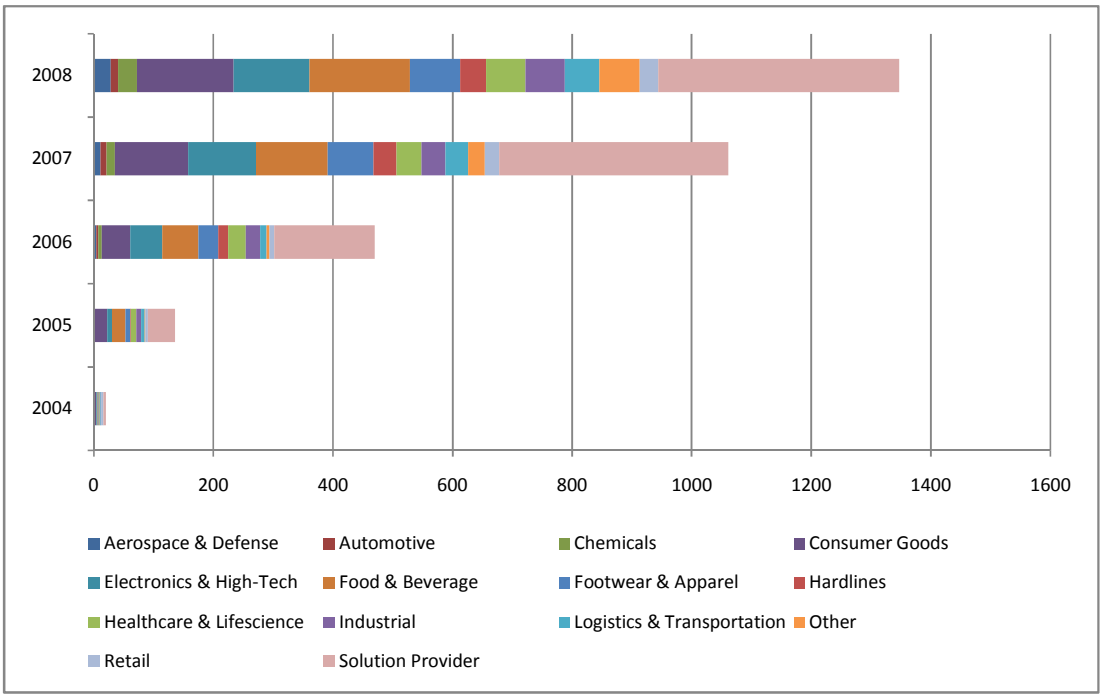

Figure 10: Development of EPCglobal subscribers 2004-2008

In contrast to EPCglobal standards, ISO's RFID standards are defined on a very generic level, focusing predominantly on the air interface. ISO standards cover the areas of technology, data content, conformance and performance, and application standards. Therefore, ISO RFID standards can generally be considered as more application-independent with regard to processes and industry-specific context. Table 3 lists various ISO RFID standards as an example, Table 4 gives an overview of the existing EPCglobal specifications and standards.

Name	Content/Application	Status
Animal Identification		
ISO/IEC 11784 ISO/IEC 11785 ISO/IEC 14223	Animal Identification	published
Contactless Chipcards		
ISO/IEC 10536	Close coupling (bis 1 cm)	published
ISO/IEC 14443	Proximity coupling (bis 10 cm)	published
ISO/IEC 15693	Vicinity coupling (bis 1 m)	published
Merchandise Management		
Air Interface		
ISO/IEC 18000-1:2004	Reference Architecture for 18000-Standard Series	published
ISO/IES 18000-2:2004	under 135 kHz	published
ISO/IEC 18000-3:2004	13,56 MHz	published
ISO/IEC 18000-4:2004	2,45 GHz	published
ISO/IEC 18000-4:2004	5,8 GHz	recalled
ISO/IEC 18000-6:2004	860-960 MHz	published
ISO/IEC 18000-6:2004/ Amendment 1:2006 (Type C)	860-960 MHz	published
ISO/IEC 18000-7:2004	433 MHz	published
Data Protocol		
ISO/IEC 15961:2004	Application Interface	published
ISO/IEC 15962:2004	Transponder Interface	published
ISO/IEC 15963:2004	Unique Identification Transponder	published
Application Interface		
ISO 17358	Application Requirements	in progress
ISO 17363	Freight Containers	in progress
ISO 17364	Reusable Shipping Units	in progress
ISO 17365	Shipping Units	in progress
ISO 17366	Product Packaging	in progress
ISO 17367	Product Identification	in progress

Table 3: Overview of RFID ISO standards [14]

Specification	
Name	*Description*
900 MHz Class 0 Radio Frequency (RF) Identification Tag Specification	Defines the communication interface and protocol for Class 0 tags at 900 MHz
13.56 MHz ISM Band Class 1 Radio Frequency (RF) Identification Tag Interface Specification	Defines the communication interface and protocol for Class 1 tags at 13,56 MHz
860-930 MHz Class 1 Radio Frequency (RF) Identification Tag Radio Frequency & Logical Communication Interface Specification	Defines the communications interaface and protocol for Class 1 tags at 860-930 MHz
Conformance Requirements Specification for Class 1 Generation 2 UHF RFID	Specifies compliance for physical parameters and commands for Class 1 Generations 2 tags at 860-930 MHz
Standards	
Name	*Description*
Architectural Framework Document	Defines and describes the fundamental structure of the EPC network
EPC Tag Data Standard	Defines the standardization of EPC tag data
EPC Tag Data Translation Standard	Deals with a machine-readable version of the EPC Tag Data Standards
Class 1 Generation 2 UHF Air Interface Protocol Standard	Defines the communication interface and protocol for Class 1 Generation 2 tags at 860-930 MHz
Reader Protocol (RP) Standard	Specifies the interactions between a RFID reader and application software
Reader Management (RM) Standard	Defines the wire protocol used by management software to monitor the operating status and health of EPCglobal compliant RFID readers
Application Level Events (ALE) Standard	Specifies an interface for the query of EPC data from various sources
Object Naming Service (ONS) Standard	Specifies the use of a Domain Name System to locate data associated with the SGTIN portion of an EPC
EPCglobal Certificate Profile Standard	Defines a special authenitication framework for the authentication of entities such as subscribers, services or physical devices

Table 4: Overview of EPC standards [20]

However, EPCglobal has submitted its standards to ISO for an additional approval aiming on conformity of both standards. The “EPC Class 1 Generation 2” (i.e. EPC Gen 2) standard for the UHF air interface corresponds to ISO’s 18000-6C standard. Earning the ISO certification was considered as a significant milestone by many researchers and practitioners toward a widespread adoption of RFID because it resolved hardware incompatibility issues and manufacturing capacity constraints [15].

Today, everybody agrees on the fact that RFID standards are available. Indeed there are a lot of them incompatible one with the other. At the radio level, two of them are emerging as the most relevant: 13.56 MHz ISO18000-3 and UHF (860-960MHz) ISO 18000-6 as they are almost adopted worldwide (in the sense that the same tag is readable in USA and in Europe as well). The first one allows for tags to be read from a distance of a few centimeters and thus is suitable for ePayments, eTicketing, and personal identification. The UHF tag can be read from a reader placed some meters away and this makes it suitable for logistics and supply chain applications.

After the RFID technology was hyped in recent years it became obvious that many issues are not resolved. The benefits of RFID over barcode technology for certain applications are undisputed but many requirements for a broad industrial use still have to be achieved.

Therefore, today and in the near future closed-loop systems will be the prevalent application until the premises for open-loop systems will be fulfilled. In this context, the term ‘closed-loop’ denotes a system with RFID transponders that are attached to an object and permanently remain on it while it is shipped or moved within a cycle and eventually returns to its point of origin. Typical examples for closed-loop systems are the (a) management of valuable assets, tools, and returnable containers or (b) inventory management where pallets or cases are equipped with a transponder for identification purposes. The main characteristic of an ’open-loop’ system is that the RFID transponder remains on an object and leaves the process or production site for a long period of time or without reuse for the same process. Examples are the tagging of specific parts, modules or vehicles for distribution, recall management, maintenance history, anti-counterfeiting, or recycling purposes.

While it seems to be clear that the UHF frequency band will be the predominantly used for industrial RFID supply chain applications some countries have not approved the corresponding frequencies until today. Additionally, country specific regulations regarding maximum power emissions of RFID systems exist as well as competing standardization concepts. Nevertheless, the increasing number of EPC subscribers especially from the retail, consumer goods, and food and beverage sector is obvious.

All the before mentioned factors respectively barriers, forecasts as well as the ongoing standardization accelerate or decelerate the widespread adoption and diffusion of the RFID technology and will therefore have an influence on the economic impact of RFID. The next paragraph will give a short introduction to the theory and backgrounds of adoption and diffusion as well as of economic impacts.

3 Theory and Backgrounds

The adoption and diffusion of a new technology is the first prerequisite for the emergence of measurable economic impacts [13]. Therefore, before analyzing the economic impact of RFID itself, an introduction to the theoretical background of the adoption and diffusion of innovations and the most important factors is given and the status quo of the adoption and diffusion is described. Afterwards, some basic macroeconomic concepts are shortly summarized.

3.1 Adoption and Diffusion of new Technologies

Over the last 20 years, quite a rich but also diverse body of theoretical and empirical work on the adoption and diffusion of innovations has been conducted. Management research has developed various theories whose explanatory power was tested empirically by many qualitative and quantitative studies. Especially network technologies, e.g. Information Technologies (IT), Information Systems (IS) or Information and Communication Technologies (IT) to which RFID belongs are frequently analyzed.

Diffusion theories model how innovations or new technologies spread within and between organizations. Rogers’ “Diffusion of Innovations” [1] provides well-developed concepts and a large amount of empirical results which are useful for the study of technology evaluation,

adoption and implementation. It provides qualitative as well as quantitative tools for assessing the rate of diffusion of an innovation or new technology and to identify factors that accelerate or impede technology adoption and diffusion. Another widely applied and very popular model is the Technology Adoption Model (TAM) developed by Davis [30] which is based on the theory of reasoned action by Fishbein and Ajzen [31] and its variants. Therefore, it is not surprising that innovation diffusion has become a very popular reference theory for current research of information and communication technologies.

The same is true for the research of the adoption and diffusion of IT/IS respectively RFID technology. Many researchers already began to study and analyze the developments and coherences. For example, Fichman [2] analyzes numerous studies of information technology diffusion and focuses on relevant factors for the adoption of information technology. Researchers usually consider two different aspects of adoption: (a) the characteristics of a given technology and the consequences for adoption and diffusion process, and (b) the locus of adoption, i.e. adoption on an individual or an organizational level. In more recent studies both organizational and individual adoption decisions are analyzed because usually many individuals are involved in the adoption decision. Additionally, the environment of an organization is observed, i.e. external influences on the adoption and diffusion process by an individual or an organization [29]. Table 5 gives an overview of different theories, models, and frameworks researchers use to analyze the diffusion of innovations.

Theory	Main author(s)	Adoption level	
		individ.	org.
Innovation Diffusion Theory	Rogers (1983, 1995, 2003)	x	x
Perceived Characteristics of Innovation	Moore/Benbasat (1991)	x	
Social Cognitive Theory	Bandurra (1986)	x	
Technology Acceptance Model	Davis (1989)	x	
Technology Acceptance Model II	Venkatesh et al. (2003)	x	
Theory of Planned Behaviour	Ajzen (1991)	x	
Theory of Reasoned Action	Fishbein/Ajzen (1975)	x	
Unified Theory of Acceptance and Use of Technology	Venkatesh et al. (2003)	x	
Diffusion/Implementation Model	Kwon/Zmud (1987)		x
Tri-Core Model	Swanson (1994)		x
Technology-Organization-Environment (TOE) Framework	Tornatzky/Fleischer (1990)		x

Table 5: Theories, models, and frameworks of adoption research (based on [3])

Rogers [1] introduces five factors which accelerate or slow down the adoption and diffusion of innovations:

- Relative advantage
- Complexity
- Trialability
- Observeability
- Compatibility

Relative advantage expresses the degree to which a new technology or innovation is perceived as being superior to the currently used. The degree of relative advantage is often described as economic profitability (e.g. by reducing costs), as conveying social prestige

(e.g. status seeking/motivation), or in other ways. The higher the relative advantage of an innovation is perceived by members of a social system, the more likely is its adoption. The complexity of an innovation is the degree to which it is perceived as relatively difficult to understand, to implement in an existing infrastructure, and to use. The complexity of an innovation, as perceived by members of a social system, is negatively related to its rate of adoption. Trialability is the degree to which an innovation and especially a new technology may be experimented with on a limited basis. For example, RFID pilot studies provide first experiences if the technology is able to work under a company's conditions and in a certain environment. The trialability of an innovation, as perceived by the members of a social system, is as well positively related to its rate of adoption. Observability is the degree to which the results or increases in efficiency of an innovation are visible to others. For example, a decrease of stock-outs is more visible than an improvement of a single piece of hardware of a computer system. Therefore, the observeability of an innovation, as perceived by the members of a social system, is positively related to its rate of adoption. Compatibility is the degree to which an innovation is experienced as consistent with the needs, past experiences, and existing values of potential adopters. Additionally, compatibility describes the fit and ease of integration of a technology into an existing (IT) infrastructure and is consequently positively related to the rate of adoption [1].

Many adoption studies based on Rogers' findings expand and detail the catalog of factors. Because his research is predominantly based on findings in social communities and early industrialization in the farming sector, there was the need to include factors that accelerate the adoption of new technologies and experiences of today's innovations. Table 6 gives an overview of recent RFID adoption studies in various fields of interest and their results, respectively the identified adoption factors.

Author(s)	Year	Results/Adoption Factors
Sharma et al.	2007	- Perceived benefits - Dominant supply chain partner - Perceived costs - IP and standard development - "Diffusions-Champion" - Top Management Support
Seymour et al.	2007	- Costs - Perceived benefits - Complexity - Performance - Top Management Support - Compatibility - Organizational readiness - Organization size - Fear of change - Skills and education - External pressure/competition - Competitive advantage - Standards
Brown & Russel	2007	- Perceived benefits - Costs - Standards - Compatibility - Complexity - Top Management Support - Organization size - Competition

Whitaker et al.	2007	- Firms with broad IT applications are more likely to adopt RFID - RFID adoption is not strictly determined by the sheer amount of financial resources - RFID implementation spending is positively associated with expectation of an early return on RFID investment - Lack of industry-wide standards delay the return on RFID investments
Wu et al.	2006	- Technological problems have to be solved in the near future - Adoption is hindered by costs for tags, infrastructure, and operations - Companies should implement closed-loop systems first to gain experiences
Riggins & Slaughter	2006	Convergent mental models - Foster adoption - Lead to social optimal solutions - Impede innovative applications of new technologies
Lee	2006	- Perceived benefits - Competition - Lack in efficiency - Market uncertainties - Diffusions-Champion - Financial resources - Technological Know-how - Organization size
Vijayaraman & Osyk	2006	- Costs - Perceived benefits - Compatibility - Complexity - Standards - Customer demand - Organization size - Security/Privacy
Yang & Jarvenpaa	2005	- Trust fosters the adoption of RFID - The smaller the analyzed groups were the higher the trust were between them

Table 6: Selected overview of recent RFID adoption studies and relevant factors [4]-[12]

Most mentioned factors responsible for fostering the adoption and diffusion of RFID are thereof:

- Perceived benefits
- Costs
- Compatibility
- Complexity
- Top Management Support
- Standards
- Organizational size

Thus, companies will only adopt if they are convinced that a new technology like RFID will generate noticeable benefits for their business (apart from the fact of being forced to implement by a so-called RFID-Mandate). Further, costs will always play a major role regarding RFID adoption, and therefore, the price developments on the RFID market will be critically observed. Additionally, the costs of an implementation will have a significant influence on the depth of RFID integration. In the end, required investments decide if there will be a complete system and infrastructure integration or a so-called “slap and ship” solution where RFID transponders will just be attached to the shipments after packaging e.g. to fulfil customer requirements. Another precondition for the adoption are the before mentioned factors of compatibility and complexity. Especially for cross-sectional technologies like RFID with significant potentials of being strategically important for a company it is absolutely necessary to be assured of the support of the top management. Another very critical factor is the progress in standardization (see previous chapter). While many

industries/supply chain leaders did not come to a final decision to use a specific standard (e.g. the EPC) dependent companies or suppliers rest in a wait and see position and do not adopt RFID. The availability of standards influences the rate of adoption significantly because standards reduce the integration risk of multiple technological solutions implemented in a supply chain [32]. Last but not least, organizational size is another important factor. Bigger companies are usually willing and able to invest a certain amount of money to analyze new technologies and conduct pilot studies compared to smaller companies.

These (and many more) factors influence the decision whether an organization will adopt or will not adopt a new technology respectively RFID. The adoption and diffusion of the technology in turn will have effects on the economy. These effects or impacts on the economy are subjects to macroeconomic concepts and circulation processes which basics will be exemplary described in the next paragraph.

3.2 Basic Macroeconomic Concepts

The macroeconomic theory analyzes the prosperity, structure, and actions within national economies as a whole. Thereby, researchers study both the short-term fluctuations in national income (i.e. the business cycle) and the determinants of long-term economic growth (i.e. increases in national income). In macroeconomics two sources of growth are differentiated: The first is extensive growth, which is the growth in the factors of production. These factors are land (i.e. all natural resources), labor (i.e. human efforts) and capital (i.e. investment in products and equipment). The second type of growth is intensive growth, which is the increase in output given the factors of production due to technological improvements, increase in production efficiency and high quality factors. The difference between these types of growth is that extensive growth is believed as finite while intensive growth is assumed as infinite [34]. Both types of growth will be relevant when analyzing the economic impact of RFID.

Figure 11 shows a basic model of circulation processes in economy which explains the elementary coherences. For example: In the long-term an increase in the consumption of households will lead to an increase of the yield/profit of the corporations. As a result, corporations will demand more labor respectively wages will increase because of the higher demand for employees. Further effects will be decreasing in prices and a lower inflation.

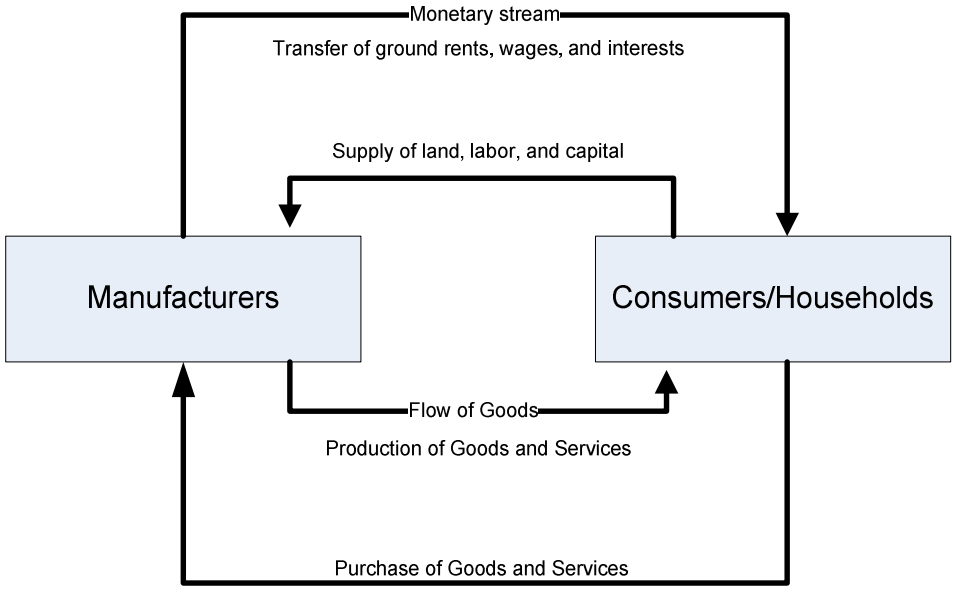

Figure 11: Basic economic cycle (adapted from [51])

For a deepened and detailed introduction to macroeconomic theory it is recommended to study the work of e.g. Mankiw [36] or Blanchard [35]. IT as well as RFID impacts on both intensive and extensive growth. The next chapter will describe these impacts in a more detailed analysis.

4 Economic Impact of RFID

Innovations and the adoption of new technologies have led to productivity improvements that generate stronger economic growth and higher standards of living. The impact of IT-enabled (RFID-enabled) supply chains should therefore not be overlooked. New IT-technologies have evolved taking supply chain operation systems from simple production and planning systems to today's real-time performance-management information systems – a transformation of supply chain operations from mass production to mass customization, where information replaces inventory. Companies become able to make better decisions as information flow can be separated from the product flow, thereby enabling enhanced real-time analysis of business conditions [33].

Previous studies found evidence that the impact of IT-technologies on supply chains have resulted in an improvement in operational and financial performance by enabling organizational capabilities and coordination with business partners. Moreover, IT has significantly reduced the cost of sharing information, enhanced real-time information sharing, coordination, and decision making among firms [40]. Results are a decreased "bullwhip effect", lower inventories, a reduction of logistics costs, and more efficient procurement processes. These advancements, in turn, influenced the reduction of inflation, reduced economic volatility, strengthened productivity growth, and improved standards of living [33].

In the following the economic impacts of Information Technology (IT) will be summarized and clarified with some examples. On this foundation, the presumable economic impacts of the RFID technology are derived and explained.

4.1 Lessons learned from Information Technology

The focus of this section is on the economic impact of Information Technology (IT). Most economic growth studies dealing with IT, point out three effects IT has on both the extensive growth and the intensive growth [13]:

1. IT is an asset and therefore investments will deepen overall capital in the economy. Furthermore, the increase in IT will foster labor productivity.
2. Technological progress in the production of IT and related services itself will lead to a higher productivity growth in the IT-producing industry.
3. Companies using more IT will increase their overall efficiency and thus generate growth by themselves. Additionally, a greater use of IT in the industry will develop and enhance infrastructure and networks, and therefore contribute to network effects (e.g. lower transaction costs) which will improve the overall efficiency of the economy.

Capital respectively investments are the most important measures for economic growth. Regarding IT, capital is a prerequisite for the needed hardware and software to apply IT in the supply chain as well as the establishment of the needed infrastructure (i.e. networks) and therefore a powerful driver of growth. Today, economists agree that the lion's share of the productivity growth since 1995 is due to the IT revolution. The impact of IT investments seemed to have an impact three to five times that of non-IT capital (e.g. machines) in the key areas productivity, employment, more efficient markets, higher quality goods and services, innovation, and new products [13][39].

In 2001 the IT investments in the OECD countries rose from less than 15% of total non-residential investments in the 1980s to between 15-30%. At the same time an increase in labor productivity and GDP could be traced back to IT investments and was estimated about 0.3-0.8%. Countries like the USA, Canada, and Japan received the greatest effects of these developments while the European countries fall short in comparison because of their lower investments. Furthermore, studies for the USA show that labor productivity in manufacturing plants with IT-networks is about 5% higher than in plants without IT-networks (productivity measure is based on gross output). The same is true for Japan, were studies were conducted regarding the use of intra-firm and inter-firm networks, using the Internet, CAD/CAM technologies, and especially Electronic Data Interchange (EDI)[13][39].

For an economy it can be very important to already have or to establish IT-producing industry. The IT producing sector is characterized by rapid technological progress and a very strong demand and is therefore very important for the economic growth of a country. From 1995 until 2001 countries like Finland, Ireland or Korea were able to generate about 1% of aggregate labor productivity growth due to the IT sector. The same is true (on a lower level) for the USA, Japan and Sweden. Furthermore, the contribution of the IT-producing services

sector (telecommunications and computers services) increased significantly in some countries over the 1990s and is partly linked to the availability of IT networks [13].

On company level IT has three separate but complementary effects on business processes. The term 'business process' includes in this context both operational processes (e.g. production processes, product/service delivery processes, design and development etc.), and management processes (e.g. coordination processes, information handling processes, control and communication processes etc.). The first effect results from automation and the possibility to substitute manual labor by using IT. Value derives predominately from productivity improvements, labor savings, and cost reductions. The second effect emerges due to informational effects of information technology and the ability to collect, store, process, and disseminate information. Business value is generated by improved decision quality, employee empowerment, decreased use of resources, enhanced organizational effectiveness, and better quality. Third, transformational effects are generated due to the ability of IT to facilitate and support process innovation and transformation, recognizable through reduced cycle times, improved responsiveness, downsizing, and service and product enhancement [50].

Figure 12 shows the economic developments and dependences regarding the adoption and diffusion of IT and their impacts on the economy. IT will help to make supply chains more flexible regarding reacting to new demands, market fluctuations and other requirements. Therefore, downturns in economy will not have such dramatic impacts. Increasing supply chain flexibility due to IT deployment will have as well positive effects on job opportunities within companies which will result in additional jobs in the long-term. As stated before, IT will help to make supply chain processes more efficient, provides more and better information for decision makers and supports the manufacturing and development of high quality products and new services. All together, these effects will result in a higher and faster overall productivity growth. An increasing productivity will result in lower prices, higher wages, increasing economic competitiveness, and a lower inflation. Furthermore, IT provides the possibility to get access to new, larger and more efficient markets which results again in an increase of productivity, new and innovative products and new services which development is additionally supported by new IT-search tools. Overall, the effects of IT will result in a higher per-capita income and an increase of the GDP which both results in higher tax revenues for the government.

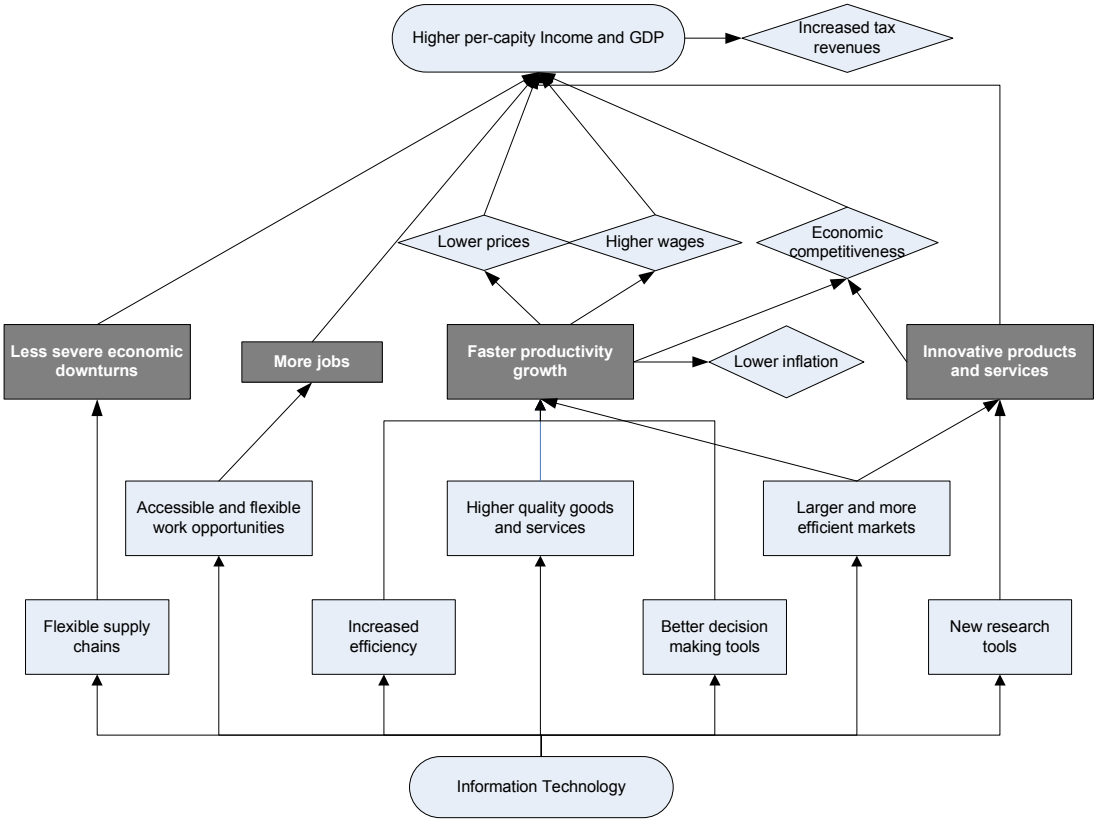

Figure 12: Path from IT to prosperity [39]

4.2 Deriving the Economic Impact of RFID

Radio Frequency Identification technology is a cross-cutting and enabling technology and is considered to be the next wave of the IT revolution. In the same way like IT, RFID will foster innovation, economic growth, and global commerce. However, RFID technology is still in its early stage of deployment. Researchers agree that the adoption and diffusion of RFID is not even completely understood or explained, as described in chapter 3 [41][42][45].

It is almost impossible to obtain systematic and reliable data to analyze the economic impact of RFID. For example, a study from 2005 finds that RFID related spending represents round about 9% of the companies' IT-budgets, the spending for 2006 is predicted with 16% and another 20% by 2007 [40]. Other reports analyze case studies and extrapolate the findings, e.g. if a single company in the retail sector is able to lower its inventory by 15% due to RFID, inventory holding costs that are generally accepted in that specific industry (e.g. 35%) are used to analyze the economic impact in its entirety [38]. Yet another studies forecast volumes of transponders to be sold until 2022 which is not even more reliable or supported by any plausible data [23]. Therefore, we will limit our analysis to qualitative factors and derive the economic impact of RFID from the findings of the economic impact of IT. Nevertheless, we will provide examples in order to give an idea of the potential of RFID.

In the field of RFID technology there is a huge amount of scientific literature, case studies, best practices etc. These publications especially emphasize the ability of RFID to expand information sharing between supply chain partners, to empower networked communities and to increase transparency due to an increase of sensing and tracking capabilities. Hence, there are numerous examples of possible RFID applications [37][43]:

- Identification of Individuals
- Track and Trace
- Process control
- Container management
- Inventory management
- Warehouse management
- Spare part management
- Asset management
- Anticounterfeiting
- Product life-cycle management
- Call backs/product recall
- Aftersales and services
- Mobile payment processes

The usually mentioned advantages of the RFID technology are also manifold, e.g.:

- Improved accuracy
- Improved security of data
- Improved operations efficiency
- Improved competitive advantage
- Improvements in process management and cycle times
- Greater integration of automated systems
- Reduced stock-outs
- Reduced inventory levels
- Reduced error rates
- Reduced data keying
- Overhead cost reduction
- Reduced inventory costs
- Improved customer service
- Faster response to orders

The economic impacts of RFID base on three general assumptions:

1. Because RFID is new in many processes it is easy to achieve efficiency improvements in a short time (e.g. by elimination of manual scanning processes, automatic inventory etc.).
2. RFID offers the opportunity to completely redesign processes and not only to enhance single tasks and therefore gaining greater efficiency improvements.
3. By adding/connecting additional users to a network, RFID will help to generate greater network externalities.

In the following the impacts on the main determinants of the economy - productivity, employment, markets, goods and services, and innovation and new products - will be described.

Productivity

Productivity is the most important determinant for the economic performance and competitiveness of a country. This determinant is even more important when competing with low-wage countries. Information technology respectively RFID is a trigger for process innovation which is in turn an accelerator for an increase in productivity. Studies show, that the productivity of IT-investing companies is significantly higher. For example, the use of computer networks raised the productivity in analyzed manufacturing plants by roughly 7.5% [39][45].

For the growth of productivity there are two main measures, labor productivity and total factor productivity: Labor productivity is defined as the output a worker is able to generate in a particular unit of work/time. Factor productivity is a measure for higher efficiency of production due to new technologies or a better education or training of a worker [39].

The deployment of RFID technology effects both labor productivity and factor productivity: At present, in the manufacturing industry RFID is predominantly used in closed-loop processes (internal or with one or more supply chain partners), on high value items, and/or returnable items (carriers, containers etc.). This situation will also remain for the next years [23]. The individual worker gains a higher productivity by increasing the efficiency of tasks of his/her work, e.g. by eliminating manual scanning processes or the needlessness of separating non-single-origin pallets due to automatic identification with RFID. Because of more information, a higher transparency in processes and in the supply chain better organizational decisions can be made. As a result the factor productivity can be increased as well, e.g. through better allocation planning of reusable containers, the elimination of process-bottlenecks, and finally a reduction of the total number of containers (decrease of fixed capital) [47].

The availability of information can be significantly increased with RFID and in most cases the data is of a higher degree of granularity and quality compared to alternative methods. Expanding RFID data-sharing between supply chain partners will additionally contribute to an increasing efficiency of all supply chain processes. For example, production and inventory concepts like Just-in-Time (JIT) or Just-in-Sequence (JIS) will significantly benefit from RFID real-time information.

Employment

While the public's attention and most studies focus on technological issues, privacy, and security concerns the impact of RFID on employment is mostly ignored. However, job losses due to the adoption of RFID will be noticeable. The substitution of manual labor due to automatic identification by RFID will reduce the demand for this type of work and will therefore motivate companies to reduce their labor force over time. Additionally, in the short term, managements could be tempted to lay off employees, in order to show significant measurable results of their RFID projects. This scenario seems to be even more likely because of the difficulty to calculate a business case or a positive ROI of many RFID projects at present. In the long term, it is expected to be a gradual development over at least 10 years whereby the loss of jobs is not expected to result in a disruption of the labor market [43].

On the other hand, the adoption and diffusion of RFID will create new jobs as well: Companies deploying RFID will demand for more qualified labor to install and to manage these systems. Employees will need new skills to work with the implemented RFID systems. The emphasis will be on information processing that is generated at different sources, tools, and applications. The increase in productivity and the resulting growth due to the use of RFID will also generate new jobs in various departments. Additionally, the RFID-industry (hardware, software, and solution provider) employs itself and the increasing production will generate more jobs. The same is true for the entire economy because of spill-over effects to other industries probably not using RFID themselves but profiting from the RFID induced growth [39][43].

Markets

Companies are highly depending on IT because it offers the possibility to reach other than their local market and to offer their products and services on a national or global scale. Without IT business would be much more difficult. IT significantly reduced the costs of communication and the amount of time until information or data is available. Faster availability of information means that companies are able to rearrange input, labor, and capital depending on market developments. As mentioned before, IT helps to increase productivity and therefore the competitiveness especially but not only in comparison to low-wage countries. Thereby the entrance barriers to other markets are much lower. For example, innovators or manufacturers of niche products are able to find customers or investors more easily and inexpensively on a global market due to IT. The same is true for markets or economies as well: Studies show that underdeveloped regions with access to the internet or other communication technology had a 15% higher income than regions without access to these technologies and therefore no access to the worldwide markets [39].

RFID with the ability to increase the transparency of the supply chain by new sensing and tracking capabilities will further support these qualities. In the same way, IT helps to allocate goods more efficiently due to a greater (worldwide) market RFID will increase the efficiency of distributing, track and trace, and monitoring of these goods. It will be easier and more secure for companies to expand their supplier network throughout the world because they are able to monitor shipments everywhere and every time [48]. A worldwide standardized accessible network like the EPCIS is an important prerequisite for those applications.

Very important in this context is the possibility to deploy RFID and the EPC network for anticounterfeiting purposes. This application will provide companies the opportunity to guarantee their costumers original, high quality products and to protect themselves and supply chain partners against financial losses due to counterfeits [47][48].

RFID will additionally help to make markets more transparent and efficient for customers by expanding consumer information. Consumers need information to make their best possible choice/buying decision, e.g. with additional data (e.g. allergy information) stored on a RFID transponder attached to the product, accessible with a mobile device (e.g. mobile phone) [49].

Goods and Services

Most of the benefits respectively improvements due to the deployment of IT flow to customers in the form of lower prices, higher quality products, and better services. Information technology helps to increase the quality of products in two ways: Because IT helps customers to get more information about products companies have a greater incentive to enhance the quality of their products and services. Additionally, companies become able to develop much more customized products and services because they have a better idea of the demands of their customers [39].

Especially the quality and authenticity of products will benefit from the use of RFID with the ability to track and trace goods or to monitor e.g. the cold chain of perishable goods in combination with sensors. For example, the Auto-ID Lab St.Gallen/Zurich developed a simulation that impressively shows the effects of a RFID/sensor-managed cold chain on the quality of perishable goods. Evidently, the rate of defective products could significantly be reduced.

Further supply chain applications would be imaginable regarding spare parts management, life-cycle management, and the aftersales and service business. Additionally, new services, e.g. in fashion stores (see Galeria Kaufhof RFID implementation[2]) where customers get additional, interactive information on displays or 'mirrors' regarding garments, available sizes, colors, or matching accessories could be implemented (for a detailed analysis of RFID in the textile industry see [52]). Other examples are new business models or (mobile) payment models based on RFID technology, e.g. PayPass®, 'pay-per-use' or 'pay-as-you-drive', which is especially interesting for insurance companies [46][47][48][49].

In this context the protection and security of data and personal privacy in customer-oriented applications supported by RFID is especially in Europe constantly discussed. The European Commission (EC) is working on a recommendation regarding a 'RFID Privacy Policy'. The EC published a draft of this privacy policy and asked industry stakeholders and the general public for comments: EPCglobal and retailers criticize that some regulations are unclear or not detailed enough. For example, the possibility that retailers would have been obligated to deactivate RFID transponders at the point-of-sale would probably be a show-stopper for many RFID applications regarding aftersales and service and would therefore have a significant influence on the economic impact of RFID [53]. Furthermore, made insecure and doubtful customers regarding the protection of their privacy could limit the long-term benefits and the development of RFID applications [22].

Innovation and new Products

In the European Union 50% of the reported product innovations and 75% of the process innovations were enabled due to the use of Information Technology. RFID and the 'Internet of Things' offers a huge potential of new ideas for innovations, new products, and new businesses. Examples are: (Mobile) payment systems, anticounterfeiting solutions, sensor-networks, improved patient monitoring in hospitals, or automated check-out in retail stores

[2] http://www.rfidjournal.com/article/articleview/3624/

and especially innovations labeled as 'smart product'. RFID makes it possible to integrate these smart products/physical objects with an identifier directly into the digital world which offers an enormous potential for new and innovative concepts [39][44][47][48][49].

Figure 13 shows the before described economic impacts of the RFID technology and the resulting effects/developments in an overview.

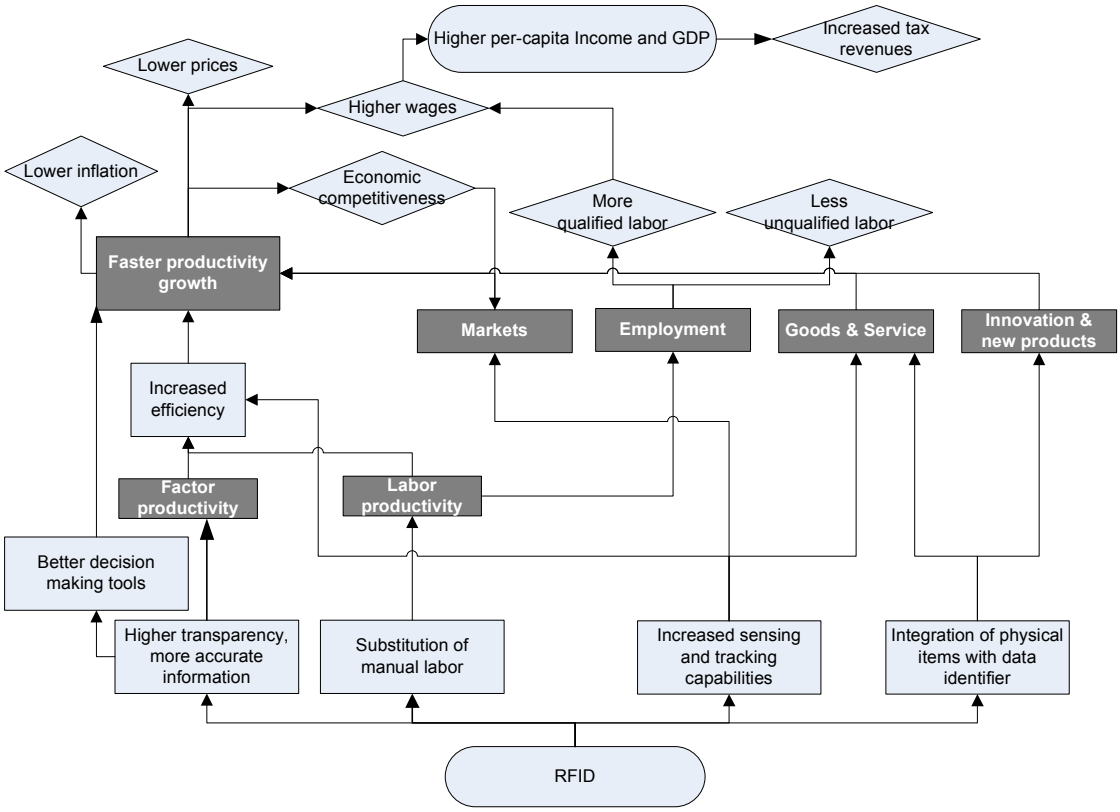

Figure 13: Economic impact and developments due to the use of RFID

5 Discussion

RFID will lead to improvements of the operational and financial performance of companies by enabling organizational capabilities and coordination with supply chain partners. Additionally, RFID will significantly reduce the costs of sharing information, enhance real-time information sharing, coordination, and decision making among business partners.

Our analyses show that the biggest economic impacts of the RFID technology result from more and better information in the whole supply chain which leads to an increase in efficiency and the ability to eliminate manual handling processes. Further economic impacts result from the influence of the adoption and diffusion of RFID on the employment, markets, goods and services, and innovations and new products.

Of course, RFID reduces the cost of collecting data at the front end but if a company is not able to analyze this information and to draw the correct conclusions from the results there will be no real advantage of using RFID technology. It is important especially for Europe to take

the chances RFID technology offers. While Europe is operating on a world wide market the average wage is higher compared to important upcoming new markets like China. Therefore, Europe has to compete and win with a higher productivity and higher quality products. Additionally, regarding RFID, other countries (particularly the USA) are already one step ahead of Europe - as they were with the adoption and diffusion, and the investments in IT years before - and are now reaping the fruits of these early decisive moves.

RFID data could be available immediately through the EPC network for all supply chain partners. As a result information asymmetries could be reduced and therefore transaction costs as well. Additionally, it is no longer necessary to actively transfer data in a complex and time-consuming process (data-push). Once transponders are read, authorized supply chain partners are able to gather their needed data from the EPC network actively (data-pull). Nevertheless, because RFID normally uses already existing infrastructure in companies or in a supply chain, it has to be admitted that the economic impacts of RFID will not be that significant compared to the emergence of IT years before – at least in this early stage of adoption.

Many companies use RFID because they are mandated to which is especially true for suppliers. Those often deploy so called 'slap-and-ship' processes. Such rudimentary integration of RFID will not result in an increase of efficiency and productivity - to the contrary it possibly will lead to higher efforts. The supplier will bear the costs and in contrast to that the mandating customer will generate the benefits of the use of RFID. Clear cost/benefit sharing models have to be put in place.

6 Conclusion

The status quo of the adoption and diffusion of the RFID technology is not that far advanced as many forecasts and market studies try to suggest. However, some important factors influencing the adoption and diffusion of RFID are well-known: Perceived benefits, costs, compatibility, complexity, Top Management Support, standards, and the size of an organization. Nevertheless, it is very difficult, rather impossible, to present reliable data for the measurement and the analysis of the economic impact of RFID. Because RFID belongs to Information Technology which is mature and extensively explored, we are able to derive qualitative findings regarding the economic impact of the deployment and use of RFID.

We argument substantially that RFID will have significant impacts on the economy as well as on the operational and financial performance of companies in the focus areas productivity, employment, markets, goods and services, and innovations and new products. RFID will especially generate significant impacts in applications with a unique selling proposition, e.g. anticounterfeiting, secure supply chains, and cold chain and quality monitoring as well as better information for decision makers.

The most important measure is capital respectively the investments in RFID technology. However, it seems to be too early to be able to quantify the economic impacts of today's RFID investments.

We were able to transfer our results into a reason-effect structure (Figure 13) which is derived from the knowledge of the economic impact of IT (Figure 12). This network will help to further analyze the economic impact of RFID in the future.

References

[1] Rogers, E.M. (2003). Diffusion of Innovations. The Free Press, New York.

[2] Fichman, R.G. (1992). Information technology diffusion: A review of empirical research. Thirteenth International Conference on Information Systems, Dallas, pp. 195-206.

[3] Jeyaraj, A.; Rottman, J.W.; Lacity, M.C. (2006). A review of the predITors, linkages, and biases in IT innovation adoption research. Journal of Information Technology, 21, pp. 1-23.

[4] Sharma, A.; Citurs, A.; Konsynski, B. (2007). Strategic and Institutional Perspectives in the Adoption and Early Integration of Radio Frequency Identification (RFID). Proceedings of the 40th Hawaii International Conference on System Sciences (HICSS'07), Hawaii.

[5] Seymour, L.; Lambert-Porter, E.; Willuweit, L. (2007). RFID Adoption into the Container Supply Chain: Proposing a framework. Proceedings of the 6th Annual ISOnEworld Conference, Las Vegas. www.information-quarterly.org/ISOWProc/2007ISOWCD/PDFs/55.pdf, Last visit: 27.08.2007.

[6] Brown, I.; Russel, J. (2007). Radio frequency identification technology: An exploratory study on adoption in the South African retail sector. International Journal of Information Management, 27 (4), pp. 250-265.

[7] Whitaker, J.; Mithas, S.; Krishnan, M.S. (2007): A Field Study of RFID Deployment and Return Expectations. Forthcoming in: Production and Operations Management.

[8] Wu, N.C.; Nystrom, M.A.; Lin, T.R.; Yu, H.C. (2006). Challenges to global RFID adoption. Technovation 26, pp. 1317-1323.

[9] Riggins, F.J.; Slaugther, K.T. (2006). The Role of Collective Mental Models in IOS Adoption: Opening the Black Box of Rationality in RFID Deployment. Proceedings of the 39th Hawaii International Conference on System Sciences (HICSS'06), Hawaii.

[10] Lee, C.-P. (2006). An empirical study of organizational ubiquitous computing technology adoption: The case of Radio Frequency Identification (RFID) in the healthcare industry. Dissertation, Mississippi State University, Mississippi.

[11] Vijayaraman, B.S.; Osyk, B.A. (2006). An empirical study of RFID implementation in the warehousing industry. The International Journal of Logistics Management, 17 (1), pp. 6-20.

[12] Yang, G.; Jarvenpaa, S.L. (2005): Trust and Radio Frequency Identification (RFID) Adoption within an Alliance. Proceedings of the 38th Hawaii International Conference on System Sciences (HICSS'05), Hawaii.

[13] OECD (2004): The Economic Impact of IT – Measurement, Evidence, and Implications. OECD Publications Service, Paris.

[14] Bovenschulte, M.; Gabriel, P.; Gaßner, K.; Seidel, U. (2007): RFID: Potenziale für Deutschland. Stand und Perspektiven von Anwendungen auf Basis der Radiofrequenz-Identifikation auf den nationalen und internationalen Märkten. Bundesministerium für Wirtschaft und Technologie, Berlin. www.bmwi.de, Last visit: 04.09.2007

[15] Tajima, M. (2007): Strategic Value of RFID in Supply Chain Management. Journal of Purchasing & Supply Chain Management, 13 (4), pp. 261-273.

[16] Sarma, S.; Brock, D.; Engels, D. (2001). Radio Frequency Identification and the Electronic Product Code. IEEE Micro, 21 (6), 50–54.

[17] Sarma, S. (2001). Towards the 5¢ Tag. Working Report, Auto-ID Center, MIT, Cambridge. www.autoidlabs.com/whitepapers/MIT-AUTOID-WH-006.pdf, Last visit: 14.02.2007.

[18] Sarma, S. (2005). A History of the EPC. In: Garfinkel, S.; Rosenberg, B. (eds.) (2005). RFID. 37–55, Addison-Wesley, Upper Saddle River.

[19] Fortune (2007): Fortune 500 - Annual ranking of America's largest corporations. Time Warner, New York. http://money.cnn.com/magazines/fortune/fortune500/2007/, Last visit: 31.08.2007.

[20] OECD (2007): RFID Implementation in Germany: Challenges and Benefits. OECD Publications Service, Paris. www.oecd.org/dataoecd/19/23/39693586.pdf, Last visit: 04.02.2008.

[21] Pigni, F. et al. (2006): A Guideline to RFID Applications in Supply Chains. REGINS-rfid (Project part financed by the EU). www.stuttgart.ihk24.de/produktmarken/innovation/Anlagen/Roadmap_Draft_v2.12_safe.pdf, Last visit: 10.09.2007.

[22] Lieshout, van. M., Grossi, L., Spinelli, G., Helmus, S., Kool, L., Pennings, L., Stap, R., Veugen, T., Waaij, van der B., Borean, C. (2007). RFID Technologies: Emerging Issues, Challenges and Policy Options. Institute for Prospective Technological Studies, European Commission, Luxembourg. www.jrc.es, Last visit: 21.07.2007.

[23] GS1 (2007). European passive RFID Market Sizing 2007-2022. Study within the EU Project "BRIDGE". www.bridge-project.eu/index.php/Publications/en/, Last visit: 20.06.2007.

[24] McGann, R. (2005). RFID market is to swell tenfold by 2009. ClickZStats. www.clickz.com/showPage.html?page=3460851, Last visit: 28.06.2007.

[25] IDTechEx (2007): IDTechEx RFID Forecasts, Players and Opportunities 2007-2017. Cambridge. www.idtechex.com/forecasts, Last visit: 04.09.2007.

[26] O'Connor, M.C. (2007): EPCglobal Developing HF Tag Standard. RFID Journal. www.rfidjournal.com/article/view/2320/1/1, Last visit: 06.09.2007.

[27] Gartner (2005): RFID Hype Cycle for Retail Technologies, Gartner, Inc., Stamford.

[28] Gartner (2007): RFID Hype Cycle for Retail Technologies, Gartner, Inc, Stamford.

[29] Brown, A.; Bakhru, A. (2007): Information Systems Innovation Research and the Case of RFID. In: McMaster, T.; Wastell, D.; Ferneley, E.; DeGross, J. (eds.): Organizational Dynamics of Technology-Based Innovation: Diversifying the Research Agenda. IFIP International Federation for Information Processing, Volume 235, pp. 363-376. Springer, Boston.

[30] Davis, F. (1989): Perceived usefulness, perceived ease of use interfaces, and user acceptance of Information Technology. MIS Quarterly, 13 (3), pp. 319-340.

[31] Fishbein, M.; Ajzen, J. (1975): Belief, Attitude, Intention and Behavior: An Introduction to Theory and Research. Addisson-Wesley, Reading.

[32] Huyskens, C., Loebbecke, C. (2007). RFID Adoption: Theoretical Concepts and their Practical Application in Fashion. In: McMaster, T.; Wastell, D.; Ferneley, E.; DeGross, J. (eds.): Organizational Dynamics of Technology-Based Innovation: Diversifying the Research Agenda. IFIP International Federation for Information Processing, Volume 235, pp. 345-361. Springer, Boston.

[33] Basu, A.; Siems, T.F. (2004): The Impact of E-Business Technologies on Supply Chain Operations: A Macroeconomic Perspective. Working Paper 0404, Federal Reserve Bank of Dallas, Research Department, Dallas, TX.

[34] Guimarães, L.C.R. (1997): Information Technology and its Social-Economic Impact in a Modern Society. Theory and Operation of a Modern Economy, The George Washington University, Minerva Program, Washington DC. www.gwu.edu/~ibi/minerva/Spring1997/Luciano.Guimaraes/Luciano.Guimaraes.html, Last visit: 15.01.2008

[35] Blanchard, O. (2003): Macroeconomics. Prentice Hall, Upper Saddle River.

[36] Mankiw, N.G. (1994): Makroeconomics. Worth Publishers, New York.

[37] Shinohara, T. (2003): Ubiquitous Network Vision for Growth. ITU Telecom 2003, Nomura Research Institute.

[38] Barua, A.; Mani, D.; Whinston, A.B. (2006): Assessing the Financial Impacts of RFID Technologies on the Retail and Healthcare Sectors. Center for Research in Electronic Commerce, Department of IROM, McComb School of Business, The University of Texas at Austin.

[39] Atkinson, R.D.; McKay, A.S. (2007): Digital Prosperity: Understanding the Economic Benefits of the Information Technology Revolution. The Information Technology and Innovation Foundation (ITIF), Washington.

[40] Whitaker, J.; Mithas, S.; Krishnan, M.S. (2007): A Field Study of RFID Deployment and Return Expectations. Production and Operations Management, 16 (5), pp. 599-612.

[41] Sharma, A.; Thomas, D.; Konsynski, B. (2008): Strategic and Institutional Perspectives in the Evaluation, Adoption and early Integration of Radio Frequency Identification (RFID): An Empirical Investigation of Current and Potential Adopters. Proceedings of the 41st Hawaii International Conference on System Sciences (HICSS'08), Hawaii.

[42] OECD (2006): Radio Frequency Identification (RFID): Drivers, Challenges and Public Policy Considerations. OECD Publications Service, Paris. www.oecd.org/dataoecd/57/43/36323191.pdf, Last visit: 04.02.2008.

[43] Lieshout, van. M.; Grossi, L.; Spinelli, G.; Helmus, S.; Kool, L.; Pennings, L.; Stap, R.; Veugen, T.; Waaij, van der B.; Borean, C. (2007): RFID Technologies: Emerging Issues, Challenges and Policy Options. Institute for Prospective Technological Studies, European Commission, Luxembourg. www.jrc.es, Last visit: 21.07.2007.

[44] International Telecommunication Union (ITU) (2005): The Internet of Things. Executive Summary. www.rfidconsultation.eu/docs/ficheiros/InternetofThings_summary.pdf. Last visit: 04.02.2008.

[45] Tzeng, S.-F.; Chen, W.-H.; Pai, F.-Y. (2007): Evaluating the business value of RFID: Evidence from five case studies. International Journal of Production Economics.

[46] Bohn, J.; Coroama, V.; Langheinrich, M.; Mattern, F.; Rohs, M. (2005): Social, Economic, and Ethical Implications of Ambient Intelligence and Ubiquitous Computing. In: Weber, W.; Rabaey, J.M.; Aarts, E. (eds.): Ambient Intelligence, pp. 5-29. Springer, Berlin.

[47] Fleisch, E.; Mattern, F. (Hrsg.) (2005): Das Internet der Dinge – Ubiquitous Computing und RFID in der Praxis. Springer, Berlin.

[48] Staake ,T.; Michahelles, F.; Fleisch, E.; Williams J.R.; Min, H.; Cole, P.H.; Lee, S-.G.; McFarlane, D.; Murai, J. (2007): Anti-Counterfeiting and Supply Chain Security. In: Cole, P.H.; Ranasinghe, D.C. (eds.): Networked RFID Systems and Lightweight Cryptography - Raising Barriers to Product Counterfeiting, pp. 33-44. Springer, Berlin.

[49] Wiechert, T.; Thiesse, F.; Michahelles, F.; Schmitt, P.; Fleisch, E. (2007): Connecting Mobile Phones to the Internet of Things: A Discussion of Compatibility Issues between EPC and NFC. Americas Conference on Information Systems (AMCIS). Keystone, USA.

[50] Mooney, J.G.; Gurbaxani, V.; Kraemer, K.L. (1996): A Process Oriented Framework for Assessing the Business Value of Information Technology. The DATA BASE for Advances in Information Systems, 27 (2), pp. 68-81.

[51] Fuchs, J. (2007): Die Volkswirtschaft. Verlag Fuchs, Rothenburg.

[52] BRIDGE Project (2007): Supply Chain Management in the European Textile Industry - Problem analysis and expected EPC/RFID benefits. Project funded by the EU. www.bridge-project.eu/index.php/workpackage7/en/, Last visit: 15.02.2008.

[53] O'Connor, M.C. (2008): EC Publishes RFID Privacy Policy Draft. RFID Journal. www.rfidjournal.com/article/view/3940/1/1/, Last visit: 07.04.2008.