UNLOCKING VALUE FROM MACHINES:

BUSINESS MODELS AND THE INDUSTRIAL INTERNET OF THINGS

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Abstract

In this article we argue that the Industrial Internet of Things (IIoT) offers new opportunities and harbors threats that companies are not able to address with existing business models. Entrepreneurship and Transaction Cost Theories are used to explore the conditions for designing nonownership business models for the emerging IIoT with its implications for sharing uncertain opportunities and downsides, and for transforming these uncertainties into business opportunities. Nonownership contracts are introduced as the basis for business model design and are proposed as an architecture for the productive sharing of uncertainties in IIoT manufacturing networks. The following three main types of IIoT-enabled business models were identified: (1) Provision of manufacturing assets, maintenance and repair, and their operation, (2) innovative information and analytical services that help manufacturing (e.g., based on artificial intelligence, big data, and analytics), and (3) new services targeted at end-users (e.g., offering efficient customization by integrating end-users into the manufacturing and supply chain ecosystem).

Keywords: Internet of Things, IIoT, Entrepreneurship Theory, Transaction Cost Theory, industrial services, business models, nonownership, uncertainty.

Introduction

Researchers and managers alike hold high expectations on the potential of the Industrial Internet of Things (IIoT). World-wide information infrastructures open-up inroads to make manufacturing more responsive to user-driven design and to align it better with customer value creation processes and contexts (Dholakia & Reyes, 2013, Parry, Brax, Maull, & Ng, 2016; Smith, Maull, & Ng, 2014; Porter & Heppelmann, 2014, 2015). At the same time, capturing value of IIoT adds uncertainty downsides, such as undermining privacy, increasing complexity of manufacturing systems, and drawing in new competitors (Britton, 2016; Dickenson, 2015; Geisberger & Broy, 2015; Malina, Hajny, Fujdiak, & Hosek, 2016). So far, businesses have had mixed experiences with industrial servitization strategies in general (Eggert, Hogreve, Ulaga, & Münkhoff, 2014; Wirtz, Tuzovic, & Ehret 2015), and with exploiting the potential of IIoT services in particular (Yu, Nguyen, & Chen, 2016; Economist, 2015). Thus, we have reason to be skeptical concerning expectations for easy realization of the IIoT-envisaged benefits (Teece 2010; Chesbrough & Rosenbloom, 2002).

In this article we advance that the IIoT offers new opportunities and harbors threats that companies are not able to address effectively with existing business models. In the face of the uncertainties of IIoT, nonownership business models empower cocreating companies to share opportunities and downsides for mutual benefit. We argue that transforming manufacturing into a service system resides on effective uncertainty sharing between providers and their clients. Specifically, business models that offer providers incentives for taking on responsibility for uncertainty to shield their clients against uncertain downsides seem to offer great potential. The core of such business models is the service contract where providers and clients agree on the sharing of opportunities and uncertainty downsides of a service (Chesbrough, 2011; NDubisi, Ehret, & Wirtz, 2015; Ehret & Wirtz, 2010; Wirtz & Ehret 2009).

Contrary to common intuition such a service-logic is not a recent development in manufacturing. Already in the late 18th century James Watt stimulated the first industrial revolution by commercializing his steam engine with a service-based value proposition whereby he offered the following to his prospective clients (see also: Lord, 1923; Roll, 1930; Rosen, 2010) :

> *"We let you have a steam engine cost free. We will install it and take over the customer service for five years. We guarantee that you will pay less for the engine's coal than you currently spend to feed the horses doing the same work. And all we are asking is that you give us one third of the money you will save."*
>
> (James Watt, cited in Hofmann, Maucher, Hornstein, & Ouden (2012), p. 97)

Watt provided a pioneering example for uncertainty sharing through service provision. By taking on potential downside-uncertainty of the operation of a technology that was not broadly understood, he lowered the barriers of adoption of his revolutionary manufacturing technology and generated an exciting profit opportunity for himself. Watt's steam engine business model shows key features of how entrepreneurs employ service business models where they transform their clients' uncertainties into business opportunities for themselves.

In this article we explore the conditions for designing nonownership business models for the emerging IIoT. An overview of the key arguments in this paper is provided in Figure 1.

Insert Figure 1 about here

Key Components of IIoT

Before we discuss the economic foundations for IIoT business model design, we briefly describe the key components of IIoT systems that are instrumental for delivering their envisaged benefits (see Table 1 for an overview). They are: (1) information protocols and middleware, (2) sensors, (3) actuators, and (4) IT-driven services such as artificial intelligence (AI) and big data analytics (Kortuem, Kawsar, Fitton, D, & Sundramoorthy, 2009; Parry, Brax, Maull, Ng, 2016; Smith, Maull, Ng, 2014; Porter & Heppelmann, 2014, 2015).

Insert Table 1 about here

Information Protocols and Middleware. The technological core of the IIoT connects physical objects, in our case manufacturing equipment like machines, robots and tools, to the world-wide information infrastructure that runs on the Internet (Geisberger & Broy, 2015). Internet standards and middleware provide the software interface for the formation of cyber-physical systems (CPS). World-wide connections transform manufacturing from largely stand-alone activities toward connected and integrated systems. Information protocols and middleware connect manufacturing across functional barriers (e.g., manufacturing, procurement, supply chain management, and sales), organizational boundaries (e.g., manufacturers, channel members, and even end-users), and geographical boundaries to nearly any operation that is connected to the Internet.

Sensors. Sensors create data about the status of manufacturing equipment and its context, and work as an information interface between physical devices and the Internet (Geisberger &

Broy, 2015). Sensors add connectivity to manufacturing equipment and material components, and are the building blocks of proactive and autonomous repair and maintenance concepts. Sensors open-up an inside-out connection revealing real-time information on status and performance of a manufacturing system.

Actuators. Actuators are all sorts of components of automated systems that drive movement and change. That is, actuators translate commanding signals into physical effects and change in manufacturing systems, such as moving robots, heating systems, or laser-cutting objects. The IIoT builds on Internet-connected actuators, which enable often centralized operators to remote control the manufacturing process, and to conduct remote repair and maintenance activities.

IT-driven Services. Because IIoT unlocks information from the manufacturing process with the potential to give access to it from anywhere in the world, the IIoT opens the door for new information-driven services that can add significant value to a manufacturing and supply chain ecosystem (Anderson & Mattsson, 2013). IT companies offer services, often based on AI and big data analytics, with the aim to generate valuable insights that affect value and costs of manufacturing.

Implications of Key Economic Theories for IIoT

Hopes on the benefit of IIoT for manufacturing draw on the assumption that information adds value to the manufacturing process. However, this is not self-evident. From an economics theory perspective, information provides value only under certain conditions. In a perfect market in equilibrium, information would offer neither value propositions nor profit opportunities. In equilibrium, market prices would match all customer wants with the full available capacity of economic resources. However, several streams in economic research argue that business flourishes in the presence of uncertainty when customer needs remain unaddressed and economic resources lay idle. We explore these ideas in the context of IIoT in this section.

Uncertainty, the Value of Information, and IIoT. Knight (1921) introduced the concept of uncertainty into economic thinking by distinguishing it from risk. Risk refers to "known unknowns" where actors are aware of potential outcomes, extrapolate past trends into future events, and calculate the probabilities of known possible events. In contrast, uncertain outcomes are not known in advance (e.g., black swan events) and hit decision-makers as genuine surprises (Gigerenzer, 2013; Knight, 1921; Mises, 2008; Nowottny, 2016; Taleb, 2012).

Uncertainty can also take on positive forms. Entrepreneurship research prioritizes its agenda on the positive form of uncertainty, that is, the business opportunity (Shane & Venkataraman, 2000; McMullen & Shepherd, 2006; Ramoglou & Tsang, 2016). We discuss next the Entrepreneurship Theory in the context of IIoT which focuses on the positive form of uncertainty, followed by the Transaction Cost Theory which focuses on the negative form of uncertainty.

Entrepreneurship Theory. From an economic perspective, business opportunities emerge in a situation where the market has not priced-in relevant information reflecting the potential value of resources. Such inconsistencies between resource and service markets provide room for enterprising activity. However, according to Entrepreneurship Theory such business opportunities are genuinely uncertain (Foss et al.2007; Lachmann, 1981; Mises, 2008) regarding customers' unfulfilled needs and/or resource markets' potential for higher valuation (Kirzner, 1997; Lachmann, 1981; Mises, 2008). Entrepreneurs drive business projects by exploring unmet demand and unused potential of resources in order to exploit these opportunities at a profit (Kirzner, 1997; Mises, 2007, 2008; Shane & Venkataraman, 2000).

Business opportunities are genuine expectations by entrepreneurs who perceive higher valued uses for resources. However, business opportunities are conjectures by entrepreneurs, and they remain uncertain until a business project is completed and resulted in profit or loss.

Entrepreneurship Theory stresses the role of asset-ownership for exploring and exploiting business opportunities as owners have residual power over assets and can use assets without the need to negotiate contracts. Thus, ownership empowers entrepreneurs to experiment with resources, identify novel product and service offerings, and define the terms (incl. fees) for resource access. This makes ownership the key instrument for capturing profits from business projects. An important implication of Entrepreneurship Theory for business model design is the synchronization of ownership titles with business opportunities (Alvarez & Barney, 2004; Audretschm, Lehmann, & Plummer; Foss, Foss, & Klein, 2007; Mises, 2007; Santos & Eisenhardt, 2005, 2009)

The IIoT opens-up a new systematic paths to the exploration and exploitation of business opportunities (Amit & Zott, 2001; Geyskens, Gielens & Dekimpe, 2003; Reuber & Fischer, 2011; Schmidt, Rosenberg & Eagle, 2014; Wirtz, 2016, Wirtz et al. 2016) that are based largely on information technology (Hayek, 1945, 1973; Kirzner, 1997; Casson, 1982; Ramoglou &Tsang, 2016). These new IIoT-enabled business opportunities include (1) asset-driven opportunities, (2) service innovations that aid manufacturing, and (3) service-driven opportunities targeted at end-users. These business models require the ownership of different value-drivers (i.e., assets, data, and end-user relationships) to capture more of the value created. We will discuss all three types of IIoT-related business opportunities in greater detail later in this article.

Furthermore, a growing body of entrepreneurship research is pointing to the role of infrastructures in the formation of business opportunities (Audretsch, Heger, & Veith, 2015; Baumol, 2010; Cumming & Johan, 2010; González-Sánchez, 2013; Ramoglou & Tsang, 2016). In the case of IIoT, information infrastructure paves the way towards business opportunities. Here, exploiting opportunities related to IIoT calls for companies a refocus from equipment-ownership towards system ownership that allows for control and use of IIoT information.

Transaction Cost Economics. Transaction Cost Economics targets the negative aspects of uncertainty that show in the form of transaction costs (Barzel, 1987, 1997; Coase, 1960; Ehret & Wirtz, 2010; Grossman & Hart, 1986). In the absence of uncertainty, market partners would be able to specify their service needs, valuate them rationally and arrive at efficient contracts that accurately reflect their service needs (Coase, 1960; Ehret & Wirtz, 2010, 2015; Grossman & Hart, 1986). Uncertainty is a dormant power. Well-understood routine forms of uncertainty include hold-up or shirking by business partners, for example single suppliers of highly specialized machines exploiting power positions against automotive manufacturers (Williamson, 2005), but it also entails highly unlikely black swan-type events with the potential to create dramatic damage, such as spontaneous social disruptions, terrorist attacks, natural disasters, and nuclear catastrophes.

Uncertainty renders writing contracts costly, if not impossible, as contracting parties may not be able to specify and value their deliverables and needs in advance. As asset owners act as residual claimants, they bear the consequences of all uncertainties not specified in a contract (Barzel, 1987, 1997; Ghosh & John, 1999; Grossman & Hart, 1986; Ng, Ding, & Yip, 2013).

For all types of uncertainty, the IIoT offers the potential to better handle uncertainty downsides by offering new paths to information and enhanced transparency. With uncertainty kept in check, negotiating parties can then focus on those elements of the contract they feel on save ground, and costs of evaluating offers, negotiating and writing the terms of a contract, and controlling compliance in contract fulfillment are reduced.

The IIoT shifts the transaction cost structure in favor of nonownership contracts for asset providers and users from two ends. First, it provides asset operators with improved capabilities to handle downsides due to reduced governance costs of asset operation. The IIoT enables greater transparency and control of the process (e.g., through predictive maintenance, remote repair, and efficient operations control), and thereby enables asset owners to better manage downsides. Second, IIoT can reduce the measurement costs of manufacturing processes, output, and quality. Both factors, lower governance and measurement costs for equipment output, offer opportunities for downstream companies to move away from asset ownership and source manufacturing output by the means of service contracts.

Performance contracts enabled by IIoT have become commonplace (Evans, Annunciata, 2012; Geisberger, Broy, 2015) with a growing number of industrial equipment vendors entering industrial service businesses (Eggert, Hogreve, Ulaga & Muenkhoff, 2014), and their industrial customers demanding service level agreements from asset their operators (Geisberger, Broy, 2015).

In sum, Entrepreneurship Theory highlights the need to synchronize ownership with perceived upside opportunities and encourages machine owners to offer assets, processes, capabilities and output as a service. Transaction Cost Theory explains the opportunities IIoT offers to better manage uncertainty downsides and encourages users of machines to give up ownership and just purchase the output. Both theories together explain the power of IIoT to encourage nonownership markets. In the following section we discuss the contribution of nonownership for the design of IIoT business models.

From Promise to Business - Foundations for the Design of IIoT Business Models

IIoT is not unique in its uncertain prospects for fulfilling its potential. Research in technology management shows plenty of examples where technologies struggled to translate their promises into business performance. For instance, Xerox initially struggled to turn its photocopy technology into a business until it finally succeeded with a razor and blade business model, leasing the machines at a low fixed rate and charging its clients per copy. Later, Xerox struggled to capture value from its Palo Alto Research Center innovations for personal computing just to watch companies like Apple and Microsoft build global businesses on its technologies (Chesbrough & Rosenbloom, 2002; Teece, 2010). The regular struggle of companies to unlock value from technology has stimulated research in business models (Teece, 2010; Chesbrough 2006, 2011; Wirtz, Pistoia, Ullrich & Göttel, 2016).

Business Models – Unlocking Value from Technology. In the context of technology, business model researchers are concerned with how technological potential can be translated into economic value. Because technology shows disruptive potential for redefining, undermining if not destructing established industries, corporate strategy concepts building on existing industry structures, like Porter's five industry-forces framework, risk to run on empty (Christensen & Bower, 1996; Ehret, 2004; Zott & Amit, 2008).

IIoT provides a point in case as it resides on the integration of IT and communication technology into the manufacturing process. Business model researchers follow an open approach for unveiling innovative ways for companies to establish valuable and profitable connections between resource and service markets. While competitive strategy approaches build on product definitions and industry structures for identifying cost or differentiation advantages, business models start with the identification of opportunities in upstream resource or downstream service markets. The key aim is to identify a promising position for the firm before making decisions on what unique value proposition to offer, which resources to own for capturing the value, and what kind of partners and complementors are needed for delivering the value.

Thus, business modelling makes use of the increased flexibility for organizational design that is enabled by markets that offer almost any asset, activity, capability, and process as a service (Ehret, & Wirtz, 2010, 2015; Zott & Amit, 2008). This is further supported by technologies that enable value creation across networks, and dynamic capital markets that provide venture capital. The starting point of a business model is to identify market opportunities before fixing organizational structures as existing organizations may seem powerful in the exploitation of proven opportunities but show strong rigidities in exploring latent ones (Chesbrough 2006; Wirtz, Pistoia, Ullrich & Göttel, 2016; Zott & Amit, 2008).

Components of Effective Business Model Design. While there are many taxonomies for business model design (Osterwalder & Pigneur, 2005; Wirtz, Pistoia, Ullrich & Göttel, 2016), the majority overlaps in four components that are particular relevant for the IIoT context (cf. Coombes, Nicholson, 2013; Ehret, Kashyap, & Wirtz, 2013). The four components are:

1. The *value proposition* follows the maxim to identify opportunities for value creation before fixing actual product or service specifications. The starting point is to identify propositions that enhance the value-in-use in the context of users (Ballantyne & Vaarey, 2006; MacDonald, Kleinaltenkamp, & Wilson, 2016). In the case of IIoT, potential value propositions for manufacturers who currently buy or lease their machines could be linked to the benefits of transparency, real-time data, and remote access and control.
2. The *value capturing mechanism* aims to translate value-in-use into financial value for the service provider. One key motivation of IIoT is to broaden potential revenue streams

beyond the sales of manufacturing equipment. In particular, business models consider contracts that include leasing, renting, maintenance and repair, predictive modelling, process optimization, licensing, and multi-sided markets where one market stimulates the cash-flow of another side of the market. For example manufacturers of industrial equipment are moving towards selling performance of the machine instead of selling the machine itself (Smith, 2013).

3. The *value network* reflects the increasing connectedness and fluidity of business organization (Frankenberger, Weiblen, & Gassmann, 2013). Value network design builds on the maxim that a firm is rarely in the position to exploit an opportunity on its own, thus requiring an ecosystem of suppliers, complementors and stakeholders to effectively serve its customers. Networking is key to the configuration of IIoT, as it resides on the cocreation of a wide range of players.
4. *Value communication* addresses that fact that cocreation of value resides on perceptions and interactions between actors in the value network. Because IIoT typically requires the cocreation several players, complexity and uncertainty are high and drive an intensive need for visibility and communication. Thus, communication, social capital and trust play a critical role in business model design.

In the following section we discuss the role of information for value propositions and its implications for the design of business models.

Nonownership and the Design of IIoT Business Models

The Contribution of Nonownership for Unlocking the Value of IIoT. Nonownership business models aim to empower client companies to share uncertainties to navigate towards their most promising business opportunities. Nonownership business models aim to establish selective approaches towards uncertainty sharing and thereby direct the firms' resources towards opportunities and delimiting uncertainty downsides (see Figure 2). In the context of manufacturing, nonownership implies the division of entrepreneurial domains of manufacturing assets, manufacturing services, and innovation on new asset-service combinations.

Nonownership contracts provide the foundation for business models by furnishing specialized entrepreneurial roles. By the means of nonownership contracts, clients can reap the benefit of manufacturing performance as an input for their own value creation. That is, nonownership shields clients against downsides from owning and operating manufacturing assets. Clients benefit if they hold their own value propositions for downstream service markets, and use manufacturing performance as one component which is needed for functionality but is no essential source of differentiation (Figure 2).

Insert Figure 2 about here

Nonownership contracts work as an insurance or hedging instrument against uncertainty downsides of manufacturing performance; they delegate uncertainty downsides to the legal domain of the owner of manufacturing assets. This opens-up a derived opportunity. By taking-on downsides of manufacturing, companies willing to own assets get access to profit opportunities. Companies willing to bear the uncertainty downsides of manufacturing can actually gain profits by keeping uncertainty and its costs in check, and turn the uncertain residual income stream positive. Here, IIoT strengthens the technical capabilities of manufacturing equipment owners to manage uncertainties of manufacturing. Specifically, by providing real-time information on the manufacturing process and prospective information on equipment reliability, owners of manufacturing get control of uncertainties and related costs. That is, nonownership business models offer the opportunity to unlock substantial value by transforming uncertainty downsides of the client into business opportunities for the provider.

IIoT facilitates the use of market and customer information for the design and control of manufacturing activities and opens up new sources of innovation through the interaction between manufacturing assets and service markets. We will discuss key types of IIoT business models in the following sections.

Business Models for Asset-Driven Opportunities of IIoT. As a technology IIoT marks a breakthrough in terms of capabilities of manufacturing operators to monitor processes, measure output and drive efficiency gains. IIoT leads to a substantial shift in transaction costs. Specifically, manufacturers of finished goods, components, or energy that cater to business or consumer markets further downstream have less pressure from transaction costs for not owning their own equipment and buying the output as a service. Supported with IIoT-driven intelligence regarding quality of outputs they can delegate the operation of assets to companies specializing on asset ownership and operation. Challenged by competition and rising customer requirements, firms need every opportunity to focus management capacity and investments on differentiation by the design of outstanding products and achieving ever higher levels of efficiency.

Nonownership business models open the door for reaping such benefits, by allocating the downsides of asset operations to the equipment operator. What used to be a burden for the client of manufacturing services offers a unique opportunity for companies capable to grant service levels and increase efficiency of operations. Thus, for downstream manufacturers, the key value proposition is to shift uncertainty of manufacturing assets to service providers. Service providers get a derived opportunity.

Here, IIoT opens a new door for machine and equipment manufacturers, that is, IIoT offers a substantial shift in transaction costs of monitoring equipment. Because IIoT empowers equipment providers to monitor processes in real-time and remotely control operations, they gain capabilities to meet service levels and reduce costs. As owners they earn the uncertain residual income. Thus, every progress in efficiency, and at least in the short term, service performance directly drives up their profits. The commercial aviation industry provides a signature example. Airlines are increasingly refraining from owning their engines. They delegate ownership to airplane manufacturers who offer “power-by-the-hour”-type contracts (Wirtz & Lovelock, 2016, p. 10). Connected IT systems provided the key to this move (Smith, 2013). With sensors connected to engines beaming real-time information to control centers, service providers gained better traction in projecting and handling disruptions, and not least control the costs of service operation that ultimately drives the profit of nonownership providers.

Electronic components and energy-utilities have also been early adopters of such asset-based services (Sousu & Voss, 2007; Smith, 2004; Evans & Annunciata, 2012). In complex manufacturing systems, even subsystems are outsourced to specialized service-providers, for example water management in the paper production process (Toland, 2005).

IIoT opens potential for even further specialization. Internet-connections enable advanced maintenance and repair services. With the appropriate designed equipment, anticipative, automated and tele-repair approaches become possible. Intelligence-driven systems empower anticipative maintenance and therefore avoid disruption of operations (Geisberger & Broy, 2015).

All the benefits of nonownership show a substantial limitation: Contract efficiency resides on the capabilities of contracting parties to anticipate future events. Thus, there is some paradox in writing contracts for sharing uncertainties, because the key characteristic of uncertainty is that it is unpredictable. Some uncertainties, like extreme events so-called "black swans" defy contractual solution. But many other uncertainties can be resolved through relationships that favor the formation of social capital and mutual trust that help companies to find solutions beyond the straightjacket of written contracts. (Morgan & Hunt, 1985; NDubisi, Ehret, & Wirtz, 2016).

To summarize: The IIoT opens up a new path towards asset-driven opportunities. Nonownership business models provide the ***value proposition*** to transform uncertainty downsides of asset operation into opportunities for manufacturing service providers. IIoT makes for a fundamental shift of transaction cost structures, empowering clients to measure outputs and providers to monitor operations. With IIoT nonownership business models offer a brilliant ***value capturing mechanism*** by shifting negative uncertainty of downstream-focused manufacturers into profit opportunities for service providers. Thus, nonownership contracts form the foundation of a smart IIoT connected ***value network,*** offering opportunities from specialization on mastering negative uncertainties of asset operation. By providing incentives for specialization on different aspects of uncertainty, networks can make manufacturing more robust. However, pure contractual arrangements have principal limitations for addressing uncertainty. Effective nonownership business models reside on interpersonal relationships and communication that support the formation of trust that helps companies to find solutions beyond the straightjacket of written contracts.

Business Models for Service Innovation that Aid Manufacturing. In the world of offline manufacturing, information remained in silos around the factory floor. When IIoT connects manufacturing to the Internet, manufacturing information can be used in ways that were unfeasible in stand-alone mass-production. Pioneering IT and industrial goods companies have started to unlock manufacturing information and develop resources and capabilities to gain intelligence and knowledge.

A first step is to use the IIoT to unlock machine information across a network of manufacturing sites in order to gain intelligence and knowledge for improving operations and optimizing repair and maintenance. For, example German machine manufacturer Trumpf established its Axoom platform that is open to users of its own machines, but also to customers who operate those of competing vendors. Trumpf provides information services for analyzing operations, orchestrating manufacturing with supply chains, and sign-posting manufacturing disruptions (Economist, 2015).

But IIoT opens doors beyond the factory floor, enabling companies to exploit worldwide available information for raising the productivity of manufacturing. This creates opportunities for innovative use of information, the creation of industrial clouds, and analyzing techniques for big data (Geisberger, Broy, 2015; Rio, 2015; Evans, Annunciata, 2012), and it allows to explore hitherto unnoticed relationships between resource and service markets by integrating and analyzing industrial data, service market data, and data from the micro- or macro-environments of manufacturing. For example for energy utilities, GE offers services to use crucial information like weather reports, energy markets and mass-events for optimizing power generation plants connected to the IIoT (Evans, Annunciata, 2012). Not least, IT companies offer capabilities for big data analytics, power computing and cloud-based services. For example, IBM established an IIoT program fed by its “Watson” power computer.

Despite the variety of value propositions, IIoT-driven information services share one common feature: The value of information will increase when it is aggregated and shared.

Companies aiming to offer IIoT innovation services need platforms for retrieving information, analyzing it and activating it through the IIoT (Chesbrough, 2011; Geisberger & Broy, 2015).

Business Models for Service-Driven Opportunities Targeted at End-Users. Linking flexible manufacturing with customers, designers and entrepreneurs provides the potential to stimulate creativity and demand for manufacturing services. Here opportunities emerge for companies who attract and stimulate Internet-driven cocreation (Breidbach & Maglio, 2016; Vargo & Lusch, 2004).

It is often of value here that the IIoT removes the traditional trade-off between costs and customization or personalization of products. While mass-customization is anything but new, IIoT offers an instant online connection opening virtually anybody connected to the Internet to manufacturing capacity. The IIoT can unleash an unprecedented wave of creativity at the front-end of the manufacturing chain, opening the gates for designers, and even end-users for turning their ideas into real-world products.

Unlocking this potential at the frontend of manufacturing require business models focused on downstream service markets, connecting customers, designers, sales channels, supply chains and manufacturers to the IIoT. Etsy provides a point in case. IIoT offered a turning point for the company that started as a web-shop for hand-crafted fashion items and accessories offered by self-employed and amateur designers. While the handmade philosophy stimulates attraction of buyers interested in unique and distinctive styles, it also worked as a bottleneck because the sales potential of successful designers is limited by their personal labor capacity. Because Etsy follows a two-sided business model, attracting buyers and capturing the value through sales commissions, capacity limitations of sellers limited its prospects too. IIoT was the key in removing the business prospects of Etsy and its designer network. Now, Etsy offers successful sellers the connection to certified flexible manufacturers that produce single items or small batches based on digital designs, transmitted via the Internet and used for programming manufacturing operations.

Etsy is just one example of a growing range of firms that establish the digital front-end of the emerging IIoT-connected manufacturing line; others include Quickparts, Alibaba, or Made-in-China (Geisberger & Broy, 2015; Wu, Rosen, Wang, & Schaefer, 2015). While such companies do not manufacture themselves, they provide the interface between designers, customers and manufacturers. The key value proposition is community building and stimulating demand by attracting designers, consumers and virtually anybody for cocreation on platforms connected by the Internet. Design software allows co-development of innovative designs. The value capturing frequently resides on multi-sided business models that engage designers and consumers for interaction on web-interfaces, while capitalizing the value through complementing services, like sales support, or design software.

IIoT allows for even further transformation by taking manufacturing out of the factory floor. With affordable digital manufacturing tools, like 3D printers connected to the Internet, even households will increasingly be able to design and produce their own physical items as well as share and use design from the Internet. Communities of self-producers emerge, meeting at Maker-fairs and coworking at Maker-spaces predominantly in urban areas. Here, IIoT provides the backbone of a decentralized manufacturing network, sharing digital designs, connecting designers, customers and decentralized manufacturers worldwide (Anderson, 2012, Rifkin, 2014).

Research Opportunities in IIoT Business Models

Linking economic theory, uncertainty, nonownership, and business models, we highlight next a number of areas we find particularly promising for further research.

Ownership Architecture Configurations and Service Performance. A growing stream in service research proposes nonownership as a key value proposition of service businesses for removing the burden of ownership from their clients (Ehret & Wirtz, 2010, 2015; Lovelock & Gummesson, 2004; Wittkowski, Moeller & Wirtz, 2013; Wirtz & Ehret 2009). Some authors go even as far as to declare the death of ownership and the eclipse of capitalism (Rifkin, 2014). However, the rise of the sharing economy does not provide strong evidence for such speculations because the value propositions of nonownership services, including renting and providing access, are direct results of a provider taking-on ownership and assuming the risks for the related downsides. The assets in use will always have to be owned by one of the parties in any value network.

Research has yet to notice the implications of nonownership for the strategic management of service providers. For offering nonownership value propositions, capabilities for managing uncertainty of service assets provide the key to sustainable competitive advantage. Property Rights Theory was developed in the context of stand-alone assets (Barzel, 1994; Furubotn & Pejovich, 1972; Grossman & Hart, 1986). However, in IT-driven service systems, such as IIoT, the role of ownership becomes highly complex (Maglio & Spohrer, 2008; Rust & Huang, 2012) and the ownership of stand-alone assets will not suffice. For example in IIoT, service systems relate to specific configurations of manufacturing assets, software, hardware, intellectual property, brands, and many more. Service providers will need to design ownership architectures that organize and orchestrate all these assets.

Configurations of ownership architectures are likely to show significant impact on key factors of service performance, including profitability and service quality. Future research should provide a fuller picture of the different asset types in order to identify their role in the context of business models and understand productive asset configurations.

Asymmetric Uncertainty and the Potential for Real-Option Valuation. Nonownership value propositions build on asymmetric perception of, and the ability to manage and underwrite uncertainties. For example, one company feels operating machines as a burden while another sees this as an opportunity. Service providers embrace uncertainties that their clients loaf and are willing to pay service fees for discarding them. Arguably, asymmetric uncertainty is a key condition and source of nonownership value, if not service value in general.

From a financial perspective, service contracts share some features with financial options. Service clients enjoy the right on benefits of a service without the obligation to bear the downsides which makes real options most valuable when uncertainty is high. Thus service clients enjoy benefits quite comparable to those of option holders who hold the right but not the obligation to sell a stock at a certain price at a certain time. Like option holders only risk the option price, service clients limit their financial risk to the service fee (Adams, 2004; McGrath, Ferrier, & Mendelow, 2004; Miller & Huggins, 2010; Shi, 2016). The main difference distinguishing real options from conventional financial options is that they are not traded securities (i.e., prices will have to be negotiates), that option holders can shape the option's underlying value (e.g., through their specific use of the deliverables), and that real options have to be created which makes it an entrepreneurial process.

Research still faces methodological challenges in real-option valuation, but the field makes progress and we can look forward to a growing stream of data on financial valuation and the environment of services (Taleb, 1997, 2012). While there are some studies on real-options for the valuation of particular services (Su, Akkiraju, Nayak, Goodwin, 2009; Wei & Tang, 2015; Wenbo, 2016), service research has not yet reflected the potential offered by real-options for the systematic valuation of nonownership services. Future research should first conceptualize service processes along the uncertainties perceived by providers and clients as a basis for simulating the role of uncertainty in financial service valuation. Empirical studies of perceived uncertainty and service prices furnish evidence based insights. The IIoT has unlocked a boon of information available for the systematic study of service valuation and pricing.

Institutions and Infrastructures for IIoT. In this article we have looked at the relationships of firms engaged in the cocreation of manufacturing services, while taking infrastructures for granted. However, key infrastructures that will affect the scale and performance of IIoT systems are still in an emergent state. Connecting a growing range of things and machines to the Internet is at the heart of current infrastructure innovations, like the fifth generation standard for mobile communication (5G) or the development of a new IPV6-protocol for sufficient identification of the growing number of items connected to the Internet (Geisberger & Broy, 2015).

Crucial as infrastructure is for the IIoT, there is no substantial body of research. Entrepreneurship research has recently established an emerging domain in exploring and explaining the role of infrastructures in stimulating the entrepreneurship process (Audretsch, Heger, & Veith, 2015). One neglected role of the service sector is its role in enabling enterprising activity because available services reduce the need of entrepreneurs to build capacity and capabilities on their own. Conceptual work should clarify this rationale and stimulate empirical research revealing evidence of the role of infrastructures.

Orchestrating Human Actors and Machines. A key ingredient of IIoT is machine-driven automation. Work on service systems has shown that automation of service systems can show surprising effects, like the struggle to raise productivity with self-service systems (Wünderlich, Wangenheim, & Bitner, 2013). In relation to the growing body of research showing the potential of IIoT, there is little evidence on the impact of the human factor in interaction with these systems. Ignoring this dimension might expose the factory to surprises, and opportunities might emerge beyond the "race against the machines" (Brynjolfsson & McAfee, 2014) through smart integration of machines and human actors. While machines and AI seem to be able to automate more and more tasks, systems building on human-machine interactions have proven to be unbeatable. For example, while supercomputers beat humanity's best chess-players, teams of chess-players supported by supercomputers outperform pure machine players (Brynjolfsson & McAfee, 2014). The IIoT provides both, a rich context as well as a promising application field for studying the performance of man-machine interaction.

Conclusions

While there are high hopes and first evidence for the potential of IIoT, to date there is a lack of systematic research and concepts for reaping the benefits of IIoT. This article contributes to this literature by identifying the impact of IIoT on business uncertainty and showing the implications for the design of effective IIoT business models. First, drawing on entrepreneurship theory, we identify the role of the IIoT for systematic shifts of uncertainty in business. IIoT unlocks information from the manufacturing process, opening a hitherto closed door for information-driven innovation for end-users and manufacturer. IIoT also shows impact on transaction costs, and thereby lowers the bar for nonownership business models.

Second, we show implications of IIoT for the systematic design of business models, such as the contribution of nonownership contracts in capturing the value of IIoT, information-driven value propositions based on service innovations for customers and end-users, and the role of value networks for IIoT service innovations targeted at end-users.

Finally, we identify key areas where service research has significant opportunities for progress, including the architecture of ownership of diverse assets needed for service provision and the contribution of real-options for valuing the uncertainty dimension of IIoT services and service in general.

Notes on Contributors

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Table 1: Opportunities Offered by the IIoT for the Transformation of Manufacturing

Key IIoT Technologies	**IIoT-Driven Capabilities of Manufacturing**	**IIoT-Driven Threats**
Internet and communication protocols and middleware	• Link manufacturing information to external intelligence (Anderson, 2012; Brynjolfsson & McAfee, 2012) • Enable self-service manufacturing (Andersonson, 2012; Ng, Scharf, Pogrebna, Maull, 2015; Rifkin, 2014)	• Increase system uncertainty by connecting hitherto isolated systems • Challenge of data and information reliability (Geisberger & Broy, 2015, pp. 77-79 Sicari, Rizzardi, Grieco,L, Coen-Porisini, 2015) • Potential industry disruption by disintermediation and new competition through start-ups and Internet-driven businesses (Anderson, 2012, Brynjolfsson & MacAfee, 2012)
Sensors	• Reveal information on manufacturing processes and their environment (Ng, Scharf, Pogrebna, Maull, 2015; Rifkin, 2014)	• Threatens intellectual property, know-how and intelligence (Geisberger & Broy, 2015, pp. 84-85)
Actuators	• Enable remote and self-service manufacturing (Anderson, 2012; Ng, Scharf, Pogrebna, Maull, 2015; Rifkin, 2014)	• Safety and security of manufacturing information, e.g., protecting against sabotage (Geisberger & Broy, 2015, pp. 82-84)
IT-driven services like AI and big data analytics	• Apply AI to manufacturing operations (Brynjolfsson & McAfee, 2012) • Transform manufacturing into a service (Ng, Scharf, Pogrebna, & Maull, 2015)	• Privacy and know-how protection against unauthorized use of data (Geisberger & Broy, 2015, pp. 84-85)

Figure 1: Business Models – Transforming IIoT Promises into Value

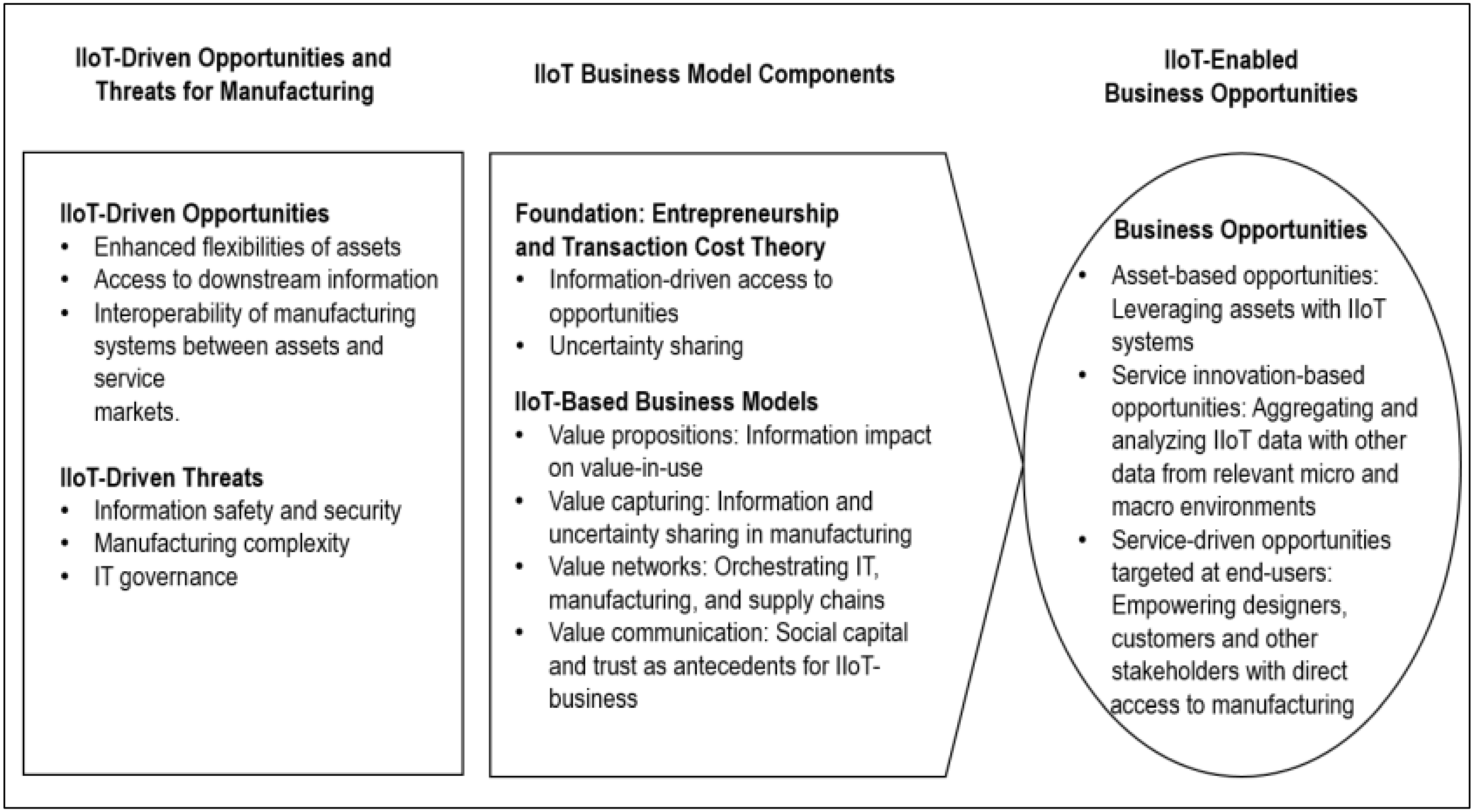

Figure 2: Nonownership Contracts for the Transformation of Uncertainty