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Resilience Analysis of the ICT Ecosystem

Work in Progress

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1. Introduction

In recent years, the global information and communication technology (ICT) industry has been facing fundamental changes. The convergence of telecommunications, internet and media leads to a complex business system with interconnected and interdependent players from different industries that often simultaneously both compete and cooperate in order to survive. Handset vendors such as Samsung and Nokia are entering online service markets while traditional computer manufacturers such as Apple or software giants like Google and Microsoft are steadily breaking into the media and telecommunications markets. On the other hand, established telco-players such as Deutsche Telekom and AT&T are extending their established value chain based on network provisioning and operations by vertical integration through the provision of value-added services such as billing and content provision (Dengler 2000). The resulting interconnectedness and interdependence, as well as the rise of new network and computing technologies (Fiber, LTE, Cloud Computing) will change cost and market structures and shorten innovation cycles. This evolution of the ICT ecosystem (Moore, 1996; Basole and Karla, 2011) is challenging for two reasons. First, the “rugged competitive landscapes” (Porter and Siggelkow 2008) in the ICT sector has led to a vast number of choice variables and to an increase in strategic uncertainty and unpredictability. This may limit the applicability of established management approaches that have previously been successfully employed to gain and maintain a competitive advantage. Second, the structure of the ICT ecosystem becomes more vulnerable to “regime shifts” due to asymmetric, interdependent relationships of market players in a dynamic, fast developing ecosystem.

These challenges also raise questions about the future role of regulation in order to achieve a resilient ICT market providing communication and information services in a sustainable and reliable manner. To create a better understanding of the converging and turbulent ICT market-policy/decision makers need adequate tools and theoretical frameworks that will enable them to manage the complexity and uncertainty of the emerging ICT ecosystem. Yet, despite wide recognition of the tension between technological development and the subsequent regulatory regime (e.g. Noam, 2010), a number of issues remain. For instance, the existence of multiple equilibria within the ICT ecosystem tends to be neglected. It may also be important to know if ICT markets/ecosystems follow patterns of evolutionary change that repeat and therefore might be predictable. Likewise, current economic analysis

may underestimate the asymmetric and delayed feedback structures between technology and markets on the one hand, and regulatory intervention on the other.

The objective of this paper is to galvanize telecommunication research on resilience. Hence, we attempt to address these gaps through the multi-disciplinary lens of “resilience thinking” (Walker and Salt, 2006) and the application of the well-known “adaptive cycle model” (Gunderson and Holling, 2002). This approach enables a holistic analysis of the ICT sector as a complex adaptive system and recognizes the evolutionary nature of the sector. Our research question is: *How can the adaptive cycle-model help decision makers to understand the dynamic, evolving and complex ICT market and plan strategies/interventions at the optimal point in the process?*

This working paper is organized as follows: The next section gives an overview of the current techno-economic developments of the telecommunication industry. Based on our observations, we highlight the need for rethinking of ICT markets as complex adaptive systems in section 3. This is followed by an explanation of the applied methodology i.e. the adaptive cycle model. Section 5 presents our initial findings and results of this study. Finally, section 6 gives a conclusion and discusses managerial and political implications as well as the limitations of our study and avenues for further research.

2. Telecom industry at a crossroads

Telecommunications investment has been identified as having a strong potential to spur economic growth and create employment (McKinsey 2011). Investments in telecommunications infrastructure not only provide a short-term boost to the economy, but also lay the groundwork for long-term improved growth perspectives (Röller and Waverman 2001, Czernich et al. 2011). Information and communications technologies (ICT) are also held to be key drivers of productive growth in modern economies. Between 2003 and 2007, ICT was responsible for 59% of productivity growth in the U.S. and 31% of productivity growth in Europe (European Commission 2010).

Policy makers have acknowledged the vital role of high speed Internet infrastructure. The European Commission believes that the availability of next generation access platforms (NGA, i.e. infrastructure such as fiber that can provide super-fast broadband speeds) can contribute materially to European GDP. Consequently, it established a set of demanding objectives as part of the Digital Agenda in 2010, including the goals that all Europeans should have access to broadband lines with transmission rates of 30 Mbit/s by the year

2020, and at least 50 percent of all households in Europe should have access to the Internet at speeds of over 100 Mbit/s.

The lion's share of the investments in fiber roll-out will have to be borne by the telecom industry. The investments required in expansion of a state-of-the-art telecommunications infrastructure are comparatively high and irreversible (i.e. sunk costs). Achieving fiber penetration levels in Europe that begin to rival those in leading Asian markets will cost in the ballpark of EUR 300 billion (McKinsey 2010). Asia's most advanced markets – Japan, Hong Kong, and South Korea – enjoy fiber household penetration rates of 44, 47, and 59 percent respectively (IDATE 2012), while many Western European markets barely reach significant single digits.

The economics of deploying fiber remain challenging for private-sector telecom operators. Investors are profoundly skeptical about prospective returns of fiber investments (HSBC 2012). A major reason for investors' reservations is the "fundamentalistic" European regulatory regime (HSBC 2008). In a recent survey of telecom investors, 91% of investors indicated that EU telecom regulation does not encourage network investment, mainly because of three reasons: i) a lack of predictability in regulatory decisions, ii) a regime that is too favorable to resellers and iii) too much of a deflationary bias in past regulatory decisions (Credit Suisse 2012).

On a related note, boundaries and contours of the relevant markets in the ICT industry are blurring. New products are brought to market, old ones disappear, products and functions that were autonomous to date are now being integrated. Companies that previously operated in different, separate sectors are now coming together in the telecommunications market and increasingly competing against each other. Global players such as Google, Apple, Microsoft and Facebook have benefitted from positive networking effects in their original segments to achieve what is almost a monopolistic position for their proprietary platforms. From the security of this prominent market position, they are now launching attacks on the core business of the telecommunications companies.

Current examples of this include Apple's iMessage messaging system, the Facebook Messenger and popular apps that enable users to send and receive short messages conveniently. These messaging systems pursue the ultimate goal of taking over users' communication activities (Schmidt 2011). The shift of text messages from mobile carriers to Internet providers signifies a fundamental change in business models: conventional text messages (SMS) are transported over a signaling channel in mobile networks and billed by mobile communications providers. Internet providers send short messages in data packets, for

which users who subscribe to today's popular data flat rates pay no extra charge. The mobile communications companies' response is to offer flat rates for text messages themselves.

New trends and developments in modern telecommunications markets require a new understanding of the market and a review and renewal of the current regulatory regime and how it has been practiced to date. Dynamic competition in technology and innovation-driven markets requires a departure from a regulatory paradigm of static efficiency, whose principle objective was to open up the market and establish competition. Instead, the focus should be placed on promoting dynamic efficiency; network access regulation should not take place at the expense of innovation and investment incentives.

3. ICT ecosystems: The New Game

According to Noam (2010), three different phases can be stylized in the development of telecommunications: Telecom 1.0 was the state monopoly in the telecommunications market. The partial liberalization of the telecommunications sector in the USA in the 1980s precipitated the start of the second phase of telecommunications development: Telecom 2.0. At the end of the 1990s, the telecom markets in Europe were liberalized, and privatization of former monopolists were pushed ahead. The Telecom 2.0 phase is also strongly characterized by the lightning advance of mobile communications and increased innovation. Regulation 2.0 (sector-specific regulation) was the counterpart to Telecom 2.0. The liberalization of the telecommunications market at the end of the 1990s cannot be equated with deregulation: on the contrary, market liberalization has led to extensive 're-regulation' of the former monopolistic operators (Haucap and Coenen 2011). Sector-specific regulation was introduced in order to open up the telecommunications market to competitors.

When the market and technology in the telecommunications sector make advances, regulation must follow. Regulation 2.0 was an important foundation on which liberalization of the telecommunications markets could succeed. However, the development toward Telecom 3.0 requires a realignment of the regulatory regime. The complexity of the new Telecom 3.0 world presents a challenge: Regulation 3.0 must create incentives for expansion of new broadband infrastructures and ensure that new, local fiber networks can interoperate. At the same time, regulators must develop a new understanding of the market and, where necessary, review and renew the regulatory regime. The key issues in Regulation 3.0 are

the transition to strictly dynamic market analysis, competition along the Internet value chain, the growing significance of digital platforms and creation of incentives for innovation and investment.

Towards an evolutionary perspectives

The theories propounded by Hayek and Schumpeter are of central importance in understanding dynamic competition. Hayek (1968) sees competition as a journey of discovery; an evolutionary process based on trial, modification and selection. Competition causes the market players to deploy their individual skills and specific knowledge intensively, and to acquire a maximum amount of new know-how as quickly as possible and put it to suitable use. Schumpeter (1942) also stresses the dynamic dimension of competition: innovations, in the form of new products, new processes and new organizational forms, are the drivers of economic growth. In the 'process of creative destruction' successful innovations give pioneers the chance to gain a competitive edge, which in turn enables them to gain 'head-start profits' (pioneer profits, Schumpeter's monopoly return). The pioneer's initial monopoly role in competition is, however, only temporary, since imitators reproduce the pioneer's innovation and catch up on its lead (Vidal 1995). Temporary pioneer profits are the central incentive for innovation.

Hayek and Schumpeter's view of dynamic competition is highly relevant for Telecom 3.0. In his analysis of the development of the American information industry, Wu acknowledges that Schumpeter's model of growth "remains in general our best account of what drives thriving economies" (Wu 2011, 311). However, there also shortcomings in Schumpeter's model, in particular his belief that the monopolist, as compared to the competitive market, is a better agent of innovation. Beginning with the work of Kenneth Arrow, this argument has been decisively refuted. The adaptive cycle model explicitly explains decline and release of a specific cluster and acknowledges the role of renewal and replacement in the reorganization and restructuring stage of a cluster.

Telecom 3.0 is characterized by a high degree of uncertainty – uncertainty about for example, the specific services, technologies and platforms that will assert themselves on the market. Seen in this context, competition is an evolutionary process, a journey of discovery. Telecom 3.0 may therefore only be flanked by regulation that combines network access obligations intelligently with innovation and investment incentives, regulation that is strictly oriented to promoting the dynamic efficiency of the market. Since it is very difficult to forecast which business models will prevail in the future, a wait-and-see approach is

appropriate. Competition and regulatory authorities should monitor market developments and respond firmly to contraventions of competition regulations. On the other hand, preventive measures involve the risk that the development of new business models could be nipped in the bud.

Scholars from different disciplines suggest that many high-tech products and services can be considered as systems of interdependent components, built around and on top of platforms and are often provided by a complex network of firms, or ecosystem. For example Kim et al. (2010) define ecosystems “as an economic community involving many companies working together to gain comparative advantages as a result of their symbiotic relationships. Ecosystems permit companies to create new values that no company could achieve alone.”

Conceptualizing markets as ecosystems is a result of theoretical extensions of work in interim networks, alliances, and innovation (Basole and Karla, 2011) and ecological economics (Moore 1996). Here, interfirm relations are a result of the fundamental determinants asymmetry, reciprocity, co-evolution, efficiency, stability and legitimacy. Recent studies have adopted a complex networked systems perspective to examine why, when, and how interfirm networks and alliances form and change (Basole and Karla 2011).

Complex Adaptive Systems

The ICT sector is increasingly characterized as a socio-technological system facing asymmetric and delayed feedback structures, which lead to turbulent changes (instability/existence of multiple equilibria) and high uncertainty. There are strong indications that telco-ecosystems represent *complex adaptive systems* as they exhibit several generic properties, e.g. emergence, self-organization and non-linearity (Mitleton-Kelly 2003). A telco-ecosystem consists of many heterogeneous components or agents that are woven into a web of causal links and respond interactively to forces in the environments via feedback. Although the decisions made evolve, as the past is co-responsible for the actual and future behavior, these systems are proven hard to predict as the feedback of interactions exhibit non-linearity. Therefore the understanding of the dynamics of one domain in isolation from the other is impossible and demands both, a systemic and evolutionary view.

Hence, we believe that existing explanations of ICT markets need to be reexamined in order to reconsider co-evolution between technological and economic as well as regulatory forces/ developments to provide a more comprehensive basis for policy makers (Boisot and McKelvey 2011). However, what direction could this reexamination take? In the subse-

quent sections of this paper, we will attempt to galvanize telecommunication research on resilience in order to address these gaps through the multi-disciplinary lens of “resilience thinking” (Walker and Salt, 2006) and the application of the well-known adaptive cycle (Gunderson 2002) which has already attracted attention from researchers with different academic background, such as ecology or economic geographers (Martin 2011). This approach enables a holistic analysis of the ICT sector as a complex adaptive system and recognizes the evolutionary nature of the sector.

4 Adaptive Cycle

Going beyond the “Gaussian world” of reductionism, equations, linearity and prediction to a complex perspective is both challenging and necessary (Boisot and McKelvey 2011). Borrowed from/rooted in ecology and system theory, we attempt to apply the “adaptive cycle model” which is intended to account for the contradicting characteristics of complex systems stability and change. According to Gunderson and Holling, a conceptual framework must satisfy the following criteria in order to provide understanding of complex systems: Careful simplicity, dynamic and prescriptive view of systems, embracing uncertainty, unpredictability and continuous change (Holling 2001). It focuses particular attention on the evolving health of a system that is operationalized by the concept of resilience, “the capacity of a system to absorb disturbance; to undergo change without crossing a threshold to a different system regime” (Walker and Salt 2006, pp. 28–38). The underlying rationale is that complex adaptive systems exhibit cyclical behavior and only temporal multiple (no stable) equilibria due to two conflicting tendencies: the tendency of systems towards increasing (internal) connectedness, order and efficiency (potential) among components or agents and the resulting reduction of resilience towards environmental (external) conditions. As a consequence, there is a trade-off between connectedness, potential and resilience. Whereas potential, as the systems inherent accumulated resources, usable knowledge, and accessible skills, sets the limits to what is possible, connectedness relates to the interdependency of (sub) levels and internal controllability of the system.

The “adaptive cycle” (Figure 1) seeks to reconcile this contradicting cycle by positing four different stages/phases of system behavior and structure in dependence of its connectedness, potential and its resilience (Gunderson 2002). Each stage of the adaptive cycle is therefore associated with a different level of the three dimensions of change. The first *ex-*

plotation or “r-“ stage describes an emerging and developing system in which resources are readily available and entrepreneurial agents exploit niches and opportunities to compete. Due to the low levels of potential and connectedness, the innovatory agents are very much influenced by external variability and initiate intense activity energized by pioneer spirit and low cost of experimentation and failure. Components, such as start-up organizations that survive, begin to intensively accumulate resources and improve productivity. This triggers an incrementally proceeding transition to the *conservation* “k-“stage of increasing stability and rigidity: the system becomes stable, well-established and maybe even path-dependent. The competitive edge shifts from innovative opportunists to specialists who reduce the impact of variability through their own mutually reinforcing relationships. In contrast to efficiency gains through high potential and connectedness, the system’s resilience is diminishing as flexibility/redundancy and adaptability decline and the system become more vulnerable to surprises. If such a surprise or crisis occurs, e.g. a drought in an ecological system or a disruptive innovation, the gale of Schumpeterian creative destruction can be suddenly released into the destabilizing *release* or “Ω-” stage. Here, the resources and connections rapidly decline, e.g. the trees in a mature forest or the flagship companies of an old industry to set the stage of reorganization (“α-”) in which the system runs through a period of transformation, experimentation and restructuring. In this most uncertain stage with little system control and connectivity, the system’s potential and resilience are slowly increasing because of openness and structural flux allowing the development of novel ideas and species. One possible outcome of this this stage is replacement, where the system re-establishes itself, and begins a new cycle of growth and accumulation of resources (e.g. a burned forest reestablishes, a bankrupt car manufacturer is acquired by another company to manufacture new cars). The other is renewal or, where the old system is replaced by a new system with different identity and function e.g. industrial transformations and restructuring (Gunderson 2002).

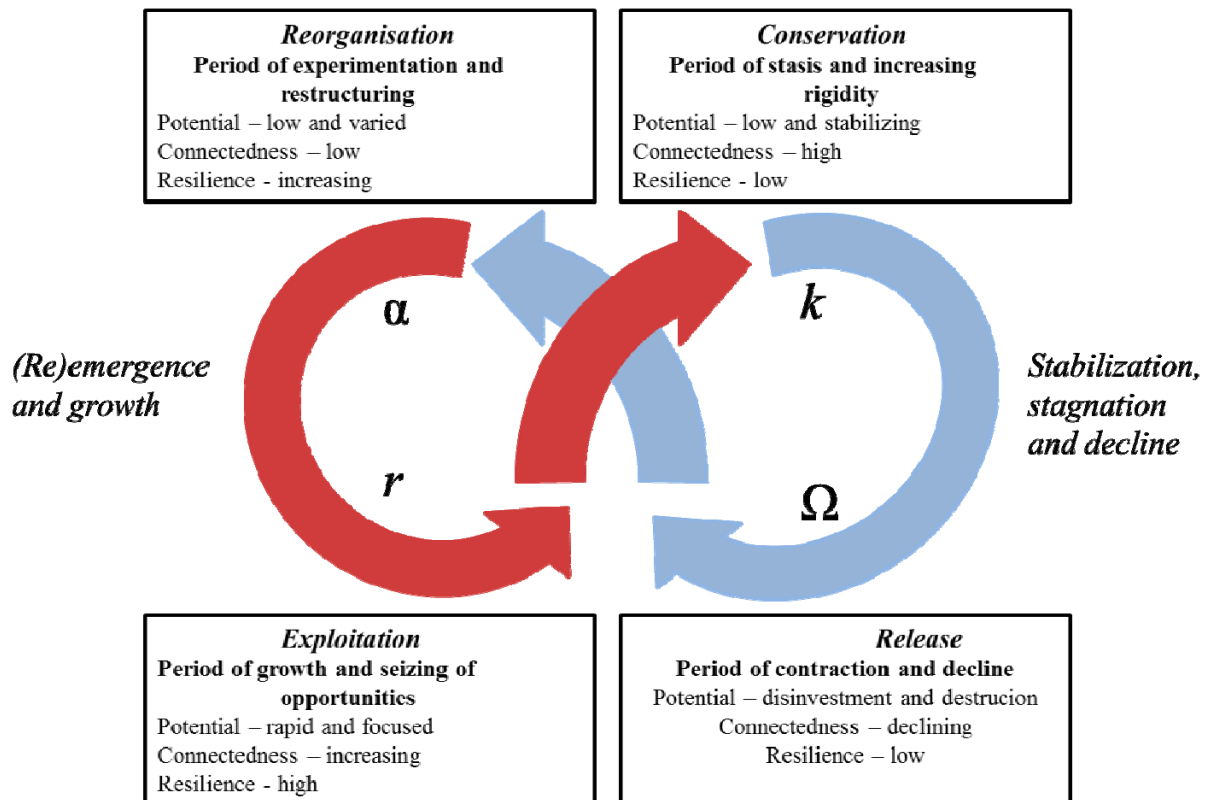


Figure 1: Adaptive Cycle

The adaptive cycle model has particular interesting implications for the understanding of the ICT ecosystem: It illustrates the limited growth and accumulation of resources and its relationship to the system's degree of connectedness. Moreover, the model further suggests that degree of connectedness may reach a critical point where it can undermine system resilience. In the following section, we aim to show that major segments of the industry such as Internet content providers and telcos have gone through the stages of the adaptive cycle described in basic ecosystem dynamics. Applying this adaptive cycle to ICT industry dynamics, we expect to find the current industry's equilibrium might not be stable in the long term, and eventually the industry will enter into a new stage of the adaptive cycle. This finding would be consistent with Friederiszick et al. (2011), who based on more conventional economic analysis, suggest that the current business models for infrastructure providers might not be sustainable in the mid and long term.

5. Resilience analysis: Applying the adaptive cycle to the ICT ecosystem

Applying the adaptive cycle, the ICT ecosystem's *resilience* will determine whether it will be able to adapt to challenging disturbances, e.g. structural instability, investment requirements, declining revenues but increasing debt, and changes of market power (Noam 2010). Or will the ICT sector eventually evolve into a qualitatively different stage. In our analysis, we attempt to identify the main drivers that may determine the resilience of various players in the sector. Therefore, we attempt to map the recent history of European telecommunication markets to the different adaptive cycles.

For many decades, telecommunications was a monopolistic system that was state owned and tightly regulated in all European countries. This era shows all the attributes of the adaptive cycle's conservation stage, in particular a low degree of resilience. The state monopolists had little reason to adapt or to respond to new developments. It took the German Bundespost fifteen years to replace the handset introduced in 1948 (the "W 48") with a new model. In his analysis of the development of the telecommunications industry, Wu (2011) concludes that over many decades, communications by wire became "stagnant, resembling a small-scale version of the Soviet planned economy" (p. 307). In the early 1990s, as market liberalization approached, the industry entered a stage of release, with increasing resilience as the monopolists had to start preparations for privatization and market liberalization.

In European telecoms, market liberalization in the late 1990s was a landmark fundamentally reshaping the industry. It triggered a stage of industry *reorganization* (Table 1). Regulatory agencies were established and sector-specific regulation came into force. The incumbent's networks were opened for new competitors. The incumbents that were culturally and traditionally shaped by engineering and state bureaucracy (Noam 2010) had to learn to adapt to the new competitive environment. The new-entrants had to build telecom-specific knowledge in order to prosper in the new industry. Resilience, i.e. a firms' capacity to adapt, gradually increased. European incumbents formed international alliances such as Global One or Concert in order to provide borderless seamless services to their internationally operating business customers (Inkpen and Ramaswamy 2006).

Consistent with the adaptive cycle logic, the reorganization stage was followed by an era of *exploitation and growth* in the first half of the 2000s. For example, in Germany telecom market revenues grew from €6.2bn in 2000 to €7.3bn in 2005 (Bundesnetzagentur 2012). In the exploitation and growth era, new-entrants were able to seize substantial mar-

ket share. In the rapidly growing market for broadband connections, Deutsche Telekom's competitors increased their market share from just 4.7% in 2000 to an impressive 40.6% in 2005. Telecom regulation was successful in opening up the telecom market for new competitors. The early 2000s also witnessed the European auctions of 'third generation' (3G) mobile telecommunication licenses. These auctions were some of the largest in history, raising cumulatively over \$100 billion (Klemperer 2004). After the cross-border strategic alliances of the 1990s had failed, major telcos changed their internationalization strategy to major cross-border acquisitions. Prominent examples include Vodafone's take-over of Mannesmann in 2000 and Deutsche Telekom's acquisition of VoiceStream in 2000 and 2001. Firms' capabilities and willingness to heavily invest in new technologies and cross-border acquisitions indicate high levels of resilience, as new opportunities are being seized and proactively created.

In German and in other European telecom markets, revenues stagnated and/or started declining in the second half of the 2000s. Following the adaptive cycle, the transition to the *conservation stage* began. In this era, mobile penetration rates surpassed the 100% threshold in most European markets. With markets increasingly saturated and a regulatory regime favouring fierce price competition, competition intensity further increased indicating a high level of connectedness between firms in the telecom sector. Even though major new investment opportunities – such as replacing copper access infrastructure with fiber became available. European telcos were hesitant to engage in large-scale investments, indicating a decreasing degree of resilience. Major innovations shaping market developments, such as the Apple iPhone in 2007 came from adjacent industries. Digital platforms such as Apple's have transformed the digital value chain, creating ecosystems with new substitutes for traditional telco services.

Again, following the adaptive cycle, the telecom sector entered a *stage of decline and release* in the early 2010s. Symptoms of this decline can be identified as further decreasing revenues and profitability and an under-average stock market performance (Friederiszick et al., 2011; Noam, 2010). There are three main reasons for the telco industry's decline. First, the "fundamentalist" regulatory regime, focused on promoting competition and static efficiency, has induced plummeting prices, revenue and profit erosion over years, and has left telecom investors highly sceptical. Second, major telcos struggle with substantial levels of debt and the sector is highly leveraged. The European debt crisis forced telco operators to reduce their debt, as companies' credit ranking is dependent on their debt/equity ratio. Poor return on investment and the current macroeconomic environment have led most telcos to

invest less. Third, technology leaps are changing the ICT ecosystem, and telcos are facing increasing competition from non-regulated OTT player.

Basically, the adaptive cycle model envisages three possible scenarios following the release and decline phase: i) the cluster disappears, ii) the cluster undergoes a phase of renewal, or iii) a new (different or related) cluster emerges and replaces the old paradigm. Telecom industry analysts emphasize that telecoms “business as usual” is being replaced by a “new normal” with a broader and more complex playing field (McKinsey 2011) operators must break out of their traditional mindsets and evolve to new business models that cut across traditional operators’ boundaries and are adapted to the shared opportunities of transforming markets (Booz 2010). In line with this perspective, the renewal of the cluster is the most likely option.

Table 1: Adaptive Cycle stages of ICT ecosystem since 1990

	Reorganization and restructuring (α) <i>(late 1990s)</i>	Exploitation and growth (r) <i>(early 2000s)</i>	Conservation (K) <i>(late 2000s)</i>	Decline and Release (Ω) <i>(early 2010s)</i>
	<i>Period of experimentation and restructuring</i>	<i>Period of growth and seizing opportunities</i>	<i>Period of stasis and rigidity</i>	<i>Period of contraction and decline</i>
Key market developments	Market liberalization allows new competitors’ market entry.	New entrants rapidly gaining market shares. Market volume growing.	Market consolidation. Market saturation, stagnant revenues. Mobile and broadband penetration at high levels.	Declining market revenues and profits. OTT players threatening telcos’ core business.
Regulation	Regulatory agencies established. Sector specific regulation comes into effect.	Sector specific regulation focused on static efficiency and regulating competitors as if they were natural monopolies		
Key technological and product developments	Fixed voice telephony predominance Emergence and fast evolution of mobile telephony	Emergence and fast evolution of broadband connections	Fiber-optics access networks (FTTx) becoming available Diffusion of mobile broadband	
Resilience (adaptability)	<i>Increasing:</i> telcos adapting to new competitive environment; new business opportunities (mobile) are being seized. Era of the global alliances (Global One, Concert).	<i>High:</i> Telcos investing heavily in new technologies (3G, DSL broadband networks) and international acquisitions	<i>Low (decreasing):</i> Telcos cautious with large scale investments in new technology (fiber optics)	<i>Low:</i> Telcos reluctant to invest in new technology (fiber optics) and trying to cope with OTT players
Connectedness (interdependencies among cluster firms)	<i>Low:</i> incumbent typically self-centered; new-entrants focused on ‘getting started’	<i>Increasing:</i> new-entrants fighting for market shares, incumbents trying to minimize market share losses	<i>High:</i> As market growth slows down, competition intensity increases	<i>Declining</i> due to increasing competition from outside the industry

6. Conclusion, discussion and outlook

The starting point of our exploration was the observation that the global information and communication technology industries have been facing fundamental changes. The convergence of related markets toward a broader interrelated ecosystem is changing the cost and market structures, putting established telco providers under massive pressure. Although policy makers acknowledge the greater importance of ICT as key drivers for productive growth and innovation, the asymmetric developments between OTT and telco are already resulting in decreasing technological and infrastructural investments. Managing the complexity and uncertainty of future ICT ecosystems in order to secure a functioning and resilient ICT infrastructure requires new tools and theoretical frameworks for regulators and industrial actors. Hence, we attempted to address these gaps through the introduction of the multi-disciplinary adaptive cycle model (Gunderson and Holling, 2002). This approach enables a holistic and dynamic analysis of the ICT sector as a complex adaptive system and recognizes the evolutionary nature of the sector.

Our research contribution is twofold in this working paper: Following the adaptive cycle, we identified several stages of industrial evolution in the European (particularly the German) ICT ecosystem based on the key variables potential, connectedness and resilience. As the first qualitative attempts indicate the consistency and transferability of adaptive cycle within the telco markets. We further derived three possible future scenarios emphasizing the renewal of the ICT ecosystem with increasingly blurred industrial borders and more cooperative, symbiotic actions across the transformative markets as the most likely option. In spite of the wide recognition of co-evolution and complex adaptive systems in ICT markets and the validity of the adaptive cycle in several different areas, there has been (according to our best knowledge) no application transfer of the adaptive cycle, thus far.

Allied to the innovative nature of our approach, we have also found substantial evidence that major segments of the industry, such as Internet content providers and telcos have gone through the stages of the adaptive cycle described in basic ecosystem dynamics. These stages include (rapid expansion of new players), the conservation stage (temporary stabilization), the) and the last two are very like Schumpeter's idea of creative destruction (Schumpeter 2005). Applying this adaptive cycle to ICT industry dynamics provides the insight that the current industry's equilibrium might not be stable in the long term. Hence, the ICT ecosystem's resilience determined whether it would be able to adapt to challenging disturbances, such as structural instability and investment requirements

The regulatory implication of our initial observation is that modern regulation must analyze the entire digital value chain. Market analysis must be future-oriented so that it does not prevent competitive processes as a result of a narrow definition. To this end, a new understanding of the market must evolve: the potential bottlenecks and gatekeepers of the future will not be the same as those in the past (Boston Consulting Group 2011). The core task for policy maker, competition authorities and the regulators will be to guarantee a level playing field along the Internet value chain, i.e. to ensure the same basic conditions, equal opportunities and competitive conditions for all players along the Internet value chain. Content providers already generate almost two thirds of their revenues in the Internet value chain, whereas high investments in broadband network expansion have to be borne by the telecommunications enterprises. In addition, telecommunications companies are subject to sector-specific regulation, while other competitors along the Internet chain can operate flexibly in the market. The result of this lack of equal opportunities to the disadvantage of the telecommunications companies is that necessary investments in broadband are not being made. Recommendations to maintain the resilience and sustainability of an ICT ecosystem are presented by Friederiszick et al. (2011). Against the background of increasing traffic volumes and the growing requirements for transmission standards, they offer a set of four alternative Internet business models: "Congestion Based" (higher prices for traffic at peak hours), "Best Effort Plus" (Best Effort network for conventional applications, premium service for innovative services), "Quality Classes - Content Pays" (content providers have the choice between different quality classes for conventional and innovative services) and "Quality Classes - User Pays" (consumers have the choice between different quality classes) which are better suited to handling the current challenges for specific services and, at the same time set more incentives for investments in infrastructure. Realizing such changes of the current Internet model is difficult, as the different actors within the ICT ecosystem have contradicting incentives, particularly when optimizing short-term performance and benefits. The perception and understanding of markets as complex adaptive ecosystems might help actors to solve tensions by highlighting the reciprocal nature of relationship within the ecosystem. The decline of telco infrastructure provider might bear unforeseeable cascading risks (delayed feedback) also for OTT and finally the consumer, as the resilient provision of internet-enabled services depends on the underlying infrastructure.

In particular, the concept of interconnectedness of levels has important applications to the ICT industry, where the cyclical rates between technology, markets and regulatory regime

substantially differ. Giving more emphasize to interconnectedness may encourage policy makers and business managers to rethink strategic moves: collaborative optimization of the ecosystem performance may pave the way for realizing a more resilient and sustainable delivery of ICT services.

The present paper was an initial step to introduce the concept of resilience and its application to the adaptive cycle in the arena of ICT ecosystems. While our current resilience analysis is purely descriptive and difficult to generalize, we aim to extent future research toward two directions:

First, we intent to measure and analyze the resilience determinants connectedness and potential within the telco markets during the last decades based on quantitative statically approaches such as network analysis (Barabási,1999; Newman 2010). Based on public available proxies we can measure the connectedness of telco actors based on well-established indicators of network theory such as size, density or centrality. This will further help to visualize the interdependencies of the different players, as for example illustrated by Basole and Karla (2011) in the context of mobile platform evolution. Secondly, we will attempt to elaborate the applicability of the extended adaptive cycle, the so called panarchy model, which takes explicitly the dynamics and cross scale interactions and interdependencies of different levels across the ICT value-generation into account (Gunderson and Holling, 2002). This may provide further insights about co-evolutionary interplay and its cascading economic consequences.

This analysis has provided insights about the historical development of the ICT ecosystem in line with the adaptive cycle. We also further envisage three possible scenarios following the release and decline phase. Our observation indicate that the need of telco operators to break out of their traditional mindsets and evolve to new business models that cut across traditional operators' boundaries and are adapted to the shared opportunities of transforming markets. This option might be the most promising way to navigate a graceful passage of the ICT through the backloop of release stage toward reorganization.

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