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Regulation and Digital Innovation: Theory and Evidence

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Regulation and Digital Innovation: Theory and Evidence¹

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Abstract

Information and communication technologies (ICTs) are an important determinant of productivity growth and innovation. This study examines the effects of sector regulation on innovation in telecommunications and related information industries. A typology of innovation processes in ICT industries is developed. The conditions conducive to innovation under varying economic conditions are explored theoretically. Conjectures derived from this conceptual analysis are tested using data for 32 countries for the years 1997-2010. Two ICT innovation indicators (number of secure servers and fixed broadband access lines) were utilized to test the effects of sectoral regulation. In line with other studies of the effects of regulation on innovation, the study finds that more stringent regulation had a statistically significant negative effect on the number of secure servers and the number of fixed broadband access lines. This result holds for a broad measure of regulatory density as well as for the stringency of market access regulation and price regulation.

JEL codes: L51, L86, L96

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1. Introduction

Information and communication technologies (ICTs) are an important determinant of productivity growth (World Bank 2009; Röller and Waverman 2001; Fornefeld et al. 2008). In an increasingly knowledge-based economy, they are also an important precondition for many types of innovation. Digital innovation affects economic growth directly and indirectly. In addition to its effects on traditional productivity metrics, it has facilitated a wide range of organizational innovations (Brynjolfsson et al. 2002; Brynjolfsson and Saunders 2010). Moreover, as discussed in detail by Brynjolfsson (2011), but also by others (e.g., Antonelli 2008; Fransman 2010), it has affected the way many innovations are carried out. In the production of digital services, it is much easier to continuously experiment, evaluate the experience with innovations, and to replicate successful changes. Moreover, digital technologies allow new forms of collaboration that further enhance these features (e.g., Chesbrough 2006, 2003)

Creating conditions that foster innovation has therefore become a central matter of policy-makers and regulators. In the highly interconnected and interrelated ICT ecosystem, innovation takes place at multiple layers. First, the information and communication technology (ICT) sector itself has a considerable innovation record and future innovation potential. Sector regulation affects the speed with which this innovation potential is brought to the market and direction of innovation efforts. Second, as the central nervous system of the knowledge economy, the telecommunication sector provides a platform technology for a broad range of other industries in manufacturing and services. The ability to innovate of firms in these sectors is critically dependent on the availability of advanced ICT infrastructure. Whether and how regulation of telecommunications influences innovation in these related sectors or the economy overall is therefore a question that should be taken into account. This study examines the influence of sector regulation on innovation in the ICT sector and on broader innovation activity.

Regulation influences innovation in multiple ways: it affects the risk of innovation projects, influences the profitability of innovations, and often constrains the scope of available innovation activities. As many forms of regulation are applied asymmetrically, the innovation activities of different participants in the information and communication ecosystem are also affected differently. The net effect of regulation at a sector level will then depend on the relative magnitude of effects that support innovation and those that impede innovation. Conceptual analysis will often not provide clear a priori answers to this question. We therefore develop an empirical approach to test major conjectures regarding the effects of regulation on ICT innovation.

After a review of the research on regulation and innovation, the study clarifies the notion of innovation in the ICT ecosystem. Different types of innovation are distinguished and supportive regulatory conditions are identified. This framework is used to design an empirical model for the study of innovation. To this end, several innovation proxies that reflect different types of innovation in and related to the ICT ecosystem (secure servers, broadband, fiber, and IPTV) are utilized. The intensity and stringency of regulation is captured using the regulatory density index developed by Zenhäusern et al. (2007) and updated by Vaterlaus et al. (2011).

The remainder of the paper is structured as follows: the next section briefly reviews the research on regulation and innovation. Section three develops a conceptual framework for the empirical analysis. The empirical model is introduced in section four and main findings are discussed in section five. Section six reiterates key conclusions.

2. Regulation and innovation

Following standard approaches, innovation is defined as the introduction of new processes, products or services, management methods, and methods to bring products to customers in market and non-market environments (e.g., Stoneman 2010; OECD 2005). In the highly interconnected and interdependent ICT ecosystem, innovation takes place at different nodes of the value network and can be operationalized and measures at different layers of the system. As a technology-intensive sector, the ICT infrastructure, including networks, equipment, devices, and services, is the locus of continuous innovation. At the same time, broadband networks are platforms upon which innovation in other industries depends. Krancke and Müller (2011) conceptualize platform innovations as significant changes in technical infrastructures that enable other process and service innovations. This is similar to the notion of general purpose technologies advanced by Bresnahan and Trajtenberg (1995). Although early communications technologies, such as the telegraph and the telephone also served as critical infrastructures, the Internet and especially advanced broadband, such as fiber optical networks, due to their very broad range of uses, are general purpose technologies in a new sense. An even broader literature has pointed out the significant spill-over effects that exist in infrastructure industries (Martin 2002; Greenstein 2004; Sidak and Teece 2010; Hogendorn forthcoming). Both approaches have in common that they point to the significant innovation potential in other industries that is generated by advanced communication platforms. In as far as regulation affects innovation in platform industries, it has potentially significant spill-over effects in related industries.

The effects of regulation on innovation in the telecommunications sector have received less direct attention than the effects of regulatory reform on static efficiency (e.g., prices, total factor productivity) (see Table 1 for a summary of important contributions). Nonetheless, this research literature captures aspects of innovation also, as static efficiency gains may also be the outcome of process and product innovations. A broadening and deepening of the available empirical data, which went hand in hand with the expansion of regulatory reform to an increasing number of countries, allowed more systematic cross-national inquiries. Taking advantage of this information, researchers increasingly employed econometric methods to examine the effects of regulatory reform (e.g., Bortolotti et al. 2002; Megginson and Netter 2001; Wallsten 2001). Although the findings are diverse and heterogeneous, a pattern is visible: liberalization and competition are strong drivers of efficiency gains (e.g., Gutierrez and Berg 2000; Cave and Valletti 2000; Eliassen and From 2007; Eliassen and Sjøvaag 1999); privatization has ambiguous effects but contributes to efficiency gains if combined with liberalization and proper regulation (e.g., Wallsten 2001, 2004; Ros 1999; Vickers and Yarrow 1988); and the introduction of independent regulation contributes to enhanced efficiency (e.g., Edwards and Waverman 2006; Bauer 2005).

The literature that touches aspects of innovation more directly falls into five areas. These are concerned with: (1) the broader national context of innovation, (2) innovation and regulated monopoly, (3) effects of early experiments with competition, (4) regulated competition, and (5) innovation in products and services. The influence of the broader institutional arrangements, such as the interaction of universities,

industry, and government, on innovation was studied in papers emanating from the national innovation systems (NIS) literature (Mowery and Simcoe 2002a; Nelson 1993; Edquist 1997, 2003; Langlois 2002a). Among the few contributions dealing with regulated monopoly were the paper by Averch and Johnson (1962) on the effects of rate-of-return regulation on the regulated firm's input choices and Bailey's (1974) research on the effects of the timing of regulation on efficiency improvements. A third group of papers, written during the early experiments with competition, explored the effects of price cap and other forms

Table 1: Selected contributions to the research literature on regulation and innovation

Author	Approach (Data and Period)	Main results regarding regulation and innovation
Sectoral regulation, innovation, and investment		
Ai and Sappington (2002)	Panel data analysis (U.S., 1986–1999)	Investigates the impact of incentive regulation on the deployment of digital switching and fiber optic focusing on operating cost. Findings: Various incentive regulatory schemes are more effective for the deployment of modern equipment (i.e., fiber-optic cable) than rate of return. Local competition and incentive regulation play complementary roles in motivating cost reductions and the deployment of new technologies. Operating costs decline as local competition increased under incentive regulation.
Bauer (2007)	Theoretical analysis	Examines the innovation incentives under different scenarios. Findings: Alternative specifications of scenarios result in various and mixed innovation incentives.
Bauer (2010)	Theoretical analysis	Examines individual and joint effects of regulatory and other policy instruments on the investment incentives in telecommunications. Findings: A more stringent regulatory approach will cause an lower level of investment in networks and services whereas a less stringent regulatory intervention will generate a higher rate of innovation and investment.
Bourreau and Doğan (2001)	Theoretical analysis	Investigates which types of regulatory schemes are likely to promote innovation. Findings: Ex post control mechanisms provide a greater flexibility for incumbents, whereas ex ante control may provide entrants a competitive advantage. Regulating standards in the markets in which there is no market dominance provides the entrants with superior incentives for innovation. Price regulation would provide the best incentives for innovation. The effect of unbundling would depend on the conditions of supply.
Bourreau and Doğan (2005)	Theoretical analysis	Examines the effects of unbundling the local loop on the entrant's timing of technology adoption and investment in new technology. Findings: unbundling results in the incumbent setting a rental price that is too low. As a result, it delays the entrant's technology adoption and investment in new infrastructure.
Bourreau and Doğan (2006)	Theoretical analysis	Investigates the effects of unbundling on facility-based competition. Findings: Since unbundling delays the entrant's investment in new

		infrastructure, it also delays facility-based competition.
Choi and Kim (2010)	Theoretical analysis	Analyzes the effect of net neutrality regulation on investment incentives. Findings: The relationship between the net neutrality regulation and investment incentives is subtle.
Distaso et al. (2006)	Panel data analysis (14 European countries / 2000 – 2004)	Examines the effects of competition policies (i.e., inter- and intra-platform) on the diffusion of broadband access. Findings: While inter-platform competition policies drive broadband adoption, intra-platform competition policies do not play a significant role in the diffusion of broadband technology.
Ehrlich, Eisenach and Leighton (2010)	Theoretical analysis	Examines the impact of regulation on innovation in wireless communications. Findings: Increased wireless regulation would severely reduce innovation and consumer choice.
Friederiszick, Grajek and Röller (2008)	Panel data analysis (25 European countries, 1997-2006)	Examines the relationship between entry regulation and infrastructure investment. Findings: Stricter entry regulation discourages infrastructure investment by entrants but has no effect on incumbents.
Grajek and Röller (2009)	Panel data analysis (20 EU members, 1997-2006)	Examines a trade-off between access regulation and investment incentives. Findings: access regulation negatively affects investment incentives of both total industry and individual firms.
Greenstein et al. (1995)	Panel data analysis (U.S., 1986–1991)	Examines the effects of different regulatory structures on the deployment of fiber optic cable, ISDN, SS7 signaling, and digital switching. Findings: price regulation has a positive effect on the deployment of modern equipment, and it is a stronger regulatory mechanism than the standard earnings sharing scheme. Therefore, regulators should focus more on price regulation than on regulating profits.
Hausman (1997)	Panel data analysis (U.S., 1991-1994 for voice mail; 1989-1993 for cellular phone service)	Measures the actual effects of regulatory delays in new telecommunications services. Findings: Benefits from the introduction of new services can be considerable and regulators should be very careful not to make regulation delay since it may cause large losses in consumer welfare.
Jorde, Sidak and Teece (2000)	Case study (U.S.)	Examines the tradeoff between innovation and mandatory unbundling regulation. Findings: Mandatory unbundling at TELRIC prices will adversely affect the ILEC's incentives not only to upgrade or maintain existing facilities, but also to invest in new facilities. Mandatory unbundling at TELRIC prices will also encourage CLECs to deviate from the socially optimal level of investment and entry. The

		confluence of mandatory unbundling and other FCC policies aggravates the distortion of investment decisions.
Prieger (2002)	Panel data analysis (U.S., 1984-1997)	Examines the effects of FCC regulation on the innovation and introduction of advanced telecommunications services. Findings: firms would have introduced more service innovations (62%) if the regulation had not been in place compared to the stricter regulation being in place.
Prieger (2007)	Panel data analysis (U.S., 1991-1997)	Examines the effects of regulation delay on the time to introduction of new telecommunications services. Findings: the reduction in regulation delay decreases time to introduce a new service.
Sidak and Teece (2010)	Theoretical analysis	Explores the effects of net neutrality regulations, including the nondiscrimination rule, on innovation. Findings: Speculative fears based on the economic arguments in favor of network neutrality regulation cannot justify the overbroad ban on optional QoS transactions embodied in the nondiscrimination rule.
Wallsten and Hausladen (2009)	Panel data analysis (27 European countries, 2002-2007)	Examines the effects of unbundling on investment in new fiber networks. Findings: There is a significant negative correlation between the number of unbundled DSL connections per capita and the number of fiber connections. The negative impact of unbundling regulation on investment in new infrastructure is also identified.
Regulation and performance		
DeMaagd and Bauer (2010)	Computational analysis	Examines the effects of non-discrimination rules on performance characteristics. Findings: network price differentiation may benefit content and application providers and does not necessarily benefit network operators.
Edwards and Waverman (2006)	Panel data analysis (15 EU members, 1997–2003)	Examines the effects of public ownership and regulatory agency independence on interconnect rates. Findings: A publicly owned incumbent charges higher interconnect rates than a privately owned incumbent since the government influences regulatory outcomes in favor of the incumbent. However, institutional features enhancing the independence of a regulatory agency can mitigate this effect.

of incentive regulation on infrastructure investment (e.g., Greenstein et al. 1995; Vogelsang 2002; Ai and Sappington 2002; Armstrong and Sappington 2006; Sappington and Weisman 1996). A recurring finding was that compared to traditional rate-of-return regulation price caps increased the incentives to pursue cost-reducing process innovations.

During the 1990s, many countries started to rely on asymmetric forms of regulation. This period of regulated competition was initially envisioned as a short transition from monopoly to competition. Consequently, an increasing number of contributions examined the effects of asymmetrically applied regulatory instruments—such as unbundling mandates on incumbent service providers—on sector performance. Papers studies effects on competition, the adoption of broadband, and investment at the network layer. Some of the dependent variables, although not directly geared to measure innovation, are influenced by the innovation rate. For example, one would expect a higher adoption level in a country with a more innovative ICT industry. Papers that focus on the network layer sometimes treat investment and innovation as synonymous because innovations typically require investment and most investment also has an innovation component. Writings in this tradition revealed noticeable effects of regulation on the type and level of investment, but there is some disagreement as to the direction and strength of the effects. A majority of the papers find that more stringent regulation favors incremental forms of service-based investment at the expense of facilities-based investment (Hazlett 2006; Friederiszick et al. 2008; Grajek and Röller forthcoming; Bacache et al. 2010, 2011; Bourreau and Doğan 2005, 2006, 2001; Bourreau et al. 2010; Wallsten and Hausladen 2009). However, a few papers reach opposite conclusions or see a role for continued regulation in support of investment (e.g., de Bijl and Peitz 2005; Distaso et al. 2006; Cave 2010).

A small fourth group of contributions studies the effects of regulation on product and service innovation. Many of the papers examine the effects of regulation on product and service innovation in general (e.g., Alesina et al. 2005) and fewer have an emphasis on telecommunications (Prieger 2001, 2004, 2008, 2007). One major difference between studies of the effects of regulation in general and those that focus on telecommunications is the symmetry of regulation. In the general case, regulation is typically applied symmetrically to all players whereas in telecommunications regulation is typically asymmetric. Independently of their scope, these studies suggest that overly stringent regulation has detrimental effects, often at considerable direct and indirect cost, to society (e.g., Hausman 1997; Alesina et al. 2005).

Innovation issues are also at the core of the pending policy discussion on vertical separation and network neutrality. Here the main issue is the principles that should govern business relations between network operators and service/application providers. During the past decade, several countries have decided to vertically separate network and service provision to minimize the incentives of a network operator to discriminate against competitors and to maintain strong innovation incentives at the application and service layer. This approach has raised many concerns with a thorough assessment still outstanding (Cave 2006, 2002; Cave and Doyle 2007). Beginning in the U.S. as a response to the elimination of common carrier obligations on network operators, the notion of network neutrality has entered the public policy debate. A nascent economic literature has made contributions by examining economic decisions under alternative rules. Due to the lack of empirical observations, most papers use game theoretic analytical models with a few that apply simulation analyses (e.g., DeMaagd and Bauer 2010). The findings of the papers are often dependent on the specific model assumptions. Several papers suggest that stringent regulatory constraints on the network operator (e.g., a zero-price rule) would diminish short-term

efficiency and would likely also reduce innovation efforts, although on the latter count the outcomes are more varied (Bauer 2007, 2011; Choi and Kim 2010; Economides and Hermalin 2010; Economides and Tåg 2007; Hemphill 2008; Hermalin and Katz 2007; Odlyzko 2009; Shrimali 2008; Krämer and Wiewiorra 2010; Yoo 2005; Spieker and Krämer 2011).

3. A typology of innovation in the ICT ecosystem

Until the 1990s, several specialized networks (voice, cable TV, mobile, satellite) co-existed and enabled specific services. Innovation took largely place within the confines of these industry segments and the associated suppliers of components and equipment. The diffusion of digital technology, the increasing availability of high-capacity networks, and a proliferation of access devices have fundamentally altered the ways in which innovation unfolds in ICT. Most importantly, the technological infrastructures supporting service and applications have become general purpose technologies (Bresnahan and Trajtenberg 1995) that enable many services. Traditional networks were engineered to support specific services; next-generation network platforms support a heterogeneous, broad range of services with varying capacity and other quality requirements. Whereas network infrastructure and applications and services have become more distinct, more separate activities, they remain highly interdependent. In some cases, the coordination between these layers can be achieved by standardized interfaces and interoperability conventions but for more complex services other types of coordination and integration are required. Standardization, interoperability, and the more complex forms of coordination—and therefore the innovation performance of the entire system—in turn depend on appropriate institutional and governance arrangements.

The new horizontal structure is an important feature but there are additional aspects that make advanced ICT a unique innovation system. The stronger separation between the physical infrastructure and the services has strengthened economic features that, while present, were weaker in earlier ICT markets. One aspect is the vertically related, multi-layer system in which the physical, network layer enables a multitude of applications and services. In between physical and application layers may be software development platforms, such as Android, that act as logical enabler of a broad range of applications and services. Freed from many of the technical constraints of the previous generation of networks, innovations in content and applications have begun to proliferate. A second, related aspect is that these technical interdependencies are also reflected in economic interdependencies, particularly the two- and multi-sided nature of the markets that link the firms (e.g., Armstrong 2006; Church and Gandal 2005). Innovation processes in vertically related and systems markets have been studied theoretically and empirically for various industries, including ICT (e.g., Farrell and Weiser 2003).

A third aspect is the presence of pervasive economies of scale, scope, and density on the supply- but also on the demand-side. The capital goods employed in networks have become more fungible and their uses are shaped by strong cumulative effects: as networks are used for a larger variety of purposes they lead to additional innovations and uses (Antonelli and Baranes 2007; Antonelli 2008). The advanced ICT innovation system is therefore characterized by many complementarities and synergies, which contribute to multiple interdependencies and “symbiotic” (Fransman 2010) relations between the players on these layers. Innovation emanates from the decisions of the variety of organizations contributing to this interrelated “ecosystem”. Innovation in any one of the layers has repercussions on the others, enabling but

potentially also constraining innovation opportunities in other layers. Open technical architectures co-exist with proprietary ones, with different implications for the dynamics of the unfolding innovation processes.

Figure 1: Key components of the ICT innovation ecosystem

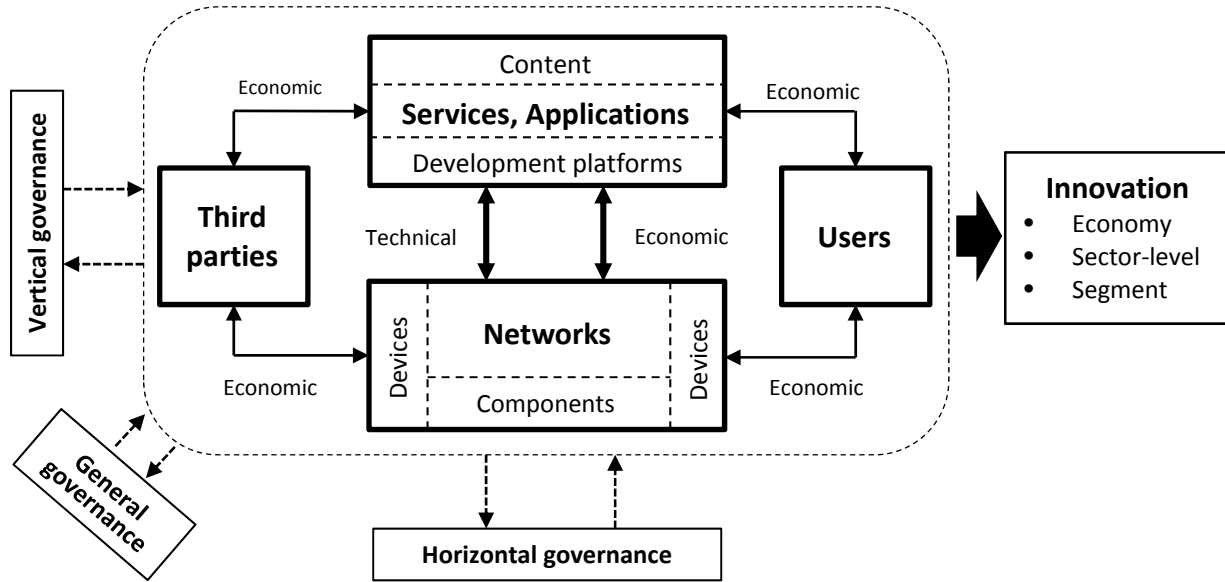


Figure 1 is a simplified representation of this new innovation system and its governance. Besides its technical and economic interdependencies, this system is also influenced by three forms of governance: (1) mandated and voluntary rules affecting horizontal relations of players on one specific layer (e.g., unbundling, interconnection, peering); (2) mandated and voluntary rules affecting vertical relations (e.g., structural separation, forms of net neutrality); and (3) general rules affecting both dimensions (e.g., general interoperability requirements). Moreover, the system is affected by general public policies that do not apply specifically to the ICT sector, such as investment tax incentives or R&D credits. These governance and public policy measures affect innovation in multiple, often contradictory ways. Their effect on ICT innovation is poorly understood and is at the heart of this study. Innovation performance can be assessed at various levels. In this study, we aim at two: (1) innovation enabled by the ICT sector overall and (2) specific types of innovation. To study the first question, broad innovation metrics were collected. To answer the second question, more narrowly construed innovation measures were utilized.

Based on their economic and technical characteristics, different types of innovation processes can be distinguished. A traditional distinction is between product innovations and process innovations. With regard to the extent of an innovation, a spectrum between radical and incremental innovations is often distinguished. Radical innovations imply that many aspects of a process, a product, or of the competencies of participants in the innovation system are affected. Incremental innovations, in contrast, only affect limited dimensions. In network industries with their vast embedded base of capital and skills, technological change and innovation is often “localized.” It may only affecting limited aspects at any point in time but with potentially far-reaching cumulative effects (Antonelli 1992, 2001, 2008; Arthur 2009). The overall innovation performance of the system will then show considerable degrees of inertia

and path dependence. With regard to the location of innovation in the overall system, “edge” innovations at the outer nodes or upper layers of the infrastructure can be distinguished from “core” innovations that affect processes and components at lower layers of the physical architecture of the network. Depending on the degree of interdependence between the layers that are involved, one can distinguish “modular” and “coupled” innovations. This is often a matter of degree. Pure modular innovations do not require any technical coordination beyond knowledge of an interface that links the modular activities to the remainder of the system. On the other hand, strongly coupled innovations require technical and economic coordination across multiple layers of system.

There are hints that the economic conditions vary that best facilitate different types of innovation processes but this issue has not yet been studied thoroughly for ICTs. For instance, several authors argue that innovations in mobile data that require high levels of coordination between the network infrastructure, devices, and applications, thrive in an environment where players are free to negotiate exclusivity arrangements (Ehrlich et al. 2010; West and Mace 2010). On the other hand, many authors point out the benefits of open platforms (Benkler 2006; Lemley and Lessig 2001; Van Schewick 2010; Benkler 2001; Blumenthal and Clark 2001; Zittrain 2008). Both claims may be correct, but for different subsets of innovation processes. To deepen our understanding of this issue, a simplified scheme using a 2x2 matrix of types of innovation processes will be employed.

Figure 2: Typology of innovation processes in ICT and conditions facilitating them

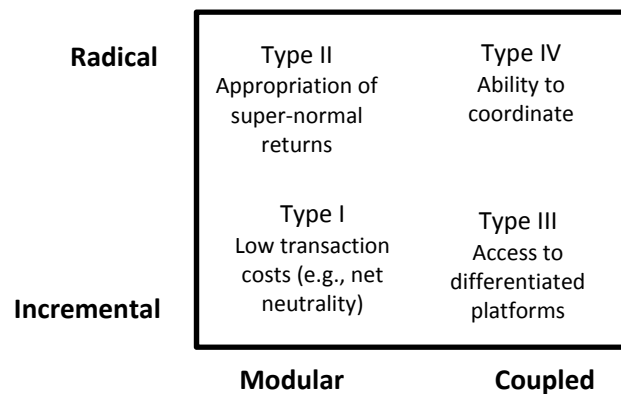


Figure 2 depicts this approach, based on the distinction of two important aspects of innovations: their extent (incremental versus radical) and the degree of inter-layer dependence (modular versus coupled). Both aspects have long been a core interest of innovation research (Baldwin and Clark 2000; Langlois 2002b; Cowhey and Aronson 2009; Van Schewick 2010). A body of economic reasoning suggests that radical innovations thrive in environments that allow firms to appropriate a higher share of innovation rents (Dosi et al. 2006; Kamien and Schwartz 1982; Freeman and Soete 1997), which is easier if they possess some degree of temporary, contestable market power. Incremental innovations, while also facilitated by the ability to appropriate rents, are nourished in highly competitive environments. With regard to the degree of inter-layer dependence it can be said that modular innovations flourish in environments with clearly specified interfaces that minimize transaction and adaptation costs among the players. Coupled innovations, on the other hand, thrive if players at complementary layers can coordinate their policies.

Consequently, one would expect that the conditions facilitating these four principal types of innovation differ, as expressed in the following conjectures: (1) Modular incremental innovations (Type I) will be highest in an environment of intense competition combined with open and transparent standards that enhance interoperability. (2) Modular radical innovations (Type II) will thrive in conditions that combine openness with the ability of those players pursuing radical innovations to appropriate supra-normal profits. (3) Coupled incremental innovations (Type III) are supported by an environment of differentiated competition that allows forms of exclusive contracts among players to facilitate the necessary coordination. (4) Lastly, coupled radical innovations (Type IV) will thrive in environments that grant players the ability to coordinate by means of exclusive agreements combined with the ability to appropriate super-normal profits. Taking care of the cross-national variations in how different types of innovation are governed, the study tests aspects of these conjectures. It investigates empirically how regulatory conditions affect various innovation processes within and beyond ICT. Different forms of regulation affect these conditions for innovation. The next section develops a conceptual framework that forms the basis for the empirical investigation of this study.

4. A stylized model of innovation in the ICT ecosystem

Innovation at the sector level, whether measured with broad aggregate measures or with metrics capturing specific innovation processes, is an outcome of firm decisions. The theoretical approach pursued in this project is therefore to model the innovation decisions of individual firms (or possibly classes of firms, such as regulated and unregulated firms) and to aggregate from the firm level to the sector level. Such a micro-foundation has several advantages. Most importantly, regulatory decisions affect sector outcomes via their consequences for individual firm decisions. Likewise, the effects of other forms of public policy, such as direct public investment in infrastructure, on sector outcomes require an understanding of how they affect the decisions of private firms. Lastly, utilization of a generalized microeconomic approach allows integration with prior research on the factors that determine firm-level innovation decisions in other industries.

For the purposes of theoretical analysis, a highly stylized model is proposed as a starting point. Two layers are distinguished: network platforms and content/application providers. Initially, it is assumed that process innovations are only pursued by firms at the network layer whereas product innovations are only pursued by firms at the content/application layer. Firms strive to optimize their profits by adopting strategies to increase revenues and reduce costs. Innovation efforts are costly but they also reduce costs (in the case of process innovations) or affect demand and hence the revenue potential (in the case of product innovations). The innovation efforts of firms are dependent on the technological opportunities, competition, opportunities to appropriate innovation rents (which will likely be influenced by the intensity of competition), management strategy, demand-side factors, and sector regulation. To isolate the effects of regulation, these other factors need to be taken into account as control variables. Because regulation often is asymmetric, a distinction is made at the network platform level between regulated and unregulated firms. Firms at the content/application layer are assumed to be free of sector-specific regulation (although they are subject to competition rules). The basic structure of the conceptual model is sketched in the following equations.

5.1 Process and product innovations

The profits of regulated network operators investing in process innovations can be represented by equation (1). A profit-seeking firm will seek to maximize the difference between revenues and costs, which include the cost of pursuing process innovations. Process innovations, in turn, reduce the cost of producing the service. Innovation efforts are influenced by technological opportunities of the sector (O), competition in the sector (C), sector demand (D), management strategy of the firm (M) and horizontal and vertical forms of regulation (R). In most cases, the innovation incentives of a regulated incumbent will be affected negatively by horizontal and vertical regulatory measures.

$$\max \Pi_i = q_i p_i(q_i, q_j) - c_i(I_i, R_h, R_v)q_i - I_i(O^N, C^N, D^N, M_i, R_h, R_v) \quad (1)$$

Similarly, the profit maximizing conditions of an unregulated competitor can be formulated as in equation (2). In contrast to a regulated incumbent, however, a new entrant typically will be affected differently than an incumbent by measures of horizontal regulation that eases market entry (e.g., local loop unbundling). On the one hand, such measures will reduce the cost of providing a service. On the other hand, such provisions will bias innovation activities in favor of forms of market entry that can take advantage of cost-reducing horizontal regulation, typically some form of services-based entry. Unregulated market entrants typically are not subject to vertical forms of regulation.

$$\max \Pi_j = q_j p_j(q_j, q_i) - c_j(I_j, R_h)q_j - I_j(O^N, C^N, D^N, M_j, R_h) \quad (2)$$

with

- q_i, q_j ... Quantities offered (regulated incumbent i, unregulated competitor j)
- p_i, p_j ... Price (regulated incumbent i, unregulated competitor j)
- c_i, c_j ... Cost of producing a unit of q_i and q_j
- I_i, I_j ... Investment-, innovation efforts (regulated incumbent i, unregulated competitor j)
- O^N, O^A ... (Technological) opportunities at the network and application layers
- C^N, C^A ... Competitive intensity at the network and application layers
- D^N, D^A ... Demand for network services and applications
- M_i, M_j ... Management innovation strategy (regulated incumbent i, unregulated competitor j)
- R_h, R_v ... Horizontal regulation, vertical regulation

Application providers seek to maximize profits subject to the condition stated in equation (3). In our simplified model, product innovation efforts affect the revenue opportunities of application providers. Application providers are also affected by vertical regulatory rules. For example, stringent vertical regulation that constrains the ability of the network operator to differentiate price and quality of service provided to application providers typically reduces the cost of service provision and expands the set of innovations that will be pursued.

$$\max \Pi_k^A = q_k p_k(q_k, q_{-k}, I_k) - c_k(R_v)q_k - I_k(O^A, C^A, D^A, M_k, R_v) \quad (3)$$

with variables analogous to the process innovation case of equations (1) and (2); k denotes application providers; q_{-k} refers to all application providers other than k .

Solving these conditions yields familiar optimization criteria. For example, incumbent service providers will invest in innovation up to the point where additional costs of innovation are equal to the additional benefits derived from innovation

5.2 Sector-level innovation

Sector-level relations can be found by aggregating over the firm level decisions (see equations (4)-(6)).

Industry-wide innovation at the network layer

$$I^N = \sum I_i + \sum I_j \quad (4)$$

Industry-wide innovation at the application layer

$$I^A = \sum I_k \quad (5)$$

Innovation at the sector level

$$I = I^N + I^A \quad (6)$$

Aggregation is complicated by the heterogeneity of innovation processes but, as the next section discusses in more detail, it is possible to define commensurable metrics that can overcome this challenge. As regulation affects classes of firms differently, with sometimes innovation-enhancing and sometimes innovation-reducing effects, sector-level data only reflect the net effect of such countervailing forces. In as far as regulations affect the types of innovation differently this will be recognized in the emerging patterns of innovation, which are captured by the research project.

5.3 Types of innovation and model extensions

The proposed modeling framework allows differentiated analyses of the types of innovation in the four quadrants (figure 1). These types of innovation processes discussed previously are characterized by different parameter assumptions and/or constellations. In the case of incremental innovations the cost of innovating are dominated by incremental cost. Radical innovations, in contrast, are characterized by high sunk costs that need to be expended before the innovation can be brought to market. In the case of modular innovations, I^A is independent of I^N (and vice versa); this is the case described in equations (1)-(3). In the case of coupled innovations, I^A is dependent on I^N (and vice versa), which can be reflected in modifications of equations (1)-(3).

Other extensions also can be accommodated in the proposed framework. Network platforms and many applications are two- or multi-sided markets (Church and Gandal 2005; Armstrong 2006). Although the basic model captures some of these effects by including demand-side variables, the model can be expanded to explicitly acknowledge this interdependence. Whereas the notion of coupled innovation addresses technical and operational interdependencies, the notion of a two-sided market broadens the perspective to include network effects that affect the economic value of a service. For example, the value of network access may be influenced by the number and diversity of services available at the

complementary application layer. The model also is capable of analyzing the effects of network fragmentation that might occur in the absence of widely adopted interoperability and other standards. In this case, application providers will face costs to adapt their services to different network and device features (e.g., operating systems). Furthermore, they may face higher transaction costs of negotiation with multiple platform operators. Both adaptation and transaction costs will reduce the set of profitable innovations and hence lower the innovation rate at the application layer, other things being equal. Lastly, in principle, the model is sufficiently general to also incorporate the effects of other forms of public policy on innovation, such as the introduction of tax incentives or of direct public infrastructure investment, as adopted by an increasing number of countries (Ruhle et al. 2011).

5. Empirical model and data

As discussed in section 3 above, innovation can be measured at different levels of the ICT ecosystem. It can be operationalized narrowly as process and product innovations that are introduced in the ICT network. Measures such as the diffusion of broadband, supported download speeds, or patents generated in the ICT industry can be utilized to capture ICT innovation in such a narrow sense. If the goal is to approximate the effects of telecommunication platforms on ICT-based industries, a broader measure of innovation is required. Ideally, metrics would be available that capture innovation directly. Value-added in new products and services could be such a measure but it is not systematically collected. Measures such as total spending on R&D that are used by the OECD are, in turn, too broad. Such measures are rarely at hand. Due to data constraints, innovation researchers often measure innovation at the input side (e.g., R&D expenditures) or on the output side (e.g., patents). Both types of measures are proxies for innovation.

In order to assess the effects of regulation both more narrowly and more broadly, innovation indicators that capture both aspects were selected. Like other studies, the availability of data that directly measures innovation activities was a constraining factor and proxies has to be used. Specifically, we sought measures that could capture innovation in the ICT infrastructure and indicators for the innovation activities in other sectors that are enabled by ICT. As a narrow measure we focused on fixed broadband access lines. Broadband can be considered a major process innovation that is the basis for innovative applications by businesses and users. As a broad-based measure, the number of secure servers was used as an innovation proxy. The number of secure servers is frequently used as a measure for the growth and diffusion of e-commerce, which can serve as a proxy for the broad range of innovations enabled by ICT (e.g., OECD 2011, p. 174). Moreover, the metric is used by a number of authors as an indicator for innovation in ICT-intensive sectors in general (Mowery and Simcoe 2002b; Vicente Cuervo and López Menéndez 2006; Bourreau 2001).

One challenge in formulating an empirical model at the sectoral level is that measures of market entry regulation (e.g., unbundling), price regulation (e.g., price caps), and vertical regulation (e.g., vertical separation) often are used asymmetrically and only imposed on firms that are deemed to possess significant market power or that historically served a market (as in the U.S., where the status as an incumbent triggers certain regulatory constraints). Moreover, these forms of regulation affect different types of stakeholders (incumbents, new entrants, platform operators, content providers) in different, often diametrically opposed ways (Bauer 2010). An empirical model formulated at the sector level therefore

can only capture the overall net effects of regulation. Given the positive and negative influences on different players, theory does not provide clear expectations as to the sign of these net effects, which becomes largely a matter of empirical examination.

5.1 Model specification

Equation (7) shows the model specification used for the empirical analysis. The dependent variable is one of the four innovation indicators while the independent variables of interest are measures of regulatory intensity. Denoting by I_{it} innovation activity in country i at time t , the following model is estimated:

$$I_{it} = \alpha \cdot I_{it-1} + \beta_1 \cdot R_{it} + \beta_2 \cdot R_{it}^2 + \delta \cdot x_{it} + e_{it} \quad (7)$$

I_{it} represents a measure of innovation activity. Two different types of innovation activity are used: the number of secure servers and fixed broadband subscriptions. Two forms were used to measure each variable: a logarithmic form and relative numbers (e.g., secure servers per 100 inhabitants). I_{it-1} is the value of I_{it} lagged by one period. R_{it} is an indicator of regulatory intensity based on the revised version of the regulatory density index (RDI) developed by Vaterlaus et al. (2011). The RDI is a very detailed metric of regulatory density. Of the sub-indices and aggregate index values that are available within the RDI, we focused on an aggregate measure (price and entry and quantity regulation) as well as sub-indices for price and entry regulations, which economic theory links most directly to innovation behavior. As several previous studies found non-linear relations between regulation and performance, we also included a non-linear term of the RDI, R_{it}^2 . Furthermore, we had to control for other factors that influence innovation activity, captured in a vector of control variables x_{it} . The list of control variables includes GDP per capita (constant 2000 USD), the population size, and urban population (percent of total population).

5.2 Empirical data

Country-level information was collected for 32 countries from 1997 to 2010. Innovation indicators originate from a variety of sources, including the World Telecommunication/ICT Indicators (hereinafter referred to as ITU-ICT) and from Point-Topic databases (see Table 1). The regulatory index was extracted from data collected by Vaterlaus et al. (2011). Additional data sources include the World Bank's World Development Indicators (henceforth WDI), the OECD Communications Outlooks (henceforth OECD-Outlook) and the political manifesto database (henceforth Political-Manifesto). OECD-Outlook and WDI were used to check for the consistency of the information and to fill missing values in the ITU-ICT data.

Table 2: Description and sources of variables

Name	Type	Description	Source
Fixed	Dependent variable	Number of fixed broadband Internet subscriptions	ITU
Servers	Dependent variable	Number of secure servers	ITU
Total regulation	Independent variable (main)	Sum of all regulation indicators (see Table 2 for more details)	Vaterlaus et al. (2011)
Prc_reg	Independent variable (main)	Sum of price regulation indicators (see Table 2 for more details)	Vaterlaus et al. (2011)
Ent_reg	Independent variable	Sum of entry regulation indicators (see	Vaterlaus et al.

	(main)	Table 2 for more details)	(2011)
GDP	Independent variable (control)	GDP per capita (constant 2000 USD)	WDI
Population	Independent variable (control)	Population	WDI
Urban population rate	Independent variable (control)	Urban population (% of total population)	WDI

With regard to the RDI, there are several points that should be noted. First, three different types of regulatory intensity were used in the analysis. The first is calculated by summing up items in three sub-indices (i.e., items in price regulation + items in quantity regulation + items in entry regulation). A second sub-index consists of the sum of items in the price regulation category. A third indicator is the sum of items in the entry regulation category. In conducting the analysis, the regulatory variables were calculated as two types: with and without the NGA regulation items. For the models that included time series starting in 1997 (secure servers, fixed broadband) we calculated the regulation intensity without the NGA regulation items that were only collected for the most recent years (2007-2010). Table 2 summarizes the approach.

Table 3: Specification and use of regulatory density variable

Independent Variable	Dependent Variable	
	Fixed broadband Internet subscriptions / mobile cellular telephone subscriptions / secure servers	Fiber internet subscriptions / IPTV subscriptions
Total regulation	20 items - Price regulation (5 items) - Quantity regulation (4 items) - Entry regulation (11 items)	20 items + 11 items - Price regulation (5 items + 3 NGA items) - Quantity regulation (4 items + 3 NGA items) - Entry regulation (11 items + 5 NGA items)
Price regulation	5 items	5 items + 3 NGA related items
Entry regulation	11 items	11 items + 5 NGA related items

Data for several control variables was collected from the World Development Indicators database. These include GDP per capita (constant 2000 USD), population size and urban population (as a percent of total population). Summary statistics for all variables are shown in table A-1 in the appendix.

5.3 Methodological challenges

Estimating the model raises several econometric problems that suggest using methods other than ordinary least squares (OLS) estimation. As pointed out by other researchers addressing similar issues, regulation needs to be considered as an endogenous variable. Since the causal relationship between regulation and innovation may run in both directions, the regulation index may be correlated with the error term. Second, unobserved effects contained in the error term may be correlated with the explanatory variables.

The most frequently used method to avoid these issues is to use instrumental variables. We therefore use instrumental variables collected from the political manifesto database. The variables measure a government's political position in terms of right versus left, government attitude toward economic planning and government attitude toward market control. In order to take dynamic aspects of the innovation process into account, we include the lagged dependent variable. However, this may cause an autocorrelation problem that we needed to watch out for.

While OLS estimation can provide useful insights into the relations, there are several econometric problems in estimating the model using OLS, including endogeneity, omitted variables, and autocorrelation. Earlier studies often have ignored these problems and used OLS regardless. Since this may lead to biased estimates, we used a different method. One option is to use two-stage least squares (2SLS) with instrumental variables. However, the 2SLS specification resulted in weak instruments, which can introduce biasedness. Consequently, we used a GMM estimator that allows overcoming these problems.

6. Findings

Tables 4 and 5 summarize the results of the difference GMM estimation for the effects of regulation on innovation. Table 4 contains selected results pertaining to secure servers. Table 5 reports selected findings for fixed broadband access.

Table 4: Regulation and number of secure servers (1997-2010)

Variable	log(Servers)	log(Servers)	log(Servers)	Servers/100	Servers/100	Servers/100
log(Servers)(t-1)	0.7236*** (0.0462)	0.6647*** (0.0369)	0.7608*** (0.0442)			
Servers/100(t-1)				1.1038*** (0.0361)	1.1014*** (0.0392)	1.0793*** (0.0416)
Total regulation	-0.3667** (0.1539)			-0.0019* (0.001)		
(Total regulation) ²	0.0184** (0.0087)			0.0001* (0.0001)		
Price regulation		-0.243 (0.3574)			-0.0082*** (0.0031)	
(Price regulation) ²		0.0842 (0.0686)			0.0017*** (0.0006)	
entry regulation			-0.217 (0.1948)			-0.0079*** (0.003)
(Entry regulation) ²			0.0104 (0.0176)			0.0007*** (0.0003)
log(GDP)	1.8694 (0.3582)	1.0122 (0.2855)	2.0954 (0.3772)	0.0161*** (0.0036)	0.0117*** (0.0038)	0.0202*** (0.0047)
log(population)	2.07 (1.3525)	2.6117*** (0.8767)	1.9689 (1.2309)			
Urban population rate	0.0344 (0.0511)	0.0729 (0.0367)	0.0357 (0.0411)	0.0007 (0.0008)	0.0006 (0.0008)	0.0009 (0.0008)
X ²	2681.40 p>0.001	5361.48 p>0.001	2421.41 p>0.001	2269.56 p>0.001	2201.35 p>0.001	1742.97 p>0.001
N	300	300	300	300	300	300

- Standard errors in parentheses.

- *, ** and *** denote significance at 10%, 5% and 1%, respectively.

Table 3 indicates that regulation is negatively associated with the number of secure servers in the observations. This finding is robust and holds across different specifications of the empirical relation. It holds for the aggregate regulation index as well as for sub-indices for price regulation and market entry regulation.

Table 4 summarizes the findings with regard to fixed broadband subscriptions. One cautionary note that needs to be made is that the broadband data contains a range of download speeds that is not fully reflected in the count of subscriptions. Nonetheless, it is a widely used metric to reflect process innovations in the network platforms. Again the effect of the regulatory density index is predominantly negative. This holds for the aggregate regulation index as well as for the price and market entry sub-indices. The empirical findings also suggest that the relation between regulation and innovation as measured by broadband subscriptions is non-linear.

Table 5: Regulation and fixed broadband Internet subscriptions (1997-2010)

Variable	log(Fixed)	log(Fixed)	log(Fixed)	Fixed/100	Fixed/100	Fixed/100
log(Fixed)(t-1)	0.6337*** (0.0432)	0.6403*** (0.0512)	0.6833*** (0.0386)			
Fixed/100(t-1)				0.8267*** (0.0359)	0.8332*** (0.0463)	0.8374*** (0.0318)
Total regulation	-0.5767** (0.2643)			-3.5179* (2.0549)		
(Total regulation) ²	0.0326** (0.0149)			0.1972* (0.1121)		
Price regulation		-1.2589 (1.3285)			-16.5032** (7.5028)	
(Price regulation) ²		0.2452 (0.2533)			3.1228** (1.3938)	
Entry regulation			0.3757 (0.2658)			-3.322* (1.7612)
(Entry regulation) ²			-0.0334 (0.0214)			0.3243* (0.1704)
log(GDP)	1.1419 (0.6576)	1.0828 (0.6436)	0.3027 (0.861)	17.5306*** (2.9368)	19.1458*** (4.5989)	18.1091*** (2.6422)
log(Population)	1.7678 (2.5728)	3.2193 (2.1843)	4.1458 (9.6366)			
Urban population rate	-0.0132 (0.0656)	-0.0533 (0.0631)	-0.094 (0.2491)	0.8728*** (0.3090)	0.4195 (0.4513)	0.8387*** (0.2287)
X ²	2456.91 p>0.001	3236.82 p>0.001	4052.00 p>0.001	3863.90 p>0.001	1995.92 p>0.001	4355.98 p>0.001
N	232	232	232	232	232	232

- Standard errors in parentheses.

- *, ** and *** denote significance at 10%, 5% and 1%, respectively.

To understand how strong the effect of regulation on innovation is, the parameter estimates reported in tables 4 and 5 were converted into effect sizes (see Table 6). These effect sizes express elasticities: the

percentage change in the dependent variable caused by a one percent change in the independent variable. Because semi-log specifications and squared forms of some independent variables were used, some transformations were necessary to calculate the effect sizes. These elasticities are calculated at the sample means.

Table 6: Effects of changes in regulation on innovation

Dependent variable: secure servers						
	log(Servers)	log(Servers)	log(Servers)	Servers/100	Servers/100	Servers/100
Total Regulation	-0.3956			-0.0517		
Price Regulation		0.3772			-0.0090	
Entry Regulation			-0.5659			-0.1315
Dependent variable: fixed broadband connections						
	log(Fixed)	log(Fixed)	log(Fixed)	Fixed/100	Fixed/100	Fixed/100
Total Regulation	-0.0634			-0.0503		
Price Regulation		-0.2151			-0.3030	
Entry Regulation			0.1562			-0.0132

Note: Table cells are shaded in cases where the coefficients of the regulatory density variable (R and R^2) are statistically significant ($p > 0.1$).

Overall, the picture that emerges from the empirical analysis is that sectoral regulatory measures have a negative effect on the innovation metrics included in this study. This is in line with the economic insight that innovation requires the ability to experiment freely, to be able to appropriate innovation premiums, and to differentiate prices and service conditions.

The findings reported here can be further refined along several paths. For one, the regulatory density index allows the examination of specific regulatory measures. This might yield interesting additional insights. The reported model specifications are the outcome of very detailed examination of alternative hypotheses and potential relations among the variables. Nonetheless, it is possible to explore further improvements. For example, one could study innovation rates rather than the level of innovation at the market level as is done in the reported findings.

7. Concluding remarks

This study set out to explore the effects of sectoral forms of regulation on innovation in the telecommunications sector and on related innovations in sectors using ICT. One of the challenges of

looking at sectoral-level relations is that regulatory measures often affect players differently. Unlike studies of product and service innovation that often examined regulatory measures that are applied symmetrically to all firms in an industry, regulation in telecommunications typically is asymmetric.

Moreover, innovation in the ICT ecosystem emerges in different forms. Thus, the study started with a review of the prior findings with regard to the potential effects of regulation on innovation and then proceeded to develop a more fine-grained typology of innovation processes in the ICT ecosystem. From the literature on innovation in general, we then derived a conceptual model of process and product innovations in vertically related markets, which served as the basis for the development of an empirical model.

Using GMM estimators, we investigated the relations between aggregate regulatory density measures and regulatory sub-indices for price and market entry regulation and four innovation indicators. For secure servers and fixed broadband, estimates are based on panels covering 1997-2010. We found a negative effect of the stringency of sectoral regulation and sectoral innovation. This holds for different specifications of the model. The effect is visible for the aggregate regulatory density index and for sub-indices measuring the stringency of market entry regulation and price regulation.

Overall, the findings shed new light on a very important issue of public policy. The study suggests that the tacit assumption, held by many regulatory agencies, that more stringent regulation is a precondition for innovation will have to be revisited. Innovation both in the ICT sector and in related sectors thrives in an environment that allows experimentation and risk-taking. The effects of regulatory measures on experimentation and risk-taking need to be taken into account explicitly to facilitate innovation both in the ICT sector and in industries dependent on advanced ICT services.

Table A1: Summary statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Log(fixed)	346	13.31322	2.335957	5.648974	18.2191
Fixed/100	346	12.7392	10.55207	0.002885	38.16386
Log(mobile)	448	15.57215	1.792626	9.780811	19.44636
Mobile/100	448	76.85681	39.64122	0.853866	156.3972
Log(s. servers)	383	6.914296	2.144114	2.079442	13.0103
s. servers/100	383	0.025914	0.036115	5.99E-05	0.227701
Log(fiber)	122	10.40276	2.633095	2.639057	16.73699
Fiber/100	122	1.550128	2.711816	0.000134	14.67463
Log(iptv)	142	11.68107	1.873671	6.361302	16.13348
Iptv/100	142	2.051577	2.785759	0.012324	16.17362
Total regulation	448	8.733705	2.652128	3	14.6
Price regulation	448	2.383036	0.817306	0	4.1
Entry regulation	448	5.172098	1.972315	1	9
Total regulation w/ NGA	448	9.541072	3.502605	3	17.3
Price regulation w/ NGA	448	2.440402	0.845066	0	4.8
Entry regulation w/ NGA	448	5.904241	2.791647	1	13
Log(gdp)	416	9.536951	0.873071	7.224949	10.9442
Log(pop)	448	16.09062	1.532258	12.87774	19.55332
Urban population rate	405	72.78571	12.84592	48.3	100

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