Effects of Regulation on Innovation in the Information and Communications Sector[1]

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Abstract

This paper examines the effects of sector regulation on innovation in telecommunications and related information industries. Building on innovation research, a typology of innovation processes in ICT industries is developed. The economic and policy conditions conducive to different types of innovation are analyzed to draw inferences on the effects of regulation on innovation. Sector regulatory measures affect innovation in positive and negative ways, leaving the overall effect somewhat ambiguous. Selected conjectures were tested empirically using data for 32 countries for the years 1997-2010. More stringent regulation was associated with a negative effect on some innovation measures but not on others.

JEL codes: L51, L86, L96

1. Introduction

Harnessing the innovation potential of ICT has been one of the main drivers of the global regulatory reform agenda since the 1980s. A key assumption was that the introduction of competition would stimulate innovation in network infrastructure as well as the applications and services they enable. Regulatory economics and practice focused on the effects of regulation on competition and static efficiency. Innovation was essentially treated as a byproduct of other efficiency improvements. Liberalization indeed went hand in hand with a virtuous cycle of innovation: increased efficiency stimulated new applications and uses, which spurred further innovation. After three decades of regulatory reform, however, new challenges have arisen that may require a reassessment of this approach. Whereas legacy networks could be upgraded to first generations of broadband networks, fixed and mobile infrastructures now require substantial new investment. Moreover, the value network of ICT industries has become more complicated and intertwined. Advanced services require coordination among players with different core competencies. Seeking to meet these challenges, regulatory analysis and practice are limited by the dearth of research that explicitly examines its consequences for innovation.

Empirical evidence showing that advanced communication networks and services are an important determinant of productivity growth is relatively unambiguous (Czernich et al. 2011; Röller and Waverman 2001; Fornefeld et al. 2008; Kretschmer 2012). Digital innovation affects economic growth directly and indirectly. Its effects on the efficiency of factor use are amplified by a wide range of organizational innovations enabled by ICT (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 changed 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. Digital technologies facilitate new forms of collaboration and social production that further enhance these features (Chesbrough 2003; Benkler 2011).

Creating conditions that foster innovation has therefore become a central matter of policy-makers. Sector regulation is one of the conditions that affect innovation although the channels of influence are often more indirect and roundabout than in traditional areas of regulation. In the densely interconnected and interrelated ICT ecosystem, innovation takes place at multiple layers and in various forms. 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 the direction of innovation efforts by equipment manufacturers and network operators. Second, as a central infrastructure of the knowledge economy, telecommunication serves as 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 and the economy overall is therefore a question that needs to be taken into account in the design of public policy.

This paper is a first step toward examining the effects of sector regulation on innovation in the ICT sector and on innovation activity in sectors using ICT. Regulation shapes 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 depend on the relative magnitude of innovation-enhancing and innovation-hampering effects. Theoretical analyses 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 brief review of research on regulation and innovation in the next section, part three of the paper revisits and clarifies the notion of innovation in the ICT ecosystem. It distinguishes different types of innovation and explores the regulatory conditions that support them. Building on these foundations, section four develops an empirical model and derives conjectures on the potential effects of regulation on different types of innovation. Section five presents and critically discusses findings, followed by a recapitulation of main points of the paper and suggestions for further research.

2. Related literature

Innovation is most often conceptualized, as expressed in the OECD's Oslo Manual, as the implementation of new processes, products, organizational methods, and marketing methods (OECD 2005). In digital industries, "soft innovation", changes in the aesthetics of products and services, plays an increasingly important role (Stoneman 2010). Despite the attention paid to innovation in the policy realm, the regulatory research literature has dealt with innovation often indirectly and tacitly. It has paid more attention to the effects of regulation and its reform on static efficiency metrics (e.g., prices, total factor productivity). As static and dynamic efficiency gains are closely related, with the former often the outcome of process and product innovations, this received literature also captures aspects of innovation. At a general level, the relationships between regulation and innovation are addressed, if often rather indirectly, in the research assessing regulatory reforms since the 1980s, in research on the national context of innovation, and in the literature on ICT as a general purpose technology. Contributions that specifically investigate the relationships between regulation and innovation fall into three broad areas, examining: (1) regulated monopoly and innovation, (2) regulated competition and innovation, and (3) effects of vertical market regulation on innovation.

Given space constraints, the contributions which only generally address the linkages between regulatory policy and innovation shall only be mentioned in passing. The regulatory reforms of the past three decades constitute natural experiments that stimulated detailed empirical research on its effects. Although the findings are diverse and heterogeneous, patterns are noticeable: liberalization and competition are strong drivers of efficiency gains (e.g., Bortolotti et al. 2002; Megginson and Netter 2001); privatization has ambiguous effects but contributes to efficiency gains if combined with liberalization and proper regulation (e.g., Wallsten 2001; Ros 1999; Vickers and Yarrow 1991); and the introduction of independent regulation contributes to enhanced efficiency (e.g., Edwards and Waverman 2006). The influence of the institutional arrangements in which ICT industries and their regulation are embedded, such as the knowledge flows between universities, industry, and government, on innovation was studied in works emanating from the national innovation systems (NIS) literature (Edquist 1997; Mowery and Simcoe 2002; Nelson 1993). Recent contributions in this vein study the differential success of nations in Asia, Europe, and North America in rolling out mobile Internet and mobile broadband services innovation (Lindmark et al. 2006; Falch et al. 2010; Funk 2009).

The role of ICT for innovation in other industries is at the heart of contributions in that recognize its nature as a general purpose technology (Bresnahan and Trajtenberg 1995). This literature is of great relevance for the design of regulatory policies but it rarely theorizes the role of regulation explicitly. Although early communications technologies, such as the telegraph and the telephone, also have to be considered critical infrastructures, the Internet and especially advanced broadband, due to their very broad range of uses, are more flexible and potentially more powerful general purpose technologies. A complementary, literature has pointed out the significant spill-over effects that exist in infrastructure industries (Hogendorn 2012; Martin 2002; Greenstein 2004; Sidak and Teece 2010; Frischmann 2012). Both perspectives emphasize the economy-wide innovation potential enabled by advanced communication platforms. As far as sector regulation affects innovation in platform industries it will also have repercussions for industries dependent on these platforms.

Innovation under regulated monopoly was first addressed in the pioneering papers 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. Both papers explore the effects of regulation on process innovation, although only Bailey explicitly raises that issue. During the early experiments with a competitive fringe, the effects of price cap and other forms of incentive regulation on infrastructure investment were at the center of interest (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 but they often did not contribute to accelerated network deployment. In several papers, Prieger (2004, 2008, 2007) studying the effects of regulation on U.S. innovation in telecommunications services, found a negative effect, much like Alesina et al. (2005) detected for regulation in general. These studies suggest that overly stringent regulation has detrimental effects on innovation, often at high direct and indirect costs to society (e.g., Hausman 1997).

During the late 1980s, an increasing number of countries started to rely on asymmetric forms of regulation, such as unbundling mandates on incumbent service providers, to facilitate new market entry. Researchers studied the effects of asymmetric regulation on competition, the adoption of broadband, and investment at the network layer but innovation was generally only captured indirectly. 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 found that more stringent regulation favored service-based competition at the expense of facilities-based competition (e.g., Grajek and Röller forthcoming; Bacache et al. 2010, 2011; Bourreau and Doğan 2005, 2006, 2001; Bourreau et al. 2010; Wallsten and Hausladen 2009; Briglauer et al. 2012). A few papers reach more nuanced conclusions and therefore see a role for continued regulation in support of investment and innovation (e.g., de Bijl and Peitz 2005; Distaso et al. 2006; Cave 2010).

Innovation aspects are most explicitly addressed in the network neutrality debate. This discussion reassesses the rules that should govern vertical relations in the ICT ecosystem, mostly between network operators and content providers, but possibly also between logical platforms and other stakeholders. A nascent, mostly theoretical, economic literature has made important contributions by examining firm decisions under alternative regulatory rules. Findings thus far are highly dependent on the specific model assumptions. Several papers suggest that stringent regulatory constraints on the network operator, such as a strict net neutrality constraint, would diminish short-term efficiency and likely also reduce innovation efforts at the complementary services layer. On the latter count, the outcomes are more varied (e.g., Bauer 2007; Choi and Kim 2010; Economides and Hermalin 2010; Hermalin and Katz 2007; Odlyzko 2009; Shrimali 2008; Krämer and Wiewiorra 2010; Yoo 2005; Economides and Tåg 2012). In as far as these papers model innovation explicitly, they use basic approximations, such as the number of new competitors, to operationalize innovation (e.g., Bourreau et al. 2012; Reggiani and Valletti 2011; Krämer et al. forthcoming).

3. Innovation in the ICT ecosystem

To more fully theorize the potential impacts of regulation, it is helpful to go beyond the traditional definition and adopt a process-oriented view of innovation. Evolutionary accounts of innovation have emphasized that it is a process of experimentation (or variation), selection, and replication (or copying). Entrepreneurs and users typically create something novel by combining and re-combining existing knowledge (Antonelli 2008; Fransman 2012). Innovation can be conceptualized as an experimental exploration of the space of "adjacent" possibilities (Kauffman 1993). Solutions that are successful in the marketplace are scaled up whereas failed ones will eventually disappear. Brynjolfsson (2011) has pointed out very eloquently how digital technology accelerates this cycle through continuous measurement, experimentation, sharing, and amplification. Seen through this lens, the innovative prowess of the Internet is rooted in the enormous expansion of innovation opportunities combined with a speeding up of the evolutionary learning process driving innovation.

How innovation unfolds in the ICT ecosystem has changed quite substantially during the past decades. Until the 1990s, several specialized networks (voice, cable TV, mobile, satellite) co-existed, each enabling a narrow range of services for which these networks were optimized. Innovation took largely place within the confines of these industry segments and the associated suppliers of components and equipment (Fransman 2002). The diffusion of digital technology, the increasing availability of high-capacity networks, and a proliferation of fixed and especially mobile access devices have fundamentally altered this innovation process. In the new innovation system, vertical relations among players at different layers (devices, networks, logical platforms, services, and applications) have become more important both technically and economically. Many forms of complementarity and substitutability as well as feedbacks between the players on these layers exist. Pervasive economies of scale, scope, and density exist on the supply- but also on the demand-side. Moreover, the innovation process benefits from institutional diversity, such as the co-existence of open and proprietary technical architectures. As the capital goods employed have become more fungible their uses are shaped by strong cumulative effects: networks are used for a larger variety of purposes, which lead to additional innovations and uses (Antonelli and Baranes 2007; Antonelli 2008). Innovation in any one of the layers has repercussions on the others, enabling but potentially also constraining innovation opportunities in other layers.

3.1 Toward a micro-foundation

This variety and heterogeneity raises the question of whether the conditions conducive to innovation also vary and how regulation interacts with them. Two steps are needed to address it: (1) a micro-foundation of how technology, market, and regulatory conditions affect innovation decisions and (2) a model of the innovation processes that unfold in the ICT ecosystem (what could be deemed their "innovation technology"). A micro-foundation can be built by taking advantage of the similarity of innovation and investment decisions. In both cases, a firm has to make a forward-looking decision under uncertainty. Practically all innovation decisions have an innovation component and most investments also have an innovation dimension (Friederiszick et al. 2008). A generic micro-model therefore can build on frameworks from investment theory to examine the channels through which regulation affects innovation (Trigeorgis 1995, 1999; Dixit and Pindyck 1994).

<Figure 1 about here>

Figure 1 is a graphical representation of the real options model augmented with insights from innovation theory and regulatory economics. The right hand side of the graph simply depicts the components of the real options model. In addition to discounted revenues and costs (which together determine the (static) net present value (NPV), options, such as to defer an innovation or to pursue it in incremental steps, are being evaluated to arrive at an expanded (strategic) net present value (ENPV) (Trigeorgis 1999, p. 4). From innovation theory it is known that three major groups of factors influence innovation decisions: (1) the available innovation opportunities, which are strongly influenced by technological and market conditions, (2) the appropriability of (temporary) innovation rents, and (3) the innovation capabilities and strategies of firms. Regulatory interventions shape firm decisions because they affect this calculus in multiple and often contradictory ways. This is the firm-level process that also drives the findings in much of the literature referenced in the previous section (although it is rarely explicated).

For example, unbundling obligations for broadband access networks reduce the appropriability of the associated process innovations (e.g., network upgrades), and possibly of complementary service innovations, of regulated firms. Likewise, such a regulation will reduce the incentive of players who benefit from unbundled access to pursue process innovations while improving the appropriability of innovation premiums for services innovations. In turn, a higher rate of service innovations will have repercussions for the incumbent player and possibly trigger higher service innovation activity. At a sectoral level, only the aggregated net effect of these counteracting incentives can be observed. It will depend on the relative proclivity of players to innovate and the sizes of the regulation effect on innovation incentives. Similar potentially positive and negative effects of innovation can be identified for other forms of regulation such as open access provisions, vertical separation, and network neutrality rules. Because of these webs of counteracting influences, it is impossible to formulate strong a priori expectations as to the net effects of sector regulation on overall innovation rates.

3.2 A typology of ICT innovation

However, it is feasible to segment the diversity of innovation processes so that stronger conjectures can be established. To this end, two important dimensions, the extent of innovation and the coordination needs of innovations, can be utilized to define a typology. Researchers in the field have long classified innovations along a continuum from incremental to radical (Stoneman 1995; Kamien and Schwartz 1982).

Incremental innovations modify a limited number of attributes of the state of the art whereas radical innovations change many attributes (and possibly to a larger extent). A second dimension – typical for many complex products but particularly strong in the ICT ecosystem – is the extent to which innovations on one layer of the system are dependent on developments by players in other layers. This opens another continuum between modular types of innovation and what we call "coupled" ones. Innovation research has dedicated considerable attention to modularity (e.g., Baldwin and Clark 2000; Langlois 2002) but less to coupled innovation (Block and Keller 2011; Bauer et al. 2012). Aspects of such interdependent innovation processes are addressed in the research on vertically related markets (e.g., Farrell 2003; Reggiani and Valletti 2011) and multi-sided markets in general (e.g., Armstrong 2006; Church and Gandal 2005) but the notion of coupling is broader and encompasses other coordination problems.

<Figure 2 about here>

Innovation is modular if the components of larger systems and the players providing them can be effectively coordinated by interfaces. Applications at the edge of the Internet, which are the focus of much of the current policy debate, are examples of such modular innovations: knowledge of the transparent TCP/IP interface is sufficient for entrepreneurs to launch new Internet applications or services. However, the overall vibrancy of the ICT innovation system is also dependent on coupled types of innovation. In that case, successful innovations require additional forms of coordination among the relevant players. For example, to offer mobile Internet services, technical, business, and legal issues need to be negotiated and settled that cannot easily be resolved by standardized interfaces. Combining these two dimensions allows identifying a two-dimensional continuum of types of innovation (see Figure 2). Innovation processes in this continuous space can be characterized by their specific innovation technologies. Simplifying to a 2x2 matrix, on can distinguish four ideal types of innovation: modular incremental innovations (Type I), modular radical innovations (Type II), coupled incremental innovations (Type III), and coupled radical innovations (Type IV). An innovation may be associated with different types along its lifecycle. For example, once the coordination challenges of a Type IV innovation have been overcome, it may be emulated by second movers and possibly become modularized. Moreover, innovations may be hybrids, combining aspects of the simple types.

Research suggests modular innovations flourish in environments with clearly specified interfaces and low transaction costs (Van Schewick 2010; Cowhey and Aronson 2009). Coupled innovations, on the other hand, thrive if players at complementary layers are allowed to coordinate their policies effectively (Ehrlich et al. 2010). Incremental innovations, while facilitated by the ability to appropriate rents, are nourished in highly competitive environments. Lastly, a body of economic reasoning suggests that radical innovations thrive in environments that allow firms to appropriate sufficient innovation rents (Kamien and Schwartz 1982; Dosi et al. 2006; Freeman and Soete 1997). This is easier if they possess some degree of temporary, contestable market power. Consequently, one would expect that the conditions facilitating these four principal types of innovation differ: (1) Type I innovations will be highest in an environment of intense competition combined with open and transparent standards that enhance interoperability and reduce transaction costs. (2) Type II innovations will thrive in conditions that combine openness with the ability of those players pursuing radical innovations to appropriate supra-normal profits. (3) Type III innovations are supported by an environment of differentiated competition that allows forms of exclusive contracts among players to facilitate the necessary coordination. (4) Lastly, Type IV innovations 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.

3.3 Effects of regulation

We are now in a position to establish conjectures on the effects of regulation on this system. Three forms of regulation are relevant: (1) rules affecting horizontal relations of players on one specific layer (e.g., unbundling, interconnection, peering); (2) 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 innovation rate in the system may also be affected by general public policies that do not apply specifically to the ICT sector, such as investment tax incentives or R&D credits. Other things being equal, modular incremental innovation should be facilitated by forms of regulatory intervention that reduce transaction costs and facilitate standardized and open interfaces. Modular radical innovation will likely be nourished by a regulatory framework that, while keeping transaction costs low, allows temporary profits. Radical incremental innovations will flourish if the regulatory framework allows differentiated arrangements and radical coupled innovations if temporary exclusive business arrangements can be negotiated. Regulators can try to balance these objectives or they can allow institutional diversity in which different models co-exist (as, for example, attempted in the Federal Communications Commission's 2010 Open Internet Order). If the overall regulatory model is built to support just one innovation scenario (e.g., modular incremental innovation) it may have unanticipated negative effects on other types of innovation.

4. Empirical model and data

Although regulation targets specific firms or sub-sectors of the ICT ecosystem, interventions are frequently designed in response to and evaluated based on observations at an aggregate level. Policy-makers would be served by a clear understanding of whether there is a stable correspondence between regulatory measures and innovation outcomes. For purposes of empirical investigation the many often contradictory channels of influence discussed in the previous section will be treated as a "black box". The attention is shifted to the relationship between sector-level regulatory inputs and sector-level outcomes. This is in line with recent research on the effects of institutional arrangements on economic performance, which has recognized that in systems with many feedbacks and interrelations it may only be possible to find such higher-level correspondences (Coleman 1990; Ostrom 2005).

4.1 Aggregate-level conjectures

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 networks. 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 understand the effects of telecommunication regulation on ICT-based industries, a broader measure of innovation that reflects outcomes in these sectors is necessary. Value-added in new products and services could be such a measure but it is not systematically collected. Other innovation measures, such as data collected in the European Community Innovation Surveys (CIS), although valuable, are not available for sufficiently long time periods.

Given these constraints, we focused on three conjectures for which detailed and complete information was available. First, we explored the effects of regulation on process innovation in the network layer, operationalized as broadband adoption. Using this data, we focus on an innovation that is accepted in the market (rather than offered in the market). Ideally, we would have been able to take the different qualities of broadband into account, especially the migration of first generation access networks from lower to higher download and upload speeds. Unfortunately, that data was not available. In the typology of innovation processes, broadband upgrades can be seen as a modular but radical innovation (Type II). Thus, we would expect that more stringent regulation that constrains the ability of key players to earn temporary supernormal profits will reduce the speed of broadband diffusion.

Second, we were interested in whether any effect of telecom sector regulation could be detected on innovation activities in e-commerce and other Internet-based applications and services. Many of these innovations can be seen as Type III, coupled incremental innovations (although some may be Type I incremental modular innovations). This innovation technology would be supported by a framework that reduces transaction costs while allowing for differentiated coordination. Again, high regulatory density can be expected to have a negative effect because it reduces the experimental space available to entrepreneurs and businesses. We approximated the extent of applications innovation with the number of secure servers. This dependent variable is influenced by factors beyond telecommunications but it 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 (e.g., Mowery and Simcoe 2002; Vicente Cuervo and López Menéndez 2006; Bourreau 2001).

Third, theory suggests that the overall number and intensity of regulatory interventions will affect innovation. Specific regulations may both constrain and enable experimentation by some of the players in the ICT system. In practice, more detailed and more fine-grained regulations are often the unintended byproduct of a maturing regulatory system. Other things equal, more numerous and more stringent regulations (high "regulatory density") will limit the ability of firms to explore innovation opportunities. Because this limits one of the main drivers of innovation, we suppose that such "regulatory sclerosis" might have, ceteris paribus, a depressing effect on innovation. It is also possible that an interaction effect exists with competition. One would expect that higher regulatory density has a weaker detrimental effect in countries with less intense competition.

4.2 The generic empirical model

Equation (1) shows the generic model specification used for the empirical analysis. As dependent variable two innovation indicators (broadband, secure servers) were explored in detail. In addition, we performed preliminary analyses with several other innovation metrics, including the number of ICT patents (as an indicator that also captures invention activity that has not yet resulted in market innovation) as well as mobile broadband Internet and IPTV. In these latter cases, only a limited number of observations were available so that the use of econometric methods seemed unwarranted until more information is obtainable. The independent variable we were most interested in was the regulatory regime in place. To isolate regulatory effects, we included additional independent variables that can be considered drivers of innovation. The following model was estimated:

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

I_{it} represents a measure of innovation activity in country i at time t. Two different types of innovation activity were used: fixed broadband subscriptions and the number of secure servers. Analyses were performed for several specifications of the dependent variable: the log of the total number of broadband lines and secure servers, relative numbers (e.g., the number of secure servers per 100 inhabitants), as well as differences. The dependent variable lagged by one period (I_{it-1}) was included to take possible network effects into account. Regulation in country i at period t (R_{it}) was measured by an index constructed to reflect the stringency of regulation. As several previous studies found non-linear relations between competition and market outcomes, we also examined the data for the presence of such effects by introducing R_{it}^2 in some of the model runs.

Factors other than regulation that influence innovation activity are captured in a vector of control variables x_{it}. Among the control variables are demand- and supply-side factors. On the demand side, income (measured as GDP per capita) and socio-demographic variables were included. On the supply side, variables reflecting cost conditions (e.g., population size, urban population as percent of total population) were used. Moreover, in some model runs we included a measure for inter-modal competition. However, the competitive regime is also reflected in the regulatory variables so that this addition raised concerns about double-counting the intensity of competition.

4.3 Data sources and variable construction

Country-level information was collected for 32 countries from 1997 to 2010 (EU-27, Australia, Japan, Singapore, Switzerland, and the United States). Innovation indicators were drawn from a variety of sources, including the OECD Communications Outlooks and Broadband Portal, the World Telecommunication/ICT Indicators database maintained by the International Telecommunication Union (ITU-ICT), and the World Bank's World Development Indicators database (WDI). Where data was available in all three sources, we sought to triangulate the information to increase confidence in the accuracy and consistency of the numbers and to close gaps in specific sources. In selected instances, we also were able to compare the information against data collected by the European Union and private sector Point-Topic data (see Table 1). The regulatory index was extracted from data collected by Polynomics (Zenhäusern et al. 2012), also triangulated with other sources. To control for country-specific political and institutional arrangements and instrument for the potential endogeneity of regulation, we harvested additional data from the Political Manifesto Database (Volkens et al. 2011). A proxy for dynamic competition in the market was calculated as the inter-platform Herfindahl-Hirschman Index (HHI). Summary statistics are shown in table A-1 in the appendix.

A key interest of the paper was the effect of the regulatory regime on innovation. The pervasiveness and stringency of regulatory intervention was measured using components of the Polynomics Telecommunication Regulation Index 2012 (Zenhäusern et al. 2012). This database is an expanded and updated version of the Plaut Economic Regulation Index (Zenhäusern et al. 2007), which was used in several prior studies to measure the degree of regulatory intervention in ICT markets (e.g., Grajek and Röller forthcoming). The database comprises time series of 28 indicators of national regulatory approaches for the time period 1997-2010. For the most recent period of 2007-2010 an expanded data set of 41 time series was collected that pays more detailed attention to the regulatory treatment of next-generation fixed and mobile networks. The time series can be groups to reflect the conditions in each market with respect to price regulation, market entry regulation, quantity regulation, and miscellaneous interventions. Each component is scored so that low regulatory stringency is associated with a 0 index score and high regulatory density with a 1. In some cases, the measure is dichotomous and in other cases intermediate values are used. This yields a source of raw data that can be linked to economic theory and used to empirically assess the effects of regulation.

<Table 1 about here>

For this paper, a broad index reflecting price, entry and quantity regulation as well as two more narrowly defined sub-indices for price and entry regulations were used. Economic theory links these forms of regulation most directly to innovation behavior. The broad index is calculated by summing up the scores of items in the price regulation, quantity regulation, and entry regulation categories. The two more narrowly construed sub-indices consist of the sum of the scores in the price regulation and entry regulation categories, respectively. One concern is the loss of information when summing index scores. In principle, the raw data could be used to estimate dummy variables for each of the items. Our conjectures, however, are formulated at an aggregate level. They seek to assess the effects of regulatory regimes on aggregate sector outcomes. Hence, aggregating scores is a justifiable strategy and is less susceptible to the information loss problem of indexing. For dependent variables that have a sufficiently long history, the regulatory scores were calculated on the items available in the database reaching back to 1997 (i.e., based on the 28 items). For innovations introduced to the mass market after 2007 (IPTV, LTE), items from the enhanced database of 41 indicators were used in experimental empirical analyses. However, due to the small number of observations for dependent variables we do not present detailed empirical results in this paper. However, where they offer additional insights we will mention selected observations in the discussion of findings.

4.4 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 problems, regulation is often endogenous to the state of the system. 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 problems is reliance on instrumental variables. We used instrumental variables collected from the Political Manifesto Database. The variables measure a national government's political position on a spectrum from right to left, government attitude toward economic planning, and government attitudes toward market controls.

In order to take dynamic aspects of the innovation process and network effects into account, we include the lagged dependent variable. However, this could cause an autocorrelation problem that we needed to control 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. Despite these concerns, there are trade-offs between using OLS and other methods and several earlier studies have proceeded using OLS. In our assessment the problem of biased estimates is a concern and we therefore applied a different method. One option was to use two-stage least squares (2SLS) with instrumental variables. However, the 2SLS specification resulted in weak instruments. To overcome these problems, we used a GMM estimator.

5. Findings and discussion

Overall, the empirical examination yields a somewhat mixed picture. More stringent regulation is often (but not always) associated with negative effects on innovation measures. From experimenting with several versions of the dependent variable and the explanatory model, we conclude that the findings are somewhat sensitive to model specification. Tables 2 and 3 summarize characteristic findings from the most parsimonious specification.

<Table 2 about here>

Table 2 summarizes the findings with regard to fixed broadband subscriptions. The effect of the total regulation variable is negative and statistically significant at the 10% level or better. For the specification using fixed broadband access lines per 100 inhabitants, the parameters of the price regulation and market access regulation sub-indices also have a negative sign. However, in the semi-log specification, these two sub-indices have mixed signs and are not statistically significant. We also find evidence in support of a non-linear relation, as indicated by the statistically significant squared regulatory index variables. Table 3 presents the findings for secure servers. A similar pattern of negative effects of the regulatory variables becomes visible. However, in the semi-log specification, the coefficients of the regulatory sub-indices are a statistically not significant. As in the case of fixed broadband access, the regulatory effects are non-linear.

To get a better sense for the strength of the effects of regulation on the innovation indicators, the parameter estimates for the regulatory variables reported in tables 2 and 3 were converted into effect sizes (see table 4). These effect sizes express elasticities: the percentage change in the dependent variable associated with a one percent change in the independent variable. Because semi-log specifications and squared forms of some independent variables were used, transformations were necessary to arrive at effect sizes. All elasticities are calculated at the sample means.

<Table 3 about here>

<Table 4 about here>

The empirical findings reported in tables 2 and 3 suggest a convex relationship between regulation and innovation: increasing regulatory density has a declining marginal effect on innovation. This is visible in the positive parameter signs of the squared regulation indices. From this observation, an interesting insight follows that warrants further investigation. Given the non-linear relation, the effect sizes of changes in regulatory density depend on the status quo ante of regulatory density. Table 4 expresses these values for the sample mean. If these effects are calculated for one standard deviation below the mean, variations in regulatory density have an even stronger negative effect. If they are calculated for one standard deviation above the sample mean, a positive relation between variations in regulatory density and innovation activity appears. However, the positive gradient of the function is much smaller than the negative gradient below the sample mean. In other words, we seem to detect an asymmetric U-shaped relation between regulatory density and innovation. For countries with a high regulatory density this could imply a temptation to further increase regulatory intervention, as it would increase innovation activity. However, this approach would strand them in a local innovation optimum that is significantly below the one associated with less regulation.

As indicated earlier, we also examined models that included the inter-modal Herfindahl-Hirschman Index (HHI) as an explanatory variable. The regulatory indices take competition into account so that this amounted to a form of double-counting. Consequently, the model yielded worse results than the more parsimonious forms represented in tables 2 and 3. Furthermore, we explored metrics intended to reflect innovation in next-generation networks and services. In all these cases, the number of observations was too small to perform reliable statistical analysis. In most of the preliminary explorations, the patterns were not as clear-cut as those visible in fixed broadband access and secure servers. This suggests further analyses once longer periods of observation are available.

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. However, several flags of caution are in order. Several of the findings are at a modest significance level. Moreover, once the non-linear relationships are taken into account, effect sizes may have the reverse sign (although this only happens in two cases of statistically not significant parameter estimates).

6. Concluding remarks

This study set out to explore the effects of sectoral regulation on innovation in the telecommunications sector and on related innovations in ICT-using sectors. One of the challenges of examining sector-level relations is that regulatory measures often affect players differently. Unlike studies of product and service innovation that 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. To reflect this diversity, the paper developed a typology of innovation processes in the ICT ecosystem based on the extent of an innovation and the degree of coupling between players in the value network. Augmenting regulatory theory with insights from evolutionary innovation theory and institutional economics, we proposed three conjectures that informed the development of an empirical model.

The relations between aggregate regulatory density measures and regulatory sub-indices for price and market entry regulation and several innovation indicators were explored using a GMM estimator. For fixed broadband and secure servers data were available for the period of 1997-2010. We found a pattern of negative effects of the stringency of sectoral regulation on sectoral innovation. This holds for different parsimonious 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. However, not all empirical estimates yielded statistically significant or negative signs of the regulation parameters. This might suggest the presence of missing variables that we were not yet able to identify. They could also point to inherent limitations that an approach aiming at sector-level correspondences faces.

The findings reported in this paper could be further refined along several paths. For one, the regulatory density index would also allow the examination of specific regulatory measures. Although we experimented in this direction, we did not yet fully utilize the available information. The reported model specifications are the outcome of detailed examinations 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. Moreover, one could further search the data for interaction effects.

Overall, despite these caveats and the need for additional research, the findings shed new light on an important public policy issue. The study suggests that the tacit assumption, held by many regulatory agencies, that regulation is a precondition for innovation mays not hold in that clarity and 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 findings are an encouragement to choose the least intrusive and least stringent regulatory approach that is available, as this keeps the space for innovation experiments more open. In any case, 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.

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Figure 1: Effects of regulation on firm-level innovation decision

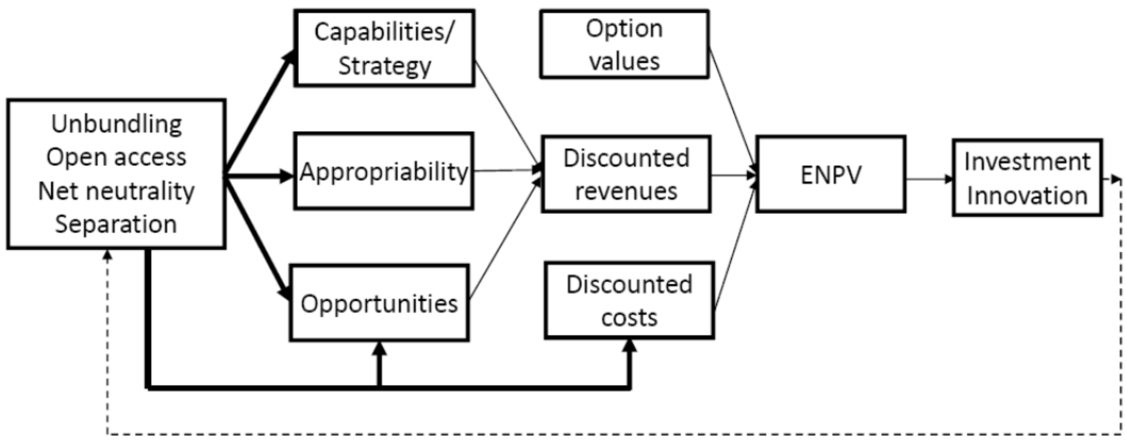

Figure 2: Types of innovation and enabling conditions

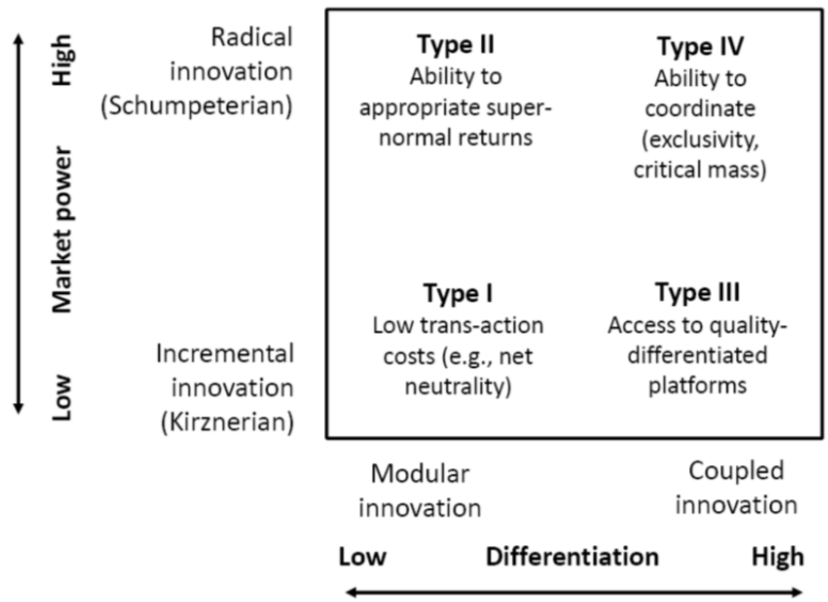

Table 1: Description and sources of variables

Name	Description	Sources
Fixed	Number of fixed broadband Internet subscriptions	ITU World Telecommunication/ICT Indicators; OECD Communications Outlook
Servers	Number of secure servers	ITU World Telecommunication/ICT Indicators; OECD Communications Outlook
Total regulation	Sum of scores of market entry, price, and quantity regulation items	Polynomics Regulation Index 2012, http://www.polynomics.ch/rdi.php
Price regulation	Sum of price regulation indicators (see Table 2 for more details)	Polynomics Regulation Index 2012, http://www.polynomics.ch/rdi.php
Entry regulation	Sum of entry regulation indicators (see Table 2 for more details)	Polynomics Regulation Index 2012, http://www.polynomics.ch/rdi.php
GDP	GDP per capita (in constant 2000 USD)	World Bank, World Development Indicators database
Population	Population	World Bank, World Development Indicators database
Urban population rate	Urban population (% of total population)	World Bank, World Development Indicators database
Inter-platform-HHI	Inter-platform Herfindahl-Hirschman Index (sum of squared shares of DSL, cable, and mobile broadband access lines)	ITU World Telecommunication/ICT Indicators; OECD Communications Outlooks

Table 2: Regulation and fixed broadband Internet subscriptions (1997-2010)

Indep. Variables \ **Dependent Variable**	**log(Fixed)**			**Fixed/100 inhabitants**		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
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)
χ^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

Notes: Standard errors in parentheses. *, ** and *** denote significance at 10%, 5% and 1%, respectively.

Table 3: Regulation and number of secure servers (1997-2010)

Dependent Variable / Indep. Variables	log(Servers)			Servers/100 inhabitants		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
log(Servers)(t-1)	0.6337*** (0.0432)	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)		
$(\text{Total regulation})^2$	0.0184** (0.0087)			0.0001* (0.0001)		
Price regulation		-0.243 (0.3574)			-0.0082*** (0.0031)	
$(\text{Price regulation})^2$		0.0842 (0.0686)			0.0017*** (0.0006)	
Entry regulation			-0.217 (0.1948)			-0.0079*** (0.003)
$(\text{Entry regulation})^2$			0.0104 (0.0176)			0.0007*** (0.0003)
log(GDP)	1.8694 (0.3582)	1.0122	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)
χ^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

Notes: Standard errors in parentheses. *, ** and *** denote significance at 10%, 5% and 1%, respectively.

Table 4: Effects of changes in regulation on innovation

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

Note: [a] coefficients of the regulatory density variables are statistically significant at $p>0.1$.

Table A1: Summary statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Log(Fixed)	346	13.3132	2.3360	5.6490	18.2191
Fixed/100	346	12.739	10.5521	0.0029	38.1639
Log(Servers)	383	6.91430	2.1441	2.0794	13.0103
Servers/100	383	0.02591	0.0361	5.99E-05	0.2277
Total regulation	448	8.73371	2.6521	3.0	14.6
Price regulation	448	2.38304	0.8173	0	4.1
Entry regulation	448	5.17210	1.9723	1.0	9.0
Log(GDP)	416	9.53695	0.8731	7.2250	10.9442
Log(pop)	448	16.0906	1.5323	12.8777	19.5533
Urban population rate	405	72.7857	12.8460	48.3	100
Inter-platform HHI	351	0.6307	0.2146	0.3417	1.0