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Access deregulation in deploying the next-generation infrastructure: an econometric analysis of mandatory unbundling

Yuntsai Chou*

Yuan Ze University, Taiwan

Many countries are contemplating the policy instruments necessary for developing next-generation networks (NGNs). Access regulation is the most effective approach for unleashing broadband competition. However, few studies have examined the applicability of access regulation to NGNs. We investigate the impact that unbundling local loops (ULL) has on broadband uptake and developing an NGN. We analyze the strategic response of market players, such as market entrants, telecommunication incumbents, and cable operators, under the ULL regime. Entrants have low incentive to own an alternative infrastructure; whereas, incumbents prefer to upgrade their networks to be exempt from ULL regulation. Because of the effects of inter-platform competition, cable operators also develop an NGN once they observe the incumbents' migration response. This paper examines econometric panel data from 42 OECD and APEC member economies between 1991 and 2009. The statistical results demonstrate that the unbundling mandate (1) significantly stimulates the DSL penetration rate; (2) indirectly influences the growth of the cable Internet penetration rate; and (3) raises the likelihood that a country deploys an NGN. A case study using Taiwan confirms the positive impact of mandatory unbundling developing an NGN. We conclude that the status quo ULL regime should remain in effect because this regime causes incumbents to invest in an NGN to be exempt from the regulation. Deregulating unbundled access should not be considered a policy option in promoting NGN deployment. We suggest that the current ULL regime could be a more favorable policy stimulus, provided the regime maintains credibility.

Keywords: next-generation network (NGN); unbundled access; unbundled network elements; intra-platform competition; inter-platform competition; regulatory asymmetry

Broadband in digital convergence

The number of Internet users has increased since the Internet was privatized by the National Science Council in 1994. Although e-commerce was once influenced by the bubble economy, Internet users worldwide tripled in quantity during the past decade, to 2.1 billion or, equivalently, 29.7% of the world population (ITU, 2010). The demand for high speed connection and guaranteed bandwidth during transmission has led telecommunications and cable companies to upgrade their infrastructure to fiber optics. These fiber optic infrastructures are often referred to as next-generation networks (NGNs). Table 1 shows that most OECD countries have developed fiber optic infrastructures, and the average penetration rate is approximately 11.16%.

Because telecommunication services have long been shown to contribute to innovation and economic growth (Greenstein, McMaster, & Spiller, 1995; Roller &

*Email: ychou@saturn.yzu.edu.tw

Table 1. Broadband subscription in OECD, 2009.

Country	DSL	Cable	Fiber	Other	Total
Australia	4 178 000	914 000	15 000		5 107 000
Austria	1 263 038	569 903	6 917	5 033	1 844 891
Belgium	1 775 409	1 331 526	1 407	6 353	3 114 695
Canada	4 440 000	5 540 000		365 617	10 345 617
Chile	882 864	758 943			1 641 807
Czech Republic	778 286	441 700	135 000		1 354 986
Denmark	1 238 000	557 000	232 000	19 000	2 046 000
Estonia	135 170	76 756	67 846	20 771	300 543
Finland	1 185 900	222 700	12 600	6 000	1 427 200
France	18 493 000	1 020 000	69 000		19 582 000
Germany	22 424 800	2 300 000	133 700	77 000	24 935 500
Greece	1 916 630	0	2 000		1 918 630
Hungary	823 275	840 589	120 291	1 071	1 785 226
Iceland	97 862		6 908		104 770
Ireland	714 016	150 910	5 636		870 562
Israel	1 035 000	719 000	2 300	2 300	1 758 600
Italy	11 995 019	0	254 174	3 936	12 253 129
Japan	10 134 491	4 300 594	17 195 696		31 630 781
Korea	3 222 419	5 147 994	7 977 303		16 347 716
Luxembourg	131 879	25 896	353	420	158 548
Mexico	7 308 791	2 097 872		82 117	9 488 780
Netherlands	3 645 000	2 351 000	134 000		6 130 000
New Zealand	927 427	60 058	1 508		988 993
Norway	1 007 587	415 214	207 589	3 202	1 633 592
Poland	2 877 286	1 389 943	67 694		4 334 923
Portugal	1 108 680	760 637	30 745	2 211	1 902 273
Slovak Republic	367 723	80 251	177 574	2 174	627 722
Slovenia	286 960	104 939	67 452		459 351
Spain	7 885 940	1 866 101	32 322	2 215	9 786 578

Table 1 – *continued*

Country	DSL	Cable	Fiber	Other	Total
Sweden	1 666 134	579 141	687 403	8 970	2 941 648
Switzerland	1 943 487	795 500	26 281	28 455	2 793 723
Turkey	6 216 028	146 622	41 000	42 724	6 446 374
United Kingdom	14 370 000	3 840 000	3 290		18 213 290
United States	31 190 000	43 392 360	3 945 977	803 000	79 331 337
OECD	167 666 101	82 797 149	31 660 966	1 482 569	283 606 785
OECD (%)	59.12%	29.19%	11.16%	0.52%	

Source: OECD, 2011.

Waverman, 2001), many countries view broadband development as an impetus for growing their economies. Governments employ various approaches for broadband projects. For example, European Union (EU) countries concentrate on open access to the incumbent's last-mile facilities to entice competitive entry. Conversely, Asian-Pacific countries prefer public interventionist approaches such as national planning and subsidies. Increasingly, more countries are preferring to adopt a mixed approach that allows broadband development while accordingly promulgating access regulation (Teppayayon & Bohlin, 2009). However, the effects of access regulation on broadband penetration are empirically less significant than the theory suggests. This uncorroborated effectiveness has cast doubt on whether unbundled access should be maintained to promote next-generation broadband access.

We investigate how mandated access influences broadband penetration and next-generation broadband deployment. Numerous studies have stated that, through the "stepping stone" approach, unbundled access could promote intra-platform competition and eventually inter-platform competition. Nevertheless, not until recently did Cave (2010) propose the adaptive and horizontal "ladder of investment" theory for NGNs. Likewise, few empirical studies have assessed the impact of unbundled access on NGN projects even though DSL uptake is well substantiated. In addition, most studies have investigated the EU or OECD experience while failing to examine the fast-growing phenomenon in the Asian-Pacific region where two countries, Japan and South Korea, enjoy the highest number of fiber subscriptions in the world. This paper, therefore, incorporates data from Asia-Pacific Economic Cooperation (APEC) member economies to quantify the impacts of unbundled access on NGN deployment in a total of 42 countries to elucidate the formation of the NGN regulatory structure. This paper is organized as follows: in Section 2, we discuss unbundled access regulation from theoretical and empirical perspectives. The applicability of "the ladder of investment" theory to NGNs is examined in particular. In Section 3, we then postulate the strategic response of market players to unbundled access regulation regarding NGN buildup. In Section 4 and Section 5, we econometrically examine data and analyze the results. In Section 6, we discuss Taiwan's unbundling policy and its effects. Finally, in Section 7, we outline the regulatory principles regarding the empirical results.

Unbundling local loops in international comparison

Theoretical underpinning of unbundled access

Encouraging entities to provide telecommunications services has become critical for regulators since market liberalization occurred in the early 1990s. An entrant carries enormous costs when competing for market share because the incumbent possesses essential facilities that cannot be replicated by the entrant within a short period. Interconnection and access (that is, one-way interconnection) regulations are then promulgated to grant rival entrants access to the incumbent's network to provide services to end users (Renda, 2010, p. 25). Unbundling local loops (ULL), which the US Congress stipulated in the 1996 Telecommunications Act, among access mandates, provides perhaps the most competitive advantages to the entrant because the incumbent under this clause must lease unbundled network elements (UNEs) of the local loops at regulated rates, usually at the long run incremental cost (LRIC) (Federal Communications Commission, 2003, p. 43). Proponents of unbundling local loops contend that competitors could accordingly save investment costs in service offering so that the entrants can compete against the incumbent.

However, scholars against mandatory unbundling argue that it presents a hurdle to the DSL investments made by the incumbent. When an incumbent cannot forestall the entrant from leasing the incumbent's network elements at below cost, the incumbent has either no or a negative incentive to invest in broadband access via DSL technology. The total amount of investment in broadband infrastructure is reduced because neither the incumbent nor the entrant has incentive to invest in its own facilities under the ULL regime. In response, Cave and Vogelsang (2003) proposed the ladder of investment theory (or the stepping stone approach) in which the rungs of the ladder are metaphors for various levels of access to the incumbent's network. As the rival entrant's customer base grows, the entrant is compelled to climb an upper rung (that is, higher investment level) that eventually leads to investing in the entrant's own infrastructure (Cave, 2006). In other words, unbundling local loops is transformed into a dynamic regulatory regime in which the unbundled price is raised over time and gradually directed toward deregulation. When the opportunity cost of providing broadband access service via unbundled local loops is at least equivalent to that of offering the service over the rival's own infrastructure, the rival competitor is more willing to engage in facility-based competition than in service-based competition.

Some scholars have examined the conditions necessary to sustain the theory. For instance, Bourreau and Dogan (2005) demonstrated that an access charge may influence the facility-based entry date. The regulator then faces a tradeoff in which a high unbundled price expedites facility-based competition while reducing the consumer welfare gained from service-based competition, and vice versa. Avenali, Matteucci, and Reverberi (2010)confirmed that increasing the access charge over time is crucial for fostering the competitor's investment in an alternative infrastructure. That is, the access charge should be determined according to the entry period, rather than the actual time, so that all the competitors are situated within the same incentive structure when they enter the market (Cambini & Jiang, 2009, p. 566). Other studies, by contrast, have challenged the practicality of the ladder of investment theory. The theory is asserted to be valid only if two assumptions hold: (1) service-based competition serves as a stepping stone to facility-based entry when the replacement effect is neutralized, and (2) the regulator has an instrument for neutralizing the replacement effect (Bourreau, Dogan, & Manant, 2010, p. 686). The competitor does not invest in its own facilities, argued Bourreau et al. (2010), once it foresees the possibility that the regulator fails to make a credible commitment to increase the unbundled price after the sunset clause attached to the unbundled local loops is due.

Regarding NGN deployment, Cave admitted that some modifications are necessary in applying the theory. Because technical difficulties persist in unbundling fiber subloops,[1] competitors are left with no choice to go either up the ladder to subloop access or down to active line access when migrating to the NGN. The competitor incurs higher investment costs when it provides services via fiber subloops, whereas facility-based competition is compromised as the competitor purchases active line access from the incumbent (Cave, 2010, pp. 83–84). Cave then proposed public investments in ducted dark fiber to facilitate competitors' movements up from a lower starting point on the NGN ladder (2010, p. 85). Bourreau et al. (2010) discussed a dilemma between promoting competition and giving firms appropriate incentives to build infrastructure when mandating unbundled fiber subloops in a not-yet-established market such as the NGN.

Empirical insignificance of the ULL regulation

Many studies have measured the ULL effects on broadband investment and penetration in OECD countries. Distaso, Lupi, and Manetti (2006) tested data from 14 European countries and confirmed that a low unbundled price increases broadband penetration. The authors also observed that while inter-platform competition (that is, cable vs. DSL) drives broadband subscription, intra-platform competition (that is, unbundled access) induces less significant results. Friederiszick, Grajek, and Roller (2008) conducted an empirical analysis on a dataset of 25 European countries over a 10-year period. The authors found no indication that unbundled access had a significant impact on the overall investment while inducing a significantly negative impact on the incentive of entrants to invest (Friederiszick et al., 2008). Wallsten and Hausladen (2009) performed linear regression models on a dataset from 27 European countries, 2002–2007, and found a significantly negative correlation between the number of unbundled lines per capita and the number of fiber connections, for the entrants and the incumbents. Hence, mandatory unbundling generates a negative impact on the NGN investment. Ware and Dippon (2010), after accounting for supply factors, such as population density, population concentration, and use of unbundling, as well as demand determinants, such as computer ownership, income distribution, gross domestic product (GDP) per capita, and price for broadband, determined there was no statistically significant correlation between the unbundling variable and broadband penetration. Bouckaert, van Dijk, and Verboven (2010) also verified that, based on the panel data from 20 OECD countries from 2003 to 2008, inter-platform competition was the main impetus behind broadband penetration. Intra-platform competition, in contrast, generated an insignificant or even negative impact on broadband penetration. These studies together pinpoint that mandatory unbundling induces less significant impacts on broadband penetration than inter-platform competition even if regulation drives more broadband subscriptions. The authors also cast doubt on the effectiveness of unbundling local loops in stimulating NGN investment. Bouckaert et al. (2010) concluded that the ladder of investment theory may not provide the justification for imposing extensive mandatory access obligations on DSL incumbents (Cambini & Jiang, 2009, p. 569).

Since the regulatory impact of unbundled access is far from clear, only two countries, Japan and the Netherlands, have extended mandatory unbundling to incumbents' fiber subloops. The Independent Post and Telecommunication Authority (OPTA) of the Netherlands mandates unbundled access to fiber-to-the cabinet (FTTC) subloops and fiber-to-the-home (FTTH) fiber optics (Independent Post & Telecommunication Authority of the Netherlands, 2008, p. 95). The Ministry of Internal Affairs and Communications in Japan began regulating the rates and terms for unbundled access to NTT East/West's optical fiber subscriber lines in 2001 (Fujino, 2010). Most countries retain the same ULL regime in regulating access to incumbents' networks, while devoting public efforts to develop NGNs through government subsidies, public private partnership, or public-owned infrastructures (as listed in Table 2).

Policy effects of mandatory unbundling

Unbundled access refers to unbundling local loops or fiber subloops; however, we restrict our discussion to local loops because countries so far have seldom exercised

Table 2. Broadband initiatives and unbundled access in selected countries.

Nation	Broadband initiative	Unbundling local loops (period)
Australia	*National Broadband Network (NBN)*, fiber-to-the-premises or next-generation wireless/satellite technologies	Yes
Canada	*Broadband Canada: Connecting Rural Canadians*, 5 Mbps in rural areas by 2015	Yes
China	*Next Generation Information Infrastructure*, triple service available by 2015	No
France	*Digital France 2012*, 512 Kbps provided by all operators in 2012	Yes
Japan	*New Broadband Super Highway*, 100% nationwide penetration of 30 Mbps by 2015	Yes
S. Korea	*Ultra Broadband Convergence Network*, 10 million FTTH households by 2015	Yes
Singapore	*Next Generation National Broadband Network (NGNBN*), 50% households with broadband access by 2012, offering 1 Gbps by 2015	Yes
Taiwan	*Digital Convergence Development Plan,* 100 Mbps broadband access in 80% households by 2015	Yes
UK	*Digital Britain*, 2 Mbps in residential areas by 2012	Yes
US	*National Broadband Plan*, 100 Mbps in residential areas by 2020	Yes (1996 ~ 2005)

Source: countries' websites, APEC Tel 44 documents (DETECON, 2011).

unbundled access to fiber subloops. We then analyze broadband access providers' investment decisions about deploying infrastructure according to the providers' strategic responses to ULL and inter-platform competition. The incentive structures of three access providers, market entrants, telecommunication firms, and cable operators, in the broadband access market, as well as NGNs are examined as follows.

Direct impact on market entrants

Figure 1 illustrates the mode of competition in which a broadband access provider is positioned, given its endowments and regulatory constraints. Mandatory unbundling highlights the intra-platform competition within the same DSL technology. Telecommunication incumbents and cable operators confront each other by engaging in inter-platform competition. In addition, inter-platform competition can be stretched to the NGN with network upgrades. The operators can compete via current technologies (that is, DSL/cable Internet) or fiber optic technologies.

Table 3 summarizes access providers' investment decisions. Unbundling local loops is viewed as the most effective instrument for consolidating intra-platform competition from rival entrants. Particularly when the unbundled price is cost-based (for example, LRIC), implementation supposedly reduces rivals' costs in providing access services. Consequently, the competitors prefer unbundled access to building an alternative infrastructure. The number of DSL connections provided by the entrants

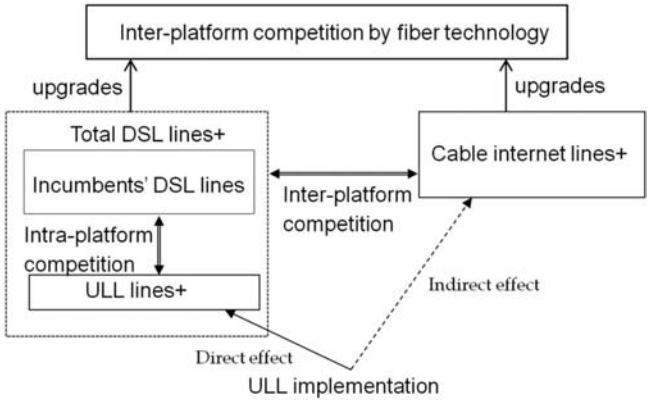

Figure 1. The mode of competition in the NGN.

assuredly increases. Because mandatory unbundling also constrains the rival entrant's willingness to deploy a network, the entrant undoubtedly defers the option of technological upgrades (Xaiver, 2009). The ULL regime allows rival competitors to continue using inferior DSL technology, constituting a hurdle for them to migrate to the NGN.

The impact on telecommunication incumbents

Mandatory unbundling compels telecommunication incumbents to engage in intra-platform competition against rival entrants in addition to inter-platform competition with cable operators (see Figure 1). Incumbents contend with two competitive forces and make investment decisions based on the aggregate impact of both modes of competition. As discussed in the literature, implementing unbundled access purportedly decreases incumbents' willingness to install more DSL lines because the incumbents' assets become stranded (Cave, 2010, p. 83; Wallsten & Hausladen, 2009). However, threatened by intense competition from cable operators, incumbents may expand DSL installation in response. With the available fiber technology, the firms could instead strategically invest in the NGN to deter others' from unbundled access to the firms' networks. If the opportunity costs of providing fiber optic connections are smaller than those of DSL, the firms would forgo DSL technology and migrate to the NGN. Likewise, incumbents will upgrade their networks to fiber optics when the incumbents foresee cable operators deploying NGNs to obtain a larger market share.

Table 3. The incentives structure of the broadband access providers.

	ULL on the DSL/cable Internet investment	ULL on the fiber investment
Competitors	Positive (+)	Negative (−)
Telecom incumbents	Undecided (?)	Positive (+)
Cable operators	Positive (+)	Positive (+)

Table 4. The strategic response to ULL by telecommunications incumbents.

	Intense competition	Less competition
Regulatory certainty	Fiber	(Fiber)
Regulatory uncertainty	DSL	No investment

The incumbents nevertheless defer investing in the NGN if the regulator fails to make credible commitments to the unbundling policy. The incumbents' investments again become stranded once the fiber subloops are classified as UNE. The firms continue to provide broadband access service via DSL technology and postpone investing in NGNs until the regulatory uncertainty is mitigated. Table 4 summarizes the incumbents' strategic response: facing fierce competition, they invest in expanding and upgrading the network. In addition, firms convert to fiber technology when the regulator credibly commits to the current ULL regime. Otherwise, incumbent firms continue to offer broadband service via DSL technology when the changes in the ULL regime are unclear. Conversely, a concentrated market (that is, lesser competition) reduces the incentive for firms to invest in expanding and upgrading the network. Incumbent firms invest in the NGN only if their upgrades are exempt from unbundled access regulation. Incumbent firms might not invest at all when the market is highly concentrated and compounded by regulatory uncertainty. The ULL regime is then hypothesized to cause telecommunication incumbents to migrate to the NGN, provided it maintains credibility. Meanwhile, the impact on the incumbents' choice of DSL technology is undetermined because they have less incentive to invest but are compelled to do so because of intense competition (as shown in Table 3).

Indirect impact on cable operators

Cable operators are seemingly indifferent to the unbundling policy. They enjoy competitive advantages against telecommunication incumbents because the operators' assets are exempt from unbundled access. Nevertheless, cable operators engaging in inter-platform competition have an incentive to invest in cable Internet connections once the operators observe the concentration of DSL connections in the broadband market. In retrospect, manufacturers supporting Betamax and VHS formats competed neck and neck in the home video market. The most effective strategy involved increasing output until one format dominated. Unbundling local loops enables competitive entrants to offer broadband access services via DSL technology and thus increases the market share of DSL lines during inter-platform competition (Distaso et al., 2006, p. 97). Hypothetically, cable operators challenged by fierce inter-platform competition invest in expanding and upgrading the network to retain their market power (as shown in Figure 1 and Table 3). Although the unbundling policy is limited to DSL technology, the policy could influence cable operators to install more cable Internet connections due to the inter-platform competition effects. That is, the unbundling policy indirectly influences the installation of cable Internet connections.

As shown in Figure 1, implementing unbundling local loops directly increases the ULL lines and the market share of DSL connections in inter-platform competition. Cable operators then in response invest in cable Internet installation. Unbundled access nevertheless indirectly increases cable Internet connections when the operators confront strong competition from telecommunications firms. Accordingly, the operators have an incentive to migrate to the NGN once their telecommunication counterparts offer fiber access services that are exempt from mandatory unbundling. Unbundling local loops again indirectly instigate operators' migration to the NGN during inter-platform competition. The unbundling policy is then hypothesized to indirectly influence cable Internet penetration, as well as the operators' migration to the NGN.

Broadband penetration induced by ULL

We examine econometric panel data from OECD and APEC member economies to verify our hypotheses (see the country list in Table A1 in the Appendix). The dataset contains 798 samples, ranging from 1991 to 2009. The sources included in the dataset are *World Telecommunication/ICT Indicators Database* (2010) of the ITU (International Telecommunication Union), *OECD Broadband Statistics* (online), and MPA (Media Partners Asia)'s *Asia Pacific Pay-TV & Broadband Markets 2009*.

Data and model specification

While we attempt to measure the impacts of mandatory unbundling on broadband penetration and NGN uptake, the DSL and cable Internet connections are assumed to be interdependent because of inter-platform competition. That is, both types of penetration rates must be estimated jointly for their synchronous correlation. The ordinary least square (OLS) regressions that run each equation independently fail to account for the problem of autocorrelation. Therefore, the seemingly unrelated regression (SUR), a particular form of simultaneous equation model, which allows correlated errors between multiple equations when they are simultaneously run together, performs a more adequate analysis for broadband penetration (Zellner, 1962). Efficiency is also improved by performing SUR on joint estimation of multiple Equations (Baum, 2006, pp. 236–238).

Ware and Dippon (2010) substantiated that broadband connections are affected by supply and demand factors. A supply factor, GDP per capita, which represents a nation's economic status, is included in our statistical modeling. Three demand determinants are exemplified by the triple play of broadband convergence: voice, data, and video. We use the fixed-line penetration rate, the ratio of the Internet population, and the subscription rate of pay TV services to extrapolate the demand levels for voice, data, and video services, respectively. The variables tested in this paper are listed in Table A2, Appendix. However, these macroeconomic data suffer from the collinearity problem that makes SUR barely operational. We therefore operate SUR under structural equation models (SEMs) to capture the non-linear and correlated relationships between the variables (Fox, 2002).[2] In addition, these macroeconomic time series data are non-stochastic; that is, the error terms are auto-correlated. Because the non-stochastic process shows an upward trend as time passes (Pindyck & Rubinfeld, 1991, p. 443), we detrend these data with algorithmic transformation (that is, the growth rate).

Figure 2 illustrates the path diagram that specifies the causal relationships between the broadband penetration rates and the independent variables, including

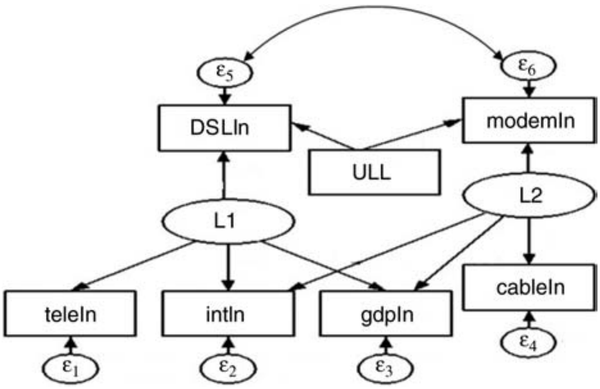

Figure 2. Path diagram of the DSL and cable Internet penetration rates. Note: DSLln is the growth rate of the DSL penetration rate; modemln is the growth rate of the cable Internet penetration rate; intln is the growth rate of the ratio of the Internet population; teleln is the growth rate of the fixed-line penetration rate; cableln is the growth rate of the subscription rate of pay-TV services; gdpln is the growth rate of GDP per capita; ε_j, j = 1–6 is the error term.

ULL. Equation 1 (E1) defines that the DSL penetration rate is affected by the fixed-line penetration rate, the ratio of the Internet population, GDP per capita, and the implementation of unbundled access.

$$\ln(Y_d) = \alpha + \beta_{ULL}X_{ULL} + \beta' \ln(X') + \varepsilon_{it} \tag{E1}$$

$\ln(Y_d)$ represents the percentage changes in the DSL penetration rate; X_{ULL} represents the ULL dummy variable; β_{ULL} is the coefficient estimator for X_{ULL}; $\ln(X')$ are the growth rates of macroeconomic variables; β' are the coefficient estimators for $\ln(X')$; ε_{it} is the residual; and α is the intercept.

Although these macroeconomic variables are correlated, the latent variable 1 (L1) is designated to capture the collinear effects among the variables by defining them as measurement variables in estimating L1's correlation coefficients. Likewise, the penetration rate of cable Internet is assumed in (E2) to be affected by the ratio of the Internet population, the subscription rate of pay TV services, GDP per capita, and the implementation of unbundled access.

$$\ln(Y_c) = \alpha + \beta_{ULL}X_{ULL} + \beta' \ln(X') + \varepsilon_{it} \tag{E2}$$

$\ln(Y_c)$ represents the percentage changes in the cable Internet penetration rate.

Latent variable 2 (L2) is created in SEM to capture the collinear effects among these variables.

As shown in Figure 2, SEM could perform SUR by allowing error terms of the DSL and cable Internet penetration rates to be correlated and jointly estimating the separate Equations (Stata, 2011). The curve line connecting ε_5 and ε_6 represents synchronous correlation between the broadband penetration rates.

Departing from the literature discussed in the previous sections, we use a dummy variable instead of the concentration status (Herfindahl–Hirschman Index, HHI) in intra-platform competition to represent the unbundling policy. Because of the assumption of interdependence between the broadband network deployments, we

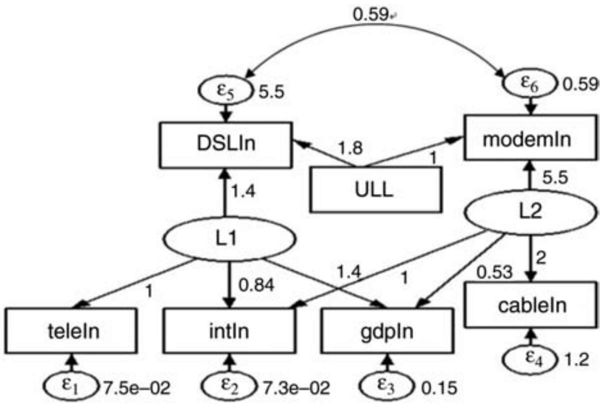

Figure 3. Coefficient estimation for broadband penetration rates.

consider the HHI numbers for DSL and all broadband markets as endogenous but not exogenous. The degree to which unbundled access is promulgated should not be approximated by the HHI. A more accurate estimate could be the unbundled price mandated in each country; nevertheless, these data are difficult to obtain in most APEC member economies. We recognize that the dummy value fails to capture the dynamic changes in the ULL regime over time; such is the basis of the stepping stone approach. The simplified connotation of the unbundling policy enables us to include APEC member economies for data completeness, supporting the importance of this study.

Significant direct impact

Figure 3 shows the coefficient estimation of the DSL and cable Internet penetration rates obtained from performing SUR within SEM. The correlation coefficient between ε_5 and ε_6 is estimated to be 0.59; that is, the error terms of the percentage changes in the DSL and cable Internet penetration rates are correlated. The DSL and cable Internet penetration rates are corroborated inter-dependently during inter-platform competition. Table 5 lists the χ^2 statistic of SEM as 527.97, and p-value < 0.001. The result confirms the valid estimation of the changes in the broadband penetration rates using SUR within SEM.

Column A in Table 5 documents the coefficient estimation against the percentage changes in the DSL penetration rate. First, the coefficient estimation of unbundling local loops is 1.825, significant at the 0.1% level. That is, mandating unbundled access remarkably increases the growth of the DSL penetration rate by 5.20%.[3] The result implies that mandatory unbundling successfully eases market entrants' costs in providing broadband access services and then increases the DSL connections offered by the entrants. Second, the β coefficient for L1 that measures the collinear effects among the percentage changes in the fixed-line penetration rate, the ratio of the Internet population, and GDP per capita is 1.382, significant at the 0.1% level. The result suggests that these macroeconomic variables together cause the DSL penetration rate to rise by 1.4% when they grow by 1%.[4] This result also indicates the macroeconomic factors generate less significant impact than the ULL regime.

Table 5. Changes in the penetration rates of DSL and cable Internet connections.

Variables	DSL penetration rate (DSLln) [A]	Cable Internet penetration rate (modemln) [B]
Intercept	− 5.475*** (0.307)	− 5.613*** (0.222)
Unbundled access (ULL)	1.825*** (0.423)	1.041*** (0.278)
Latent variable 1 (L1)	1.382*** (0.322)	
Latent variable 2 (L2)		5.536*** (0.872)
Test of Model		
Observation	234	
χ^2 statistic	527.97	
p-value	<0.001	

Note: *5% significance level; **1% significance level; ***0.1% significance level; (x): standard error.

Unbundling local loops is an effective policy instrument for increasing the DSL penetration rate.

Indirect impact validated

Column B in Table 5 shows the coefficient estimators of the cable Internet penetration rate. Regarding ULL regulation, its coefficient estimation is 1.041, significant at the 0.1% level. That is, mandatory unbundling of local loops causes the cable Internet penetration rate to grow by 2.83% ($= (e^{1.041} - 1)\% = (3.83–1)\%$). Compared with the degree to which the impact on the changes in the DSL penetration rate, unbundled access yields less than half the effect on those in the penetration rate for cable Internet. As competitors' access to local loops is granted, unbundled access generates direct and strong impact on the growth of the ULL lines. Unbundled access nevertheless influences cable operators' decisions to invest in cable Internet installation through inter-platform competition. This impact is indirect and thus less significant.

Second, the coefficient estimation for L2 is 5.536, significant at the 0.1% level.[5] The result indicates that a collective 1% increase in the growth of these macroeconomic variables will cause the cable Internet penetration rate to rise by 5.54%. Comparing the impacts of the ULL regime and the macroeconomic variables, we conclude that macroeconomic status is a more important factor than the regulatory mandate to increase the cable Internet penetration rate. Unlike the determinant impact generated on the percentage changes in the DSL penetration rate, ULL regulation is an indirect and less effective policy instrument for augmenting cable Internet connections.

Lagged impact on telecommunications incumbents

Although the regulatory impact may not be immediately present after the mandate is carried out because of the regulated parties' learning costs and subsequent behavioral changes (Wheelan, 2011, pp. 385–389), we modeled the lagged impact of ULL

Table 6. Lagged impact of the unbundling policy.

Variables	DSL penetration rate (DSLln) [C]	Cable internet penetration rate (modemln) [D]
Intercept	− 5.462*** (0.264)	− 5.403*** (0.208)
Lagged unbundled access (ULL-1)	2.031*** (0.383)	0.785** (0.274)
Latent variable 1 (L1)	1.328*** (0.296)	
Latent variable 2 (L2)		5.539*** (0.841)
Test of model		
Observation	234	
χ^2 statistic	61.44	
p-value	<0.001	

Note: *5% significance level; **1% significance level; ***0.1% significance level; (x): standard error.

regulation using SUR within SEM. The results in Table 6 demonstrate that all estimations of the coefficients of the variables produce consistent outcomes.

ULL regulation is corroborated to have lagged impact on the DSL and cable Internet penetration rates. The β coefficient in Column C is 2.031, significant at the 0.1% level. The DSL penetration rate continues to rise by approximately 6.62% (= ($e^{2.031}$ − 1)% = (7.62–1)%) after one year of ULL implementation. Column D shows the coefficient estimation is 0.785, also significant at the 0.1% level. The cable Internet penetration rate in contrast grows at a slower speed by 1.19% (($e^{0.785}$ − 1)% = (2.19–1)%) just one year after ULL promulgation. The result seems initially counterintuitive. Although statistically significant, the impact of ULL regulation on cable Internet connections decreases considerably from 2.83% in the previous year to 1.19%. The decrease implies that cable operators have simultaneously learned the positive impact of the ULL regime on DSL connections during inter-platform competition when unbundled access is mandated. Operators invested in cable Internet connections immediately after ULL was implemented. The indirect impact of ULL implementation is thus not lagged.

However, the continuous augmentation of DSL connections one year after ULL implementation may stem from the telecommunication incumbents' investment decisions. The incumbents indeed have a disincentive to invest in DSL connections to be exempt from ULL regulation. The incumbents nevertheless have to install more DSL lines after they observe an increase in the cable Internet penetration rate during inter-platform competition. The incumbents have learning costs in perceiving the indirect effects incurred by mandatory unbundling so that they make lagged investment decisions.

As shown in Figure 4, unbundling local loops stimulates entry providing ULL connections and thus increases DSL concentration in the entire broadband market (Distaso et al., 2006, p. 97). Observing the competitive threats from the DSL increase, cable operators invest in cable Internet connections. ULL regulation then indirectly affects the operators' investment decisions and the deployment of cable Internet. Consequently, telecommunications incumbents invest in DSL installation, in a lagged way, through enhanced competition from cable Internet technology. In addition to the direct impact on the growth of ULL lines, our econometric analysis substantiates

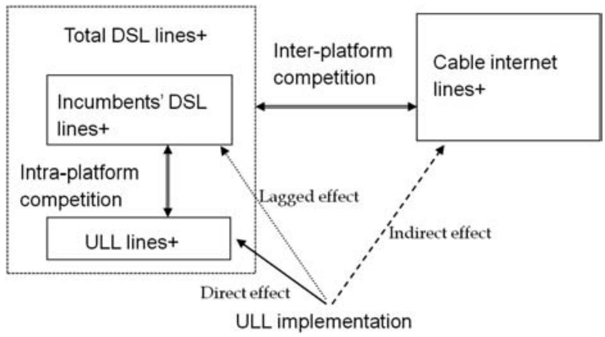

Figure 4. The competition effects of the ULL regime.

the hypotheses that ULL regulation entails indirect and lagged impact on cable operators' and telecommunications incumbents' investment decisions, respectively.

The statistical findings are consistent with the literature previously discussed. Although the direct impact (5.20%) of the ULL regime is greater than the indirect impact (2.83%), the effects of inter-platform competition should be attributed to the indirect and the lagged impact (6.62%) as cable operators and telecommunication incumbents compete for market share dependent on each other's investment decisions. The inter-platform effects are hence greater (9.45% = 2.83% + 6.62%) than those of intra-platform competition (5.20%) in promoting broadband penetration.

Second, Table 6 shows that the coefficient estimations for L1 and L2 are 1.328 and 5.539, respectively, both significant at the 0.1% level. The results are robust because they confirm the collinear effects among the macroeconomic variables.[6] A 1% increase in the fixed-line penetration rate, the ratio of the Internet population, and GDP per capita together causes the DSL penetration rate to rise by 1.33%. Likewise, a 1% increase in the ratio of the Internet population, the subscription rate of pay TV services, and GDP per capita collectively entails a 5.54% increase in the penetration rate of cable Internet. Mandatory unbundling is comparatively a more effective policy approach than macroeconomic factors in growing the DSL penetration rate; whereas, mandatory unbundling becomes less effective than macroeconomic factors in terms of the growth of the cable Internet penetration rate.

NGN uptake by mandatory unbundling

The likelihood of NGN deployment

Because only 27 out of the 42 countries in our dataset have commenced fiber access services and thus 12% of our 798 samples have fiber penetration rates greater than zero, we found the OLS regressions hardly applicable in examining NGN development. We then adopted conditional logistic regressions to estimate the undertaking, that is, the occurrence of the event whether or not a given country migrates to NGNs via mandatory unbundling.[7] Value 1 of the dependent variable is defined as fiber subloops being deployed in a given country, while value 0 is the fiber subloops not yet deployed in that country. For the large dataset, the linear probability model could replace conditional logistic regression because the maximum likelihood

Table 7. The discrete choice of the fiber subloop deployment.

Variable	Fiber subloop uptake (fibergo) [E]	Fiber subloop uptake (fibergo) [F]
Intercept	−3.147*** (0.417)	−2.780*** (0.435)
Unbundled access (ULL)	0.038 (0.030)	
Lagged unbundled access (ULL-1)		0.091** (0.034)
Fixed-line penetration (teleln)	−0.149*** (0.043)	−0.121** (0.044)
Internet user ratio (intln)	0.018* (0.007)	0.015* (0.007)
GDP per capita (gdpln)	0.333*** (0.043)	0.296*** (0.045)
Observation	714	696
F statistic	44.78	45.64
p-value	<0.001	<0.001

Note: *5% significance level; **1% significance level; ***0.1% significance level; (x): standard error.

estimation of such a binary regression is computationally difficult (Kennedy, 1992, p. 378). We then employ the linear probability model running against the discrete event of the fiber subloop deployment.

Table 7 shows the synchronic and the lagged effects of ULL regulation on fiber subloop deployment. The *F* statistics of both estimations are approximately 44.78–45.64 and p-value < 0.001, meaning that they are valid estimates of the discrete event of the uptake. Column E shows that the coefficient estimation of unbundled access is insignificant; whereas, the results in Column F corroborate the lagged impact on deploying fiber subloops. The β coefficient is 0.091 and significant at the 1% level. That is, the odds ratio for the developed fiber subloops is 9%. The probability of a country migrating to an NGN is 9% higher than not engaging in developing an NGN, one year after local loops are unbundled.

Regarding the extent to which the migration choice is affected by the ULL regime, we calculate the cross-elasticity ($E_{ULL\text{-}1}$) of the β coefficient based on the assumption of normal probability distribution (Train, 2003, p. 51).

As $E_{ULL\text{-}1} = \beta_{ULL\text{-}1} * \mu_{ULL\text{-}1} * P_{ULL\text{-}1}$ (Baum, 2006, p. 249),
$\mu_{ULL\text{-}1}$ = (ULL-1)'s mean = 0.32,
$P_{ULL\text{-}1}$ = (ULL-1)'s probability $= \frac{\exp^{(\mu*\beta)}}{1+\exp^{(\mu*\beta)}} = \frac{\exp^{(0.32*0.091)}}{1+\exp^{(0.32*0.091)}} = 0.51$,
$E_{ULL\text{-}1} = 0.091*0.32*0.51 = 0.015.$

The probability that a country will deploy an NGN increases by 1.5% one year after unbundled access is promulgated.

As shown in Column F, the β coefficient of the ratio of the Internet population is 0.015, significant at the 5% level; meaning that the probability of a country deploying fiber subloops is 0.02% higher than not deploying fiber subloops when the ratio of the Internet population increases by 1%. The GDP per capita is positive and significant at the 0.1% level. The probability of a country deploying fiber subloops is 0.3% higher than not deploying fiber subloops when the GDP per capita grows by 1%. The coefficient estimator of the fixed-line penetration rate is, conversely, negative but significant at the 1% level. The explanation for the result is that telecommunication incumbents have to replace fixed lines with fiber subloops as they migrate to the

NGN. Therefore, the negative growth rate of the fixed-line penetration rate indicates the greater probability a nation migrates to the NGN. The -0.12 coefficient value means that the probability of a country undertaking fiber subloop deployment is 0.12% higher than not deploying the fiber subloops when the fixed-line penetration rate decreases by 1%.

The unbundling policy in the NGN era

This econometric analyses confirm the positive impact created by mandatory unbundling on broadband penetration and NGN projects, although to varying degrees. As mandatory unbundling encourages entry using DSL technology, unbundling increases the ULL access lines offered by entrants in intra-platform competition. Moreover, the statistically positive correlation between the lagged ULL regime and the growth in the DSL penetration rate indicates that telecommunication incumbents still invest in DSL technology because they face fierce competition from rival entrants and cable operators. The incumbents nevertheless have learning costs in evaluating the inter-platform competition effects, resulting in delayed deployment of DSL connections. Our statistical findings confirm that the changes in the DSL penetration rate increase to 11.82% ($= 5.20\% + 6.62\%$), and intra-platform and inter-platform competition effects occur, due to the promulgation of unbundled access.

The unbundling policy, in contrast, is shown to indirectly provoke positive impacts on the cable Internet penetration rate. Unbundling local loops increases the ULL access lines and therefore results in a higher concentration of DSL connections in the broadband market. Meanwhile, cable operators invest in cable Internet connections to retain market share when encountering excessive inter-platform competition. Cable Internet penetration rate rises by 2.83% due to implementation of the ULL regime. Cable Internet is comparatively less beneficial after unbundled access to local loops occurs, approximately one fourth of the DSL connections.

The ULL regulation supports increasing the probability of developing an NGN. When the regulator credibly commits to the current ULL regime, incumbent firms are inclined to invest in the NGN to be exempt from unbundled access to their network assets. Considering the APEC member economies as an example, South Korea exhibited a DSL penetration rate of 7.7% in 2008, down from 9.5% in 2007; the fiber subscription rate in 2008 was 13.8%, up from 10.4% in the previous year (OECD, 2010). These figures clearly indicate that the trend of incumbents' migration is led by mandatory unbundling.

Because of the inter-platform competition effects, cable operators also invest in an NGN when they observe incumbents deploying fiber subloops. Market entrants, in contrast, have low incentive to build their own infrastructure under the current ULL regime. The willingness of the incumbent and cable firms to invest in network migration is equivalent to a 1.5% increase in the probability that a country will build an NGN one year after ULL is mandated.

The unbundling policy in Taiwan

The Administrative Yuan of Taiwan initiated the "three million broadband households in three years" project in 1999, and the "six million broadband households" plan during Stage II in 2001 (National Information and Communication Initiative [NICI] Committee, 2008). The Administrative Yuan of Taiwan also announced the "digital convergence development" strategic plan in July 2010, aiming to achieve a goal of six million fiber optic households by 2015 (NICI Committee, 2010). Broadband access subscriptions amounted to 5.31 million in 2010: among which there were 2.36 million ADSL users, 0.93 million cable Internet users, and 1.96 million FTTx subscribers. The average penetration rate of broadband access per 100 inhabitants was 22.9%. However, broadband development since 2008 has lagged behind most East Asian countries, such as South Korea, Japan, Hong Kong, and Singapore. The penetration of fiber subscriber lines in Taiwan has not grown as swiftly as anticipated. As the number of fiber subloop connections has increased, the DSL subscription rate has decreased drastically from the peak of 4.37 million in August 2008. The net increase in NGN connection has been offset by DSL disconnection, causing sluggish growth in Taiwan's broadband access penetration. As demonstrated in the previous section, implementing unbundled access could increase the growth rate of broadband access penetration, as well as the probability of developing an NGN. Taiwan's stagnated broadband development must be examined from the perspective of access mandates.

The Telecommunication Act of Taiwan stipulates interconnection obligations among Type I carriers. Article 17 of "Regulations Governing Network Interconnection among Telecommunications Enterprises" designates UNEs as (1) local subscriber loops, (2) local switch transmission equipment, (3) local trunks, (4) toll switching transmission equipment, (5) long-distance trunks, (6) international switching transmission equipment, (7) network interface equipment, (8) directory equipment and service, and (9) signaling network equipment. Article 18 requires that the tariff for UNEs is determined by negotiation on a cost basis. Article 37 of "Regulations for Administration on Fixed Network Telecommunications Business" then permits market entrants unbundled access to bottleneck facilities that cannot be replicated within a reasonable period. The National Communications Commission (NCC), Taiwan's regulatory authority, declared in 2006 that fixed-line bottleneck facilities include (1) the distribution frames of bridges, tunnels, and subscribers' buildings, or cabinets at curbside; (2) ducts in subscribers' buildings; and (3) the access point of local subscriber loops between the distribution frames of the local exchange office (MDF) and customer premise equipment (CPE) (NCC, 2006). The local subscriber loops are consequently unbundled, and access to them is charged on a cost basis. Nevertheless, this unbundled access is limited to full unbundling only, not line-sharing and bitstream access (Telecom Technology Center [TCC], 2009, p. 5).

Taiwan's ULL regime is comparatively moderate because it does not regulate the wholesale price of access to local loops. Hypothetically, market entrants cannot access the network of the telecommunication incumbent, Chunghwa Telecom, at the lowest cost and have little incentive to provide broadband access services using DSL technology. Meanwhile, Chunghwa Telecom has a strong incentive to upgrade its network to the NGN for exemption from ULL regulation. We thus observe a negative correlation between DSL and fiber access connections. The number of DSL connections decreases because the entrants and Chunghwa Telecom disregard such technology. Cable Internet penetration, consistent with our statistical results, shows a steady but slow growth trend. Furthermore, mobile broadband access subscriptions in Taiwan have recently surged, indicating that mobile broadband access may play a more critical role in inter-platform competition and provoke Chunghwa Telecom's investment in an NGN.

The regulator in Taiwan could commit to the status quo ULL regime so that Chunghwa Telecom is more willing to deploy an NGN. The regulator can also create a wireline-friendly regulatory environment so that market players have more incentive for deploying an NGN. In addition, the growth in Internet population has demonstrated a positive influence on NGN development. The Taiwanese government could develop "digital inclusion" projects to empower people to become net citizens. Once they are accustomed to consuming broadband services, people will demand NGN access with higher speed and greater bandwidth.

Mandatory unbundling promotes NGN deployment

This paper discusses the strategic behaviors of market players in response to mandatory unbundling and empirically examines the impact on broadband penetration and deploying an NGN. The results of the econometric tests on 42 OECD and APEC member economies substantiate that mandatory unbundling (1) effectively stimulates the DSL penetration rate, (2) indirectly creates a slight impact on the cable Internet penetration rate, and (3) raises the probability that a country will migrate to an NGN. The results elucidate the regulatory structure that adequately promotes NGN deployment. The status quo ULL regime that applies unbundled access only to local loops should continue to be enforced as it causes telecommunication incumbents to invest in the NGN to escape the unbundling mandate. Cable operators are also motivated to migrate to the NGN because of inter-platform competition. Unbundling local loops raises the likelihood a country will deploy an NGN. Hypothetically, deregulation of unbundled access should not be considered a policy option in promoting NGN deployment.

However, telecommunication incumbents migrate to an NGN under the condition that the regulator makes credible commitments to the current ULL regime. To avoid stranded assets, the incumbents do not invest in the NGN until the regulatory uncertainty is mitigated, whether or not fiber subloops are announced as UNE. Consequently, countries must commit to the current ULL regime without foreseeable changes to ensure the firms invest in the NGN.

The question remains whether unbundling fiber subloops should be promulgated to deploy an NGN. Regrettably, no data from empirical tests are available because few countries have mandated fiber subloop unbundling. We postulate the negative impact fiber subloop unbundling has on NGN uptake. As unbundling local loops reduces telecommunication incumbents' investments in DSL connections, unbundling fiber subloops seemingly entices a negative incentive for incumbents to deploy an NGN. Incumbents reduce investments in the NGN to avoid stranded assets. Unbundling fiber subloops inspires a policy concern that competition might be created at the expense of reduced investment. Unbundling fiber subloops should not be executed before additional empirical findings are available. That is, the status quo unbundling mandate could be a more favorable policy stimulus, provided the mandate maintains credibility.

The validity of the stepping stone approach can be tested when applied to NGN development if the unbundled price is set as the proxy for unbundled access. Again, the price information is extremely costly to obtain, particularly in developing countries. We propose a tradeoff between accurate measurement and data completeness. Further research should be conducted to quantify more precisely the impact of unbundled access once the necessary data are available.

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Notes

1. Fiber optic deployment involves the high costs of civil projects in building the conduit. According to European Equity Research, the costs of conduit and duct work in deploying an fiber optic network accounts for 68% of the total, while the fiber optics line comprises only 6% and line installation 3% (HeChen, 2009, p. 7). The so-called bottleneck facility of the fiber optic network does not lie in fiber subloops but in civil work, street cabinet, and ducts (Xavier, 2009, p. 19). The technical problems increase the difficulties and costs involved in embarking on open access to incumbents' fiber optic network.
2. The structural model within the SEM estimates causal dependencies between endogenous and exogenous variables, and the measurement model controls for the collinearity problem by creating latent variables that are not measured directly but are estimated from several measured variables (Wothke, 2010). SEM could then test and estimate the causal relations between the variables with the co-variant error terms.
3. Since ULL has a discrete value, the extent to which the DSL penetration rate is influenced is $(e^{\beta} - 1)\% = (e^{1.825} - 1)\% = (6.20\text{–}1)\% = 5.20\%$ (Kennedy, 1992, p. 257).
4. As the result shows that all the estimators are significant at the 0.1% level, strong correlations between the macroeconomic variables are suggested.

The estimation of the correlation coefficients for L1 and L2 is listed as follows:

	L1	L2
Teleln	1 (constrained)	
Cableln		1.96*** (0.27)
Intln	0.81*** (0.06)	1 (constrained)
GDPln	1.35*** (0.08)	0.58*** (0.12)

Note: ***0.1% significance level; (x): standard error.

5. The result deriving from the measurement model confirms a strong correlation between the three macroeconomic variables (see note 4).
6.

The estimation of the correlation coefficients for L1 and L2 is listed as follows:

	L1	L2
Teleln	1 (constrained)	
Cableln		2*** (0.28)
Intln	0.84*** (0.06)	1 (constrained)
GDPln	1.4*** (0.08)	0.53*** (0.13)

Note: ***0.1% significance level; (x): standard error.

7. We assumed the probability of a given event happening as p, the probability of the event not happening (1-p), and the odds ratio of the event occurring becomes $\frac{p}{1-p}$. The conditional logistic regression runs the coefficient estimation of $\ln\left(\frac{p}{1-p}\right)$. The conditional logistic regression is shown as (E3):

$$\ln\left(\frac{\hat{p}}{1-\hat{p}}\right) = \alpha + \beta_{ULL}X_{ULL} + \beta_i' \ln(X_i') + \varepsilon \tag{E3}$$

$\left(\frac{\hat{p}}{1-\hat{p}}\right)$ represents the changes in the odds ratio of the NGN uptake happening.

Notes on contributors

Yuntsai Chou obtained her PhD in Public Policy from George Washington University, USA, in 1999, and is Associate Professor of Social Informatics in Yuan Ze University (Taiwan). Her research focus includes telecommunications policy, regulatory theories, broadband regulations, and e-government. Dr Chou was recently awarded the Eisenhower Fellowship for her study of comparing the US and Taiwan's digital convergence policies.

References

Avenali, A., Matteucci, G., & Reverberi, P. (2010). Dynamic access pricing and investment in alternative infrastructures. *International Journal of Industrial Organization*, *28*(2), 167–175.

Baum, C. (2006). *An introduction to modern econometrics using Stata*. College Station, PA: Stata Press.

Bouckaet, J., van Dijk, T., & Verboven, F. (2010). Access regulation, competition, and broadband penetration: An international study. *Telecommunications Policy*, *34*(11), 661–671.

Bourreau, M., & Dogan, P. (2005). Unbundling the local loop. *European Economic Review*, *49* (1), 173–179.

Bourreau, M., Dogan, P., & Manant, M. (2010). A critical review of the "ladder of investment" approach. *Telecommunications Policy*, *34*(11), 683–696.

Cambini, C., & Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, *33*(10–11), 559–574.

Cave, M. (2006). Encouraging infrastructure investment via the ladder of investment. *Telecommunications Policy*, *30*(3–4), 227–237.

Cave, M. (2010). Snakes and ladders: Unbundling in a next generation world. *Telecommunications Policy*, *34*(1–2), 80–85.

Cave, M., & Vogelsang, I. (2003). How access pricing and entry interact. *Telecommunications Policy*, *27*(10–11), 717–727.

DETECON. (2011, September). *Enhancing broadband development and Internet usage for improving network services in APEC member economies*. Paper presented at APEC TEL 44, Malaysia.

Distaso, W., Lupi, P., & Manetti, F. M. (2006). Platform competition and broadband uptake: Theory and empirical evidence from the European Union. *Information Economics and Policy*, *18*(1), 87–106.

FCC (Federal Communications Commission). (2003). *Report and order and order on remand and further notice of proposed rulemaking: in the matter of review of Section 251 unbundling obligations of incumbent local exchange carriers*. FCC-03–36, CC Docket No. 01-338. Retrieved from http://transition.fcc.gov/Document_Indexes/WCB/2003_index_WCB_RO_NPRM.html

Fox, J. (2002). Structural equation models. *An R and S-PLUS companion to applied regression*. Retrieved from http://cran.r-project.org/doc/contrib/Fox-Companion/appendix-sems.pdf

Friederiszick, H., Grajek, M., & Roeller, L. -M. (2008). *Analysing the relationship between regulation and investment in the telecom sector*. ESMT White Paper WP-108–01. Retrieved from http://www.wu.ac.at/ipm/institutes/iqv/mitarbeiter/gugler/reg_fgr_esmt.pdf

Fujino, M. (2010). *Law and policy for broadband deployment in Japan*. Speech delivered at American University, Washington, DC.

Greenstein, S., McMaster, S., & Spiller, P. (1995). The effect of incentive regulation on infrastructure modernization: Local exchange companies' deployment of digital technology. *Journal of Economics and Management Strategy*, *4*(2), 187–236.

HeChen, Z. (2009). *Open access to ducts and fiber subscriber lines*. FarEastone Telecome, Taiwan. Unpublished manuscript.

Independent Post and Telecommunication Authority of the Netherlands. (2008). *Fixed telephony, broadband and leased line preliminary draft decisions: Context and perspective*. Retrieved from http://www.opta.nl/en/about-opta/tomorrow-is-made-today

ITU (International Telecommunication Union). (2010). ICT Statistical Database. Retrieved from http://www.itu.int/ITU-D/ict/statistics/at_glance/KeyTelecom.html

Kennedy, P. (1992). *A guide to econometrics* (3rd ed.). Cambridge, MA: MIT Press.

MPA (Media Partners Asia). (2009). *Asia Pacific pay-TV & broadband markets 2009*. Singapore: Author.

NCC (National Communications Commission). (2006). *Public announcement on bottleneck facilities of the fixed-line telecommunications services*. Document no. 09505150780

NICI (National Information and Communication Initiative) Committee. (2008). *2008 information security policy white paper*. Retrieved from http://www.nici.nat.gov.tw/content/application/nici/generalb/guest-cnt-browse.php?cnt_id98

NICI Committee. (2010). *Digital convergence development strategic plan*. Retrieved from http://www.nici.nat.gov.tw/content/application/nici/generala/guest-cnt-browse.php?cnt_id13936

OECD (Organisation for Economic Co-operation and Development). (2010). OECD Broadband Statistics. Retrieved from http://www.oecd.org/sti/ict/broadband

OECD. (2011). *OECD communications outlook 2011*. Paris, France: Author.

Pindyck, R., & Rubinfeld, D. (1991). *Econometric models & economic forecasts*. New York, NY: McGraw-Hill.

Renda, A. (2010). Competition-regulation interface in telecommunications: What's left of the essential facility doctrine. *Telecommunications Policy*, *34*(1–2), 23–35.

Roller, L. H., & Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *American Economic Review*, *91*(4), 909–923.

Stata. (2011). *Stata quick reference and index*. College Station, TX: Author.

Teppayayon, O., & Bohlin, E. (2009, September). *Government intervention: Why is competition not sufficient for broadband deployment*. Paper presented at the 37th Research Conference on Communication, Information, and Internet Policy, Arlington, VA.

Train, K. (2003). *Discrete choice methods with simulation*. Cambridge: Cambridge University Press.

TTC (Telecom Technology Center). (2009). *The tariff regulation of the dominant carriers in the telecommunication market*. PowerPoint file distributed at the expert seminar, Taipei, Taiwan.

Wallsten, S., & Hausladen, S. (2009). Net neutrality, unbundling, and their effects on international investment in next-generation networks. *Review of Network Economics*, *8*(1), 90–112.

Ware, H., & Dippon, C. M. (2010). Wholesale unbundling and intermodel competition. *Telecommunications Policy*, *34*(1–2), 54–64.
Wheelan, C. (2011). *Introduction to public policy*. New York: Norton.
Wothke, W. (2010). *Introduction to structural equation modeling course notes*. Cary, NC: SAS Institute.
Xaiver, P. (2009, December). *When can ex ante access regulation be withdrawn?* Paper presented at the CPRsouth4 Conference: Speaking Truth to Power, Negombo, Sri Lanka.
Zellner, A. (1962). An efficient method of estimating seemingly unrelated regression equations and tests for aggregation bias. *Journal of the American Statistical Association*, *57*, 348–368.

Appendix

Table A1. The countries listed in the dataset.

The European region	The Americas region	The Asia-Pacific region
Austria	Canada	Australia
Belgium	Mexico	China
Czech Rep.	United States	Hong Kong
Denmark		India
Finland		Indonesia
France		Japan
Germany		Korea
Greece		Malaysia
Hungary		New Zealand
Iceland		Pakistan
Ireland		Philippines
Italy		Singapore
Luxembourg		Sri Lanka
Netherlands		Taiwan
Norway		Thailand
Poland		Turkey
Portugal		Vietnam
Slovak Republic		
Spain		
Sweden		
Switzerland		
United Kingdom		

Source: author.

Table A2. Variable specifications.

	Value	Definition
Dependent variable		
DSL penetration rate	continuous; 0–1	DSL subscribers/population
Cable Internet penetration rate	continuous; 0–1	Cable modem subscribers /population
Fiber optic deployment	dummy; 0/1	1 = the fiber subloop line offered; 0 = the fiber subloops not yet offered;
policy variable	dummy; 0/1	1 = ULL implemented;
access regulation		0 = ULL not implemented
Independent variable		
Fixed-line penetration rate	continuous; 0 ~ 1	fixed-line users/population
Ratio of Internet population	continuous; 0 ~ 1	Internet users/population
pay TV penetration rate	continuous; 0 ~ 1	(cable TV households + satellite TV households + IPTV households)/TV households
GDP per capita (US$)	continuous;	GDP (US$)/population

Source: by author.