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碩 士 論 文

進入雙面市場上的關鍵效應
Keystone Effect on Entry into Two-Sided Markets

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ABSTRACT

We investigate a market entry scenario where a technologically-superior new platform can overcome its installed base disadvantage through its "keystone effect" advantage over the incumbent in a market that also exhibits indirect network effects. This is an application of the ecological keystone species concept to business ecosystems where the effects of keystone species lack empirical quantification. After adapting a dynamic economic model from Zhu & Iansiti (2011) to fit these market conditions, we map a market landscape that shows the internal condition (entrant's keystone effect) and external conditions (incumbent's keystone effect and indirect network effects) under which a new platform can successfully enter (i.e., maintain oligopoly or monopoly share) or fail to enter the two-sided market in a winner-takes-all scenario. We then illustrate the model's applicability by examining the entry of Worldwide Interoperability for Microwave Access (WiMAX) into the mobile telecommunications market in both the United States and the global market, employing recent data from 2009 to 2011. We find that WiMAX's keystone effect disadvantage and the market's indirect network effects were cumulatively strong enough to prevent the new technology standard from successfully competing with the incumbent (3G) for oligopoly or monopoly share in the long run.

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SYMBOLS

π_{jt}	Profit (myopic) of a manufacturer on platform *j* in period *t*
Π_{jt}	Forward-looking profit of a manufacturer on platform *j* in period *t*
U_{jt}	Utility the representative customer gains from platform *j* in period *t*
Q_j	Quality of platform *j*, $j \in \{E, I\}$
Q	Quality ratio of the two platforms on the customer's side, $Q = Q_E/Q_I$
e	Strength of indirect network effects
h_{jt}	Hardware produced for platform *j* in period *t*
Δh_{jt}	Change in number of manufacturers producing for platform *j* in period *t*
b_{jt}	Installed base of platform *j* in period *t*
B_{jt}	Discounted present sum of future installed base of platform *j* from period *t* until time horizon T_j, subject to discount factor φ_{jt}
ΔB_{jt}	Change in installed base of platform *j* in period *t*
T_j	Time horizon for manufacturer consideration of future installed base on platform *j*
φ_j	Discount factor for manufacturer's future consideration of installed base of platform *j*
K_j	Strength of keystone effect for platform *j*
KR_j	Keystone effect ratio for platform *j* over competitor *x*, $KR_j = K_j/K_x$, $x \in \{E, I\}, x \neq j$
F_{jt}	Fixed cost of operating on platform *j* in period *t*
F	Ratio of fixed cost of operations for the two platforms, $F = F_{It}/F_{Et}$
S_{jt}	Proportion of new subscribers choosing platform *j* in period *t*
β_j	Technology standard-specific constant
α_t	Time specific constant of manufacturer adoption

Note: The term "platform," used here for uniformity, represents the mobile telecom technology standard, on which other platforms (e.g., mobile phone operating systems) are also based.

1. INTRODUCTION

The "biggest auction ever," a moniker for the sale of third-generation (3G) telecom licenses in Britain, which raised £22.5bn and accounted for 2.5% of its GNP (Binmore & Klemperer, 2002), was only one of many such 3G auctions held by national governments, totaling €109bn in Europe alone at the turn of the millennium. Mobile network operators (MNOs) bet billions to secure their 3G spectrum allocations in the hopes of reaping higher average revenue per user (ARPU) rates for the advanced services that could be utilized on its 3G speeds (S. Chou, 2011). By 2004, a select few wireless telecom developers and chipset makers, notably Qualcomm and Ericsson among them, were sitting on nearly 8,000 3GPP and 3GPP2[1] patents waiting to realize their potential value through licensing patented technologies for use in 3G equipment (Goodman & Myers, 2005). But despite the hype surrounding 3G, its initial take off, at least in data usage levels, was a flop: unmet revenue expectations nearly bankrupted the telecom industry in Europe, even prompting some operators to give the licenses back to the government ("Mobile 3G telecoms," 2004). When 3G data usage finally started to accelerate from 2004 to 2005, it was no surprise that the 3G incumbency—both wireless technology developers and MNOs—were in no hurry to see the mobile technology standards shift toward a fourth-generation (4G) overhaul that would cut short the returns on 3G investments and require new outlays for 4G spectrum auctions and infrastructure deployments.

Then Worldwide Interoperability for Microwave Access (WiMAX) arrived as the first commercially available 4G technology standard. WiMAX was designed to be a data-driven technology standard alternative to cellular 3G that would beat the cellular 4G technology, Long Term Evolution (LTE), to market by at least two years. It was termed "Wi-Fi's big brother" with predictions that it would turn whole cities into hotspots, and it was backed by some computer industry heavy-hitters ("Wi-Fi's big brother," 2004). In 2004, even major telecom incumbents like AT&T and Nokia were eager to support the technology that offered a relatively cheap alternative for faster data sooner ("Wi-Fi's big brother," 2004). By 2007, WiMAX seemed to be carrying all the momentum. It had a set standard, IEEE 802.16, around 300 networks were deployed across the globe, and manufactures were beginning to get on board as the prospect of sufficient consumer demand was looking more and more like a reality ("Wireless telecoms," 2008).

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[1] The 3GPP and 3GPP2 technology standards will be addressed collectively henceforth as the incumbent group of technology standards termed "3G." For simplicity and uniformity, the term "3G" used throughout this study signifies technologies, providers, and consumers associated with both 3G and pre-3G technologies (e.g., "2.5G," "2.9G," etc.).

However, it only took five years for the WiMAX experiment to reach a nearly inevitable end. As the majority of the mobile telecom community have turned their attention and their money to LTE, the global demand for WiMAX chips is dropping (Chen, 2012). This signals the end for the nascent technology standard. While it will likely still continue to serve other communications functions, WiMAX did not manage to earn its spot as the future dominant 4G technology standard (Kobie, 2009). A driving question behind this investigation is: Why did it fail? WiMAX had a technologically superior position for the start of 4G that allowed it to capture some of the global mobile broadband user base before 3G could catch up. This quality advantage and user base momentum, with backing from some large names (e.g., Intel and Google), seemingly should have given WiMAX a fighting chance at contending with the incumbent 3G standards. So was this a case of mismanagement or disadvantageous entry timing—one that could have been handled differently or at a different juncture for a favorable outcome? Or was there more to it than that? Were there other forces impacting WiMAX's chances for success which actually made the new technology standard's market entry an exercise in futility? It has been argued that WiMAX's deficiencies were systematic and pervasive, evident through an ecosystem perspective of the mobile telecom market, in which WiMAX's keystone species were small and weak relative to those of 3G (Kang, Lee, & Tsai, 2011). We aim to investigate the merits of this argument by quantifying WiMAX's keystone species weakness (i.e., its keystone effect disadvantage) vs. 3G.

This study intends to contribute to the ongoing discussion of market entry in the literature, and extend the discussion of product platforms by examining the conditions under which a new technology standard can successfully enter a two-sided market. We examine the empirical failed entry attempt of WiMAX and evaluate it according to a dynamic model that incorporates indirect network effects, relative quality advantage, and a third factor that we introduce here, the "keystone effect." To accomplish these objectives, the rest of this study will proceed in the following order: Chapter 2 presents a review of the literature on market entry, two-sided markets, telecommunications market dynamics, and the keystone effect. Chapter 3 describes the dynamic market entry model, which we have adapted from Zhu and Iansiti (2011) to fit this market context, and explain the equilibrium outcome conditions allowing for a hypothesis to be made regarding WiMAX's position, vis-à-vis 3G, within the market landscape. Chapter 4 presents the empirical analysis by detailing the entry of the WiMAX technology standard into the global, and specifically the US, mobile telecom market, and then adapting regression equations from the theoretical model. Chapter 5 presents the method and results of the regression analysis on the WiMAX technology standard entry. Finally, Chapter 6 presents the conclusions drawn from these results and their implications for management, as well as addresses the limitations of this research and areas for further investigation.

2. LITERATURE REVIEW

2.1 Market Entry and Two-Sided Market Competition

The ongoing debate over market entry highlights opposing views of the necessary and sufficient conditions for firms to successfully enter new markets. Whether or not early mover advantages are sustainable is of predominant importance in explaining market entry success (Lieberman & Montgomery, 1988). Both understanding the order of entry effect (Dowell & Swaminathan, 2006; Fuentelsaz, Gomez, & Polo, 2002; Mitchell, 1991; Robinson, Fornell, & Sullivan, 1992) and the firm's resources or dynamic capabilities that allow it to main successful operations post-entry (Helfat & Lieberman, 2002; Klepper & Simons, 2000; Lee, 2008; Schoenecker & Cooper, 1998) are argued to be necessary for understanding this issue. However, answering the question of first-mover advantage divides scholars into two camps. The first finds that the advantages of early entry are substantial (Lambkin, 1988; Lieberman, 1989; Makadok, 1998; Urban et al., 1986; Yip, 1982), while the second argues that early entry itself is not sufficient to ensure a sustainable market position (Cho, Kim, & Rhee, 1998; Christensen, 1997; Christensen & Bower, 1998; Dowell & Swaminathan, 2006; Freeman, 1997; Schnaars, 1995; Shankar, Carpenter, & Krishnamurthi, 1998). The extensive literature supporting and countering both sides of this debate serves to underscore the critical importance of situational factors that make overarching inference untenable without consideration for the particular market's contextual factors in addition to the firms' relative capabilities.

One type of market which has been the subject of extensive study precisely because of its contextual factors—namely, the presence of network externalities—is the two-sided, or platform-based, market. Increasingly many industries are organizing around these two-sided platforms (Boudreau, 2010; Eisenmann, Parker, & Van Alstyne, 2006; Iansiti & Levien, 2004a), which heightens the need not only for businesses to refocus on their business model and the benefits to be gained from complementors but also to understand and plan for the substantial impact of network effects (Rochet, 2003). These network effects may come in the form of same-side (direct) network effects, by which users are either positively or negatively affected with the addition of users on the same side, such as positive same-side benefits experienced by social network users. Or they may be present as cross-side (indirect) network effects, through which users are either beneficially or adversely affected by the addition of users on the other side of the market, like positive cross-side network effects between automobile drivers and retail gas stations (Eisenmann et al., 2006). While these two types of network effects seem similar, in practice they can produce very different results (M. Clements, 2004).

There are numerous different examples of two-sided markets (see Rochet 2003; Eisenmann, Parker, and Alstyne 2006; Zhu and Iansiti 2011), but some of the most commonly studied are high technology products: namely video games, (M. T. Clements & Ohashi, 2005; Corts & Lederman, 2009; J E Prieger & Hu, 2006; M. A. Schilling, 2003; Shankar & Bayus, 2003; Srinivasan & Venkatraman, 2008, 2010; Strube et al., 2007), PDAs (Nair, Chintagunta, & Dube, 2004), VCRs (Ohashi, 2003; Park, 2004), and software (Church & Gandal, 1992; Cottrell & Koput, 1998). The opinions in this discussion, as with market entry in general, are divided. One group of scholars argue that network effects will compound a slight installed base advantage into an insurmountable force as new consumers and developers disproportionately join the leading platform (Lieberman, 2007; Park, 2004; M. Schilling, 1999; M. A. Schilling, 2003; Shapiro & Varian, 1999; Sheremata, 2004). The second group, however, holds that quality advantage is still critical in platform-based markets, and this quality advantage can allow an entrant with an installed base or application base disadvantage to catch up to, even overtake, the incumbent platform of inferior quality (S J Liebowitz & Margolis, 1994; S. Liebowitz, 2002; Stanley J Liebowitz & Margolis, 1999; Rangan & Adner, 2001; Suarez & Lanzolla, 2007; Tellis, Yin, & Niraj, 2009). In fact, Evans' (2003) survey of empirical aspects of these two-sided markets, demonstrated that many late entrants platforms are indeed able to erode the early mover's market share and enter successfully.

The source of this disagreement in the literature stems from the conflicting views of the determinants of success for the incumbent and entrant platforms. Predominantly quality and network effects are included as two key factors, but there is disagreement over their relative importance and which one, if either, can be a fundamental determinant of platform success. Gretz (2010), for example, found that quality was overwhelming more influential in determining a platform's market share and predicting platform success than network size. Conversely, Park (2004) demonstrated network advantage to account for over 70.3% of the VCR sales in the 1980, and Zhu and Iansiti (2011) found that, when considered with the additional factor of consumer's discounted expectations for future applications, indirect network effects can be impactful enough to categorically determine the entrant's success or failure. Specifically in their model, the new platform's equilibrium market share increases from oligopoly to monopoly as the indirect network effects strength increases from less than 1.0 to greater than 1.0, but there is a threshold beyond which the strength of the indirect network effects will completely shut out the entrant platform from the market, due to its applications disadvantage. Furthermore, Corts and Lederman (2009) consider application exclusivity and finds that indirect network effects are not only platform-specific but also generation-specific among platforms, which means the network effects themselves are actually moderated by levels of hardware quality. The evidence on both sides suggests that regardless of their relative levels of importance, quality and network effects must both be considered together in order to accurately evaluate entry into two-sided markets.

Network effects and quality are both influential factors in telecommunications as well, which is the focal industry of this study. Network effects, when considered on their own, have been shown to be substantial in mobile telecom markets (Doganoglu & Grzybowski, 2007). On the other hand, when quality and network effects are considered together, as Sunada (2008) did in a study of the late 1990s Japanese mobile telecom market, then the impact of quality can be shown to exceed that of network effects.

However, these are same-side network effects and not the cross-side network effects previously discussed in the literature on high tech products. The majority of the literature examining network effects in the mobile telecom market focuses on same-side network effects. These have been attributed to the users preference for large user base and greater compatibility (Grajek, 2010). Direct network effects are also argued to result from sub-networks, or user groups' social networks, impacting the telecom operator selection (Sobolewski & Czajkowski, 2012). This may be due to in-network calling discounts and other pricing considerations (Birke & Swann, 2005; Fu, 2004), as well as due to the signaling effect that large network size implies for the quality of MNOs service or coverage (Kim & Kwon, 2003). Finally, in addition to personal network effects, switching costs are also influential in determining consumer's MNO subscribership decisions (Maicas, Polo, & Sese, 2009)

There are some key differences between the high tech product markets evaluated in the literature and the market of concern for this investigation, mobile telecommunications. For one, subscribers usually only buy one handset, or at most a few pieces of mobile hardware from the network equipment providers (NEPs) and subscribe for service with an MNO, but the content that they use on those devices (e.g., mobile applications) are the products of developers from another platform, the mobile operating system (e.g., iOS, Android, MS mobile, Symbian, etc.) with different platform providers (e.g., Apple, Google, Microsoft, Nokia, etc.). Of course these mobile telecom service providers and mobile phone operating system platforms are all interconnected within the mobile telecom ecosystem; however, an evaluation of mobile telecom technology standards competition, though affected by mobile phone operating systems, is focused more on the consumer choice of MNO and purchase of hardware, as well as the NEPs' provision of hardware. It is not strictly concerned with the users' consumption of mobile software and auxiliary services.

Furthermore, even within the mobile telecom market, the focus of the aforementioned literature on same-side network effects impacting subscribers' choice of MNO is not representative of the 3G vs WiMAX technology standards battle. Since many different MNOs operate either within the 3G technology standards group of incumbents or the WiMAX 802.16 entrant standard, then users switching between MNOs that operate on same technology standard is inconsequential, as we consider their user bases collectively. Consequently, a deeper investigation into the factors affecting the mobile telecom market, which potentially extend beyond quality and network effects, is necessary to inform the design of a dynamic model of market entry that can represent WiMAX's entry versus 3G.

2.2 Mobile Telecommunications

2.2.1 The Converging Mobile Ecosystem

The mobile telecom market has been changing functionally and compositionally at a rapid rate during the past decade, as new players entered with the introduction of 3G services and mobile computing, and as incumbent players pivoted or refocused to adapt (Hazlett, 2009; "Your television is ringing," 2006). Increasing attention has been paid to the reconfiguring of the mobile value chain (Dedrick, Kraemer, & Linden, 2011; Peppard & Rylander, 2006a; Yang et al., 2004). Hazlett (2009) explains that the modularization within the industry augmented value creation by allowing the entry of innovative firms with competitive advantage in their specialized area; this could happen despite those firms' lack of experience or competence as integrated service providers. Figure 1 shows the increasing modularity of mobile telecom services with each successive generation of mobile telecom technology, notably the addition of mobile content with 3G. Interestingly, from a 2009 perspective, the composition of the future 4G value chain was beyond speculation, and given the decreasing role of operators from the pre-cellular to 3G stages, even the future role of MNOs was uncertain.

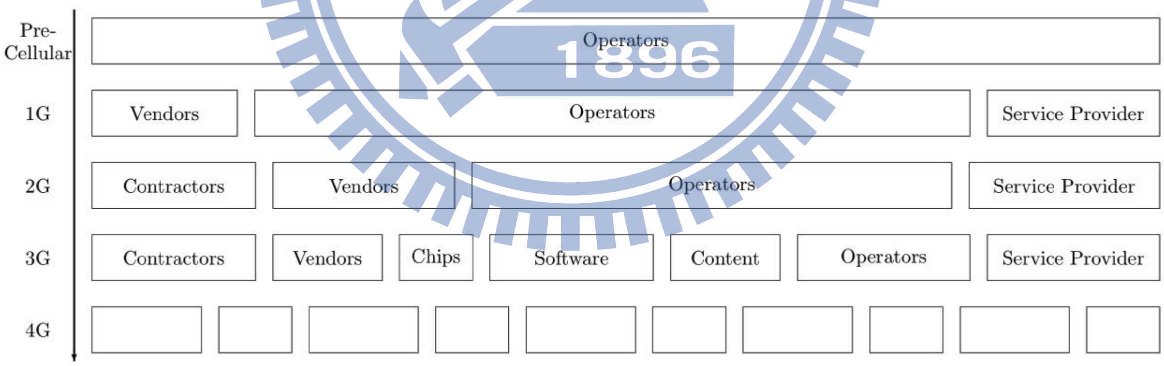

Figure 1. Vertical Evolution of Mobile Networks
Source: Reproduced from Hazlett (2009)

However, Basole et al. (2012) confirm, through network structural analysis and visual analytics, the still vital role of MNOs in the converged mobile telecom ecosystem. The importance of hubs in network analysis is often quantified through each hub's degree of centrality. Basole et al. (2012) find that the normalized degree of centrality of MNOs in the converged mobile telecom ecosystem is still highest among all functional segments. Their high centrality indicates that each MNO is connected to many players within the ecosystem and thus occupies a position through which value flows. The converged mobile ecosystem is also found to be more centralized as a whole, and the emerging segments (see Figure 2)—namely content providers, digital imaging, gaming providers, internet service providers, etc.—are playing increasingly prominent roles.

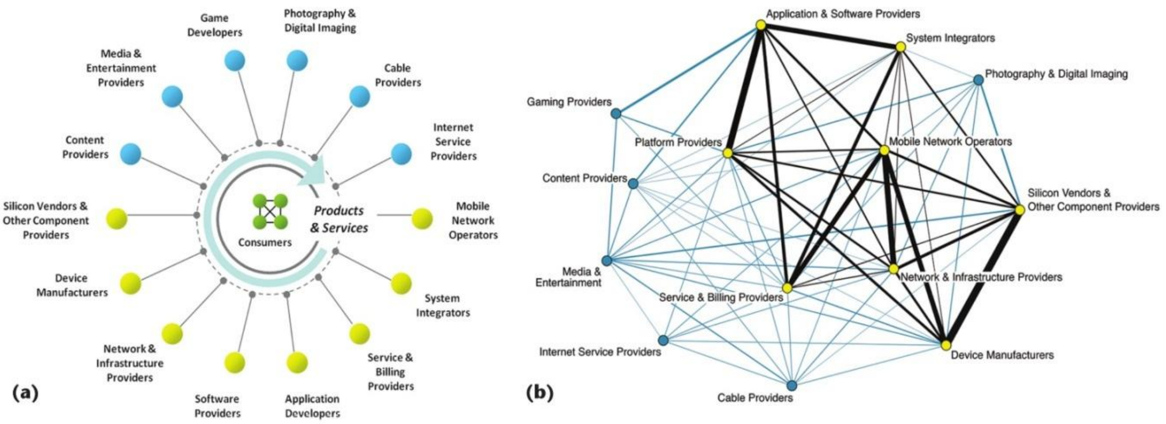

Figure 2. Value Co-creation (a) and Segment Interaction (b) in the Mobile Telecom Market
Source: reproduced from Basole (2009)

Within this converged ecosystem the relationships between NEPs, MNOs and the newly arrived content providers are of vital importance in understanding the market dynamics that would affect the entry of a new technology standard. While the focus of previous literature addressing the mobile telecom market has been on same-side network effects, this is at best insufficient, at worst inaccurate, for address the adoption of a technology standard upon which other platforms are based. This is because when subscribers choose their operator, their operator has already chosen its technology standard, and its NEP partners have already produced the handsets from which the end-use customer is allowed to choose. Thus, the mobile telecom market is influenced much more by NEPs, and other B2B relationships than by the end use customer. Excluding a tech savvy minority, the average mobile subscriber is unconcerned with the removed considerations such as their phone's tech standard; even if they were concerned, certainly this wasn't the case 5 years early when the decision was being made for them. The newly converged structure of the mobile telecom market, along with the increasingly vital importance of partnerships, only serves to highlight the relative importance of the supply side over the demand side in a this situation of competing technology standards. In order to characterize accurately, and later to model, the mobile telecom technology standards adoption process, a revision of the existing views of mobile telecom market dynamics is necessary.

2.2.2 Mobile Telecommunications Ecosystem Dynamics

Figure 3 shows the mobile telecommunications ecosystem as it applies to technology standards adoption, which will serve as the basis for determining the user's demand function and NEP's profit function in our dynamic model. The incumbent technology standards, 3G (shown as the top oval in the diagram), has a large installed base of users. This presents a strong advantage particularly since mobile telecom subscribers have been shown to be very loyal to their MNO which negatively affects switching intention (Chuang, 2011; Sobolewski & Czajkowski, 2012). So, while most subscribers would be willing to use a new technology standard if their MNO adopted it, a devastating problem for WiMAX was the comparatively tiny installed bases of the MNOs that adopted it as their future 4G standard. In the 3G standards group, a large installed base of loyal users offers essentially guaranteed demand to ensure that NEPs, as well as content providers, are clamoring to be able to produce products for the technology standard because the stable and high-volume demand allows for cost reduction through economies of scale. Simultaneously, the extensive selection of customer premises equipment (CPE), PC cards, dongles, handsets, etc., produced by 3G's NEPs keeps the 3G user base satisfied. And in addition to subscribers' loyalty to their MNOs, handset consumers are also aware of phone brands and display loyalty to those brands (Karjaluoto et al., 2005). The business relationships within the ecosystem are primarily mediated by the MNOs, as we already discussed their central, value-transferring role. And the strength of these relationships is evident in the result: the volume and variety of equipment that is produced. In this study we consider the MNOs to be a "keystone species," and we term the *production based not solely on historical demand but also on the expectation of future demand, moderated by the strength of the keystone species*, to be the "keystone effect." These are two concepts that will be addressed in detail in later sections.

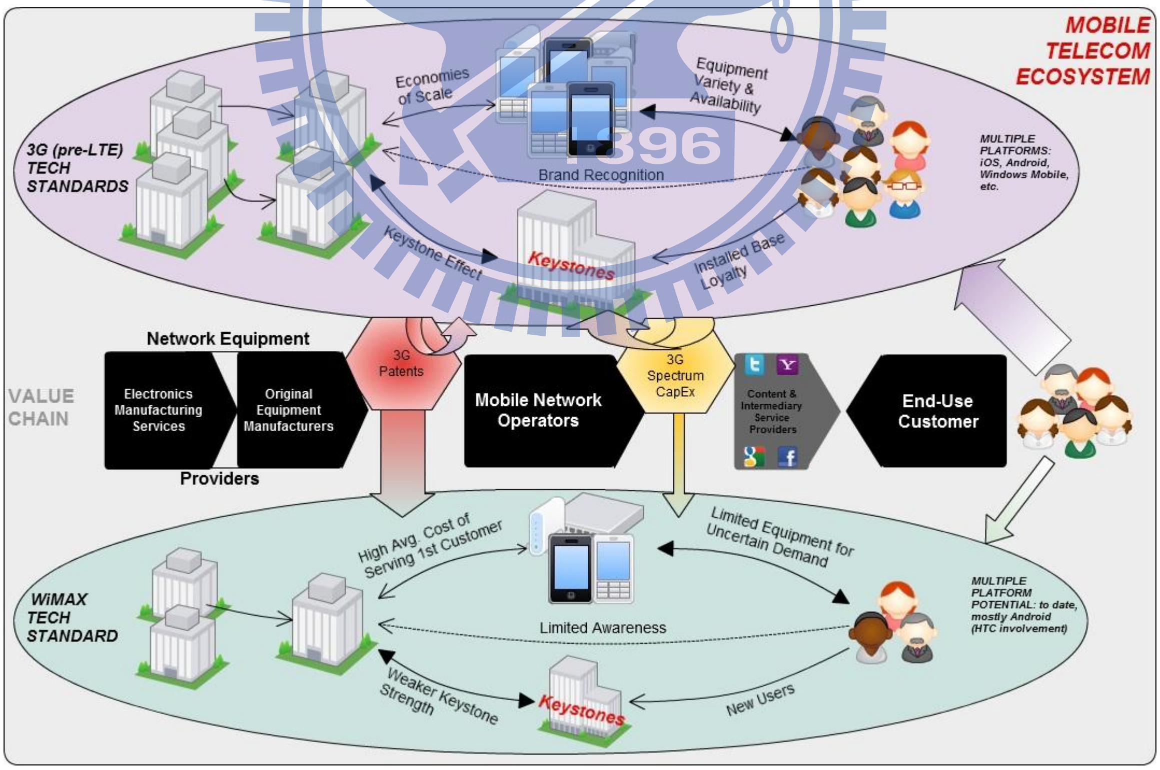

Figure 3. Technology Standards Competition in the Mobile Telecommunications Ecosystem
Source: Author's research and assessment, drawing particularly from the US ITC report on wireless handsets (Gaffney, Rogowsky, & Laney-cummings, 2010)

WiMAX, as a start-up technology standard, garnered support from smaller or entirely new MNOs. These operators brought a much smaller user base than the incumbent 3G. This lacking user base and uncertainty of both current and future demand prevented many NEPs from joining the standard and resulted in a limited product offering, in some cases, even in technologically-delayed network deployments ("Wireless telecoms," 2008). Those NEPs that did join WiMAX had to bear the high average costs of selling products in low volume to the early adopters with no guarantee of ever reaching a scale anywhere near that of 3G. The weakness of the WiMAX technology standard originated in the closed telecom market structure, dominated by an overwhelming and powerfully entrenched incumbent, and it manifested itself in the weak business relationships that WiMAX supporters could form between MNOs and NEPs.

Additional profit function components and considerations in this mobile telecom ecosystem at the time of WiMAX's development were 3G royalties and the not-yet-recouped portions of 3G spectrum capital expenditure. While 3G patent licensing fees for 3G's IP protected technologies cut into many NEPs margins, providing some incentive for NEPs to switch, in practice this still was not sufficient incentive for most to commit to WiMAX production. The 3G spectrum investment was huge and returns on it were slow to materialize. This provided a strong disincentive for legacy operators to switch away from 3G service. Both of these external considerations, though present, were not of critical importance in many NEPs decisions to develop WiMAX products or stay with 3G.

One potential issue of complication for modeling the ecosystem is that competing technology standards may share cooperators as well as competitors. Notably in the WiMAX vs 3G situation, devices equipped with chips for either data transmission standard could be used on any number of mobile operating systems, subject of course to the MNOs' and NEPs' exclusivity and licensing constraints. Furthermore NEPs could, and most did, produce equipment for both technology standards. This, however, is an inevitable consequence of any manufacturing industry so dependent upon scale for profitability. The fixed cost of developing products for the new technology standard was a necessary expense for entering the WiMAX standard, but production was limited by demand projections for the start-up technology, and no rational firm could be expected to discontinue production of guaranteed product to open up production capacity for a new product merely in anticipation of its future demand. However, if WiMAX were to have taken off and seen demand grow to a level that could profitably sustain the NEPs' operations, then we expect many would have switched over to WiMAX production entirely. The issue of non-exclusivity is therefore one that affects the mobile ecosystem, but it affects both sides equally.

In accordance with the literature on market entry and two-sided markets we will include both quality and network effects in the representative consumer's utility function when modeling the market dynamics. However, although it is true that a wealth of empirical studies on telecom markets confirm same-side network effects (Grajek, 2010; Madden, Coble-Neal, & Dalzell, 2004; Niculescu, Shin, & Whang, 2011; Sobolewski & Czajkowski, 2012; Sunada, 2008)**,** we find cross-side network effects to be the type of network effects that fits the mobile telecom technology standards competition most accurately and will therefore include indirect network effects in the dynamic model. We based this decision on two main considerations. First, during the foundational stages of development, the initial decision to adopt the technological standard is made first by the MNOs and NEPs, and then later, once the service and equipment are available, by the subscribing customer. Subscribers who would be enticed to leave their service provided to join a superior technology standard would make such a decision because of the quality of data service, not because of direct network effects. But their decision would be affected by the availability or lack of handsets and other products that meet their acceptable standards of use, which is an example of a cross-side network effect from the demand perspective. Second, since operating as an OEM in the mobile telecommunications industry is characterized by substantial fixed costs with relatively low marginal costs, then manufacturers experience increasing returns to scale, which is an example of cross-side network effects from the supply perspective (Chou & Shy, 1990). Even without considering the software and mobile content that would be the subject of most indirect network effects discussions, our examination of mobile telecom hardware provision and user subscriptions alone must still account for cross-side network effects.

However, these two factors--indirect network effects and quality—are yet insufficient to accurately capture the market dynamics affecting the entry of a new mobile telecom technology standard. In discussing the mobile telecommunications ecosystem, we broached the topic of keystone species and their related keystone effect. We argue that in addition to the quality considerations for the adopting subscribers and the indirect network effects influence by both the supply and the demand sides, there is still a need to explain the higher order of importance of the adoption decision by the supply side. Because the mobile telecom market is a push, not a pull, market, products are created ahead of the recognition of customer needs (Gerstheimer & Lupp, 2004). But even before the decision of what products to manufacture was the decision of which technology those products would use. This B2B decision fundamentally changes the potential product offerings made available for the customer’s B2C decision. Furthermore a mobile technology standard is itself a platform on which other platforms (e.g., mobile phone operating systems) are based. If the technology standard first fails to attract NEPs to produce its products then content providers cannot make applications or games functional on that technology standard, and in turn customers cannot make their purchase decision based on the hardware and software combination. A prime example of this would be Apple selling the iPhone first exclusively on AT&T’s network, and then later through both AT&T and Verizon. The equipment, namely iPhones and iPads, were thus exclusively available on 3G and excluded from WiMAX, which lost out on all iPhone and iPad users as potential customers. Such is the higher order of importance of B2B technology standard adoption.

In our model of the mobile telecom technology stands adoption process (to be discussed in chapter 2), we represent this higher order of decision-making importance by including not only the indirect network effect, which also impacts the NEPs adoption, but also the potential for increasing or decreasing returns to the scale of the installed base. This difference in proportional subscriber base change and the NEP base change we posit can be explained—above and beyond macroeconomic conditions—by the NEP's future expectations of continued or increasing user base to consume their products. This, we argue, is a keystone effect, and it is empirically quantifiable from market data in the levels of equipment production for the completing technology standards relative to each standard's base of users. This effect is therefore the product of the MNOs user base size and loyalty, and the MNOs themselves are the central and connected hubs that promote value transfer. The stronger MNOs attract more adoption and later more production from NEPs—relative to competitors and excluding macroeconomic changes. For these reasons, in this study we consider MNOs to be the primary keystone species of the mobile telecom market.

The introduction of an external concept into this study's attempt to model the mobile telecom market dynamics, especially doing so with such emphasis on the new factor, merits sufficient explanation and consideration of the factor in question. The following section therefore reviews the origins of this keystone species concept in ecological literature and its recent application to business. It concludes by addressing our assertion of MNOs as keystone species and operationalizing the keystone effect for use in this study of technology standards adoption.

2.3 The Keystone Effect

The concept of the business ecosystem (Moore, 1993, 1998) has grown increasingly relevant in the literature in the last decade. The vital importance of business relationships and business communities working together to ensure competitive advantage cannot be overstated (Iansiti & Levien, 2004b; H. Kim, Lee, & Han, 2010). The ecosystem framework allows for explaining the ability of companies to achieve collectively greater value than any one company or isolated group of companies could achieve (Adner, 2006). Strategy alone has been shown to be limited in its ability to generate valuable products and services; it is thus essential that businesses collaborate to survive and thrive (Kandiah & Gossain, 1998; H. Kim et al., 2010; Moore, 1993). But all companies are not created equal. The mobile telecommunications ecosystem like all ecosystems has members of varying functions and levels of impact upon other members. A species with disproportionate impact upon the ecosystem composition relative to its physical presence is termed a "keystone species" (Paine, 1969).

2.3.1 Biological Origins of the Keystone Species Concept

The concept of keystone species is originally biological. It was employed to describe the disproportionately large impact that certain predators had in controlling other species' overabundance and overconsumption (Paine, 1966, 1969). This was pursued with special interest in the field of conservation biology and was applied to the study of food webs for explaining the keystone effect through trophic position (e.g., Pimm 1980a; Pimm 1980b; Pimm and Lawton 1980; Pimm 1980c; Paine 1992; Post 1983; Jordán, Liu, and Davis 2006). Mills and Soule (1993) then categorized keystone species as five groups: predator, prey, link, plant, and modifier. Numerous studies have addressed the quantifiable effect of keystone species, particularly focusing on keystone predators; though a disadvantage of such attempts is that they are primarily done through experimental removal of the keystone species for observation (e.g., Fletcher, 1987; Owen-smith, 1987; Paine, 1966, 1969; Terborgh, 1986). Among these studies, Navarrete and Menge (1996) found that a keystone species of sea stars has an exponential effect over time on the population density of mollusks, the magnitude of which they termed "interaction strength." In Chapter 3, we apply this interaction strength concept to business ecosystems by incorporating the keystone effect in the dynamic model of mobile telecom technology standards adoption.

2.3.2 Keystone Species Application in Business

The concept of special importance of keystone species within an ecosystem has been taken from its biological origins and, like the ecosystem concept before it, applied to business as well (Iansiti & Levien, 2004a, 2004b). Iansiti and Levien classify companies according to their function and advise strategies based on the industry or market context: hubs companies can choose to pursue keystone strategies to ensure the greatest value creation for the ecosystem as a whole while maintaining a small physical presence, they can act as dominators by growing their physical presence and decreasing the availability for external niche creation, or they can act as landlords by draining a disproportionate amount of value from their ecosystem over and above that which they produce (Iansiti & Levien, 2004a). Telecom operators are a prime example of a former dominator turned keystone species. As previously shown in Figure 1, operators' physical presence in the industry value chain has been decreasing with successive telecom technology generations, through a process of modularization that allows for the entrance of new, specialized niche firms that increase the value in the value chain. MNOs, now with a relatively small physical presence in the value chain create disproportionately more value by serving the function of a central hub through which value flows.

In mobile telecommunications numerous scholars have adopted the concept of MNOs as a mobile telecom keystone species by analyzing their strategies and business model implementations (e.g., Basole, 2009; Stanoevska-Slabeva & Wozniak, 2010; Tobbin, 2011; Zhang & Liang, 2011). Zhang and Liang (2011), in particular, applied Iansiti and Levien's entire keystone framework to evaluate China Mobile's keystone strategy. They find that China Mobile overcame its initial inexperience at managing a large network by successfully implementing a keystone strategy wherein it successfully promoted innovation, shaped its external network and enhanced value creation, accelerating the growth of its VAS market scale and allowing its mobile data services platform, "Monternet," to thrive.

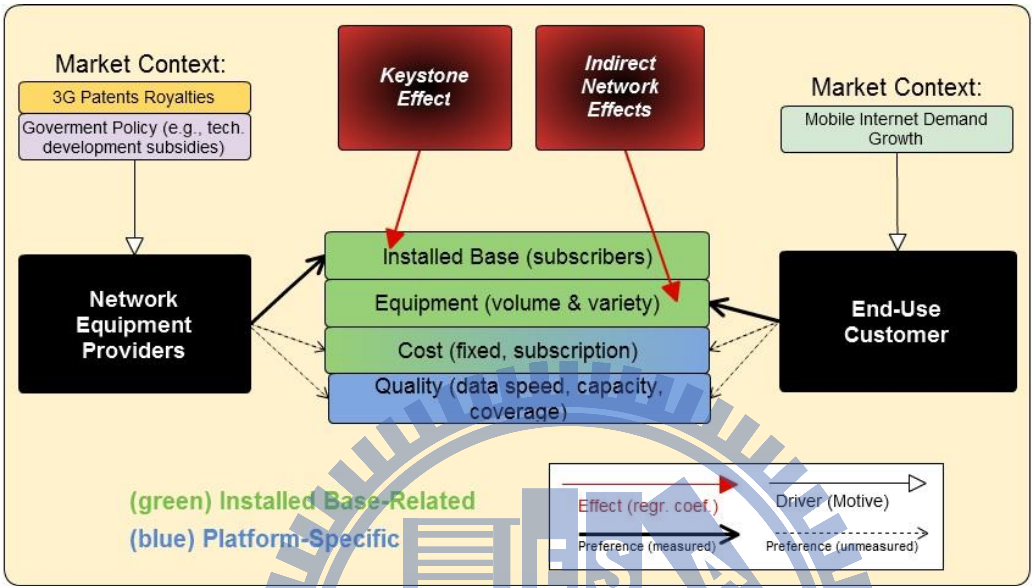

Figure 4. Platform Adopters' Preferences Moderated by Market Effects

2.3.3 Operationalizing the Keystone Effect Variable for Use in Business Ecosystems

As previously described, a keystone spices is one that produces disproportionate effects relative to its size. For our evaluation of the entry of the WiMAX technology standard into the mobile telecom ecosystem, we consider MNOs to be keystone species. Since the MNOs control loyal user bases, upon which NEPs base their adoption decision for current and future production volume and variety, then the production of equipment above (or below) the change in the MNOs' user base during can serve as an indicator of their platform's keystone effect. It indicates—among other factors, and when controlled for macroeconomic effects—the suppliers' production that is based on discounted future expectations of revenues to be earned from the MNOs loyal customers. It must be noted, however, that this is primarily useful as a relative measure to evaluate the advantage or disadvantage of the entrant technology standard relative to that of the incumbent since it may have little explanatory worth as an absolute value. This keystone effect will be combined with the market's indirect network effect and the entrant platform's quality advantage in establishing the utility and profit functions in the Chapter 3. Figure 4 displays the two sides of the mobile telecom market. The MNOs, acting as platform providers, are not included here as a "side" of the market. While market contextual factors drive the consumers and suppliers in making their adoption choice, and platform specific considerations such as costs and quality certainly impact their decision, the primary interactions on which we will focus are these: (1) the customer's desire for equipment variety and availability is moderated by indirect network effects, and (2) the supplier's preference for a larger user base is moderated by a keystone effect resulting from the MNOs' subscriber loyalty and central role of value transfer, both of which compound the potential for future value by partnering with them.

3. THE MODEL

We adapt a dynamic model from Zhu & Iansiti (2011), to examine the conditions under which a new technology standard can successfully enter a market dominated by an incumbent technology standard. The model was chosen for its ability to address both quality and indirect network effects simulaneously. We limit the following explanation to present only the equations necessary for understanding the model's underlying concepts and, primarily, to highlight the changes we make to the original version by applying it to the mobile telecom market. For full discussion of the concepts, we refer the reader to Zhu & Iansiti (2011), and for proofs and derivations of the equations, along with simulation results, please see their earlier working paper (Zhu & Iansiti, 2007).

The model assumes head-to-head competition between two incompatible platforms[2] competing for subscribers from the same consumer population and manufacturers,[3] herein termed network equipment providers (NEPs). Each representative consumer adopts one platform, and each supplier produces for one platform. In each period of the dynamic model, (1) a certain number of new consumers subscribe to mobile network operators (MNOs) on one of the two technology standards and puchase hardware that is currently available for that standard. and (2) a group of new NEPs each select a standard, incur fixed costs and produce hardware for the installed base of subscribers. These two actions are assumed to occur simultaneously. The process then repeats until the two technology standards reach equilibrium levels of subscribers and NEPs. As price is not a focal consideration of this investigation, we assume each platform's hardware is priced similarly. Finally, assuming perfect compeition with zero economic profit for each manufacturer facilitates our desire to isolate the combined impact of the indirect network effects and keystone effects.

3.1 Consumer Adoption

We us b_j and h_j to represent the installed base of subscribers and NEPs (equivalently the volume of hardware produced) on platform $J \in \{E, I\}$ at the beginning of period *t*. Quality is denoted by Q_j on each platform and is assumed to be a constant over the technology standard's life. This quality constant captures both the quality of both the data transmission potential of the

[2] For the purposes of this economic model explanation, the term "platform" is equivalent to and used to represent a technology standard. While these two are not strictly identical, and we do distinguish between them in other sections, temporarily conflating the two concepts here allows for a simpler explanation of the model.
[3] The original model used "consumers," though not specifically subscribers of a service. Additionally, it termed the supply side "application developers" since it was intended for video game production. We maintain the same concept of a third party designer and producer, but in the mobile telecom technology standards competition, we focus on the role of hardware supplier (i.e., manufacturers) herein termed network equipment providers (NEPs).

technology standard and the hardware that is available for it.[4] Each platform's life expectancy is necessarily greater than zero. And—of particular importance since it represents a change from the original model—consumers are not forward-looking, but suppliers are. Subscribers typically sign one- to two-year contracts with MNOs and often buy handsets at the time of subscription. This relatively long timeframe, considered with each consumer's limited quantity of hardware purchases, limits the impact of customers' future considerations. However, suppliers do consider not only the current installed base but also the MNOs' subscriber loyalty and future expectations of demand for their products. Thus, this forward-looking supplier trait will be factored into their profit functions for the dynamic simulation.

Our model follows a representative consumer approach to demonstrating subscriber preferences that is well established in the literature (Church & Gandal, 1992; Nair et al., 2004; Zhu & Iansiti, 2011).[5] This provides an aggregate description of the entire subscriber population. After solving the representative consumer's utility maximization problem, we can derive the utility that each customer gains by adopting a particular platform. Chapter 2's review of the literature on consumer preferences for high tech and telecommunications products, along with the factors that affect entry into two-sided markets and the changing structure of the mobile telecom ecosystem, forms the basis for our function of customer utility, U_{jt}, demonstrating the utility received by each customer on platform j in period t:

$$U_{jt} = \beta_j + \ln Q_j + e(\ln h_{jt}) \tag{1}$$

where β_j is a platform-specific constant, Q_j represents the quality of platform j, $e > 0$, and h_{jt} is the number of manufacturers producing for platform j in period t. The variable e, representing the indirect network effects, captures the subscriber's preference for hardware variety, which moderates the independent consideration of the number of manufacturers. Thus the utility function describes the average mobile telecom subscriber as valuing both hardware variety and availability, as well as technology standard quality. The relative strengths of these factors, however, may vary between subscribers in the population.

In order to determine the customer's adoption decision, we proceed with a standard logit model to capture heterogeneity of customer preferences (e.g., M. T. Clements & Ohashi, 2005;

[4] However, we do not include in the quality variable the MNOs network coverage quality as it is a related but external consideration.

[5] Another common approach to representing consumer utility is a discrete choice model (e.g., Ohashi, 2003; James E Prieger & Hu, 2010; Sobolewski & Czajkowski, 2012). However, since our representative consumer approach is based on a constant elasticity of substation (CES) function that allows us to capture the consumer's preference for product variety in addition to the separate consideration for quality (Zhu & Iansiti, 2011), we judged this to be the model most aptly suited for the present study of mobile telecom technology standards competition.

Nair et al., 2004).[6] The percent of new subscribers that choose platform *j* in period *t*, denoted as S_{jt} is represented by (McFadden, 1974):

$$S_{jt} = \frac{exp(U_{jt})}{exp(U_{Et}) + exp(U_{It})} \quad (2)$$

Substituting in equation (1) produces:

$$S_{jt} = \frac{Qh_{jt}^{e}}{Qh_{Et}^{e} + h_{It}^{e}} \quad (3)$$

where $Q=Q_E/Q_I$, and represents the quality ratio advantage of the entrant.[7]

3.2 Supplier Entry

We first express the myopic (i.e., not forward-looking) profit function of a representative manufacturer on platform *j*:

$$\pi_j = b_j h_j^*(\rho_j - c_j) - F_j \quad (4)$$

Where b_j is the current installed base of platform j, h_j^* is the optimal quantity of hardware manufactured, ρ_j is the price and c_j the marginal cost of products on platform *j*, and F_j is the fixed cost of operating on platform *j*. We then allow the representative manufacturer to consider the potential revenues from future customers, which represents a change from the strictly myopic profit function used by Zhu & Iansiti (2011). This yields the manufacturer's hyperopic (i.e., forward-looking) profit function on platform *j* in period *t*:

$$\Pi_{jt} = B_{jt} h_{jt}^*(\rho_j - c_j) - F_{jt} \quad (5)$$

where: B_{jt} is the discounted present sum of the future installed base of subscribers that are considered by the manufacturer on platform *j* in time *t*, and it is limited within the manufacturer's time horizon for future considerations of investment decisions. This captures the intuitive notion that the number of manufacturers joining a platform, and in turn the production volume and hardware variety of that platform, is determined not only by the current installed base at the time of adoption, but also, perhaps more so, by the expected number of customers that offer the highest potential for guaranteed demand in the future and allow for cost reduction through increasing returns to scale.

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[6] For addressing the concerns associated with the logit model's potential violation of the independence of irrelevant alternatives (IIA) assumption, we direct the reader to Zhu & Iansiti's explanation (2011). Essentially, since the focus of our study, like Zhu & Iansiti's, is head-to-head competition, wherein the second of two parties (WiMAX) is entering the market to compete with the first party (the combined 3GPP technology standards), there is no inherent danger of violating the IIA assumption. Furthermore, any addition of future alternatives, such as a third party, would still not violate the IIA assumption since it would affect both existing parties' market shares equally. It would, therefore, not change the market positions of WiMAX and 3G relative to each other. Of course, this says nothing of their market positions relative to that hypothetical third technology standard; these resulting market shares would depend upon the market's acceptance of the new standard.

[7] The study assumes an entrant with superior platform quality.

Denote: $B_{jt} = b_{jt} + \sum_{s=t+1}^{T_j} \frac{(b_{js}-b_{js-1})}{(1+\varphi_j)^s}$, or the discounted present sum of the future installed base of platform *j* from period *t* until the investment decision time horizon, T_j, subject to the future period discount factor, φ_j, where s represents the time period in the future. Now we introduce the platform keystone effect variable, K_j, and let: $K_{jt} = log_{b_{jt}}\left[b_{jt} + \sum_{s=t+1}^{T_j} \frac{(b_{js}-b_{js-1})}{(1+\varphi_j)^s}\right]$, $K > 0$, where φ_j is the discount factor for the future subscriber base of platform *j*, within the investment decision time frame limited by the time horizon, T_j, for manufacturers on platform j. This expression can be rewritten as $K_{jt} = log_{b_{jt}} B_{jt}$, which we can rewrite thus: $B_{jt} = {b_{jt}}^{K_j}$.

We proceed from the assumption that manufacturers of products in two-sided markets choose platforms that will maximize their profits, and then apply the free entry condition that each manufacturer is a price-taker in a competitive market. Following Zhu & Iansiti (2007) we obtain Δh_{jt}, the number of new manufacturers joining the technology standard *j* in period *t*, or equivalently the quantity of new hardware produced by forward-looking manufacturers in that period:

$$\Delta h_{jt} = \alpha_t \frac{{b_{jt}}^{K_j}}{F_{jt}} \quad (6)$$

where α_t is a platform-specific time constant, F_{jt} is the fixed cost of manufacturing for platform *j* in period *t*, and ${b_{jt}}^{K_j}$ is the keystone effect-moderated subscriber base of platform *j* in period *t*. If the representative manufacturer were only to consider the current user base when making its adoption decision (i.e., consider zero future periods, $T_j = 0$), then $b_{jt} = {b_{jt}}^{K_j}$, and equivalently $\Pi_{jt} = \pi_j$; however, we don't expect that this is true for the overwhelming majority of real-world adoption decisions, or for investments of any nature. From this equation we can see that a decrease in the fixed cost of operating on platform j, an increase in the base of platform j, or, most substantially, an increase in the keystone effect of platform *j*, K_j, causes the number of manufacturers adopting the platform to increase as well.

3.3 Evolution of Market Structure

We now extend the single-period decision scenario into a multi-period market simulation. In order to allow subscribers and manufacturers to leave their platform or switch platforms, we follow Zhu and Iansiti (2011) and introduce platform decay at a rate of between 0 and 1, $\delta_b \in (0,1)$, $\delta_h \in (0,1)$. M_t is defined to be the total number of subscribers that join a technology standard in period *t*. Then, incorporating expression (3), the change in the subscriber base of platform E in period *t* —both the increase from adopters and the decay from those leaving the platform—is:

$$\Delta \boldsymbol{B}_{Et} = \boldsymbol{M}_t \left(\frac{\boldsymbol{Q} \boldsymbol{h}_{Et}^{e}}{\boldsymbol{Q} \boldsymbol{h}_{Et}^{e} + \boldsymbol{h}_{It}^{e}} \right) - \boldsymbol{\delta}_b \boldsymbol{b}_{Et} \tag{7}$$

Applying the same method for the entrant and incumbent customers and manufacturers yields the market evolution system of equations:

$$\Delta B_{Et} = M_t \left(\frac{Q h_{Et}^{e}}{Q h_{Et}^{e} + h_{It}^{e}} \right) - \delta_b b_{Et} \tag{7.a}$$

$$\Delta B_{It} = M_t \left(\frac{Q h_{It}^{e}}{Q h_{Et}^{e} + h_{It}^{e}} \right) - \delta_b b_{It} \tag{7.b}$$

$$\Delta h_{Et} = \alpha_t \frac{{b_{jt}}^{K_E}}{F_{jt}} - \delta_h h_{Et} \tag{7.c}$$

$$\Delta h_{It} = \alpha_t \frac{{b_{jt}}^{K_I}}{F_{jt}} - \delta_h h_{It} \tag{7.d}$$

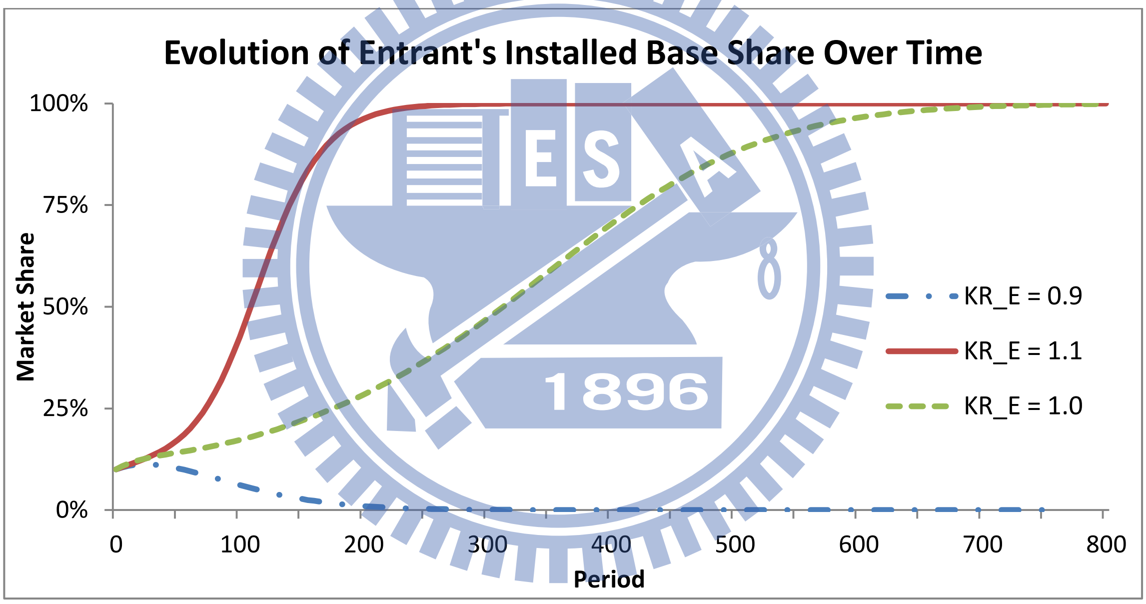

Figure 5. The Impact of the Keystone Effect Ratio on Installed Base Share Over Time

The objective of this study is to determine when an entrant technology standard can succeed in securing an oligopoly or monopoly share of the market. We examine the market evolution from equation set (7.a-7.d) with a computer simulation[8] to ascertain when the market will progress to equilibrium shares for incumbent and entrant. We assume indirect network effects are 1.05, which is greater than 1.0 but less than the threshold level that makes successful entry impossible for entrants (Zhu & Iansiti, 2011). We then set the incumbent's keystone effect strength at 1.1, slightly greater than the network effects, and we test three different keystone strengths for the entrant that yield entrant keystone effect ratios, KR_E, (i.e., K_E/K_I) of 0.9, 1.0, and 1.1. The three scenarios reach equilibrium within 800 periods, *T*=800. We assume that the

[8] The market evolution simulation was performed iteratively with MS Excel 2010.

incumbent controls 90% of the market user base at the time of the simulation's start. Since we are interested in the growth stage of the technology, the new subscribers grow at a constantly increasing rate of 3.67%, which is equivalent to the monthly compound aggregate growth rate (CAGR) of the telecom services industry from 2006-2010 ("Global Wireless Telecommunication Services," 2011), and the time constant, α_t, is set at 0.1 to keep hardware production reasonably in line with subscribership in the early stages of the simulation. We assume an entrant quality advantage ratio and fixed cost ratio of 1.5, Q=F=1.5. We set the decay rates at 2% for the subscribers, which approximates the churn rate of many MNOs in the United States, and at 0.1% for the manufacturers since they are far less likely to leave a technology standard after having invested substantial fixed cost in joining it. Figure 5 shows that a keystone effect ratio greater than 1.0, in this case KR_E=1.1, with moderate indirect network effects, e=1.05, when the incumbent's keystone effect is 1.1, will allow the latecomer to enter successfully, earning monopoly share. When the entrant's keystone effect ratio is less than 1.0, KR_E=0.9, the entrant will be completely driven from the market, and when KR_E=1.0, the entrant can enter the market successfully albeit slowly.

Magnitude of Indirect Network Effects (e) \ Magnitude of Entrant's Keystone Effect Ratio (K_E/K_I)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.0	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
0.1	3%	3%	4%	6%	9%	13%	19%	27%	37%	49%	61%	72%	81%	88%	92%	95%	97%	98%	99%	99%	100%
0.2	0%	0%	0%	0%	0%	1%	3%	7%	16%	36%	63%	84%	94%	98%	99%	100%	100%	100%	100%	100%	100%
0.3	0%	0%	0%	0%	0%	0%	0%	1%	5%	21%	65%	93%	99%	100%	100%	100%	100%	100%	100%	100%	100%
0.4	0%	0%	0%	0%	0%	0%	0%	0%	1%	10%	67%	98%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	71%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.6	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	77%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	85%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.0	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
1.1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%
1.9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%
2.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 6. Entrant Technology Standard's Market Landscape: Table View

Figure 6 maps the entrant platform's market landscape for a simulation length of 1000 periods. It displays the entrant's equilibrium[9] market share according to the strength of the market's indirect network effects and the entrant's keystone effect ratio. Squares in red mark 100%

[9] It would be the equilibrium if the market were to remain in a growth stage ad infinitum.

subscribership share for the entrant; those in blue signify 0% for the entrant; those in shades of yellow or orange range from niche shares to oligopoly shares of the market.[10] This result is displayed more clearly with depth in Figure 7**Error! Reference source not found.**. From the arket landscape we can see that the keystone effects play a significant role in determining the equilibrium monopoly party. A slight keystone effect ratio advantage enjoyed by the entrant, KR_E >1.0, would generally allow the entrant to win a monopoly share of the market. And if the keystone effect ratio were strong enough (i.e., KR_E >1.3), then the entrant could overcome even high levels of indirect network effects, which would otherwise make the market determined by installed base advantage and thus unwinnable for an entrant.

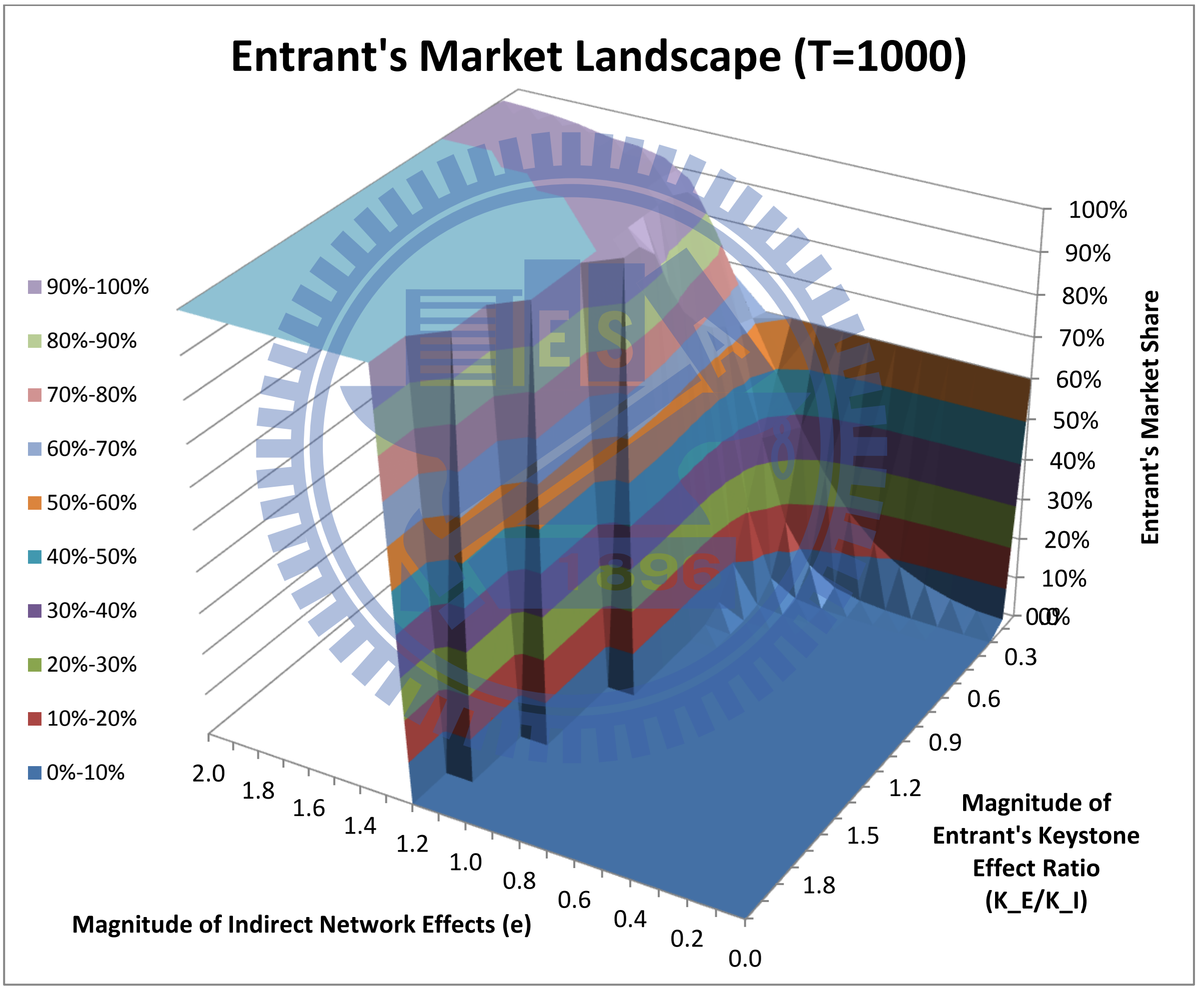

Figure 7. Entrant Technology Standard's Market Landscape: 3D View

This simulation is of course sensitive to the assumptions used (see Appendix A. Model Simulation Sensitivity for the sensitivity test simulation results and explanations). A higher starting

[10] However, if the simulation were allowed to proceed for more than the 1000 periods (i.e., T>1000), some of these would likely evolve toward one extreme or the other. This leaves the vast majority of the market landscape with a binary market share outcome set: either all or none. The primary exception is when e=0.0, in which case the entrant's equilibrium market share is determined by the platform's quality advantage and the fixed costs of operation associated with the platform.

percentage of the total user base will increase the area of the landscape in which the entrant can win in the long run, as will a larger quality advantage. Also, the results are sensitive not only to the relative strengths of the entrant's and incumbent's keystone effects but also to the relative strengths of the keystone effects (both ratios KR_E and KR_I) and the indirect network effects. Keystone effect absolute values well above the indirect network effect (e.g., e=1.0 while K_I or K_E=2.0) seem to lessen, or even negate, the indirect network effects' impact. This implies that the impact of the keystone effect ratio and the absolute keystone effect strengths are critically important in understanding the conditions under which a new platform can successfully enter the market. There is very little space in the market landscape where an entrant with a keystone effect disadvantage, KR_E<1.0, can hope to enter the market successfully. And since this only occurs where the indirect network effects are very low, e<0.2, which is practically impossible in a two-sided market, then operators of a platform with relatively weak keystone species should think twice about entering a market where they will be at a keystone effect disadvantage to the incumbent—and all those manufacturers considering joining such a platform should certainly think twice as well.

4. EMPIRICAL ANALYSIS

4.1 Entry of the WiMAX Standard

The 2007 release of the first generation iPhone began, albeit slowly at first, to drive the handset transition from feature phones to smartphones, which offered consumers an increasingly wide range of handsets that made it easier for them to utilize more of the data-heavy 3G services. As is clearly evident in Figure 8, the convergence of services through multi-functional devices that had been anticipated with 3G, finally, after 2007, became a reality (Gilstrap, 2012; "Your television is ringing," 2006).

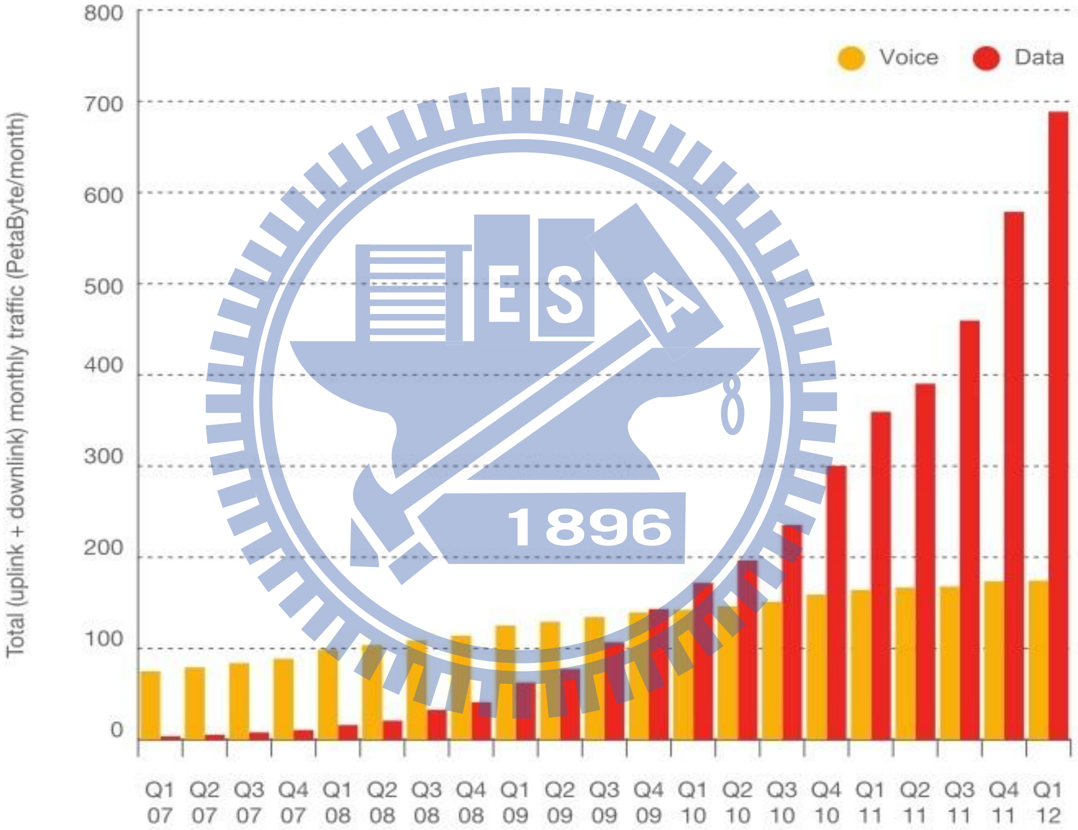

Figure 8. Global Total Traffic in Mobile Networks, 2007-2012
Source: Ericsson (2012)

By this time, however, another mobile data technology standard, WiMAX, had already been standardized, IEEE 802.16. Its Orthogonal Frequency Division Multiple Access (OFDMA) approach to wireless data presented a different option for the future of mobile data service provision—one that was poised to arrive sooner than the entrenched telecom power players would have wanted. Figure 9 shows WiMAX's time-to-market advantage, projected in 2009, ahead of the cellular standards' future OFDMA 4G technology, LTE. While 3G technologies were mobile data services built around the primary function of digital voice, WiMAX was entirely designed for data and offered with it the ability for voice services via VoIP. Thus, WiMAX presented a challenge from an outsider to the mobile telecom industry, driven by equipment makers that had not done well in 3G and wanted to jump into 4G early ("Wireless internet," 2007).

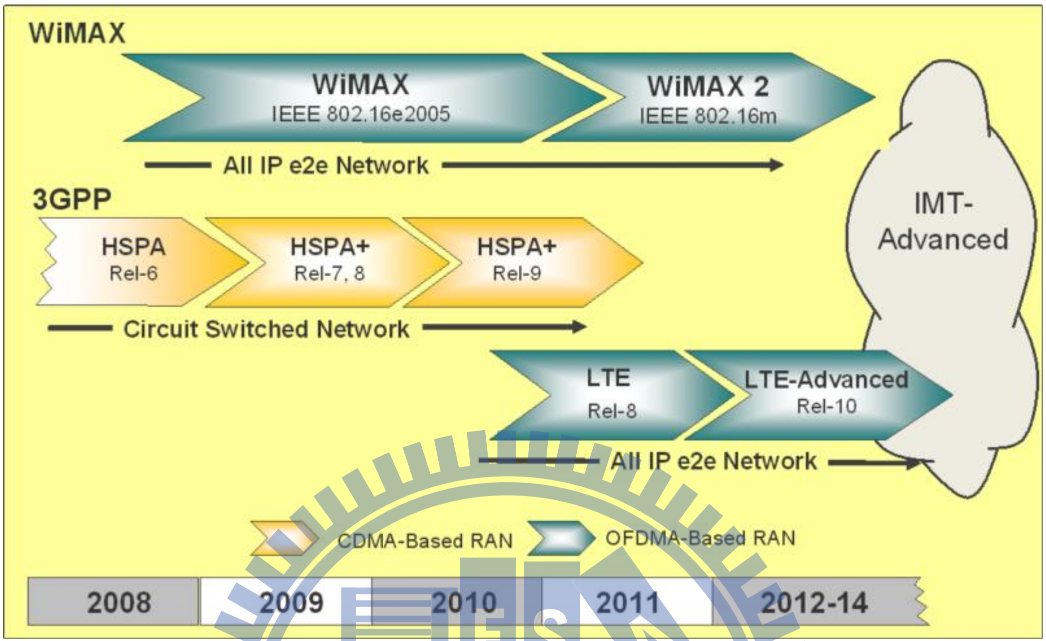

Figure 9. Timeline for Mobile WiMAX and 3G Technological Standards
Source: Reproduced from WiMAX Forum Report (Gray, 2009)

It was hoped that the changing landscape of the mobile telecom market would allow more competition where there was once only oligopoly (Peppard & Rylander, 2006b). With flagship companies, notably Intel, from the wireless fidelity (Wi-Fi) and computer hardware industry, and supported by smaller (e.g., Sprint in the US) or entirely new (i.e., non-legacy) operators, WiMAX was the computer industry's attempt at extending their product reach into the telecom industry in time for the transition to mobile computing. WiMAX was ready to beat 3G data speeds with pre-4G fixed (802.16d) and mobile (802.16e) standards, and with full 4G (802.16m) being developed to follow a few years afterward. Its proponents hoped that, with comparatively low network costs,[11] WiMAX would be able to open up the previously closed telecom market. In order for this to happen, WiMAX would need to succeed at snatching away early 4G adopters from incumbent 3G carriers to grow its way toward a critical mass of users. However, some financing and technical problems delayed early WiMAX deployments in certain markets ("Wireless telecoms," 2008), and the cellular camp began accelerating its plan to answer with Long Term Evolution (LTE), its own pre-4G technology standard supported by the major MNOs and 3G equipment providers (which would later be succeeded by LTE-Advance 4G). By the end of 2008, WiMAX could reasonably

[11] WiMAX's Orthogonal Frequency Division Multiple Access (OFDMA) approach to wireless data promised not only faster data speeds but also lower network costs than the Code Division Multiple Access (CDMA) technology used in 3G networks (Rysavy, 2011).

have expected a window of two years, at most three, during which it could shift the market's momentum in its favor before LTE would be operational.

The data in Table 1, which are also visually represented in Figure 10, chronicles WiMAX's entry into the mobile telecom ecosystem, both globally and in the United States. This allows for comparison between the technological standard's entry into two different market settings: (1) the national market of a developed country, and (2) the global market that encompasses both developed and developing countries. Additionally, the evaluation of a national market allows for the observation of localized attributes, which will not be present in the global market data due to its aggregation of many local markets. Furthermore, the inclusion of the United States market, and the comparisons that can be made between WIMAX's success in it and in the global market, have important implications for the measurement of keystone effects; namely, Brose, Berlow, & Martinez, (2005) find not only that the community context of the target species determines whether strong keystone effects are realized but also simple, measurable, and local attributes of complex communities may explain much of the empirically observed variation in keystone effects.

Table 1. Summary Statistics of Subscribership and Equipment Production for WiMAX and 3G Technology Standards

	WiMAX			3G		
	2009	2010	2011	2009	2010	2011
World (%)						
Share of total installed base	1.05	1.48	2.10	98.95	98.52	97.90
Share of new subscriptions	1.25	2.18	3.41	98.75	97.82	96.59
Share of new hardware produced	0.57	1.34	1.51	99.43	98.66	98.49
United States (%)						
Share of total installed base	0.74	2.86	4.95	99.26	97.13	95.04
Share of new subscriptions	0.40	3.85	8.44	99.60	96.15	91.56
Share of new hardware produced	0.97	3.36	4.67	99.03	96.64	95.33

WiMAX started with a relatively larger share of the world mobile broadband subscriber base than of the U.S. mobile subscriber base, but it grew faster in the United States. The biggest jump in new hardware produced for the U.S. market came from 2009 to 2010, growing over 300%, which was because the first WiMAX phone in the US, HTC's Evo 4G, was not released until the second quarter of 2010 (Middleton, 2012). WiMAX managed to grow its user base share of both the world market, at a modest 7% CAGR, and the US market, at an impressive 159% CAGR. However, the most telling statistic of WiMAX's relative keystone weakness vis-à-vis 3G is the difference between WiMAX's share of new subscriptions and its share of new hardware production. By the end of 2011, WiMAX's share of new subscriptions in the world was still over twice (2.26x) its share of new hardware production, which was up from a multiple of 2.12x in 2009. And WiMAX's share of new subscribers in the United States was nearly twice as many (1.81x) as its share of hardware production volume, which was over four times higher than 2009. It would seem from these figures that WiMAX's keystone species deficiency is evident in its relatively weak commitment from its suppliers compared with that of its customers.

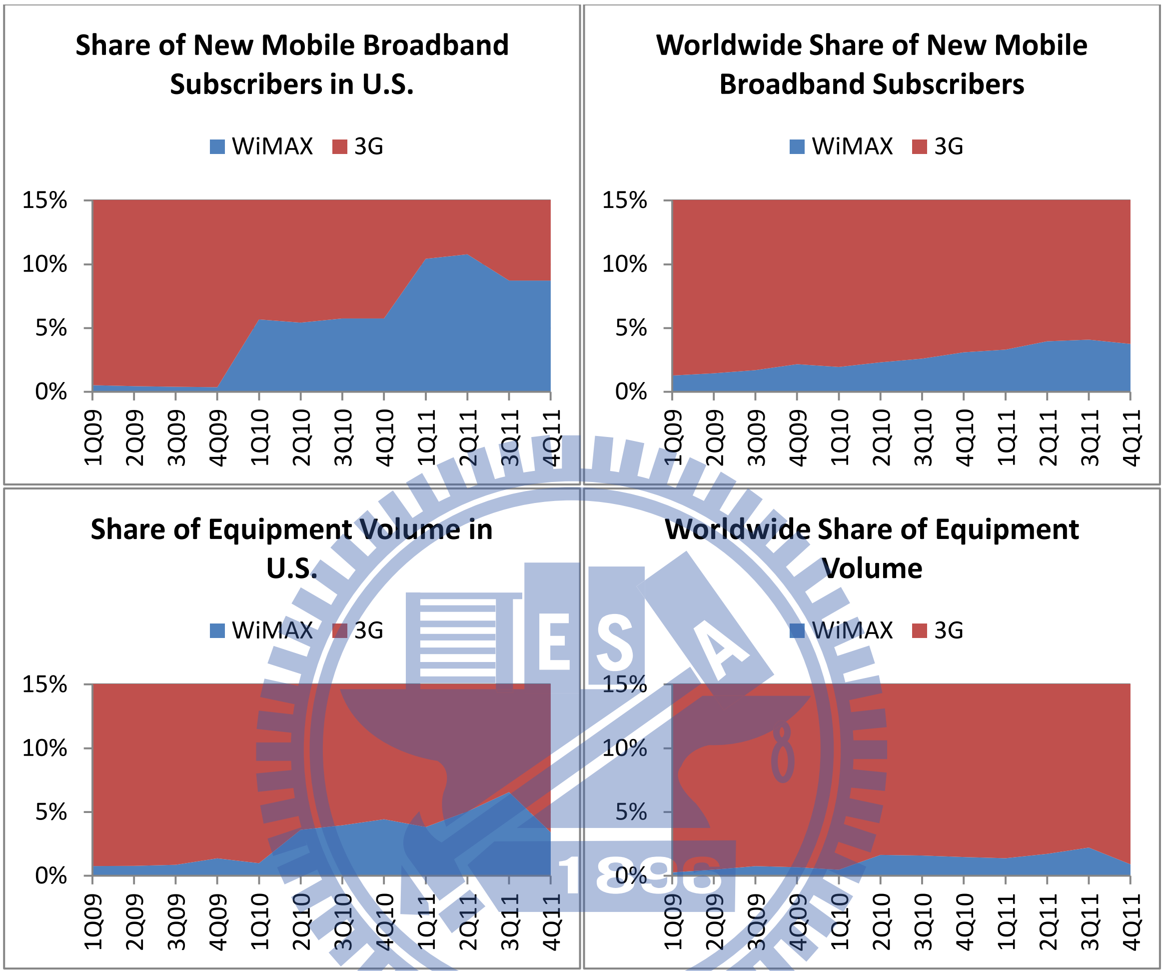

Figure 10. WiMAX's Entry vs. 3G

Barely three years after WiMAX entered the US market, five years after it entered the world market, the wireless telecom technology standards "battle" for the future of 4G was all but decided—and there wasn't even a fight. WiMAX failed to garner support from the undecided operators and equipment developers, who migrated en masse to the LTE camp. Key WiMAX flagships scaled back operations or defected entirely, notably Intel discontinuing the WiMAX Rosedale chip and closing its WiMAX operation in Taiwan (Tofel, 2010; Weissberger, 2009). Toward the end of 2011, even the formerly staunch backers of WiMAX—namely Sprint in the U.S. who had based its comeback on the early 4G data service differentiation that WiMAX offered—were jumping ship, announcing they would begin to pursue LTE either jointly with WiMAX or instead of it in the future (Bensinger, 2011). The global tide shifted toward LTE as major markets, China, Russia, even India, began to deploy LTE networks ("Aircel, Huawei complete LTE field trial in India," 2011; Bensinger, 2011; Gabriel, 2011a, 2011b). Although WiMAX will still serve an important function in bringing last mile broadband internet to less developed countries, particularly in rural areas, such a niche role is hardly what WiMAX backers were hoping two see over half a decade earlier when they invested in WiMAX hoping to take a central role in the future of mobile computing ("Wireless internet," 2007) . It has been argued that WiMAX served the beneficial function of accelerating the 4G timeline in developed countries ("Wireless telecoms," 2008), which is certainly a benefit realized by mobile telecom subscribers in those countries. However, the same cannot be said for WiMAX NEPs and MNOs who had to absorb the unrecouped cost of WiMAX product development and network deployment and then pay, as well, the costs of the transitioning to LTE. Of course since the technologies are similar, this isn't exactly like paying the full price twice. Nevertheless, it is hard to argue, either from a brand equity or ROI perspective that WiMAX was the right choice. This is true especially for Spint who suffered considerably while attempting to maintain both a CDMA2000 network and WiMAX networks (Gompa, 2012).

WiMAX faced an optimistic outlook prior to 2008. It entered the pre-4G standards race over two years ahead of cellular 3G's future 4G technology standard, LTE. It thus had a mobile data quality advantage for subscribers, and it offered WiMAX operators a network cost advantage, from its OFDMA approach, over 3G's CDMA-based technologies. Given these considerations, WiMAX might reasonably have expected to make a dent in 3G's user base and successfully enter the market. Instead, however, WiMAX failed in the United States and has been relegated to a niche or transitional technology in developing countries. We therefore assert the following hypothesis:

HYPOTHESIS 1: *WiMAX's keystone effect disadvantage and the mobile telecom market's indirect network effects were cumulatively strong enough to prevent the WiMAX standard from achieving a successful market entry (i.e. maintaining oligopoly or monopoly share in the long run).*

4.2 Data

Market data of mobile broadband subscribership and hardware production used in this empirical analysis were obtained from numerous sources. WiMAX data was provided by the Market Intelligence and Consulting Institute (MIC), a leading Asian information and communications technologies research firm. Quarterly production volume of WiMAX 802.16e (i.e., mobile WiMAX) equipment was used to represent the market entrant's supply of hardware. Smartphone and 3G tablet shipment volumes were used to represent the incumbent's hardware volume. Smartphone totals came from MIC data on global mobile handsets shipment figures, which were multiplied by the smartphone penetration percentage of total handset sales for the global and for the United States markets, as reported by Chetan Sharma, a technology and strategy consulting firm. Additionally 3G tablets were calculated as the ratio of total handset sales to tablet sales reported by Information Data Corporation (ICD). The entrant's subscriber base was available from MIC data on WiMAX subscriptions, and the incumbent's subscriber base came primarily from International Telecommunications Union (ITU) figures. Additionally, U.S. Federal Communications Commission (FCC) wireless competition reports for 2009-2011, as well as annual and quarterly reports from Sprint, AT&T and Verizon, were used for the US market.

Table 2. Regression Data Summary

	Mean	Std. Dev.	Min.	Max.
World (Obs: 12)				
Subscriber share difference ($\%B_E$-$\%B_I$)	-97.28%	0.88%	-98.40%	-95.79%
Hardware volume difference (N_E-N_I)	-8.02E+07	3.37E+07	-1.47E+08	-3.47E+07
Entrant subscriber base (B_E)	1.19E+07	7.19E+06	3.72E+06	2.54E+07
Entrant hardware volume (N_E)	1.56E+06	8.73E+05	2.45E+05	3.12E+06
Incumbent subscriber base (B_I):	7.88E+08	2.37E+08	4.60E+08	1.18E+09
Incumbent hardware volume (N_I)	8.18E+07	3.44E+07	3.49E+07	1.49E+08
United States (Obs: 7)				
Subscriber share difference ($\%B_E$-$\%B_I$)	-92.86%	2.22%	-95.83%	-90.09%
Hardware volume difference (N_E-N_I)	-3.22E+07	5.10E+06	-4.17E+07	-2.56E+07
Entrant subscriber base (B_E)	6.36E+06	3.15E+06	2.49E+06	1.08E+07
Entrant hardware volume (N_E)	1.56E+06	4.99E+05	9.92E+05	2.52E+06
Incumbent subscriber base (*BI*):	1.63E+08	3.28E+07	1.17E+08	2.08E+08
Incumbent hardware volume (N_I)	3.37E+07	5.32E+06	2.65E+07	4.32E+07

Table 2 presents a summary of the regression data. The most glaring inadequacy with this data is the limited number of observations. The relatively recent entry of WiMAX only allows three years of consistent data for it subscribers and equipment production in the world market. The availability of only quarterly market data thus limits the number of observations to 12 for the world market. And since the first WiMAX phone in the US was only introduced in the second quarter of 2010, data from 2009 doesn't accurately represent WiMAX's entry into the mobile telecom market; it instead disproportionately presents fixed WiMAX subscriptions and customer premises equipment sales. Consequently acceptable market data only exists in the US market after the first quarter of 2010, which allows 7 observations. More observations would of course be ideal, but the recent and brief entry of WiMAX makes this as an unavoidable limitation of the data required for this research.

4.3 Empirical Specifications

Our empirical analysis involves two steps to address the previously posited hypothesis. First, we measure the strength of the indirect network effects, e, and keystone effects for the entrant, K_E, and the incumbent, K_I, through regression analysis of the mobile telecom market data. Then we use these market effect strengths to locate WiMAX on the market landscape presented in chapter 3 (i.e., Figure 6).

We develop the regression framework, according to Berry (1994), by transforming the consumer adoption expression (3) to yield the following regression equation:

$$\ln S_{Et} - \ln S_{It} = \beta_Q + e(\ln H_{Et} - \ln H_{It}) + \beta_3 Dummy_{LTE} + \varepsilon_t \qquad (8)$$

where S_{jt} is the proportion of new subscribers who choose platform *j* in period *t*, and β_Q is a coefficient roughly representing the quality advantage of the entrant, since the quality ratio is $Q=exp(\beta_Q)$. We include a dummy for the numerous announcements of LTE deployments and WiMAX operators planning to switch to LTE toward the end of 2011 in order to control for their disproportionate effect on the focal coefficient, indirect network effects, *e*.

On the supplier side, we take the natural logarithm of the supplier adoption expression (6) and transform it into the following regression equation:

$$\ln H_{jt} = \beta_O + K_j \ln b_{jt} + \beta_2 Dummy_{F_j} + \sum_{i=1}^{2} \beta_i Dummy_{2009+i} + \varepsilon_{jt} \qquad (9)$$

where K_j represents the keystone effect on platform *j*, β_O is a constant equivalent to α_t in equation (6), and β_2 is a platform dummy that captures the fixed cost ratio of operations between the two platforms.[12] Since we have no reason to assume (i.e., no anecdotal information or exogenous data) that this ratio changed during the regression timeframe, then each platform variable's data set will be uniform over the life of the regression. This variable is thus suppressed in the regression results. Furthermore, as we are not interested in differences between the two platforms across periods, we need to control for time-specific changes in demand, which were exacerbated during the regression timeframe due the effects of the global recession. We therefore include yearly time dummy variables.

[12] This was originally used as a dummy to distinguish the platforms which were analyzed jointly with little focus on the supplier side by Zhu &Iansiti (2011). We instead evaluate the supplier equations according to their platform. Since we do not have exogenous data to ascertain on which platform it was more expensive to operate during each period, and primarily because there were no major developments that would have affected one platform's cost of operations over the other's, then we are left with a uniform variable set (i.e., either all 0 or all 1) for each platform. This dummy variable is therefore omitted from the regression results due to collinearity when processed in STATA.

5. RESULTS

Table 3 and Table 4 present our regression results for the world and the US markets.[13] First, in Specification 1, we employ ordinary least squares regression since our model assumes that indirect network effects enter the market linearly and each log-transformed dependent variable has a linear relationship with its log-transformed independent variable(s). Each of the three regression equations—for the subscribers, the entrant suppliers, and the incumbent suppliers—is significant in the world market at a 99% confidence level and in the US market at between 90% and 99% confidence. Then in Specification 2, we employ robust OLS, which can account for certain irregularities like non-normality of data. While it doesn't substantially affect the adjusted R-squared values, this robust method has the benefit of substantially decreasing the coefficients' standard errors. Finally, in Specification 3, we perform a second robustness check: seemingly unrelated regression (SUR). It is designed for multiple equations models, such as ours, in which data for separate equations is drawn from the same populations of observations. These data are inherently dependent even if the same variable is not used twice in two different equations, and consequently their errors terms will be correlated. SUR produces coefficients similar to OLS regression with standard errors similar to or, in most cases, less than those of the robust OLS regression. SUR also offers the benefit of checking for heteroscedasticity. The Breusch-Pagan test results yield p=0.43 in the world market model and p=0.14 in the US market, neither of which are significant at α=0.05. Therefore we do not reject the null hypothesis of homoscedasticity[14] and can accept the statistical significance of the multiple equation models as valid. For the second part of our empirical analysis, locating WiMAX on the market landscape, we will use the SUR results since their standard error terms are among the lowest and they rule out heteroskedasticity by accounting for related error terms.

These results show that the US market was characterized by strong indirect network effects and relatively weaker keystone strengths, while the world market exhibited weaker indirect network effects and very strong keystone effects. The indirect network effects were twice as strong in the US market as they were in the world market during the WiMAX's attempted entry. WiMAX's keystone effect was weaker than that of 3G in both markets, but interestingly the absolute values of these keystone effects varied considerably between the world and the US market. The stronger keystone effect strength in the world market implies that many countries have

[13] All statistical calculations were performed using STATA 12.
[14] This confirmation of homoscedasticity means the variances of the residuals in the equations do not depend on their respective independent variables, and this ensures that they present no danger of invalidating the statistical significance of the model.

Table 3. Regression Results for World WiMAX vs. 3G Supply and Demand

Panel A: Mobile Telecom (≥3G) Service Demand						
Dependent Variable Subscriber diff. ($\ln B_E$-$\ln B_I$):	Specification 1: OLS Regression		Specification 2: Robust OLS		Specification 3: SUR	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Independent Variable						
Volume diff. ($\ln N_E$-$\ln N_I$): ***e***	0.571***	0.169	0.571***	0.112	0.591***	0.145
Dummy Variable						
LTE Announcement	0.715***	0.229	0.715***	0.064	0.718***	0.195
Adjusted R^2	0.580***		0.657[a]		0.656***	
Observations	12		12		12	

Panel B: Entrant (WiMAX) Equipment Supply						
Dependent Variable Volume ($\ln N_E$)	Specification 1: OLS Regression		Specification 2: Robust OLS		Specification 3: SUR	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Independent Variable						
Subscriber Base ($\ln B_E$): $\boldsymbol{K_E}$	1.818***	0.426	1.818***	0.489	1.795***	0.348
Dummy Variables						
2010	-0.248	0.367	-0.248	0.356	-0.231	0.300
2011	-1.250*	0.637	-1.250*	0.568	-1.209**	0.520
Adjusted R^2	0.851***		0.891***		0.891***	
Observations	12		12		12	

Panel C: Incumbent (3G) Equipment Supply						
Dependent Variable Volume ($\ln N_I$)	Specification 1: OLS Regression		Specification 2: Robust OLS		Specification 3: SUR	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Independent Variable						
Subscriber Base ($\ln B_I$): $\boldsymbol{K_I}$	1.864***	0.165	1.864***	0.135	1.911***	0.133
Dummy Variables						
2010	-0.118	0.071	-0.118	0.073	-0.138**	0.057
2011	-0.334**	0.119	-0.334**	0.110	-0.382***	0.096
Adjusted R^2	0.985***		0.989***		0.989***	
Observations	12		12		12	

Panel A reports regression results for world technology standard adoption by subscribers. Panel B reports regression results for world WiMAX 802.16e equipment supply, and Panel C reports regression results for world 3G equipment supply. Results are presented *significant at 10%, **significant at 5%, and ***significant at 1% for regression coefficients and the model's adjusted R-squared.

[a] F-test score cannot be calculated due to the use of a dummy variable with only one non-zero datum.

Table 4. Regression Results for United States WiMAX vs. 3G Supply and Demand

Panel A: Mobile Telecom (≥3G) Service Demand						
Dependent Variable Subscriber diff. ($\ln B_E$-$\ln B_I$):	Specification 1: OLS Regression		Specification 2: Robust OLS		Specification 3: SUR	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Independent Variable						
Volume diff. ($\ln N_E$-$\ln N_I$): ***e***	1.115*	0.410	1.115**	0.366	1.201***	0.285
Dummy Variable						
Clearwire Announcement	0.768***	0.259	0.768**	0.179	0.741***	0.183
Adjusted R^2	0.605*		0.737[a]		0.731***	
Observations	7		7		7	

Panel B: Entrant (WiMAX) Equipment Supply						
Dependent Variable Volume ($\ln N_E$):	Specification 1: OLS Regression		Specification 2: Robust OLS		Specification 3: SUR	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Independent Variable						
Subscriber Base ($\ln B_E$): K_E	0.437**	0.148	0.437**	0.157	0.451***	0.122
Adjusted R^2	0.565**		0.637**		0.637***	
Observations	7		7		7	

Panel C: Incumbent (3G) Equipment Supply						
Dependent Variable Volume ($\ln N_I$)	Specification 1: OLS Regression		Specification 2: Robust OLS		Specification 3: SUR	
	Coeff.	Std.Err.	Coeff.	Std.Err.	Coeff.	Std.Err.
Independent Variable						
Subscriber Base ($\ln B_I$): K_I	0.725***	0.091	0.725***	0.101	0.738***	0.076
Adjusted R^2	0.913***		0.928***		0.927***	
Observations	7		7		7	

Panel A reports regression results for U.S. technology standard adoption by subscribers. Panel B reports regression results for U.S. WiMAX 802.16e equipment supply, and Panel C reports regression results for U.S. 3G equipment supply. Results are presented *significant at 10%, **significant at 5%, and ***significant at 1% for regression coefficients and the model's adjusted R-squared.

[a] F-test score cannot be calculated due to the use of a dummy variable with only one non-zero datum.

stronger, more interconnected and value-transferring MNO's, as well as other potential keystone species, than those in the United States.[15]

When we apply the results from the SUR to WiMAX's market entry we get the results shown in Figure 11. The top two charts show the market landscape in the world (right) and US (left), and the bottom two graphs show the progression of WiMAX's share of the total user base over time in the world (right) and US (left) markets. The exact locations of WiMAX in the two markets, based on its keystone effect ratio and the market's indirect network effects, are indicated with a bold outline. WiMAX is located in the areas that are governed by installed base and keystone advantage, which are entirely unreceptive to newcomers. This confirms our hypothesis that WiMAX's failure to enter the mobile telecom market was a result of the combination of market effects, both external (incumbent's keystone effect and indirect network effects) and internal (entrant's keystone effect), that make it nearly impossible for an entrant in WiMAX's predicament (i.e., relatively weak keystone effect) to enter the market successfully in the long run.

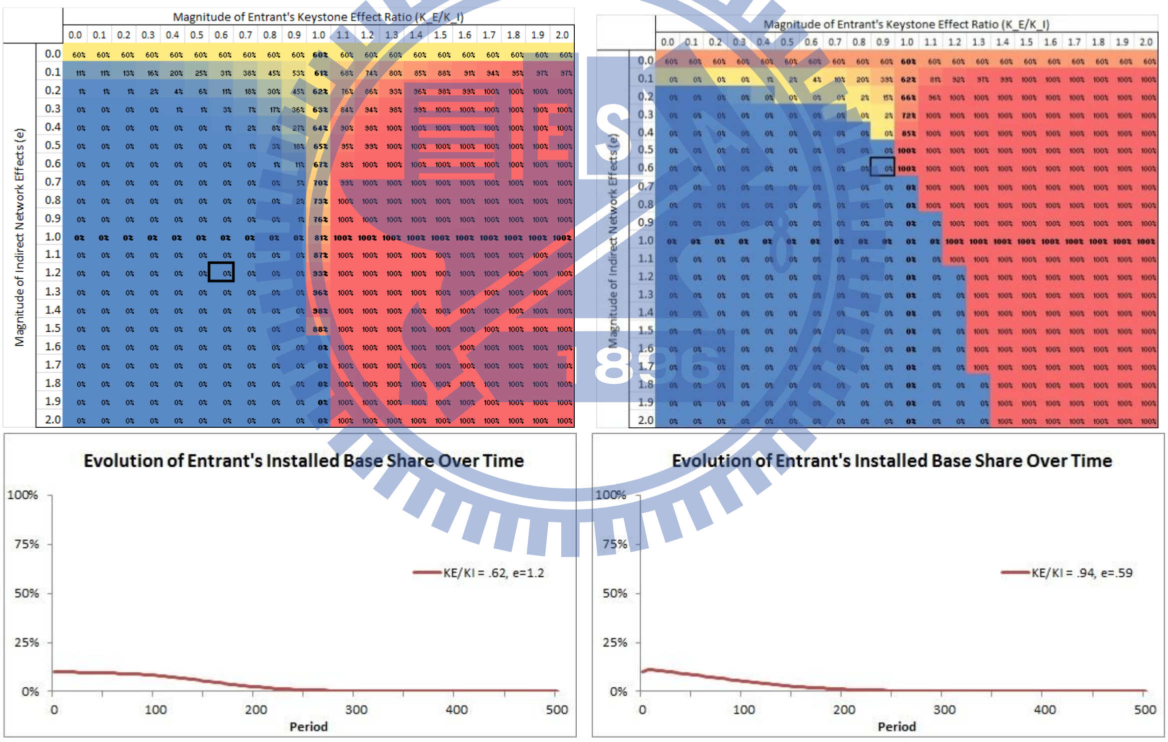

Figure 11. Plot of WiMAX's Market Entry Positions (above) and Installed Base Shares over Time (below) in the United States (left) and World (right) markets

15 It could feasibly be argued that the keystone effect variable can also be interpreted to mean that the average customer in the world market, where 3G penetration rates are still increasing, bought more hardware than the average customer of the U.S. market, where 3G penetrations rates were already higher and the global financial crisis disproportionately affected consumer confidence, negatively impacting discretionary spending on goods such as tablets and smartphones. This potential alternative interpretation of the keystone effect variable as an indicator of average consumption volume per consumer limits the keystone effect's explanatory worth to comparative measures between incumbent and entrant, provided that the market data includes the same scope of products for each technology standard.

6. DISCUSSION AND CONCLUSION

This study contributes to the literature on two-sided markets, market entry, indirect network effects, and keystone effects by presenting a dynamic model, adapted from Zhu & Iansiti (2011), which combines quality, indirect network effects, and relative keystone effect strength in a dynamic model that allows appropriate levels of influence to be exerted by the manufacturers on the supply side. This is crucial for accurately modeling a technology standard entry scenario, yet it is something that has been lacking in previous, primarily customer-focused, market entry studies (Church & Gandal, 1992; Farrell & Klemperer, 2007; Gandal, Kende, & Rob, 2000; Park, 2004; Zhu & Iansiti, 2011). One conclusion we can draw from the results of this investigation is that WiMAX had lost before it even entered the market just by choosing to enter a market whose effects were stacked against it. Since two-sided markets are increasingly prevalent and economically important, they have become a popular topic in the literature (Basu, Mazumdar, & Raj, 2003; M. T. Clements & Ohashi, 2005; Corts & Lederman, 2009; Cottrell & Koput, 1998; Dranove & Gandal, 2003; Gandal, Greenstein, & Salant, 1999; Gandal et al., 2000; Gupta, Jain, & Sawhney, 1999; Nair et al., 2004; Ohashi, 2003; Park, 2004; Rysman, 2004; Shankar & Bayus, 2003; Shurmer, 1993; Stremersch et al., 2007; Venkatraman & Lee, 2004). This study extends the existing literature scope and both empirically and theoretically underscores the importance of evaluating not only the internal factors (i.e., a platform's own keystone strength) but also the external factors (i.e., network effects and the opponents' keystone effect when firms make investment decisions, such as platform entry or adoption.

6.1 Managerial Implications

The substantial impact of the keystone effects suggests that ecosystem dynamics may explain another means of successfully entering a market late and succeeding against its incumbent. Besides offering either revolutionary product or service functionality, and in addition to platform envelopment (Eisenmann, Parker, & Van Alstyne, 2011), this study's model demonstrates that superior keystone strength can allow for successful entry despite installed base disadvantage. However it also shows that keystone inferiority can be costly for entrant platform participants. A prime example of successful entry due to keystone strength, we argue, is Microsoft's Xbox console successfully entering the video game market (Zhu & Iansiti, 2011). We disagree with Zhu & Iansiti (2011) that the Xbox's success was the sole result of indirect network effects being strong enough to support their user base growth without being too strong to stifle it. While it is true that indirect network effects played an important role in that market entry, we feel the greater impact came from Microsoft's keystone strength and experience. Microsoft was able to leverage its experience dealing with third party developers and orchestrating a vast network of business connections (Iansiti & Levien, 2004a) and apply these intangible assets in a new market that actually quite resembled their old market—one in which they had experience functioning as a powerful keystone. Thus, while keystone effect disadvantage can make market entry impossible despite positive prospects, as in WiMAX's case, keystone effect advantage can alternatively make successful market entry a realistic expectation.

However, the impact that keystone species have on their respective ecosystems still depends on each ecosystem's composition. Markets that are highly susceptible to keystone effect influence likely have a high degree of interconnectivity or central hubs that link different sides or sections of the markets with others through a path of least distance. Two-sided markets are therefore a prime example of a keystone-dominated market type. The keystone species, like MNOs in mobile telecommunications, link the two sides of the market by keeping the loyal user base and managing business relationships with equipment suppliers and content providers. The interconnectedness of this triangular relationship increases the impact that the hub (i.e., the keystone species) has on a greater number of parties within the ecosystem than would be impacted in a traditional, two-party business relationship. The result is that the keystone species produces an impact within the ecosystem that is comparatively large relative to it physical size. Furthermore, since two sided networks have been shown to exhibit network effects, both direct and indirect, then studying this interaction between keystone effects and network effects on both sides of the two-sided market is necessary for accurately modeling the market dynamics and advising investment decisions within the market. This study offers a starting point for achieve these ends and it presents a novel way of quantify the keystone effect that is observable from empirical and widely available market data.

6.2 Limitations and Future Research

Despite its strengths, this study also has its limitations. The limited data is of course a limitation that may affect the models ability to adequately capture market effects through regression analysis. The model itself is a potential limitation as well. Since it is based on a CES model that was originally developed for software, it might actually overstate the value that customers place on hardware variety. Furthermore the model assumes both monotonically increasing growth in applications (i.e., hardware production in this study), which limits its potential applicability since market data is very likely to show fluctuating growth. And the assumption of constant growth is not entirely realistic, especially for products or in markets with short technology lifecycle; in these cases it can be hard to find sufficient market data for use in the regression analysis that entirely occurred in the product's growth stage. A possible alternative to this CES model would be the discrete choice model (e.g., M. T. Clements & Ohashi, 2005; Doganoglu & Grzybowski, 2007; Gretz, 2010). Future research in the areas of keystone effects, indirect network effects and two-sided market entry could try employing such a discrete choice model.

Our model also incorporated certain assumptions that could potentially, if violated, invalidate the results, or distort the relative strengths of the market effects. For example, we assume prices between the entrant and incumbent were equal, but we did not have exogenous price data to test this assumption. Future studies should try to find such pricing data for inclusion in their analysis, and this data could also be applied in the discrete choice model to solve for the price elasticities within the market and their interaction with the newly introduced keystone effects.

Finally, the existing literature on business ecosystems would certainly benefit from future research that attempts to quantify the keystone effect in different markets—both other two-sided markets and conventional one-sided markets—and using different theoretical models. Recent utilization of visual analytics software tools have focused attention on the mapping of business ecosystems (Basole, 2009; Basole et al., 2012a, 2012b; Basole & Karla, 2011), analogous to the mapping of biological interaction networks (e.g., Vasas & Jordán, 2006) and food webs (Berg et al., 2011; Dunne, Williams, & Martinez, 2004; Jordán, 2009), for the purposes of identifying important ecosystem players according to density, connectedness and centrality. However, the effect that these hubs (i.e. keystones) have on their fellow ecosystems members and on the ecosystem as a whole still needs to be quantified for use as a decision making tool. Since studies of business ecosystems cannot, for obvious reasons, measure keystone effects the same way that biological researchers do, through the experimental remove of the keystone species, then scholars of business ecosystems will have to continue to look for novel or innovative ways to quantify the keystone effect in practice as it is happening. Only then can business ecosystem researchers hope to move beyond merely classifying and describing keystone species to offering predictive tools or heuristics for operating in business ecosystems.

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APPENDIX A. MODEL SIMULATION SENSITIVITY

	Magnitude of Entrant's Keystone Effect Ratio (K_E/K_I)																				
Magnitude of Indirect Network Effects (e)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.0	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%	**60%**	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
0.1	3%	3%	4%	6%	9%	13%	19%	27%	37%	49%	**61%**	72%	81%	88%	92%	95%	97%	98%	99%	99%	100%
0.2	0%	0%	0%	0%	0%	1%	3%	7%	16%	36%	**63%**	84%	94%	98%	99%	100%	100%	100%	100%	100%	100%
0.3	0%	0%	0%	0%	0%	0%	0%	1%	5%	21%	**65%**	93%	99%	100%	100%	100%	100%	100%	100%	100%	100%
0.4	0%	0%	0%	0%	0%	0%	0%	0%	1%	10%	**67%**	98%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	**71%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.6	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	**77%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**85%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**95%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
0.9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**100%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.0	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
1.1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1.8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%
1.9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%
2.0	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%

Figure A.1. Base Simulation Scenario

The base scenario for the 1000-period simulation uses the following assumptions: The installed base of subscribers for the incumbent platform at the beginning of the simulation, $B_{I,t=0}$, is 90%. The quality advantage of the entrant platform over the incumbent, *Q*, is 1.5. The keystone effect strength of the incumbent platform, K_I, is 1.1. The indirect network effect strength, *e*, and the strength of the entrant's keystone effect ratio, KR_E, are the two variables that are shown as a range of values from 0.0 to 2.0, in increments of 0.1, in order to produce the entrant's market landscape table. Each cell within the table represents the share of the total subscriber base that the entrant will control after 1000 periods, approximating the equilibrium state, for the associated values of the indirect network effects and keystone effect ratio. Red cells indicate the entrant controls 100% of the market at equilibrium; blue cells represent 0% market share for the entrant; shades of yellow and orange represent entrant market shares between 0% and 100%. Each of the following sensitivity simulations will test one variable, while holding the remaining assumption variables constant, in order to ascertain the effect of each variable on the equilibrium market share landscape of the entrant platform.

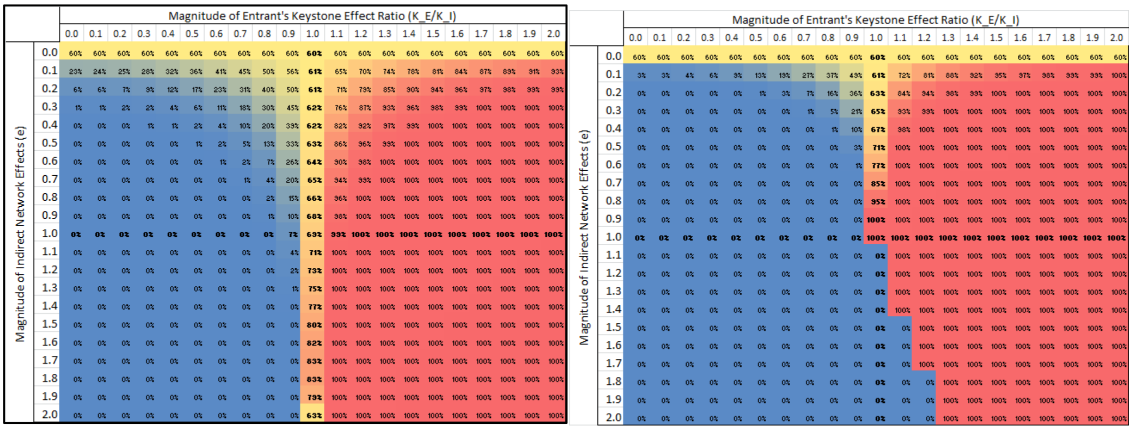

Figure A. 2. Sensitivity Variable K_I=0.5 (left) vs. Base Case (right)

A weaker incumbent's keystone effect strength, K_I=0.5, essentially negates the indirect network effects, increasing the area of the region in which the new platform can successfully enter the market at higher indirect network effect strengths. For nearly all values of the indirect network effect, *e*, the entrant will dominate the market, earning 100% share at equilibrium, as long as the entrant has a keystone effect advantage over the incumbent, KR_E>1.0 (i.e., K_E>K_I). The total monopolistic dominance that the keystone effect advantage affords the entrant is only limited slightly (i.e., reduced to oligopolistic market share) in regions where both the indirect network effect strengths and the entrant's keystone effect advantage are minimal.

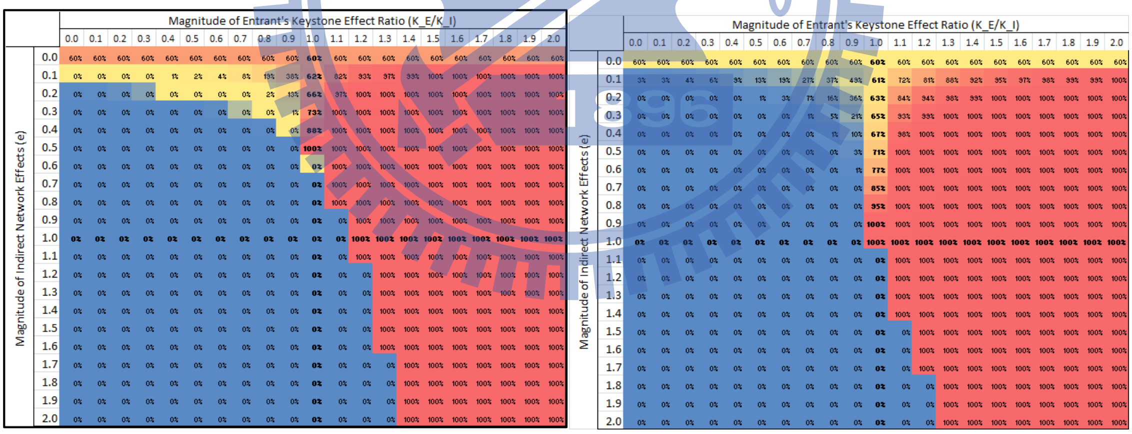

Figure A. 3. Sensitivity Variable K_I=2.0 (left) vs. Base Case (right)

Conversely, a stronger incumbent's keystone effect strengths, K_I=2.0, compounds the indirect network effects' exclusionary influence on the entrant platform. At sufficiently high values of indirect network effects, *e*>0.6, the interaction of the two effects prevents the entrant platform from successfully entering the market when it has only a moderate keystone effect advantage over the incumbent (i.e., 1.1<KR_E<1.4).

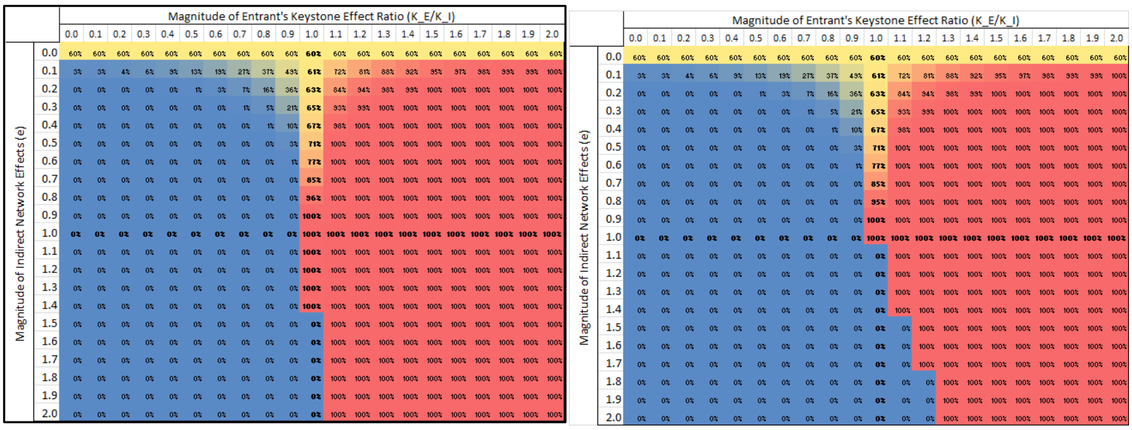

Figure A. 4. Sensitivity Variable: $B_{I,t=0}$ = 67% (left) vs. Base Case (right)

A decrease in the installed base advantage enjoyed by the incumbent at the start of the simulation, $B_{I,t=0}$=67%, negates the indirect network effects' influence on an entrant with a weak keystone effect ratio. Thus an entrant with a slight keystone effect advantage (i.e., 1.1<KR_E<1.3) is now able to secure a monopoly share of the market in the long term, even with indirect network effect strengths greater than 1.0.

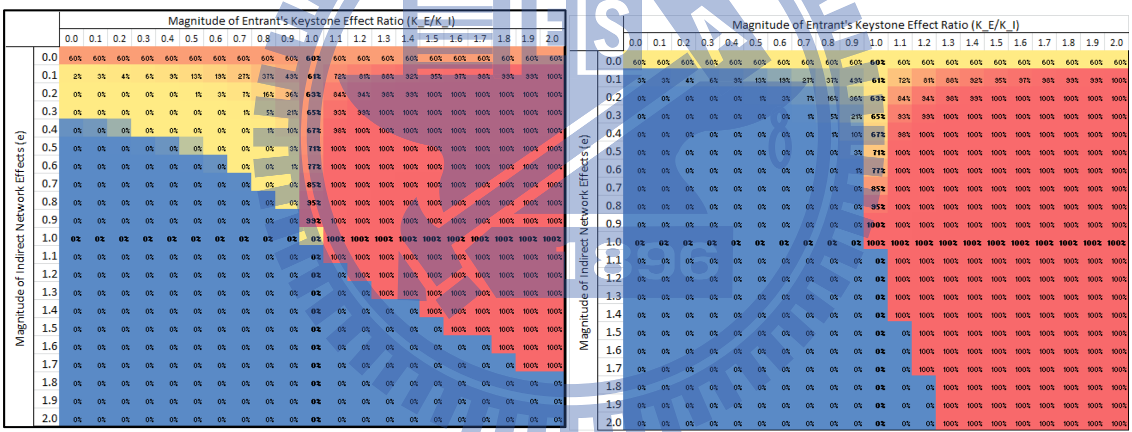

Figure A. 5. Sensitivity Variables: $B_{I,t=0}$=99% (left) vs. Base Case (right)

On the other hand, an increase in the incumbent platform's initial installed based advantage, $B_{I,t=0}$=99%, significantly decreases the entrant's chances of success at higher values of indirect network effects (i.e, e>1.0). If the indirect network effects are strong enough (i.e., e>1.7) they completely negate the keystone effect advantage of the entrant (i.e., 1.0<KR_E≤2.0) by preventing the new platform from being able to overcome its sizeable installed base disadvantage, despite strong keystone species. This shows that projections of the entrant's future outcome in the market made at different times—as if taken as a snapshot when the entrant has different initial installed base market shares, first when it has only 1% of the total user base and then later when it has 10% of the total users—will predict two different likelihoods of success for the new platform. This corroborates the intuitive notion that as the entrant's installed base grows, its chances of survival increase because the forward-looking exclusionary influence of the market's network effects has diminished.

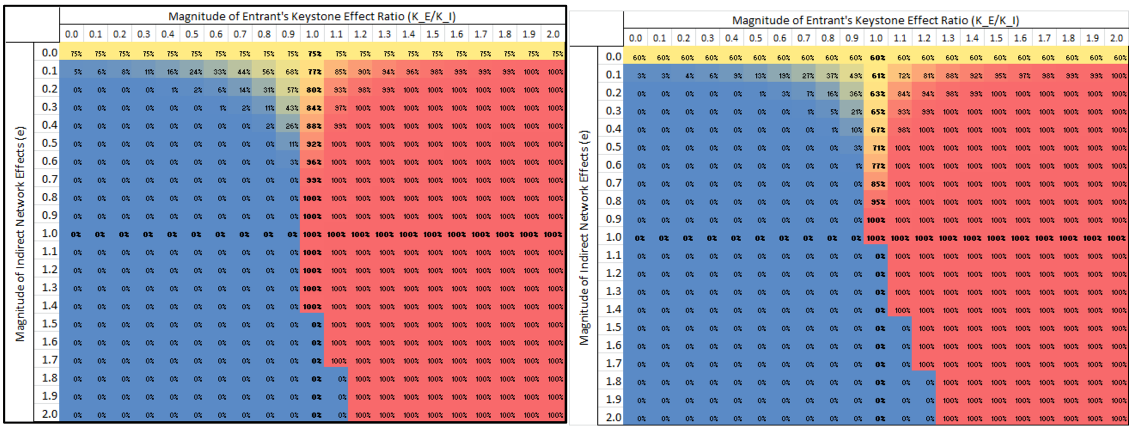

Figure A. 6. Sensitivity Variable: Q=3.0 vs. Base Case (right)

An exogenous increase in the quality advantage of the entrant platform, *Q*=3.0, increases the entrant's chances of successful market entry slightly at higher values of indirect network effects (i.e., *e*>1.0).

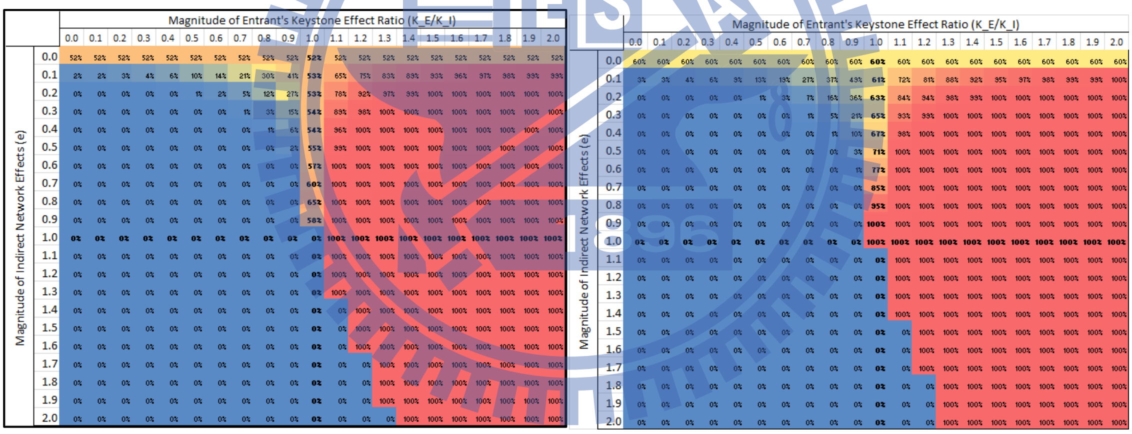

Figure A. 7. Sensitivity Variable: Q=1.1 vs. Base Case (right)

Conversely, a decrease in the entrant's quality advantage hurts the new platform's chances of successfully entering the market. However, the impact of changes in quality appears to be relatively minor compared with the effects of changes in the incumbent's initial installed base and the incumbent's keystone effect strength.