Innovation, Resource Constraints, and Mergers in Network Industries

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I. Introduction

We analyze how resource constraints and market structure interact in network industries to impact innovation. This issue has arisen recently in the United States where AT&T proposed to acquire T-Mobile's U.S. assets at least in part to obtain T-Mobile's radio spectrum, which AT&T says it needs to effectively deploy fourth generation (4G) wireless communications services in the country. However, our analysis has implications for other market concentration issues in network industries. For example, there is concern in the United States and Europe about Google's growing market share in many information communications and telecommunications (ICT) markets. Facebook is also coming under increased scrutiny for its size and reach. Both companies are known for their innovations and adoption of new technologies, so whether there is a causal relationship between market share, or more specifically the number of customers an operator serves, and the propensity to adopt advanced technologies is relevant to assessing the impacts of market dominance on consumers.

We find that adoption of more advanced technologies is more likely with larger firms in part because of scale economies, their incentives to respond to network effects, and their opportunities to capture economic surplus. We also find that when a merger prompts the merged firm to adopt a more advanced technology and stimulates innovation by rivals and in other markets, including markets for consumer devices, such as mobile handsets, and consumer software applications (apps).

We demonstrate these results by examining a network industry á la Katz and Shapiro (1985) in which operators choose their technologies and network sizes after customers have formed expectations. We define equilibrium as the situation in which customers' expectations are met and each operator has no incentive to change its decisions given the choices of customers

and other operators. Operators incur larger fixed costs if they adopt the more advanced technology than if they choose the other technology. We identify threshold levels of fixed costs for the advanced technology. If fixed costs for the advanced technology are less than (alternatively, greater than) than the threshold, then a profit maximizing operator would (alternatively, would not) optimally adopt the advanced technology. We find that a merger between two operators decreases the threshold level of fixed costs for the merged firm and for its rivals, which implies that the merger increases the likelihood of adoption of the advanced technology.

We also examine how a merger impacts innovation in markets for devices and apps. We consider a situation where network providers choose investment in diversity and functionality in devices, and app developers choose whether to supply apps. Our assumption that network operators invest in device diversity and functionality is analogous to the situation in the United States where cellular phones are locked, meaning that customers are prohibited from using a particular phone for a network other than the one for which the phone was purchased.[1] In some countries operators are prohibited from locking phones. We find that the merger increases investment in devices for the advanced technology because fixed development costs can be recovered from a larger number of subscribers, but this incentive can be reversed when network effects are higher. We find that the merger increases the availability of and investment in apps.

The remainder of this paper is organized as follows. Section II describes the wireless communications industry, with emphasis on the U.S. situation. Section III describes our analytical model. Section IV analyzes incentives to adopt the advanced technology, Section V

[1] More specifically, customers are prohibited from changing SIM (subscriber identify mobile) cards without violating an agreement with the network provider. Changing the SIM card allows the customer to use the device for a network other than the one for which he or she purchased the device. Unlocking the phone (changing the SIM card) might violate the network subscription agreement or might void the device warranty.

considers the resource constraint issue, and Section VI analyzes impacts on devices and apps. Section VII is the conclusion.

II. Wireless Communications

The industry issue that prompts our research is a proposed merger in cellular telecommunications in the United States. Although cellular telephony was technically feasible in the late 1960s and early 1970s, the service was not made commercially available the United States until the 1980s. This delay occurred in part because potential service providers needed permission from the Federal Communications Commission (FCC) to use a portion of the radio spectrum for the service, and the FCC moved slowly in issuing cellular licenses. Different types of radio communications use specific parts of the radio spectrum, denoted by frequency, and the FCC requires operators to have licenses to use the spectrum. (Crandall and Jackson, 2001)

Cellular telephony works by allowing customers' phones to communicate via signals carried in the electromagnetic radio spectrum. What differentiates cellular telephony from other forms of radio communications is that cellular technologies allow customers to move about more freely while continuing a communications session. (Padgett, Gunther, and Hattori, 1995) This is accomplished by dividing geographic areas into cells, each of which is served by a radio antenna, and using the cellular technology to hand off a customer from one cell to another as the customer moves, all without disrupting the customer's session as long as each cell involved in the session has sufficient capacity to serve all of the customers trying to engage in sessions simultaneously in that cell.

Technologies for cellular telephony have changed over time. The first generation (1G) technologies, launched in Japan in the late 1970s, used analog signals. Second generation (2G) technologies became commercially available in the 1990s. There were several 2G technologies,

but many governments around the world directed their telecommunications providers to use a technology called GSM. The United States was one of the few countries to allow operators to choose their technologies and so a number of technologies were deployed in the country, including GSM, CDMA, and TDMA. 2G technologies used digital signals and so could provide better service than 1G technologies, but 2G services were limited to traditional voice communications and small amounts of data. (Padgett, Gunther, and Hattori, 1995; Hommen and Manninen, 2003)

Broadband cellular service evolved out of the 2G technologies. Even though there were several incremental steps, taken in the form of 2.5G and 2.75G technologies, the first widely used cellular broadband was 3G, which stands for third generation. A primary difference between 2G and 3G was that 3G allowed for greater data transmission and for certain types of video transmission. 3G provides superior data services than 2G, but lacks sufficient functionality and bandwidth for many advanced services. (Roche, 2003; Suk and Yeung, 2003; Frattasi et al., 2006; FCC, 2011)

4G technologies are intended to address this shortcoming of 3G (Govil, 2008). There are competing 4G technologies, including HSPA+ used by AT&T and T-Mobile, WiMAX used by Clearwire / Sprint Nextel, and LTE being deployed by AT&T, Verizon, and MetroPCS (FCC, 2011). HSPA+ is a higher bandwidth form of HSPA (High Speed Packet Access), which is used in some 3G networks. An advantage of HSPA+ is that it can evolve from some 3G networks. LTE (Long Term Evolution) and WiMAX are often viewed as being more advanced and offering higher transfer speeds than HSPA+, but they cannot evolve from existing 3G networks and so require additional radio spectrum.[2] (McCormick, 2010; FCC, 2011)

[2] There are disagreements on the performance differences between HSPA+, LTE, and WiMax. For examples of tests, see phone.Arena.com (2011) and Segan (2010).

An issue for operators trying to deploy 4G is the availability of bandwidth in the radio spectrum. To deliver the services promised, LTE requires additional unencumbered radio spectrum. Radio spectrum is unencumbered in this context if it is not currently being used for other services or other technologies. This presents challenges for service providers because, in many instances, governments are slow in providing additional radio spectrum for 4G services. There are various reasons for the delays, but there is general consensus that additional radio spectrum for cellular service would speed deployment of 4G. Operators may be able to overcome this spectrum limitation in part through improved engineering of their systems and migration of customers off of older technologies, but this approach raises costs and does not eliminate the physical limitation of radio spectrum capacity. (FCC, 2011; McCormick, 2010)

According to the companies involved, this spectrum limit was a motivating factor behind AT&T's and T-Mobile's recent announcement that AT&T would acquire T-Mobile's operations in the United States. Although both operators advertise 4G HSPA+ services, T-Mobile has no plans to upgrade to LTE (FCC, 2011). AT&T plans to upgrade to LTE, but holds that spectrum limitations make the LTE rollout more costly and more limited than would otherwise be the case. According to the two companies, if AT&T had T-Mobile's radio spectrum, AT&T's rollout of 4G LTE would be faster, more widely spread and more economical. (AT&T et al., 2011)

However, a merger of two operators serving essentially the same markets raises antitrust issues, especially when markets appear concentrated. For example, AT&T and Verizon together account for over 60 percent of the cellular customers served nationwide. (FCC, 2011) A typical horizontal merger analysis would probably indicate that a merger involving at least one of these two carriers would decrease competition and reduce net consumer surplus. What is different for the AT&T acquisition of T-Mobile's operations is the potential impact on technology evolution.

If the acquisition makes faster deployment of 4G LTE technologies more economical, both operators and customers could benefit from the merger despite the increased industry concentration. Furthermore, a more rapidly expanding 4G platform could stimulate the development of advanced consumer devices and apps that customers use for advanced information services. These are the issues we address in this paper.

III. The Model

We consider a situation where up to $N = 3$ profit maximizing firms compete à la Cournot in the market for the network service. Let n represent the number of firms actually competing in the market. Each firm i, $i = 1, 2, 3$, chooses its technology $t = \{x, y\}$ at the start of the game and can choose only one technology. Technology x could be 3G or HSPA+ services and y could be the provision of 4G LTE services, which requires additional radio spectrum or additional costs and service upgrades if additional radio spectrum is unavailable. The requirement of a firm choosing only one technology biases our results against the advanced technology because upgrading necessitates the adopting firm giving up the profits it could receive from the less advanced technology. With the proposed acquisition, AT&T could technically continue to provide services using HSPA+ while offering LTE-based services.

Each firm providing x incurs a fixed cost $f_i \geq 0$ and constant marginal production costs $c_i \geq 0$, both of which we normalize to zero to simplify our model. This symmetry of costs leads to symmetric market shares in the situation where all firms produce x. This could bias our analysis against the proposed T-Mobile acquisition because T-Mobile serves only a small portion of U.S. customers (FCC, 2011), which causes the actual proposed merger to lead to smaller change in market concentration than we analyze with our model. If a firm chooses to provide y,

then the firm incurs a fixed cost $F_i > f_i$ and constant marginal production costs $C_i > c_i$. We analyze threshold levels for fixed costs, above which it is unprofitable for an operator to adopt the advanced technology. A higher (conversely, lower) threshold decreases (conversely, increases) the chances of adoption of the advanced technology.

Let ${p_i}^t$ represent the price that firm i charges for its service. Following Katz and Shapiro (1985), we assume that consumers are continuously and uniformly distributed with density one, where $r = [-\infty, A]$ is the location of customer r and $A > 0$. Each customer buys at most a single unit of output and seeks to maximize individual net consumer surplus. The network service is characterized by direct network effects, meaning that the utility an individual customer receives from consuming the network service is increasing in the number of customers connected. Customers are homogeneous in their valuations of the network effect $v = [0, {}^1/_2)$, which is the value an individual customer receives from another customer purchasing the network service. We assume v is unaffected by the firms' technology choices. This biases our results against the advanced technology because 4G technologies improve customers' experiences in sharing video files, gaming, and other services that have network effects.

Customers are heterogeneous in their willingness to pay. A customer of type r has a willingness to pay $r + \alpha^t + \sum_{j=1}^{n} vt_j$ for firm i's service, where $\alpha^t = 0$ if $t = x$ and $\alpha^t = \alpha > C_i \; \forall \; i$ if $t = y$. At equilibrium, the marginal customer $\hat{r}$ is indifferent between purchasing or not purchasing the network service and is indifferent between providers, which implies $\hat{r} + \alpha^t + \sum_{j=1}^{n} vt_j - {p_i}^t = 0$ and ${p_i}^x = {p_i}^y - \alpha$ for all firms. This condition that net consumer surplus is zero for the marginal customer in equilibrium allows us to express equilibrium prices as ${p_i}^{t^*} = \hat{r} + \alpha^t + \sum_{j=1}^{n} vt_j$. The number of customers purchasing the network service is $A - \hat{r}$, so we can express the equilibrium prices as ${p_i}^{t^*} = A + \alpha^t - (1 - v) \sum_{j=1}^{n} t_j$.

We can now specify firm i's objective function as

$$\max_{t_i, T_i} \pi_i \equiv T_i\left(A - \sum_{j=1}^{n}(1-v)t_j\right)x_i + (1-T_i)\left[\left(A + \alpha - \sum_{j=1}^{n}(1-v)t_j - C_i\right)y_i - F_i\right] \quad (1)$$

subject to

$$0 \leq x_i \leq \bar{x}_i$$
$$0 \leq y_i \leq \bar{y}_i$$

where $T_i = 1$ if the firm chooses technology *x* and is 0 otherwise.

We assume an exogenous merger of two of the firms, 1 and 3, and denote the merged firm as *m*. To go into effect, the merger must be approved by a regulator, whose objective is to maximize weighted social welfare, where $\lambda = (\frac{1}{2}, 1]$ is the weight placed on net consumer surplus and $1 - \lambda$ is the weight placed on producer profits. We can now specify weighted social welfare as

$$W \equiv \sum_{i=1}^{n}\left(\lambda \int_{\hat{r}}^{A}\left(r + \alpha^t + \sum_{j=1}^{n} vt_j - p_i{}^t\right)dr + (1-\lambda)\pi_i\right) \quad (2)$$

The sequencing of decisions is as follows. First, the regulator decides whether to approve the merger and then firms' choose their technologies. Then customers form expectations about each firm's output. Next firms choose outputs and prices result. Finally, customers choose their network providers and services and payments are provided as promised.

IV. Incentives to Adopt Advanced Technology

In this section we analyze how an exogenous merger impacts incentives to adopt the advanced technology. Proposition 1 provides the primary result.

Proposition 1. An exogenous merger between two firms increases the likelihood of one of the post-merger firms adopting the advanced technology relative to the likelihood before the merger.

The merger increases the incentives to adopt the advanced technology in two ways: (1) The merger increases the number of customers from which the adopting firm can recover the fixed costs of the advanced technology; and (2) The merger decreases competitive pressures, which allows firms to capture a greater portion of the economic value created by new technologies. We demonstrate this result by comparing operators' incentives to adopt the advanced technology in the pre-merger situation to the post merger situation. Figure 1 illustrates the pre-merger incentive. The vertical axis is firm 1's output and the horizontal axis is the sum of the other two firms' outputs. We sum the outputs of firms 2 and 3 for the horizontal axis so that the firms' choices can be shown on a two-dimensional graph. Outputs are expressed as numbers of customers served.

Figure 1 shows the firms' reaction functions.[3] We show firm 1's reaction function if it chooses to produce *x* and its reaction function if it chooses to produce *y*. Choosing to produce *y* shifts firm 1's reaction function upward relative to its reaction function producing *x*. Thus for any particular output levels that firms 2 and 3 might choose, if firm 1 has adopted the more advanced technology, its output choice is higher by a factor of $\frac{\alpha - C_1}{2-v}$ relative to the amount it would have produced with the other technology. This shift represents the greater value that customers place on the advanced technology, less the production costs and adjusted for impacts of the demand elasticity and network effects. Firm 1's choice of technology does not impact the other firms' reaction functions with respect to their output of *x*, assuming they choose to produce *x*.

[INSERT FIGURE 1 ABOUT HERE]

[3] A firm's reaction function is its optimal output choice, taking the other firms' output choices as given.

The intersections of the reaction functions show the firms' equilibrium choices. If all firms choose to produce *x*, the equilibrium output for firm 1 is $\overline{AO}$ and for firms 2 and 3 together is $\overline{CO}$. Given the symmetry in costs, $2 \cdot \overline{AO} = \overline{CO}$. As is standard for Cournot competition in these types of models, a firm's equilibrium price is equal to its equilibrium output plus its marginal production cost, so firm 1's price is $\overline{AO}$, and the profit for firm 1 is simply its output squared, or $\overline{AO}^2$, which is represented by the area of the square *ADEO*.

Now consider firm 1's incentive to adopt the more advanced technology in the three-firm market. We consider the intersection of "Firm 1's reaction function providing *y*" and "Firm 2's + Firm 3's reaction function providing *x*." The new equilibrium output for firm 1 increases to $\overline{FO}$ and the combined outputs of firms 2 and 3 decreases to $\overline{HO}$, as do their prices. Firm 1's price increases to $\overline{FO} + C_1$ and its profits are now its output squared minus its fixed costs, or $\overline{FO}^2 - F_1$. Firm 1's revenue for producing *y* in the pre-merger setting can be represented by the square *FIJO*, which illustrates that firm 1 could profitably adopt *y* as long as the fixed cost is no greater than a threshold amount measured as the difference between square *FIJO* and square *ADEO*, i.e., firm 1 will adopt the more advanced technology in the pre-merger setting if $FIJO - ADEO \geq F_1$.

We are interested in how this incentive to adopt the advanced technology is impacted by decreasing the number of firms from 3 to 2, so we now turn our attention to technology adoption in the post merger setting illustrated in Figure 2. The vertical axis is the merged firm's output (firm *m*) and the horizontal axis is firm 3's output. The figure shows the firms' reaction functions.

[INSERT FIGURE 2 ABOUT HERE]

If all firms choose to produce *x*, the equilibrium output for firm *m* is $\overline{KO}$ and for firm 3 together is $\overline{MO}$, which are equal because of our assumption of symmetric marginal production costs. Each firm's equilibrium price is equal to its equilibrium output (because marginal production costs are zero) and each firm's individual profit can be represented by the area of the square *KLMO*.

Now consider the merged firm's incentive to adopt the more advanced technology. Figure 2 shows the new reaction function, which we label as "Firm *m*'s reaction function providing *y*." The new equilibrium output for firm *m*, $\overline{NO}$, is higher than before and and the output of firms 3, $\overline{QO}$, is lower than before. Firm *m*'s price is higher ($\overline{NO} + C_m$) and its profits are now its output squared minus its fixed costs, or $\overline{NO}^2 - F_m$. Firm *m*'s revenue less production costs for producing *y* in the post-merger scenario can be represented by the square *NRSO*, which illustrates that firm *m* could profitably adopt *y* as long as the fixed cost is no greater than the than a threshold amount measured as the difference between square *NRSO* and square *KLMO*, i.e., firm *m* will adopt the more advanced technology in the post-merger setting if $NRSO - KLMO \geq F_m$.

We demonstrate Proposition 1 by comparing the thresholds for fixed costs under the pre-merger and post-merger settings. If the threshold in the pre-merger setting ($FIJO - ADEO$) is greater than the threshold in the post-merger setting ($NRSO - KLMO$), we can confirm Proposition 1 that the merger encourages the adoption of the advanced technology. Visual inspection of Figures 1 and 2 appears to support Proposition 1, but looks can be deceiving. The comparison also does not solve analytically, so we demonstrate Proposition 1 with a simulation shown in Figure 3.

In Figure 3 the vertical axis shows fixed cost thresholds, the horizontal axis shows values for the network effect (v), the upper line in the graph is the threshold for the post-merger setting, and the lower line is the threshold for the pre-merger setting. The post-merger line is above the premerger line for all values of v, indicating that the merger increases the profitability of adopting the advanced technology, which we interpret as increasing the likelihood of adoption, increasing the speed of adoption, or both. This relationship holds for all values of A, α, and C_m permitted in our model assumptions, so we conclude that Proposal 1 is true.

[INSERT FIGURE 3 ABOUT HERE]

We are also interested in how the merger impacts other firms' incentives to choose the more advanced technology. Proposition 1 applies to all firms. But we would also like to know how the merger impacts incentives for a second firm to also adopt the advanced technology, given that another firm is upgrading. This leads to Corollary 1.

Corollary 1. Adoption of the more advanced technology by one firm increases the incentives for another firm to also adopt the more advanced technology.

We demonstrate this result with simulations using the analytical results shown in the Appendix. Figure 4 shows the simulation results. The vertical axis represents the fixed cost thresholds and the horizontal axis shows various values for network effects. The maximum economically feasible fixed costs for the advanced technology is consistently higher for the post-merger market than the pre-merger market, indicating that the merger improves incentives for advanced technology adoption for both merging and non-merging firms.

[INSERT FIGURE 4 ABOUT HERE]

The merger increases the economic incentives for adoption of the advanced technology for two reasons. First, the merger increases the number of customers from which a firm can

recover the fixed costs of the technology. The second reason is that, with less intense competition, the upgrading firm can capture more of the surplus created by the higher valued service.

V. Resource Constraint

We now turn our attention to the resource constraint, which is radio spectrum in the case that prompted our research. The merging companies state that AT&T cannot migrate to LTE without unencumbered radio spectrum and that the company's existing spectrum resource is encumbered by other uses. Some critics of the merger argue that the migration could be accomplished without additional radio spectrum if AT&T used better engineering.

Our interest in this section is to consider whether the claimed resource constraint is real and, if it is, whether a merger is the most effective means of addressing it. We assume that it is at least technically feasible for AT&T to use existing spectrum to implement LTE and then analyze through revealed preferences whether it is more costly or less costly to migrate to LTE using unencumbered radio spectrum instead of encumbered spectrum. Proposition 2 states our primary conclusion for this section.

Proposition 2. If a merger results in the merged firm having greater opportunity to overcome a resource constraint than do either of the pre-merger separate firms, then industry rivals are more likely to oppose the merger.

We demonstrate Proposition 2 using revealed preferences of the industry participants and the results of our analytical model. Statements and choices of the industry participants indicate that it is less costly to use unencumbered spectrum than encumbered spectrum to implement LTE. If the reverse were true, then the motive for the merger would be primarily to eliminate a rival. If that were the case, then we would expect the merging companies' rivals to support or at

least not oppose the merger because they would benefit from the decreased competition. However, in the immediate case we find that many of the parties opposing the merger are rivals to AT&T and T-Mobile (AT&T et al., 2011), indicating that these opponents of the merger do not see themselves as benefiting from decreased competition.

Inspection of the analytical results shown in the appendix further supports Proposition 2. In the pre-merger market, the profits of an adopting firm are lower if another firm also adopts. More specifically the profits of adopting firm i are $\frac{1}{4-3v}(1-v)(\alpha - C_j)\left(2(A + (3-2v)(\alpha - C_i)) + (1-v)(\alpha - C_j)\right)$ lower if a second firm j adopts the advanced technology, and lower by the corresponding amount again if a third firm k adopts the technology. Profits of non-adopting firms are similarly decreased when other firms adopt. This confirms our second proposition. Corollary 2 extends these results.

Corollary 2. If one of the reasons for a merger is to provide greater opportunity for the merging firms to overcome a resource constraint to adopting a more advanced technology, and if rivals' profits would decrease as a result of the merged firm adopting the more advanced technology, then the merger is the least cost method of overcoming the resource constraint.

Corollary 2 follows directly from our proof of Proposition 2. If merged firm can technically adopt the more advanced technology even without a merger, but the merger makes the adoption more economical, then the merger either lowers the fixed cost threshold as we demonstrate in Section IV, lowers marginal production costs for providing service using the advanced technology, or both. Lowering the fixed cost threshold increases the likelihood of adoption, which would lower rivals' profits. Comparative statics of the analytical results shown in the appendix demonstrate that lowering marginal production for the merged firm would lower

rivals' profits. Lowering fixed costs, marginal production costs, or both results in lower costs for the advanced technology. This confirms Corollary 2.

VI. Devices and Apps

Adoption of the advanced technology creates markets for devices and software applications. In the United States devices for mobile networks are sometimes exclusive to a network operator, at least for some period of time, as was the situation with the iPhone and AT&T. In other instances manufacturers create devices that may work on multiple networks, but that include network-specific features that customize the device to a network. Likewise, app developers create products that are specific to a device at least for some period of time, such as was the case with iStudiez for iPhone, or that can be used on multiple devices, but with some customization to ensure compatibility, such as Urban Spoon. Apps are not the only software that adds value to devices that take advantage of the advanced technology: 4G networks are better able to access Internet content than 3G networks.

We are interested in how a merger might impact innovation in devices and apps. To consider this we extend our model in the following ways. We assume that customers form expectations about devices and apps when they form their expectations about networks, device makers choose whether to produce after network operators have chosen their technologies, and app providers choose whether to produce last. App and device providers seek to maximize individual profits.

In the United States, network operators often bundle devices with the network service and provide discounts on device prices if customers sign contracts. We incorporate a simple form of this mechanism into our model. We assume that customers value options and functionality in

devices and that operators that choose the advanced technology can create this value by incurring costs $D(d_i) \geq 0$, where $d_i \geq 0$ is the value each customer purchasing from network i because of the diversity and features of the devices and apps associated with the network. Customers are homogenous in their valuation of d_i.We assume that D is well behaved, namely that $D' \geq 0$, $D'' \leq 0$, and $D(0) = 0$. In a sense this approach provides an opportunity for network operators to subsidize devices. Proposition 3 provides this section's primary conclusion.

Proposition 3. The merger increases (alternatively, decreases) the incentive for a network operator to invest in device and app diversity and functionality when network effects are low (alternatively, high).

Our model does not solve analytically, so we illustrate the results in Figure 5. Figure 5 compares premerger and post-merger the optimal choices for device and app diversity and functionality when a single network operator upgrades to the more advanced technology. The vertical axis shows the value an individual customer places on diversity and functionality. The horizontal axis shows possible values of network effects. When network effects are lower, a firm in the post-merger market would choose a greater amount of diversity and functionality than in the premerger market. As network effects become larger, the difference diminishes and eventually a firm in the premerger market prefers greater diversity and functionality than the firm in the post-merger market.

[INSERT FIGURE 5 ABOUT HERE]

VII. Conclusion

In this paper we examine how a merger in a network industry where technology innovation is of interest. We find that despite the conclusions of a traditional horizontal merger

analysis that a merger in a concentrated market harms customers, a horizontal merger in a network industry where technology advancement is of interest can make customers better off by increasing the likelihood of advanced technology adoption. The merger makes the advanced technology more profitable by increasing the number of customers that can cover the fixed costs of technology adoption and by increasing the adopting firm's ability to extract economic rents from the adoption. The increased industry output improves net consumer surplus and industry profits, so a competition regulator should approve the merger.

Results are mixed for the device and apps markets. We find that the merger increases a network operator's incentives to invest in device and app diversity and functionality with network effects are smaller, but decreases the incentive when network effects are larger.

More research is needed in this area. We do not model the device and app markets separately, nor do we examine the device and app providers' choices. We also assume uniform pricing for the network service, which is rare in the United States.

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Figures

Figure 1. Impact of Single Firm Adopting Higher Technology in 3-Firm Market

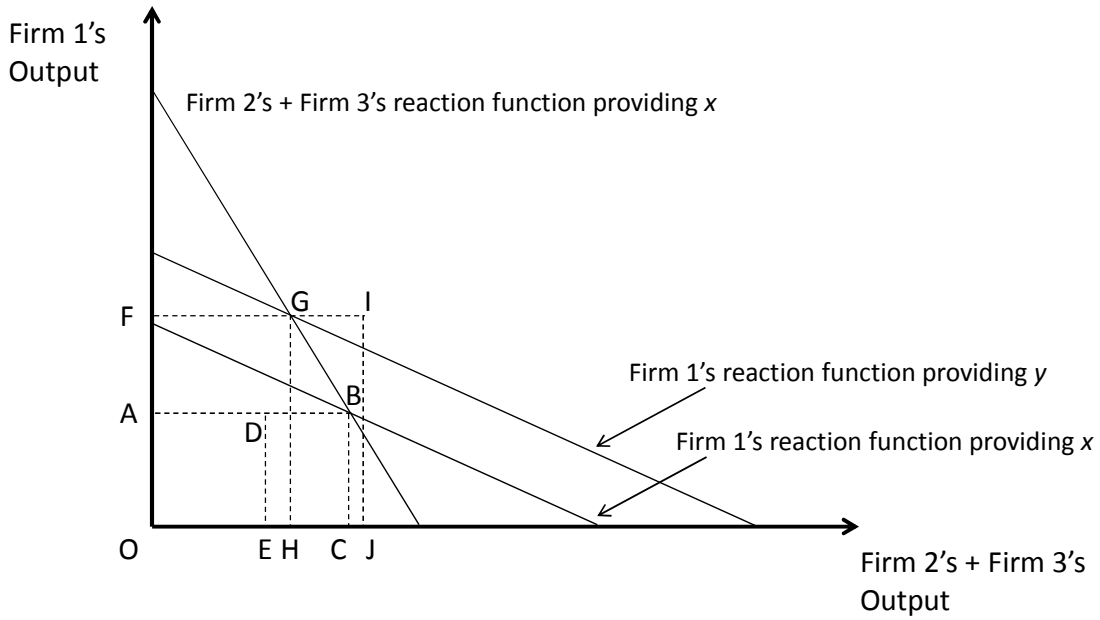


Figure 2. Impact of Single Firm Adopting Higher Technology in 2-Firm Market

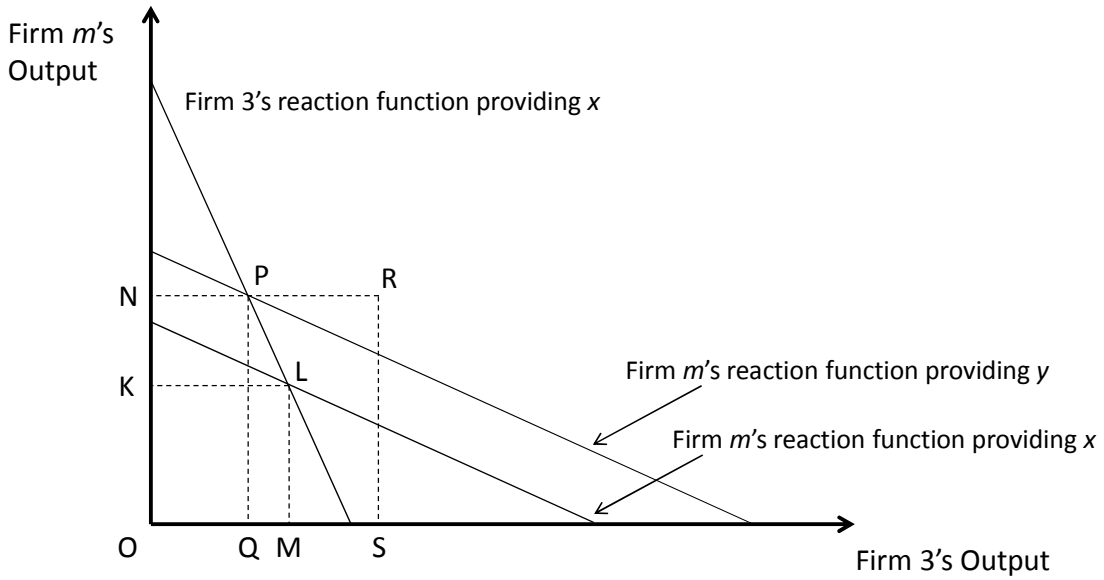


Figure 3. Simulation Results: Comparison of Pre-Merger and Post Merger Fixed Cost Thresholds for Advanced Technology Adoption by Single Firm

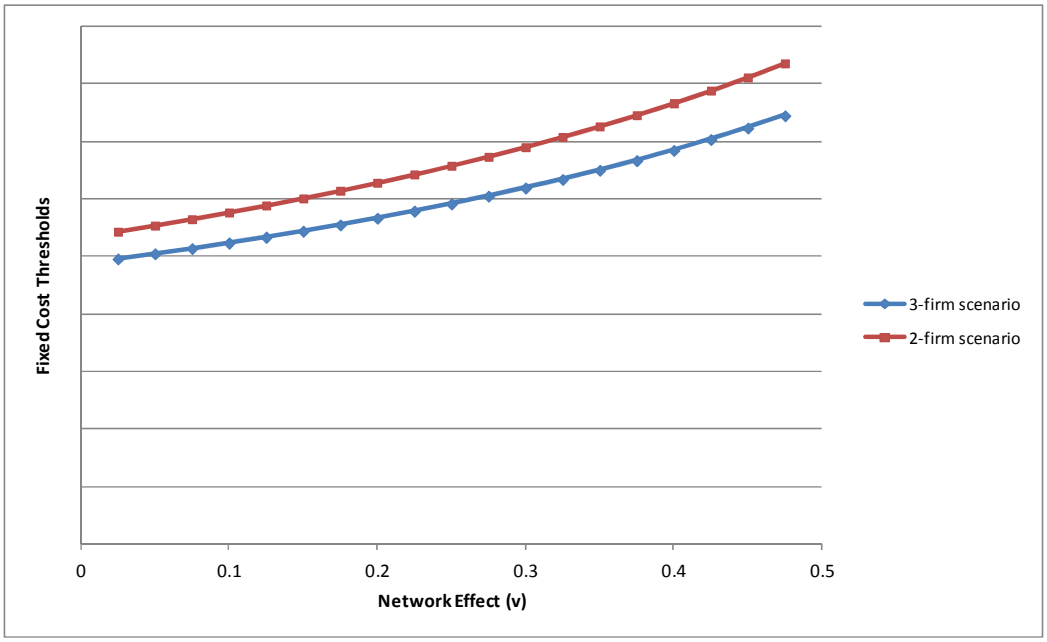


Figure 4. Simulation Results: Comparison of Pre-Merger and Post Merger Fixed Cost Thresholds for Advanced Technology Adoption by a Second Firm

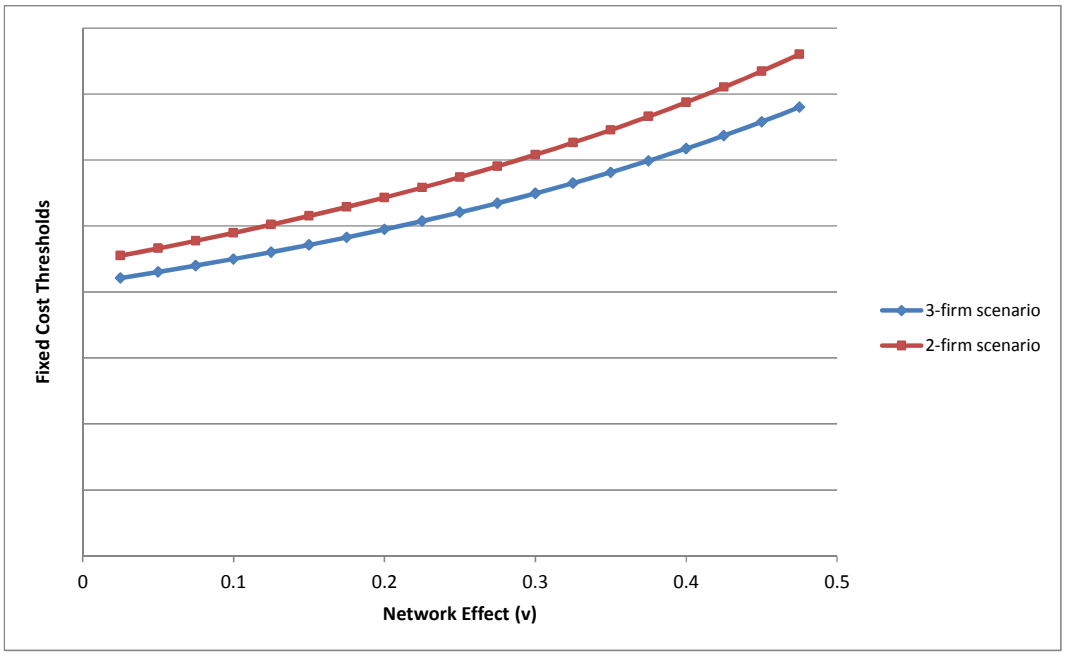
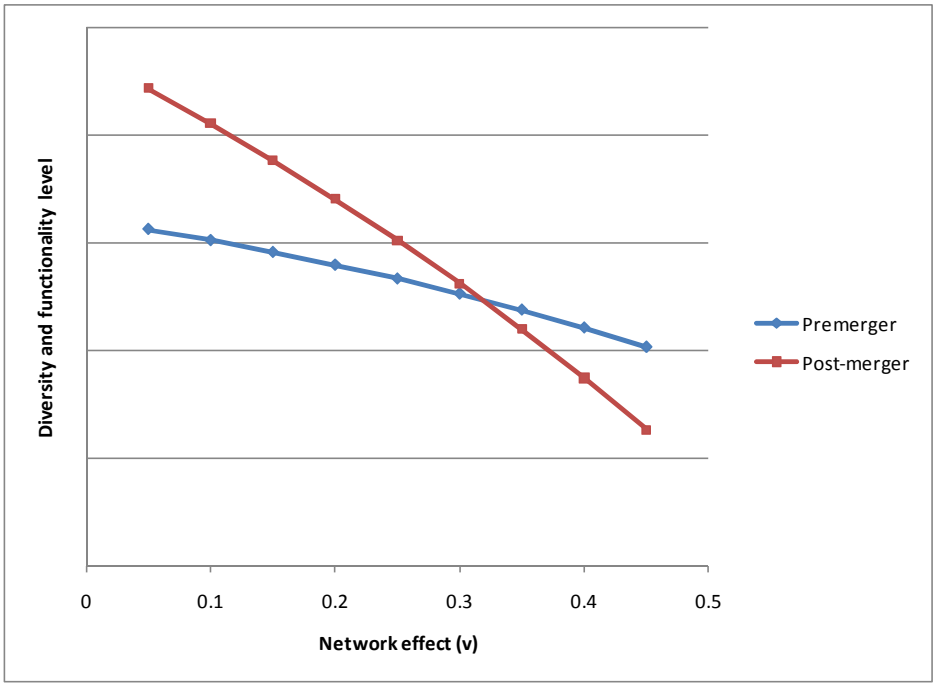


Figure 5. Simulation Results: Comparison of Pre-Merger and Post Merger Choices for Device and App Diversity and Functionality



Appendix

Table 1. Analytical results for the pre-merger market.

	3-firm results			
	No upgrade	**1 upgrade (*i* upgrades; *j*, *k* do not)**	**2 upgrade (*i*, *j* upgrades; *k* does not)**	**3 upgrade**
Non-upgrading firm output	$\frac{A}{4-3v}$	$\frac{A-(1-v)\alpha+(1-v)C_i}{4-3v}$ $\frac{A-(1-v)\alpha^t+(1-v)C_i}{4-3v}$	$\frac{A-2(1-v)\alpha+(1-v)(C_i+C_j)}{4-3v}$	NA
Upgrading firm output	NA	$\frac{A+(3-2v)(\alpha-C_i)}{4-3v}$	$\frac{A+(2-v)\alpha-(3-2v)C_i+(1-v)C_j}{4-3v}$ $\frac{A+(2-v)\alpha-(3-2v)C_j+(1-v)C_i}{4-3v}$	$\frac{A+\alpha-(3-2v)C_i+(1-v)(C_j+C_k)}{4-3v}$ $\frac{A+\alpha-(3-2v)C_j+(1-v)(C_i+C_k)}{4-3v}$ $\frac{A+\alpha^t-(3-2v)C_k+(1-v)(C_j+C_j)}{4-3v}$
Industry output	$\frac{3A}{4-3v}$	$\frac{3A+\alpha-C_i}{4-3v}$	$\frac{3A+2\alpha-C_i-C_j}{4-3v}$	$\frac{3(A+\alpha)-C_i-C_j-C_k}{4-3v}$
Non-upgrading firm price	${x_i}^*$ or $\frac{A}{4-3v}$	${x_j}^*$ or ${x_k}^*$ $\frac{A-(1-v)\alpha+(1-v)C_i}{4-3v}$	${x_k}^*$ or $\frac{A-2(1-v)\alpha+(1-v)(C_i+C_j)}{4-3v}$	NA
Upgrading firm price	NA	${y_i}^*+C_i$ or $\frac{A+(3-2v)\alpha+(1-v)C_i}{4-3v}$	${y_i}^*+C_i$ or ${y_j}^*+C_j$ $\frac{A+(3-2v)\alpha+(1-v)(C_i+C_j)}{4-3v}$	${y_i}^*+C_i$ or ${y_j}^*+C_j$ or ${y_i}^*+C_k$ $\frac{A+\alpha+(1-v)(C_i+C_j+C_k)}{4-3v}$
Non-upgrading firm profit	$({x_i}^*)^2$ or $\left(\frac{A}{4-3v}\right)^2$	$({x_j}^*)^2$ or $({x_k}^*)^2$ $\left(\frac{A-(1-v)\alpha+(1-v)C_i}{4-3v}\right)^2$ $\left(\frac{A-(1-v)\alpha+(1-v)C_i}{4-3v}\right)^2$	$({x_k}^*)^2$ or $\left(\frac{A-2(1-v)\alpha+(1-v)(C_i+C_j)}{4-3v}\right)^2$	NA
Upgrading firm profit	NA	$({y_i}^*)^2-F_i$ or $\left(\frac{A+(3-2v)(\alpha-C_i)}{4-3v}\right)^2-F_i$	$({y_i}^*)^2-F_i$ or $({y_j}^*)^2-F_j$ $\left(\frac{A+(2-v)\alpha-(3-2v)C_i+(1-v)C_j}{4-3v}\right)^2-F_i$ $\left(\frac{A+(2-v)\alpha-(3-2v)C_j+(1-v)C_i}{4-3v}\right)^2-F_j$	$({y_i}^*)^2-F_i$ or $({y_j}^*)^2-F_j$ or $({y_k}^*)^2-F_k$ $\left(\frac{A+\alpha-(3-2v)C_i+(1-v)(C_j+C_k)}{4-3v}\right)^2-F_i$ $\left(\frac{A+\alpha-(3-2v)C_j+(1-v)(C_i+C_k)}{4-3v}\right)^2-F_j$ $\left(\frac{A+\alpha-(3-2v)C_k+(1-v)(C_j+C_j)}{4-3v}\right)^2-F_k$

Table 2. Post-merger analytical results

	2-firm results		
	No upgrade	**1 upgrade (*i* upgrades; *j* does not)**	**2 upgrade**
Non-upgrading firm output	$\frac{A}{3-2v}$ $\frac{A}{3-2v}$	$\frac{A-(1-v)(\alpha-C_i)}{3-2v}$	NA
Upgrading firm output	NA	$\frac{A+(2-v)(\alpha-C_i)}{3-2v}$	$\frac{A+\alpha-(2-v)C_i+(1-v)C_j}{3-2v}$ $\frac{A+\alpha-(2-v)C_j+(1-v)C_i}{3-2v}$
Industry output	$\frac{2A}{3-2v}$	$\frac{2A+\alpha-C_i}{3-2v}$	$\frac{2(A+\alpha)-C_i-C_j}{3-2v}$
Non-upgrading firm price	$x_i{}^*$ or $x_j{}^*$ $\frac{A}{3-2v}$	$x_j{}^*$ $\frac{A-(1-v)(\alpha-C_i)}{3-2v}$	NA
Upgrading firm price	NA	$y_i{}^*+C_i$ $\frac{A+(2-v)\alpha+(1-v)C_i}{3-2v}$	$y_i{}^*+C_i$ or $y_j{}^*+C_j$ $\frac{A+\alpha+(1-v)(C_i+C_j)}{3-2v}$
Non-upgrading firm profit	$(x_i{}^*)^2$ or $(x_j{}^*)^2$ $\left(\frac{A}{3-2v}\right)^2$ $\left(\frac{A}{3-2v}\right)^2$	$(y_j{}^*)^2$ $\left(\frac{A-(1-v)(\alpha-C_i)}{3-2v}\right)^2$	NA
Upgrading firm profit	NA	$(y_i{}^*)^2-F_i$ or $\left(\frac{A+(2-v)(\alpha-C_i)}{3-2v}\right)^2-F_i$	$(y_i{}^*)^2-F_i$ or $(y_j{}^*)^2-F_j$ $\left(\frac{A+\alpha-(2-v)C_i+(1-v)C_j}{3-2v}\right)^2-F_i$ $\left(\frac{A+\alpha-(2-v)C_j+(1-v)C_i}{3-2v}\right)^2-F_i$