Pricing and Entry Incentives with Exclusive Contracts

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Abstract

Exclusive dealing arrangements may soften competition but also create pro-competitive dynamic entry incentives, implying an ambiguous effect on welfare. This paper examines the equilibrium effect of exclusive contracts between upstream and downstream firms when both are differentiated to consumers. Using a detailed monthly market-level dataset of US consumer decisions over 2008-2010, the paper studies the effect of such contracts on the US telecommunications sector, by estimating smartphone and carrier demand , exploiting exogenous variation in network quality to separate preferences. Counterfactual simulations show that AT&T had the highest willingness to pay for exclusivity with Apple only after accounting for equilibrium price effects, and that this exclusivity increased entry incentives for rivals, highlighting both the positive and negative effects for consumer welfare.

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Exclusive dealing arrangements between firms are common and take many forms (Dept of Justice, 2008). Early models of exclusive contracts argued that such arrangements cannot be harmful, as the firm seeking the arrangement would only be willing to sufficiently compensate the other party for the reduced market potential if the exclusive arrangement were efficient.[1] However, later work showed that such arrangements could lead to inefficient outcomes, such as the foreclosure of entry (Aghion and Bolton, 1987). While these contracts may have anti-competitive effects, they have also been shown to be pro-competitive in some settings, such as for protecting investments and addressing externalities (Bernheim and Whinston, 1998; Segal and Whinston, 2000).[2] Indeed, courts in the United States evaluate such restraints under the Rule of Reason, instead of declaring them to be illegal *per se*.[3]

Empirical investigations of these arrangements are therefore important for policy. In this paper, I examine exclusive arrangements for smartphones in the United States mobile telecommunications market that link a handset to a single particular carrier.[4] The setting itself is an important market in the United States, with wireless carriers collecting over $170B in revenue in 2010, and global mobile operator revenue surging to $1.13T in 2012.[5] Perhaps the most well-known exclusive contract was between Apple and AT&T, which saw the former's iPhone handset exclusively available on AT&T's network from its launch in the summer of 2007 until February of 2011.[6] The popular press devoted much attention to the wisdom of the Apple decision, as AT&T was plagued by complaints of poor network quality with the iPhone, despite being the largest carrier in the US at the time.[7] In addition, many customers of other wireless carriers expressed interest in purchasing an iPhone, but could not do so without switching carriers. This led to political and regulatory attention being paid to exclusive contracts between handset makers and wireless networks. The Federal Communications Commission (FCC) and United States Senate have held hearings on the potentially negative impact on consumers of this particular arrangement, with regulatory bodies in other countries in-

[1] These arguments, referred to as the Chicago School approach to this topic, are articulated in Posner (1976) and Bork (1978).

[2] See Katz (1989) for a survey of the theory literature on vertical contracts.

[3] United States Supreme Court (1977)

[4] For example, in Consumer Reports' 2009 annual review of smartphones, 6 of the 10 devices that were rated as "Recommended" were exclusive to one of the four major US wireless carriers (Consumers' Union of US, 2009).

[5] "The US wireless industry directly/indirectly employs more than 3.8 million Americans, which accounts for 2.6% of all U.S. employment.... The U.S. wireless industry is valued at $195.5 billion, which is larger than publishing, agriculture, hotels and lodging, air transportation, motion picture and recording and motor vehicle manufacturing industry segments. It rivals the computer system design service and oil and gas extraction industries." CTIA-The Wireless Association (2012)

[6] While many handsets are released exclusively, the Apple arrangement was notable for its initial 5 year term. For example, the Palm Pre smartphones launched exclusively on Sprint, while the first touchscreen Blackberry was exclusive to Verizon and the first Blackberry Pearl exclusive to T-Mobile. Exclusive contracts are typically in the 6-12 month range.

[7] Apple Press Release "Apple Reinvents the Phone with iPhone," http://www.apple.com/pr/library/2007/01/09Apple-Reinvents-the-Phone-with-iPhone.html

vestigating similar contracts.[8] The view of the major wireless carriers was that these arrangements increased welfare through greater incentives for innovation, as wireless carriers have a stronger incentive to invest in new innovations for which they will be the exclusive provider.[9] The view of consumer groups was that exclusivity leads welfare losses from higher prices and fewer choices for consumers.[10] Indeed, the effect on welfare is ambiguous.[11]

This paper proposes a simple motivation for exclusivity in this market based on the relative market power of handsets versus wireless carriers, building off of the model developed by Rey and Stiglitz (1995). Consider a static setting where all wireless carriers offered identical assortments of handsets: handset-network bundles in the market would be differentiated only on the wireless service dimension. If wireless services from competing providers were good substitutes for one another, then we would expect low markups on all handset-network bundles in equilibrium. An exclusive contract in this setting has two effects: the first is to differentiate the bundle with the exclusive handset, allowing for higher markups on that handset-network bundle. Exclusivity also has a secondary effect: if prices are strategic complements,[12] then the increase in price for the exclusive bundle also results in higher prices for all other bundles in equilibrium. This softening of price competition in the final goods market can increase joint profits for the contracting parties in a static setting, making exclusive arrangements profitable. However, these contracts may also increase incentives for new handset manufacturers to enter. The net effect of these two forces on consumer welfare is therefore ambiguous.

In order to estimate the magnitudes of these competing forces, estimates of the price elasticities of the various handsets and wireless carriers are needed. However, estimating demand in such a setting poses several challenges. Demand is dependent between months as this is a durable good where a consumer's current demand is a function of the consumer's current "state" (her current handset, contract status with her wireless carrier, and any switching costs that her contract

[8] See Press Release, "Kerry, Wicker, Dorgan, Klobuchar Call for Increased Choice for Wireless Consumers", Sen. John Kerry, Jun 15, 2009.

[9] AT&T gave its "visual voicemail" feature for the iPhone as an example of such an investment. However, other carriers subsequently added this capability to their networks for handsets running Windows Mobile, Blackberry, Android, and Symbian operating systems.

[10] A specific concern was that, at the time, AT&T did not have a wireless network in several rural areas as well as the states of Vermont and Alaska. Consumers in those areas could not purchase an iPhone even if they were willing to switch carriers.

[11] This paper will not provide an estimate of the welfare effect of allowing exclusive contracts in this setting. There are two competing forces affecting welfare: higher prices in a static context, but increased entry in the dynamic context. While the effect of exclusive contracts on entry incentives can be measured, the change in entry probability is not identified, and so the latter force cannot be estimated. I can provide bounds on the latter force, but they are not informative for setting policy. For a paper that focuses on the welfare question of Apple's exclusivity, see Zhu, Liu and Chintagunta (2011).

[12] If the prices of two firms' products are strategic complements, then an increase in the price of one good gives the other firm an incentive to increase the price of the other good as well. See Bulow, Geanakoplos and Klemperer (1985). This condition is satisfied in most different product demand systems, including the Logit and Hotelling models.

imposes). A consumer's state evolves according to a known process and the consumer's history of choices. I build a choice model closely related to the Pure Characteristics Model of Berry and Pakes (2007), where random coefficients rationalize decisions and individual tastes are invariant over time.[13] Consumers choose between bundles every period by comparing discounted future utility flows conditional on their current state. The analysis avoids a fully-dynamic sequential model by simplifying consumer beliefs, which are supported by the data.[14] An advantage of this approach is that it avoids i.i.d. taste shocks for every product in every period. As noted elsewhere, for example in Ackerberg and Rysman (2005), such taste shocks can lead to bias in elasticities in the current setting, as well as bias in counterfactuals that increase the size of the choice set. This approach is contrasted with a standard Logit demand model approach in Appendix A.5, which discuss how a typical Logit model would face numerous challenges in this setting.

A proprietary large-scale monthly survey dataset of United States consumers is then used to estimate the empirical model. Twenty-six months of the repeated cross-sectional demand data are combined with city-level data on network quality for all carriers in 90 markets as well as handset characteristics and prices. The data have several unique advantages and disadvantages. First, wireless carriers charge the same prices in all markets, even though the quality of a given carrier's network differs greatly across markets.[15] I argue that variation in network quality across markets is plausibly exogenous and can be used to identify tastes for carriers and for network quality. However, a major disadvantage of this dataset is that it is not a true panel of consumers over time, it is a repeated cross section, and so an individual's sequence of decisions over time is not observed.

The results from the econometric analysis are then used to address a number of counterfactual questions. First, if all prices are held constant, the observed contracting appears irrational as Verizon could have sold more iPhones than AT&T. However, once price can adjust to new product configurations, AT&T had the highest willingness to pay and Verizon's network quality insulated them from price competition. Second, Apple's exclusivity with AT&T created sizable entry incentives for rivals, on the order of $1.5B during the time period in question. Finally, AT&T would have been willing to sufficiently compensate Apple for lost sales against the threat of Verizon exclusivity. Had the alternative been iPhone availability on all carriers, AT&T would not have been

[13] This model has been applied in other settings, such as Nosko (2012).

[14] An important contribution to the dynamic discrete choice literature is Gowrisankaran and Rysman (2011), which nests a demand system within a dynamic optimization decision framework, fully internalizing for a consumer the decision to buy now or wait. A more recent example of durable good demand modeling is Conlon (2010). An example of a prior paper which avoids dynamic programming in such a setting is Geweke and Keane (1996).

[15] Asked why prices do not vary across markets, one industry source expressed concern that such a move would attract regulatory scrutiny. It may also simply be difficult to implement such a pricing scheme given the incentives it would create. Network quality itself is influenced by a number of factors, including topology, building materials, density of buildings, historical contracts, zoning regulations, and other factors. I discuss the issue more throughout this paper.

willing to pay enough to justify exclusivity.

This paper contributes an extension of the theoretical understanding of exclusive contracting to the case of bundles of horizontally differentiated goods and an empirical investigation of such a setting, where magnitudes of the competing forces are estimated. Empirical applications of exclusivity models are a recent but growing phenomenon; for examples see Asker (2005), Mortimer (2008), Lee (2010), and Crawford and Yurukoglu (2012). This paper's setting is an advantageous one in which to study the effect of relative market power of multiple goods, as the two goods are bundled one-to-one to produce a final good. This work is also informative about recent contracts where competing platforms have acquired exclusive content, such as in streaming video services and video game consoles.

The paper proceeds as follows: Section 1 discusses a theoretical motivation for the choice of vertical contracts in this setting. Section 2 describes the industry and data I will use for the empirical analysis. Section 3 presents reduced-form evidence. Section 4 develops an econometric model of consumer choices. Section 5 discusses the results from estimation. Section 6 provides the results from counterfactual simulations. Section 7 summarizes.

1 Theoretical Background

This section considers how an exclusive contract can affect market outcomes in the wireless telecommunications setting to inform the design of the empirical model that follows. The setting in question is one where handsets and wireless networks are bundled together and sold to consumers.[16] It may be convenient to think of handset manufacturers as "upstream" firms that provide an input to "downstream firms" (wireless carriers), as there is a well-developed literature on vertical exclusive contracts.[17] Furthermore, carriers are primarily responsible for setting prices in the final goods market and a large majority of consumers purchase their handset from the wireless

[16]The specific terms of contracts between handset manufacturers and wireless carriers are unobserved in the mobile telecommunications sector. Research on exclusivity, such as Bernheim and Whinston (1998), focus on the joint surplus of the contracting parties is the determinant of the market structure. The first principle from Bernheim & Whinston's analysis of manufacturers and exclusive retailers: "the form of representation (exclusivity or common representation) that arises in equilibrium maximizes the joint surplus of the manufacturers and the retailer, subject to whatever inefficiencies may (or may not) characterize incentive contracting between the retailer and the manufacturers." To this end, one must allow for flexible contracts so that classic results such as double-marginalization are not an issue.

[17]Models of vertical settings are common in economic theory, although most models are limited to "triangular" market structures, with either one upstream firm and two downstream firms, or vice versa. Whinston (2006) notes this and further states that most markets in reality have multiple participants at each level. One exception is Besanko and Perry (1994), which has two upstream firms and multiple downstream firms spatially differentiated as in a Salop circle model. However, the contracts are restricted to be linear and an exclusive contract in their setting only restricts the upstream competitor from every 2nd downstream firm.

carrier or an agent of the wireless carrier, as opposed to from a handset manufacturer.[18] In this market, any smartphone is an imperfect substitute for another; that is, while a given consumer may prefer an iPhone to, say, a Blackberry, there exists a set of prices at which the consumer would prefer the Blackberry. This imperfect competition allows for a pricing motivation for exclusive contracts.

The main results from Rey and Stiglitz (1995) apply to this setting if one assumes that wireless carriers are perfect substitutes. The authors of that paper show that in a full information game where producers of imperfect substitute goods (handset manufacturers) first simultaneously choose wholesale prices, followed by retailers (wireless carriers) simultaneously choosing retail prices, an exclusive contract can increase the joint profits of the contracting parties. The mechanism is that the contract reduces interbrand competition in the final goods market: if all downstream firms offer all upstream goods, then perfect competition eliminates retail markups. Therefore, a first-order effect is that the wireless carrier offering the exclusive handset can charge a monopoly markup on the bundle of that handset and its wireless network. In addition, the contract increases incentives for rival upstream firms to raise wholesale prices on their competing handsets.[19] The equilibrium effect is higher prices for all bundles offered. Appendix B.1 demonstrates the forces in a Hotelling framework, and also shows that such an arrangement can increase entry incentives for rival upstream firms.

1.1 Application to the Market for Smartphones

A key component in the Rey and Stiglitz (1995) model is that downstream firms are perfect substitutes, and so an exclusive contract does not limit an upstream firm's market potential. In the United States wireless telecommunications market, wireless carriers are not perfect substitutes. Consequently, if wireless carriers have market power, there is an additional cost to exclusivity: foregone sales from not making a handset available on additional carriers. In the extreme case where carriers are monopolists over their consumers, a handset manufacturer would do strictly better if they were available on all carriers. Appendix B.2 generalizes the model of Appendix B.1 to show that the relative market power of upstream and downstream firms is the determinant of whether or not exclusive contracts are able to maximize the joint profits of the contracting parties.

The final considerations are that (i) wireless carriers in the United States differ in the quality of their networks (a form of vertical differentiation), and that (ii) the quality of handsets and wire-

[18] Among all respondents in the data, 73.1% reported that they purchased their handset directly from their carrier. Among smartphone owners, this increases to 75.4%. Among Apple handset owners in the data, 69.9% reported having purchased their handset from the carrier, and while data for purchases from Apple's stores is not broken out separately, 22.3% report purchasing from a "major retail store" which may include the Apple Store, but also includes Best Buy, RadioShack, and WalMart.

[19] Martimort and Piccolo (2010) show a similar mechanism via quantity forcing contracts.

less networks may be substitutes or complements in the utility consumers receive from a bundle of each. Appendix B.2 shows that these are empirical considerations when examining the value of an exclusive handset to a wireless carrier. Specifically, if consumers are willing to substitute between handset and network quality, then an exclusive handset is worth relatively more to a lower quality carrier.[20] If consumers instead view handset and network quality as highly complementary, a higher quality carrier will have a higher value for the exclusive contract. This tells us that measuring whether or not consumers are willing to substitute between handset and network quality will be a determinant of a carrier's willingness to pay.

1.2 Affirmative Evidence

The previous section established a hypothesis for why exclusive contracts might be rational in the current setting: exclusivity insulates a handset-network bundle from direct competition on the network dimension. If networks are good substitutes, then bundles including non-exclusive handsets should see strong price competition and lower markups. If this hypothesis is correct, an obvious place to seek supportive evidence would be to look at what happened to prices after the iPhone became non-exclusive in a market.

A first piece of evidence comes from France, where the competition authorities canceled Apple's exclusive contract with the carrier Orange in that country in 2009 (discussed below). As the handset became available on multiple carriers, Orange, the previously exclusive carrier, immediately dropped the price of an iPhone 3GS 16GB from €149 ($225) to €59 ($89) on the same 24-month contract with a monthly payment of €40.90 ($62),[21] while the price remained steady at AT&T in the United States at $199 on a 24-month contract. Orange's rivals SFR and Bouygues Telecom offered the iPhone at similar prices. Price changes from new carrier competition occurred in other markets as well, such as Japan,[22] and most recently China.[23] In the United States, AT&T lost exclusivity in 2011, and while they did not change their pricing at the time they lost exclusivity, they did make their existing plans more generous and awarded "bonuses" to their customers, effectively lowering prices of monthly plans.[24]

A number of alternative arguments have been put forward to explain Apple's decision to limit the iPhone to a single carrier, although none appears to survive scrutiny. A first such argument

[20] The intuition is that if consumers are willing to substitute between handset and network quality, a high-quality handset can be worth incrementally more to a lower quality network.

[21] http://bgr.com/2009/12/22/apple-iphone-prices-plummet-in-france/

[22] http://blogs.wsj.com/digits/2013/09/15/docomos-move-to-carry-iphone-triggers-price-war-in-japan/

[23] http://blogs.wsj.com/digits/2014/01/08/chinese-carriers-cut-iphone-contract-prices/

[24] Specifically, AT&T had previously offered free "in-network" mobile calling, and switched to offering free calls to any mobile phone on any network, effectively reducing the number of minutes a consumer needed to purchase. They also awarded 1,000 bonus "anytime" minutes to their iPhone customers. http://www.att.com/gen/press-room?pid=19039.

was that Apple had a limited supply capacity: this was their first mobile phone, and so they were concerned that they could not meet demand if they launched on all carriers. However, if this were the case, it is unlikely that they would then have entered into a 5-year exclusive contract with AT&T and their other partner carriers around the globe. Apple launched the iPhone globally less than 6 months after the initial US launch, indicating that any supply issues were short-term. A second argument was that exclusivity was essential to guarantee carrier investments in network technologies to support the iPhone. However, this argument was specifically tested and rejected by the French competition authorities when they prematurely ended Apple's exclusive contract in that country. The exclusive carrier there was unable to show a significant investment that needed to be protected.[25] A third argument was that the value of the iPhone was greater as an exclusive device than as a non-exclusive device, perhaps due to better training of AT&T salespeople in selling the device. While it is not possible to entirely rule out this explanation, there are many alternative mechanisms suggested by the contract theory literature on overcoming this problem, such a profit-sharing arrangements. Given that Apple operated a network of retail outlets at this time, it is likely that if they were concerned about the sales experience, they could have sold the device only through their own outlets, with network plans from all carriers.

Finally, Apple and AT&T renegotiated their contract after 3.5 years, even though the contract had called for a 5 year term. The pricing motivation described above requires strong upstream differentiation to justify the costs of exclusivity; however, by 2010, smartphones running Google's Android operating system were outselling Apple's handsets in the United States and had become very competitive. If there are good substitutes to an iPhone, theory says exclusivity is less valuable to AT&T. From Apple's perspective, the initial iPhone was not a platform for third-party "apps" and Steve Jobs was opposed to allowing any such applications to be developed (Isaacson 2011). However, a year later, such applications became possible and were hugely successful. If a large user base were essential to attracting developers to the iPhone over rival smartphone systems, there would be an added cost to Apple of maintaining an exclusive relationship. Therefore, the renegotiation of this contract appears consistent with the motivation presented above, and to have been mutually beneficial for both Apple and AT&T.

[25] Conseil de la concurrence: Décision n° 08-MC-01 du 17 décembre 2008 relative à des pratiques mises en oeuvre dans la distribution des iPhones. The court found €16.5 million in investment related to the iPhone, compared to €222 million in profits generated from iPhone sales three months into a 5-year period of exclusivity with the carrier Orange.

2 Industry and Data Description

2.1 The United States Wireless Market

There are four major nationwide wireless carriers in the United States who together control approximately 85% of the market: Verizon, AT&T, Sprint, and T-Mobile. Smaller, regional carriers such as US Cellular account for the balance. Mobile phone penetration is high, with 95% of adults owning mobile telephones by the end of 2010. Smartphones are a fast-growing segment of mobile telephones: despite the first smartphones appearing in the 1990s, smartphones never achieved widespread consumer adoption until advances in cellular data networks and increases in the power of mobile devices led smartphones to dominate new mobile telephone purchases in 2011.[26] Smartphones differ from traditional mobile phones ("feature phones") in that they offer rich data services such as e-mail, web browsing, photo and video capture, and multiple software applications in addition to voice features. The dominant smartphone operating systems are Apple's iOS, Google's Android, and Research in Motion's Blackberry during the time period being studied. Of those three, Android is the only one whose owner does not control hardware as well: Google has several hardware partners that build and market smartphones, including Motorola, Samsung and HTC.

Wireless carriers purchase spectrum from the US government and construct and operate wireless networks, offering consumers various monthly packages of voice and data usage.[27] During the time period in question, smartphones are primarily sold by carriers on subsidized two year contracts: consumers commit to two years of a monthly plan that includes a data component in exchange for being able to purchase a smartphone at a reduced price. The vast majority of smartphones are purchased at a subsidized price between $0 and $250, while the unsubsidized listed retail price is often between $500-$700.[28] Monthly plans for smartphones range from $65 to $130 during this time period, depending on the features that are included.

The fact that smartphones are sold on two-year contracts introduces the fact that the choice to buy a new handset is a dynamic one. Purchasing a handset-network bundle in the current month creates a switching cost for the next 24 months due to the early termination fee (ETF) clause common in all contracts, above any search costs or costs of moving information to a new device. These fees start between $175 and $350, and decrease by $0-10 per month over the length of the contract.[29] Smartphones are subsidized by wireless carriers, so this fee prevents consumers from

[26] See Nielsen Press Release "In US, Smartphones Now Majority of New Cellphone Purchases," June 30, 2011.

[27] The business can be very profitable. In 2010, AT&T's wireless segment earned income of $15.2B on revenue of $53.5B.

[28] In the demand data discussed below, over 90% of smartphone consumers report signing a two-year contract that includes an early termination fee.

[29] Over the time period in question, T-Mobile's ETF is $200 for the entire contract length. Verizon and AT&T are both $175 decreasing by $5 per month at the beginning of the data period but switch to $350 less $10 per month in November 2009 (Verizon) and $325 less $10 per month (AT&T) in June 2010. Sprint starts at $200 and falls by $10

leaving before the subsidy has been recovered by the carrier.

2.2 Demand data

I use proprietary datasets gathered by The Nielsen Company in my estimation: Nielsen conducts a monthly survey of the United States wireless telecommunications market. Roughly 20,000 to 25,000 individuals are contacted every month (though, not the same individuals every month) and are asked a series of individual questions including income range, age, race, gender, household size, employment, and education level. They are also asked whether or not they subscribe to mobile phone service, and if so, on which carrier and using which handset with which price plan. The geographic market of the individual is also observed, as is the time since they acquired their current handset, and whether or not they have switched carriers in the previous 12 months.[30] I have access to the survey months of November 2008 until December 2010, a total of 26 months. People under 18 years of age and people who identify that their employer provided their phone to them are dropped.[31] Table 1 provides some summary statistics of the sample after trimming. The survey observations are assigned weights by Nielsen to correspond to census data.[32]

2.3 Product data

The demand dataset contains the name of the chosen handset and carrier as well as basic data on product characteristics: flags for keyboard, touch screen, smartphone, and brand. The data are augmented with additional characteristics for smartphones including software operating system, processor speed, and the number of "apps" available each month for each software platform.[33] Self-reported prices are available by device-carrier in the demand dataset.[34] Network prices are publicly available. I use the network price for each carrier's introductory smartphone bundle, which are the modal plans selected by consumers in the survey data. During this sample, these plans consist of 450 "peak" minutes (500 on T-Mobile), unlimited evening and weekend minutes, unlimited

per month until it reaches $50, where it remains until the end of the contract.

[30] Unfortunately, I do not observe the previous handset-network bundle, or even the identity of the previous carrier for these individuals.

[31] Combined, these represent approximately 4% of observations.

[32] See Appendix Table 9 to compare the weighted survey respondents to Census data.

[33] The primary source for the added data was the database of handset characteristics maintained by the website www.phonearena.com.

[34] Due to the high variance in the price reported for a handset on a given carrier purchased in a given month, I omit self-reported prices for purchases that occurred more than 3 months before the survey and take the mode of reported values for a given month of purchase. Further, as some models have few reported purchases in a given month, I impose that handset prices be weakly decreasing over time: that is, if the median reported prices paid for a handset in months t and t+1 are p_t and p_{t+1}, I impose that the price in month $t+1$ is p_t in the event that $p_{t+1} > p_t$. Discussions with industry sources confirm that at the monthly level, prices for a given handset rarely increase.

in-network calling, unlimited text message, and unlimited data.[35] There are many combinations of features that can result in different prices, but this package is representative as many add-ons and features are the same price across networks.[36],[37]

The demand data are combined with carrier network performance data at the market level taken from periodic "Drive Tests", where a team from Nielsen drives around a market with devices that simulate cell phones and record signal strength, dropped calls, and other performance data of all of the available carriers in the market. The data gathered for each drive test is based on over 15,000 calls per visit to a market. The piece of data of interest will be the dropped call rate, which can be interpreted as the percentage of calls that are determined to be successful, defined as a call that was connected and lasted at least two minutes. This data is collected every 4-6 months for approximately 100 markets across the USA. Data for months in between visits are linearly interpolated for these metrics, which are then matched to the markets identified in the demand data. In addition, local advertising expenditures measured by Nielsen are included at the market-month level. The dataset used for estimation consists of the 90 markets for which both demand and network quality data are observed. These 90 markets represent most of the 100 largest MSAs, covering over 190 million Americans.

All non-smartphone models are collapsed into a single "feature phone", available on every carrier at the same fixed price with a mean utility to be estimated. The data then show 211 smartphone-network bundles over the course of 26 months, roughly half of which are available in a given month.[38] In terms of individual handsets, there are 4 models of iPhones, 18 models of Blackberries, and 43 models of Android phones, each available on one or more carriers. Due to the large number of Blackberry and Android devices that are often very similar variants of a base model customized to a specific carrier, products are further collapsed within each smartphone operating system by groupings of processor speed, which effectively creates "generations" of devices comparable to Apple's releases. This gives four iPhone models (Original, 3G, 3GS, and 4), 3 Blackberry models, and 6 Android models over this time period.

[35] I abstract away from the choice of specific plans or features; see Grubb and Osborne (2013) for research investigating such choices.

[36] The website BillShrink.com compiles a comparison of feature costs for all major carriers and concludes that there are over 10 million possible plan combinations.

[37] There are other minor differences between the plan prices I use, such as different hours for what qualifies as "evening" and different definitions of "in-network calling", however I allow these differences to be absorbed by carrier fixed effects. For example, Sprint allows free calls to any mobile number, not just other Sprint customers.

[38] I perform additional data-cleaning activities, such as removing observations of T-Mobile iPhones, which were unauthorized "unlocked" models of the original iPhone, and I correct and brand/handset mismatches reported by respondents.

2.4 Data Description and Trends

There are two dominant wireless carriers in the United States: AT&T and Verizon, who each control approximately 30% of mobile customers. They are followed by Sprint (16%) and T-Mobile (11%). A key feature of the wireless networks is that network quality appears to be highly persistent over time within a market, but exhibits significant variation across markets for all of the carriers. Figure 1 shows a non-parametric density plot of the rate of dropped calls across markets for each carrier in a given month.[39] In the density plot, it is apparent that each of the carriers competes in markets where their network quality is high (few dropped calls) and others where it is low (many dropped calls). However, it is also apparent that some some networks are generally better, with their distributions concentrated to the left, and some are generally worse, with their distributions more diffuse. Figure 2 shows that even though some carriers have a higher quality network on average, each competes in markets where it has the best or worst network. Every carrier has markets where they are ranked each of 1st, 2nd, 3rd and 4th out of the four major carriers in terms of network quality. As a comparison, Consumer Reports conducts an annual survey of 50,000 cell phone customers and publishes carrier ratings for between 25 and 50 metropolitan areas in every January issue.[40] For the years 2008-2011, Verizon is the highest rated carrier in their survey, although there are individual markets where other carriers are rated superior.[41]

In contrast to the cross-section Figure 3 shows a time-series plot of the dropped call rates within a sample market over time. In this large sample market, the relative rankings of the carriers' network quality does not change over the 26 months used for estimation. In fact, the rates and ranks move very little over the 26 months of data.[42] One concern about the variation in network quality is that it may be endogenous to other market-level factors affecting demand. Appendix A.7 provides evidence that network quality is exogenous to other demand factors such as bundled television services, and argues that potential bias from the endogeneity of network quality would work against counterfactual results.

A key trend in this time period is the rapid adoption of smartphones. In the first month of the data, 8% of adults own a smartphone, which triples to 24% in the final month. The share of device purchases in a given month that are smartphones increases from 4% to nearly 20% during this period. In the same period, the share of adults that own any phone increases from 89% to 95%.

[39] Note that for contractual reasons, there are certain pieces of data that cannot be fully labeled. As some summary statistics from Nielsen's research are made public, there will be occasions where firm names are included.

[40] See, for example, Consumers Union of United States (2009).

[41] For example, in the January 2010 issue, 75% of the market-level top-ranked carriers in Consumer Reports' survey have the lowest dropped call rates in their market in the Nielsen drive test data for December, 2009. An unreported ordered logistic regression of the Consumer Reports ranking on the Nielsen dropped call rate is significant at the 1% level.

[42] In 61.4% of markets, the carrier ranked 1st in network quality in the first month of data is also ranked first in the last month of data; another 25% are ranked 2nd in the last month.

The mix of smartphones that consumers own also undergoes a dramatic swing: iOS (the operating system used on iPhones) and Google's Android see strong growth, while Blackberry's growth lags the growth of smartphones overall. By the end of 2010, iOS and Android each control nearly 30% of smartphones. Another interesting trend is the share of customers under contract: figure 7 shows that the share of customers that are currently on a contract for their mobile phone does not change much over the sample period, even when restricted to only smartphones.

3 Reduced-Form Evidence

The primary reduced form evidence focuses on the identification strategy of exploiting quality differences in networks across markets while prices and products remain fixed. Figure 4 graphically shows the relationship between demand and network quality using a binned scatterplot. Market shares and dropped call rates are residualized by market and carrier fixed effects, the sample means are added back, and the results are summarized by bins of dropped call rates. The negative relationship is clear: in markets where a carrier has a higher dropped call rate, they have a lower market share. Table 2 shows the results of a discrete choice Logit regression estimating the effect of a carrier's dropped call rate in a market on its market share. These results rely on cross-sectional variation only: prices are constant across markets, and as all specifications include a carrier fixed effect, no price coefficient is estimated. Instead, the dropped call rate varies across markets, and market fixed effects control for differences in topography that would affect the quality of all carriers in a market. The dependent variable is $ln\left(\frac{s_j}{s_0}\right)$, where s_j is the share of consumers in a market that purchase any phone from carrier j during the time period and s_0 is the share of consumers who purchase no new phone from any carrier in the time period. The regressions are performed for multiple time ranges, and using either all markets, or only those markets with regional carriers.[43] Two important results are that the coefficient on the dropped call rate is negative and significant in all specifications, indicating that a higher dropped call rate can be interpreted as lowering the utility from a given carrier, and that the estimate is generally stable across all specifications.[44] Even though there is little variation over time in network quality, Appendix Tables 13 and 14 show using a "long difference" approach that carriers that improved their network quality over the sample period were weakly likely to increase their market share, and were likely to have increased their share of purchases at the end of the time period. Appendix A.7 shows results from the "long difference" approach graphically.[45]

[43] 21 markets in the data have only the four national carriers, the remainder include a regional carrier.

[44] The coefficient should be expected to fall to some degree as the shares are computed over longer time periods, as consumers have more time to make a purchase, moving from the outside good to one of the inside goods.

[45] The general result is also confirmed in Sun (2015), which examines cell tower density as a determinant of quality.

4 Empirical Model

A consumer's decision is a dynamic one: buying a new handset on a two-year contract introduces additional switching costs for the next 24 months. This section begins with a fully-dynamic model of the consumer's problem and then introduces assumptions supported by the available data to simplify the problem and make it tractable in the current setting.

In every time period t, a consumer i knows their current state and maximizes their discounted future utility by either staying with their current handset-network bundle, or purchasing a new one. The Bellman equation for this problem is given by:

$$V(b|\Omega_{it}) = \max\left\{u_{ibt} + E\left[V(b|\Omega_{ib,t+1})\right], \max_{b'}\left\{u_{ib't} - \alpha_i\left(p_{b't} + \beta_i^s + ETF_{it}\right) + E\left[V(b'|\Omega_{ib',t+1})\right]\right\}\right\} \tag{1}$$

Utility maximizing consumers choose every month among competing handset-network bundles b', including their current one b, with flow utility u_{ibt}. They may also choose the bundle of having no mobile phone (with discounted present value of utility normalized to 0). Note that choosing an alternative bundle may entail paying an early termination fee (ETF_{it}), as well as an individual specific switching cost β_i^s.[46] Of course, purchasing a new handset alters a consumer's state. A consumer's state in a given month, Ω_{it}, consists of three sets of information:

$$\Omega_{it} = \{\theta_i, \Omega_{ib}, \Omega_t\}$$

The first, θ_i , are the consumer's preferences. The second, Ω_{ib} is the consumer's history with bundle b, and the last, Ω_t are the characteristics and prices of all available bundles at time t.

Since a new contract introduces 24 months of switching costs, solving this problem is complex and would require consumer beliefs over 24 months of the characteristic space at the time of purchase. The following assumptions lead to a tractable model for this setting.

Assumption 1. *Consumer preferences are constant and the evolution of Ω_{ib} is deterministic and common knowledge.*

This assumption implies that consumers have perfect foresight on the evolutions of θ_i and Ω_{ib}. Note that a consumer's bundle history Ω_{ib} evolves in a perfectly deterministic fashion: every month: a consumer's device ages by one month and their ETF falls by the amount specified in their contract with their carrier. If they purchase a new device, both their device age and ETF are reset.

Assumption 2. *A consumer's best alternative in their current choice set is a sufficient statistic for predicting their best alternatives in future months.*

[46] This switching cost could include search costs or the costs of transferring data, for example.

For example, a consumer's belief about their best option 5 months from now is a function of their best option this month. Without this, a consumer would need to have beliefs over characteristics and prices of all alternatives for each future month. Assumption 2 greatly simplifies the evolution of Ω_t. This assumption is used in the literature when the dimensionality of the state space is beyond what is considered reasonable for a typical consumer. [47]

Assumption 3. *Consumers do not expect to break their contract at the time of signing; that is, when purchasing a new device, they expect to own it for 24 months.*

This assumption simplifies the consumer's problem of comparing their current bundle to alternative ones. Under this assumption, they do not account for the possibility of purchasing a new device, only to pay an early termination fee and switch to a new device in 2, 6, or 10 months' time.[48] This is strongly supported by the data: less than 1.4% of observations report paying termination fees in the previous 12 months in the survey data, so one may infer that this assumption may be incorrect for approximately 0.1% of consumers per month. Discussions with industry sources indicate that consumers who pay such fees have often either broken their handset, rendering it useless, or are responding to a another truly unexpected event such as a relocation.[49] These are consistent with consumers not expecting to break their contract at the time of signing.[50]

Given these assumptions, the consumer's decision every month reduces to the following: consumer i that currently owns handset-network bundle b with r_{it} months remaining on their contract has the following present value of utility from that handset-network combination:

$$U_{ihnt} = \sum_{m=0}^{r_{it}-1} d^m u_{ibt} + d^{r_{it}} \cdot \gamma_{it}\left(r_{it}\right) \tag{2}$$

In every period, a consumer will compare this value to other possible choices available to them. The present value of utility from purchasing a new bundle handset-network pair in period t is

$$U_{ib't} = \alpha_i \cdot (p_{b't} + ETF_{it} + \beta_i^s) + \sum_{m=0}^{23} d^m u_{ib't} + d^{24} \cdot \gamma_{it}\left(24\right) \tag{3}$$

The first term in the above equation captures the cost of purchasing the handset at price $p_{b't}$, paying an early termination fee (ETF) of ETF_{it},[51] and paying some individual specific intrinsic

[47] See Gowrisankaran and Rysman (2011) and Geweke and Keane (1996)

[48] When estimating the model, consumers are indeed able to break their contract and switch to a different bundle.

[49] Given the high "retail" (unsubsidized) listed prices of handsets, if a handset is broken, it can often be less expensive to pay an ETF and purchase a new subsidized handset than to replace the previous handset.

[50] Unreported estimates of this model omitting observations who claimed to have broken contracts yields similar results to the reported results.

[51] Early termination fees vary by carrier and typically decrease every month from the date of purchase until the contract expires after two years. Consumers who are off-contract in period t have $ETF_{it} = 0$.

switching cost β_i^s, designed to capture the cost of learning about new devices, learning how to use a new device, and transferring data. The discount factor d is fixed at $0.9916 = 0.9^{(1/12)}$, giving an effective annual discount rate of 10%. The term $\gamma_{it}(x)$ is the consumer's value function when off-contract in x months. It is modeled as $\gamma_{it}(x) = \theta_\gamma^x \max_{b'}\{U_{ib't}\}$, as per Assumption 2. That is, a consumer looks at the discounted utility available from other bundles this month, and expects the maximum of that set to grow by a fixed percentage every month.[52] The 24-month discounting reflects the two-year length of contract.

Therefore, the consumer's decision to consume handset-network bundle b in a given period is captured by the inequality

$$U_{ibt} \geq U_{ib't} \ \forall b'$$

Combined with a model for monthly flow utilities u_{ibt} and a value for the parameter vector, the above could be used to simulate an individual's path of choices over time: every month, consumer's compare the present value of their current bundle to the present value of competing bundles, accounting for the fact that alternatives are expected to improve over time.

Monthly Flow Utility Consumers live in different markets, and since network characteristics differ across markets, this affects an individual's flow utility.

An individual i in market m receives flow utility from handset-network bundle b consisting of handset h on network n in month t. Utility consists of a handset component, a network component, an interaction between those two, and a monthly access fee:

$$\begin{aligned} u_{imbt} &= (1-\beta_t)^{(t-t_{i0})}\left[\delta_{imnt} + \delta_{iht} + \beta^c \cdot \delta_{imnt} \cdot \delta_{iht}\right] - \alpha_i \cdot p_n \\ \delta_{imnt} &= \beta_{in} \cdot X_{mnt} + \xi_n \\ \delta_{iht} &= \beta_{ih} \cdot X_{ht} + \xi_h \end{aligned} \tag{4}$$

The term $(1-\beta_t)^{(t-t_{i0})}$ captures a deterministic rate of decay of a handset purchased in month t_{i0} over time, with the monthly decay rate β_t to be estimated. The term β^c allows consumer utility to be non-linear in the utility of the individual bundle components so that network and handset utility may be complements or substitutes, as discussed in Section 1.1. The network's monthly access fee is p_n. An individual's price sensitivity, α_i, will be modeled as

$$\alpha_i = \mathbf{Z}_i \cdot \beta_\alpha + \eta_i^\alpha \tag{5}$$

where $\mathbf{Z}_i$ are indicators for an individual's income group,[53] β_α are fixed coefficients and η_i^α

[52] The maximum of the set is selected as though the consumer were not currently on a contract, as that is the proper benchmark for modeling the value of being off-contract.

[53] I use 7 income groups in total, as all groups above \$100K in income have similar rates of ownership of smart-

is an i.i.d. mean-zero normal draw with variance σ_η to be estimated. Utilities from the handset and network, δ_{imnt} and δ_{iht} respectively, are modeled as projections on to the characteristics of the networks and handsets. Consumers have individual-specific draws for their tastes for dropped calls, and for each of the four major national carriers.[54] Similar to network quality, handset quality depends on a vector of handset characteristics over which consumers have random and fixed coefficients: random coefficients over indicators for the Android, iOS, and Blackberry handheld operating systems, and fixed coefficients over indicators for feature phone and smartphone, the log of the number of "apps" available on the handset platform, and whether or not a given device is that network's "flagship" device[55] at that time.[56] Smartphone bundles also include a handset generation effect ξ_h that is constant over time, and a carrier-specific data-network fixed effect ξ_n to capture carrier differences in smartphone offerings and advertising at the national level. The individual-specific random coefficients $\beta_i = [\beta_{in}\, \beta_{ih}]$ are distributed jointly normal according to $\beta_i \sim N\left(\overline{\beta}, \Sigma\right)$ and are constant over time. All off-diagonal elements of Σ are set to 0, except those corresponding to covariances between random coefficients of the handset OS dummies and the rate of dropped calls, which are to be estimated.[57]

To summarize, individuals have individual-specific taste draws for network quality, handset platforms, and carriers. Their price coefficient is a function of their household income. Consumers will purchase a new handset-network bundle as new devices are introduced or characteristics (such as the number of apps) increase, as their switching cost falls due to their contract ending, and as their current device decays over time.

4.1 Estimation Approach

The approach taken to estimate the above model will be to use the simulated non-linear least squares (SNLLS) estimator proposed by Laffont, Ossard and Vuong (1995). The model described above could also be estimated using a simulated GMM estimator in the spirit of McFadden (1989)

phones in the dataset. Note that the mean income coefficient of the lowest income group is normalized to -1, but for the remaining groups is estimated freely.

[54] The dropped call rates used in estimation are relative to the market average. There exist markets where, for geographic reasons, all major carriers have poor quality networks, but I do not observe less adoption of mobile phones in those markets. Instead, the primary driver of differences in overall mobile phone adoption across markets is the income distributions of the markets. Conditional on owning a mobile phone, the relative shares of the carriers is heavily influenced by their relative quality, as discussed in Section 3.

[55] While I observe advertising spending by carrier and market, I do not observe it at the device level. Conversations with industry sources confirm that carriers focus their device advertising on one "flagship" device at a time. Therefore, I have identified each network's "flagship" device for the period in question, and assigned it an indicator equal to that carrier's share of advertising spending in that market and month.

[56] Additional characteristics such as GPS, wifi, memory, screen size, screen resolution, and camera resolution have also been gathered. However, trends in these are highly collinear with processor speed, and so they are not included.

[57] This allows that tastes for say, Blackberry devices, is correlated with tastes for high-quality networks.

or Pakes and Pollard (1989). Given a parameter vector, the model would predict market outcomes for every market and every month given product characteristics and prices. Simulation methods could be used to integrate over the random coefficients, and the simulated moments of the model could then be matched to observed moments of the data. However, as is well-known in this literature, minimizing a naive sum-of-squares of the difference between simulated and observed moments is biased for any fixed number of simulation draws.[58] The SNLLS estimator explicitly corrects for the simulation bias in the objective function, resulting in a consistent estimator that is far less computationally demanding than alternative approaches.[59] Due to the highly-nonlinear objective function for this problem, I estimate the parameter vector by nesting the SNLLS estimator inside an Markov Chain Monte Carlo (MCMC) framework, as proposed by Chernozhukov and Hong (2003). As they show, for an estimator such as SNLLS, a Markov Chain can be constructed that shares the same distribution as the asymptotic distribution of the estimated parameter vector. Parameter estimates can be taken as the mean of the Markov Chain, although I will use the inference method suggested by Laffont, Ossard and Vuong (1995).[60]

A major challenge is that this type of model faces the "initial conditions problem" (Heckman, 1981), where the process that determines a sequence of outcomes must somehow be initialized. For example, when simulating this model, most individuals already own a mobile phone in the first month of data. This empirical distribution cannot be taken as given and the random coefficients will not be distributed independently of the state observed in the first month; a given parameter vector must rationalize that initial state (as discussed in Appendix A.5). If the conditional distribution is not known, then the ideal approach is to start where there is no initial condition (Pakes, 1986). Therefore, simulation begins 5 years prior to the data, allowing consumers to make decisions once per year in a random month, and then up to 4 times in the final year depending on their random month.[61] The choice set in this initial period is limited to a smaller set of smartphones than truly

[58] See Appendix A.6 or Laffont, Ossard and Vuong (1995) for details.

[59] An alternative approach to this problem proposed by Gourieroux and Monfort (1993) uses moment conditions of the form

$$E\left[\left(\psi_l^0 - \psi_l^{NS}(\theta)\right)\frac{\partial \psi_l^{NS}(\theta)}{\partial \theta}\right] = 0$$

where different sets of draws are used to compute the simulated moments and their derivatives, respectively, to eliminate correlation. Computing the derivative of the simulated moment is computationally costly in this setting.

[60] The Laffont, Ossard and Vuong (1995) correction term is accurate for any linear transformations of the objective function. However, the MCMC method involves an exponential transformation that leads to incorrect confidence intervals. Therefore, the inference suggested by Chernozhukov and Hong (2003) is not valid in this setting. I compute the inference as suggested by Laffont, Ossard and Vuong (1995) using 6 times as many simulation draws to increase the precision of the estimated derivatives.

[61] I chose 5 years because 98.6% of observations in the first month of data claim to have purchased their current smartphone within 5 years; 98.0% is the average for all months.

existed, but that captures the most popular models observed in the first month of data.[62] The effect of this is that a simulated individual who arrives in November, 2008 with a Blackberry device on Sprint has a vector of tastes that rationalizes this choice.

What does a sequence of choices for a "simulated individual" look like? As an example, a sequence of choices may be that an individual in a certain market with a set of taste draws emerges from the initial period and arrives in month 1 of the data with a Blackberry on Sprint and four months remaining on contract. In months 2-7, this individual perceives greater discounted flow utility from her current device, even though her contract expired in month 5 and her handset is decaying at a monthly rate of β_t. However, in month 8, a new iPhone is released and this consumer perceives a higher level of discounted flow utility from the iPhone-AT&T bundle, even after paying for the new handset and paying an internal "switching cost".[63] This consumer buys that bundle and then remains with this bundle through month 26, as no other bundle offered enough of an increase in discounted flow utility in any of months 9-26 to overcome her contract termination fees and internal switching cost. This is a single sequence for a single drawn individual in a single market: many such sequences are simulated for each market based on different draws of unobservables.[64] Once many sequences have been simulated, they can then be aggregated into moments such as market shares and average characteristics of products.

Each moment $l = 1..L$ observed in the data, ψ_l^0, can be compared to its simulated counterpart $\psi_l^{NS}(\theta)$.The bias-corrected objective function subtracts a consistent estimate of the simulation error (discussed in Appendix A.6), resulting in

$$Q_{LNS}(\theta) = \frac{1}{L}\sum_{l=1}^{L}\left\{\left(\psi_l^0 - \psi_l^{NS}(\theta)\right)^2 - \frac{1}{S(S-1)}\sum_{s=1}^{S}\left(\psi_{sl}^{NS}(\theta) - \psi_l^{NS}(\theta)\right)^2\right\} \tag{6}$$

where $\psi_{sl}^{NS}(\theta)$ is the value of the simulated moment for a single simulation draw and $\psi_l^{NS}(\theta) = \frac{1}{S}\sum_{s=1}^{S}\psi_{sl}^{NS}(\theta)$. Thus, the consistent estimate of the parameter vector is $\theta^* = \arg\min_\theta Q_{LNS}(\theta)$. Once the above method has recovered an estimate θ^* of the true parameter vector θ^0, the standard inference methods for simulation estimators can be used to recover confidence intervals for all parameter estimates.[65] The MCMC estimation routine uses 200 simulated individuals per income group per market, for a total of 126,000 individuals. Additional details on the simulation are in

[62] The prices and release dates for the smartphones available in this "initial period" were gathered by hand. The smartphones included are all iPhones, the Blackberry Curve, Pearl, Bold, 7200 series and 8800 series, the Motorola Q series of Windows phones, the Nokia N75 series, and a "generic" smartphone available on each carrier to capture all others. The generic "feature phone" is also included for each carrier.

[63] I estimate the distribution of the switching cost, β_i^s, as a normal truncated at 0 with mean μ_s and standard deviation σ_s. While this captures the implicit cost of learning a new device and transferring data between old and new devices, it may also be capturing frictions such as search costs.

[64] An important feature is that the same draw of unobservables may result in different paths in different markets, due to differences in network quality.

[65] Appendix A.6 provides additional details on the objective function and the MCMC algorithm.

Appendix A.4.

In summary, consumers have individual-specific taste draws for each carrier, for each of the three handset operating systems, for price sensitivity (as a function of income), for network quality, and for switching costs. These individual tastes are persistent over time. A large number of sequences of consumer decisions are simulated and moments of the simulated model are matched to moments of the raw data, correcting for bias introduced by simulation error. The total number of parameters to estimate is 35, plus an additional 14 fixed effects corresponding to each generation of handsets on each smartphone platform, and carrier-smartphone fixed effects.

The above model is similar to the Pure Characteristics demand model described by Berry and Pakes (2007), which omits i.i.d. Logit draws for each possible good and opts instead for only random coefficients to rationalize tastes. If, instead, we were interested in estimating a version of this model with Logit tastes, we could indeed add i.i.d. Logit errors to each discounted flow utility U_{imnht} every period and directly estimate a likelihood for each survey respondent. However, such a model has many drawbacks give the available data, the largest being that if a given survey respondent purchased a new device in a survey month, the econometrician does not observe their previous state (device and contract status) and so cannot construct the correct choice set that they faced when making that decision. A further discussion of the drawbacks of a standard Logit setup is found in Appendix A.5.

4.2 Identification and Moments

Network monthly access prices do not change over this period, and so identification of preferences for networks comes primarily from cross-sectional variation in the quality and market share of each network, controlling for each market's income distribution. Prices and characteristics of handsets are changing significantly over time but are the same across markets, and so the time-series variation in these are identifying preferences for handsets, as well as parameters relating to switching costs and the handset decay rate. The variation in ownership rates of feature phones and smartphones between income groups identifies differences in price sensitivities between income groups. The age distribution and the purchase rate of smartphones identify the handset decay and switching cost parameters.

A common concern when estimating tastes for a bundle of two goods (a handset and a network in this case) is confounding correlation of tastes with complementarity between the elements of the bundle.[66] In this setting, these separate elements are identified by the cross-section variance in network quality. If, for example, tastes for Blackberries and network quality are correlated, one would expect to see the share of consumers with Blackberries roughly similar across markets,

[66] See Gentzkow (2007) for an analysis of this issue in the context of online newspapers versus print newspapers.

but that consumers sort into the higher quality carriers in each market. If instead, the two elements of the bundle are complements, then one would expect a carrier's share of consumers with smartphones to increase across markets as its network quality increases.

The moments used in estimation are the following for each of the 90 markets and each of the 26 months of data: the share of consumers buying a smartphone this month (1); the share of consumers with a smartphone in each of the smartphone-generation segments (14); the number of smartphones in the market that are over 1, 2, 3, and 4 years old (4); the market share of each carrier for smartphones and for feature phones (10); the shares of each income group owning smartphones and owning feature phones (14); and the average network quality by smartphone operating system (3). This is a total of 46 moments per month-market, and a market's moments are weighted in the objective function by the share of respondents they represent in the survey to account for the greater measurement error in moments for markets with fewer respondents.

5 Estimation Results and Discussion

Parameter estimates for price coefficients, mean utilities and structural parameters are found in Table 3. Estimates of random coefficient parameters are found in Table 4. Looking at Table 3, all price coefficients are negative and significant, and also show the expected trend that higher income groups are less sensitive to price. Estimates of the distribution of individual switching costs show a mean of $108, although a very large standard deviation of $88. Given that the distribution is restricted to be positive in estimation, this implies approximately 10% of individuals have a switching cost of 0 at the estimated parameter vector. This is consistent with other work that has documented important search and switching costs in telecommunications.[67] The complementarity parameter β^c is slightly negative, indicating that bundle utility is slightly nonlinear and that consumers may be willing to substitute handset and network quality.

In Table 4 are estimates of the random coefficient parameters. Most are significant, except for the correlations between handset tastes and tastes for dropped calls. Of those, only that for Blackberry is significant at the 5% level. Consumers have a strong distaste for dropped calls, although there is significant heterogeneity captured by the large standard deviation of that distribution. While the large negative estimates for the means of tastes for the three smartphone platforms may appear odd at first, any of these handsets benefits from the base smartphone utility estimated in Table 3 as well as from the effects of apps, advertising, and smartphone generation fixed effects.

The model fits the data well, with the average absolute difference between the simulated and true value of a moment of 1.4%. The survey nature of the data implies that there is substantial measurement error in some moments, particularly in smaller markets, and so some absolute error

[67] See for example Knittel (1997).

is to be expected. The average difference between simulated and true moments is less than 0.04%, implying that the simulated model fits the trends of the data well. The moments that are fit with the largest error are the shares of consumers owning a feature phone by income group, which is not surprising as little effort is made at modeling feature phone choices.[68]

5.1 Elasticity Estimates

Of most interest are estimates of price elasticities for each carrier's monthly access price for smartphones as well as for handsets themselves. Computing an elasticity in this setting is complicated as it depends on a consumer's state: a consumer's current device and contract status in a given month will greatly alter the effect of price changes on their decisions that month. To address this, elasticities are computed using the quantity over the entire sample time period of 26 months, effectively averaging the elasticity over the entire set of states experienced by consumers in the sample period. That is, for a wireless carrier, the quantity used in computing the price elasticity of the demand they face is the sum total of customer-months of smartphone service plans that they sell over 26 months. The simulated effect of a small price change for monthly smartphone service or a given manufacturer's handsets on demand at the parameter estimates is used to estimate elasticity. Confidence intervals are computed by drawing 200 times from the posterior distribution of the parameter estimates and re-computing the demand elasticity.

Table 5 shows estimates of price elasticities for AT&T and Verizon's monthly smartphone access price at the observed monthly smartphone access prices and handset contracts in the "Base" scenario. As can be seen, both firms face elastic demand for smartphone service at their observed prices. The subsequent rows decompose the elasticity estimates by altering model parameters. The second scenario replaces Verizon's random coefficient distribution with that of AT&T. The third scenario also sets consumers' tastes for dropped calls to 0. The fourth scenario replaces Verizon's handset assortment and monthly access price with AT&T's (including the iPhone). By the fourth scenario, both firms face the same elasticity of demand. The base scenario elasticity estimates imply marginal costs over this time period of roughly $30 for both carriers, as shown in Appendix Table 11.

Ideally, handset elasticities should be computed as well. One complication is that some Android and Blackberry handsets are offered at a price of $0 on contract after they have been displaced on the market by newer generations of devices. Elasticity is 0 at a price of 0, and so instead the elasticity of demand is computed for only Apple devices at their observed prices. As can be seen from the estimate of approximately -0.4, demand for Apple handsets is inelastic at the observed

[68] In particular, for low income levels, overall mobile adoption is increasing, although there are no time trends estimated in the model to account for an increase in feature phone utility in this time period.

prices, which is not consistent with typical monopolistic price-setting. Instead, it appears as though the handset price is artificially low, to attract consumers onto two-year service contracts.

6 Counterfactuals

The parameter estimates from the model can now be used to simulate a number of counterfactual scenarios involving alternative contractual arrangements among handset firms and wireless carriers.

6.1 Willingness to Pay for Exclusivity

This counterfactual examines, ex-ante, which of the national wireless carriers had the most to gain from an exclusive contract with Apple in 2007. The values for AT&T and Verizon are the most relevant, as these are the two largest carriers and they were the only ones rumored at the time to be in discussions with Apple. Prices for the iPhone devices are fixed at their values from AT&T regardless of the carrier, but monthly access prices are allowed to re-adjust where indicated in Table 6. The willingness to pay is defined as the total monthly plan profit[69] with exclusivity less the total monthly plan profit from rival exclusivity over all 26 months.[70] The simulated market shares are scaled by the US Census figure of American adults in 2012 to arrive at dollar amounts.

If prices are held fixed (upper panel of Table 6), Verizon has a higher willingness to pay by approximately $3.8B, as they are able to attract a large number of subscribers when offering the iPhone in the "base" scenario. The subsequent rows reconcile the carriers' willingness to pay with different features of the model: first, consumers' tastes for Verizon's network are set to be the same as AT&T's, which closes the gap to $2.9B. Then consumers' tastes for dropped calls are eliminated, which decreases the gap to less than $1B. Finally, Verizon's assortment of devices and monthly plan price are replaced with AT&Ts, and the willingness to pay is nearly identical. This is evidence that Verizon differentiates itself largely via the quality of its network, and that without the iPhone, Verizon offered a more compelling assortment of Android and Blackberry devices than AT&T.[71] As a robustness check, Appendix Table 12 shows estimates of willingness to pay with

[69] The plan profit is the plan price less the estimated marginal cost of $30 for both carriers (Appendix Table 11). While the estimates for the two carriers differ, I choose to use the same marginal cost as the carrier-specific costs are not estimated with great precision. Using the point estimates would not change the qualitative results of the counterfactuals.

[70] Verizon is considered to include Alltel, which was acquired in June of 2008. The willingness to pay excludes the first 15 months of iPhone availability as no empirical moments are matched until November of 2008, and so these values are likely underestimated. Furthermore, I omit any revenues from premium plans, as I use the (modal) base smartphone monthly service price.

[71] Verizon began offering a wide array of Android handsets in 2009, and invested heavily in promoting Android.

$\beta^c = 0$, so that handset and network quality are not substitutable, and with marginal cost set to 0 (i.e. using only the change in revenues from exclusivity).[72]

However, the theory motivation presented earlier indicated that the primary driver of exclusivity being optimal is the change in price equilibrium. In order to determine a new price equilibrium, the estimated marginal cost from the price elasticity of demand estimates is taken as given, and the iPhone devices are re-assigned to Verizon. Starting at the observed monthly smartphone plan prices, firms iterate best responses until a new equilibrium is found.[73] The change in smartphone service profit from the new equilibrium is then computed.

Once prices are allowed to adjust (lower panel of Table 6), AT&T has a significantly higher willingness to pay than Verizon. This is due to the fact that without the iPhone, AT&T's share of the market falls significantly and their equilibrium price drops by $5.69, while Verizon's equilibrium price with the iPhone falls by $1.55 in response. Verizon's higher quality network helps insulate it from price competition, and so it suffers less harm from rival exclusivity than AT&T. These simulation estimates illustrate the asymmetric cost of rival exclusivity in this setting, and the importance of equilibrium price effects on the observed market outcome.

6.2 Effect of Apple Exclusivity on Android Entry Incentives

This counterfactual considers the expected profits of the manufacturers of smartphones running Google's Android operating system (the "Open Handset Alliance")[74] had Apple instead chosen to be available on all carriers. The scenario compares the variable profits from handsets earned from sales of Android units between November 2008 and December 2010 under the alternative scenario that the iPhone had initially launched on all four national carriers.[75] This is accomplished by summing all simulated handset purchases by handset operating system over the time period covered by the dataset. All prices and characteristics are held constant at their observed values.[76]

Table 7 shows that the exclusivity between Apple and AT&T created a significant opportunity for the Android handset manufacturers. Consistent with intuition, had Apple not chosen to be exclusive, expected profits for Android handset makers would have been lower by approximately

[72] Since setting β^c to 0 effectively increases utility from all handsets, I cannot compare the values to those discussed above. However, I still observe similar patterns in the simulations.

[73] I cannot prove that there is a unique equilibrium, although in all simulations the prices converged to a new equilibrium in fewer than 10 iterations.

[74] The "Android Consortium", a consortium of 84 companies that includes 22 handset manufacturers, among them Motorola, Samsung, and HTC.

[75] Marginal contribution per handset to the manufacturer is assumed to be $168, which is the average equipment subsidy paid by Sprint in 2009. This value was obtained from Sprint's 2010 10-K report. Verizon Wireless does not publish a comparable figure. These subsidies are said to have been increasing during the time period studied.

[76] The most obvious characteristic that may change would be the number of "apps" available on Android, as we might expect this to be a function of the installed base of Android phones. This leads to a more conservative estimate of the number of lost sales. Future work will examine this more closely.

$1.4B during this time period. In the interest of comparing magnitudes, the 2009 operating profit of HTC, one of the most successful Android handset makers at the time, was $750M,[77] while another major Android handset manufacturer, Motorola, reported annual operating losses on its mobile handsets business for 2008 through 2010. Therefore, this represents a sizable change in incentives.[78] This indicates that the existence of exclusive contracts creates a significant incentive for entry in this setting.

6.3 Apple's Tradeoff

In order to determine the answer to the question of how much AT&T would have been willing to compensate Apple for the lost market potential due to exclusivity, a Nash bargaining framework is used. Apple negotiated with carriers over dividing the surplus created by exclusivity between the two parties. Analysis of this type of situation goes back to Nash (1950) and has inspired a rich literature since. Suppose all parties are risk-neutral and the total surplus from exclusivity to be divided is S. Apple and the carrier each have threat points denoted s^0_{Apple} and $s^0_{Carrier}$, which are their payoff should agreement not be reached. Nash proved that the unique solution would allocate a share λ of the surplus to Apple where

$$\lambda = \arg\max_{\lambda} \left(\lambda S - s^0_{Apple}\right)\left((1-\lambda)S - s^0_{Carrier}\right)$$

Using the counterfactual exercises above, the surplus created by exclusivity and threat points can be estimated. Effects on each firm's quantity and price are summarized in Table 8. Using these, the expected surplus allocated to Apple in negotiations with AT&T is computed, and then divided by the total number of handsets they could have sold in the absence of exclusivity to determine the compensation Apple was able to extract per-unit from AT&T. The threat point for AT&T, s^0_{ATT}, is estimated as their smartphone service profits over this time period if the iPhone were exclusive to Verizon and prices are able to adjust to a new equilibrium. The surplus created by exclusivity, S, is the incremental smartphone service profit from AT&T having the iPhone as an exclusive device (the observed case). Finally, Apple's threat point, s^0_{Apple}, is computed as Verizon's incremental smartphone service revenue with an exclusive iPhone versus having the iPhone on all carriers.

Solving, there is an estimated $144.91 per-unit equilibrium compensation. This is the expected payment for every iPhone that Apple sold and *could have sold* had they been non-exclusive. As a comparison, Apple's 2010 net income for the entire firm was $14B, and the firm sold 40M

[77] HTC Corporation 2009 Annual Report. Operating income is 24.174B TWD

[78] Furthermore, it is a conservative estimate. In addition to the issue mentioned in the previous footnote, this does not take into account changes in subsidies or handset prices. It is not feasible to recompute a new handset price equilibrium given the number of prices this would involve (every handset, every month). This also does not take into account any effect on the number of apps available for the Android platform.

iPhones worldwide.[79] If half of the current year's profits are from current iPhone unit sales, that would represent $175 profit per unit, which is comparable to what AT&T would have willing to compensate Apple for unit sales foregone due to exclusivity. Without more details on Apple's per-unit profit level, it is not possible to conclusively state that exclusivity was optimal, but this calculation shows that AT&T's willingness to pay was comparable to what Apple is likely able to earn per iPhone sold.[80]

6.4 Bargaining Structure

The final counterfactual examines the alternate outcomes of the bargaining game that Apple played with AT&T and Verizon. In particular, it illustrates the importance to Apple of negotiating with both carriers. Consider instead if Apple had only been negotiating with AT&T, and so if negotiations failed, the iPhone would have been available on all carriers. This would change the threat points as well as the surplus created by exclusivity. The Nash bargaining solution is re-estimated where s^0_{Apple} comes from the iPhone being available on all carriers with Apple earning the industry average equipment subsidy per unit, s^0_{ATT} comes from recomputing equilibrium prices if the iPhone were available on all carriers, and S comes from AT&T's change in smartphone plan profits should the iPhone be available on all carriers instead of exclusive. AT&T is far better off if all carriers (including itself) offer the iPhone than if Verizon is the exclusive provider, and so s^0_{ATT} is now higher. This also implies a lower surplus from exclusivity, S. Combined, the result is that the compensation AT&T would be willing to pay per-unit falls to $78.88 in equilibrium, nearly half what they were willing to pay when Verizon exclusivity was the alternative. It is possible to conclude from this that being able to negotiate with multiple major carriers for exclusivity was essential to the observed market outcome, as it greatly increased the amount of surplus Apple was able to extract in negotiations.[81]

7 Conclusions

This paper proposes a simple motivation for exclusive contracting in the smartphone market: if consumers are more willing to substitute between downstream goods (wireless networks), an ex-

[79] Apple Corporation 2010 Annual Report

[80] Some may argue that the relevant comparison is with the case where Google's Android does not enter, as Apple may not have anticipated Android's 2008 entry into the market. However, Google had purchased the software developer responsible for Android in 2005, and so it is reasonable to assume that Apple anticipated such an entry.

[81] This is consistent with the outcome in Canada, a market less than one tenth the size of the US market. At the time of the iPhone's global launch, only a single Canadian carrier's network was compatible with the iPhone, and so while the device launched only a single carrier, there was no exclusive contract, and Apple was not able to extract any terms from the carrier (Rogers Communications). Rival carriers launched a compatible network in 2010, at which point the iPhone became available on all Canadian carriers.

clusive contract between a wireless carrier and a handset maker can reduce price competition and lead to higher equilibrium prices. However, since the downstream goods are not in fact perfect substitutes, exclusivity leads to a smaller market potential, and so the question of whether or not it leads to higher joint profits of the contracting parties is an empirical question.

An econometric analysis of this market shows that consumers are more price sensitive with respect to wireless networks than handsets, and so exclusivity can be a profit-maximizing strategy. Counterfactual simulations show that AT&T was indeed willing to sufficiently compensate Apple for the smaller market potential caused by exclusivity once equilibrium price effects are computed, and that this exclusive contract significantly increased the entry incentives of rival smartphones, such as those running Google's Android operating system. In addition, being able to negotiate with major rivals was essential for Apple to be able to extract sufficient compensation for exclusivity.

This analysis helps quantify the competing forces that shape policy relating to vertical restraints. While no point estimate of the welfare effect of Apple's contract is identified, the magnitudes of the competing forces are both large: exclusive contracts created upward pricing pressure, but also strong incentives for innovation in this setting. Regulators should continue to be concerned about such arrangements, although the tradeoff between them will continue to be difficult to measure.

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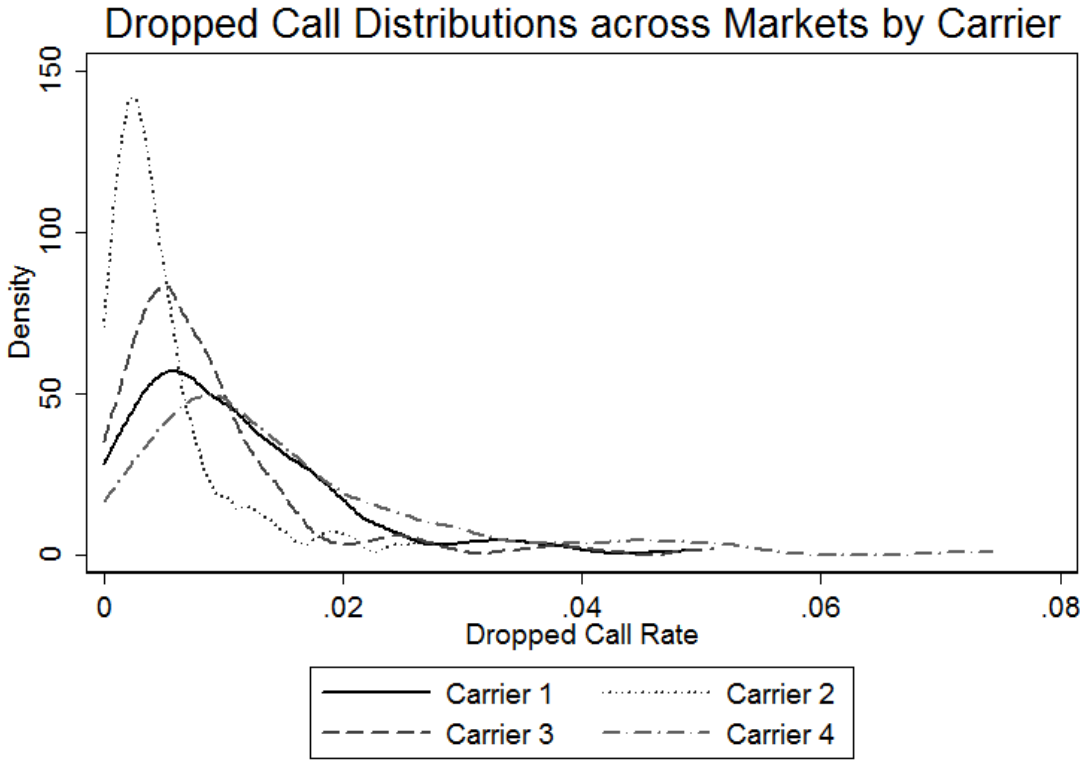
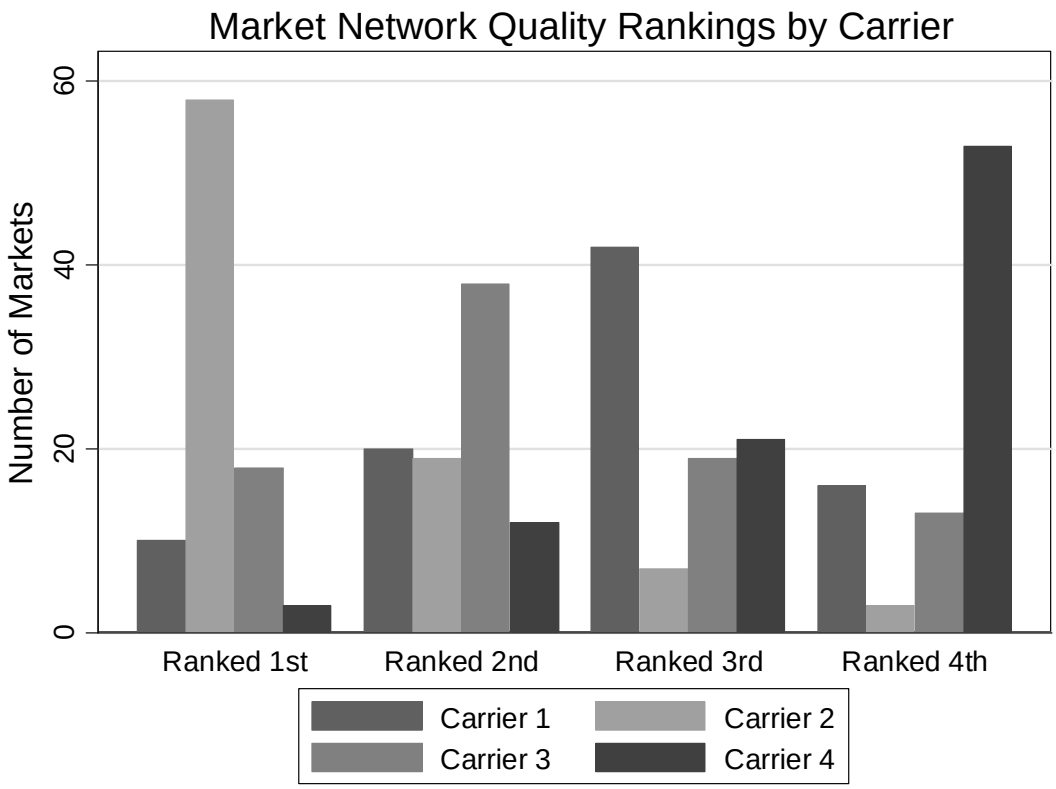
Figures

Figure 1: Network Quality Across Markets



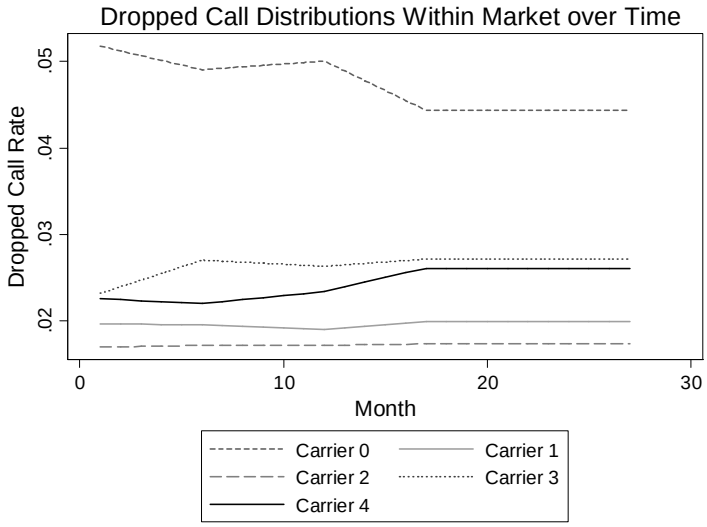
Notes: The above graph is a kernel density plot using the Epanechnikov kernel of the distribution of each national carrier's dropped call rate across 90 markets in survey month 50 (early 2010). A greater mass towards the left indicates a lower dropped call rate overall.

Figure 2: Network Quality Rankings



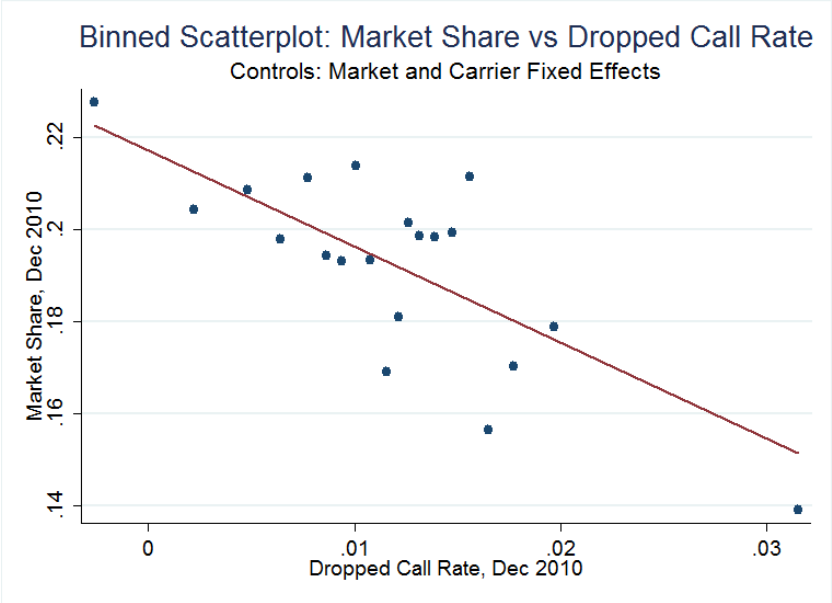
Notes: The above histogram shows the count of markets in which a national carrier is ranked first through fourth among the national carriers in a market for its dropped call rate (lowest is ranked first). Data is for all 90 markets in survey month 50 (early 2010).

Figure 3: Network Quality Within Market



Notes: The above graph shows dropped call rates over time for the four national carriers as well as a regional carrier (Carrier 0) in a representative, large US market. The time frame is November 2008 to December 2010.

Figure 4: Binned Scatterplot: Market Share vs Dropped Call Rate



Notes: The above scatterplot uses data for all carriers in all markets in Dec 2010. Total market shares for each carrier (feature phones and smartphones) and dropped call rates are residualized by carrier and market fixed effects to produce the regression line. The dots represent means within binned groups of residuals after adding back sample means.

Tables

Table 1: Summary Statistics

Demand Survey Data Characteristics		Market Shares and Trends	
Number of Markets	90	Monthly rate of smartphone purchase	1.55%
Number of Months	26	Smartphone Ownership by Income:	
Total Observations	573,121	Low Income, First Month	3.80%
Min Monthly Respondents	18,836	Low Income, Last Month	19.31%
Max Monthly Respondents	24,030	High Income, First Month	14.58%
		High Income, Last Month	36.76%
Dropped Call Rate:		Smartphone Ownership by Type:	
Average	0.0116	Android, First Month	0.08%
Standard Deviation	0.0124	Android, Last Month	7.78%
Minimum	0	Apple, First Month	1.78%
Maximum	0.1254	Apple, Last Month	6.91%
		Blackberry, First Month	2.92%
Markets with Only Four Carriers	21	Blackberry, Last Month	6.87%

Notes: Demand survey data comes from proprietary Nielsen Mobile Insights survey. Dropped call rate is from the Nielsen Drive Test Database. The average dropped call rate can be interpreted as 1.16% of attempted calls fail, in that they fail to connect or disconnect within two minutes. "First month" indicates November 2008 while "Last Month" indicates December 2010.

Table 2: Carrier Choice Logit Model Estimates

	Logit Outcome Variable: Market Share of Purchases					
	Oct 2008		Oct-Nov 2008		Oct-Dec 2008	
	(1)	(2)	(3)	(4)	(5)	(6)
Dropped Call Rate	-57.874^{**}	-54.757^{**}	-55.585^{***}	-47.621^{**}	-43.615^{***}	-50.140^{***}
	(23.834)	(27.135)	(20.283)	(22.255)	(14.127)	(17.111)
Carrier Fixed Effects	**X**	**X**	**X**	**X**	**X**	**X**
Market Fixed Effects	**X**	**X**	**X**	**X**	**X**	**X**
Sample:						
All Markets	**X**		**X**		**X**	
5-Carrier Markets		**X**		**X**		**X**
N	429	345	429	345	429	345
R^2	0.450	0.442	0.424	0.409	0.425	0.445

Notes: Standard errors are clustered at the market level. "Dropped Call Rate" is the average over the time period of purchases. The dependent variable is $ln\left(\frac{s_j}{s_0}\right)$, where s_j is the share of consumers purchasing any phone from carrier j during the time period, and s_0 is the share of consumers purchasing no new phone during the time period. Observations are weighted by respondent weights in the Nielsen Mobile Insights survey when computing shares. The symbols *, **, and *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Table 3: Estimates of Price Coefficients, Mean Utilities, and Structural Parameters

Income Group	Price Coefficient Estimate
<$15K	-1
	-
$15-25K	-0.9658***
	(0.0334)
$25-35K	-0.9379***
	(0.0470)
$35K-50K	-0.9145***
	(0.0620)
$50-75K	-0.8759***
	(0.0846)
$75-100K	-0.8517***
	(0.0819)
$100K+	-0.7922***
	(0.0981)
Standard Deviation	0.3608***
	(0.0833)

Parameter	Estimate
Base Smartphone Utility	15.123***
	(5.195)
Voice Mean Utility	43.479***
	(8.380)
Log(Apps)	9.4505***
	(2.1103)
Flagship Device	14.331**
	(4.395)
Switching Cost Mean	108.90**
	(52.098)
Switching Cost	87.68**
Standard Deviation	(41.913)
Handset Decay Rate (β_t)	0.00216***
	(0.00053)
Continuation Value (θ_γ)	1.0037*
	(0.00235)
Handset-Network	-0.00141**
Complementarity (β^c)	(0.00065)

Notes: Coefficient for lowest income group is normalized to -1. Estimates denoted by *, **, and ***, are statistically significant at the 10%, 5% and 1% levels, respectively. The Continuation Value parameter is tested for significance against a value of 1.

Table 4: Estimates of Random Coefficient Parameters

Network Estimates			Handset Taste Estimates		
	Mean	St. Dev.		Mean	St. Dev.
Carrier 0	0	0	Android	-43.654***	14.824**
("all other" carriers)	-	-		(11.357)	(8.3852)
Carrier 1	-2.1557**	3.8089***	iOS	-43.497***	9.3164***
	(1.0302)	(1.4746)		(11.633)	(2.6961)
Carrier 2	-0.8234**	3.5393**	Blackberry	-27.894***	18.878**
	(0.3897)	(1.6012)		(9.6848)	(8.9566)
Carrier 3	-1.5793**	4.6115***	Handset-Dropped Call Taste Correlation		
	(0.6717)	(1.5878)	Android	-0.0992*	
Carrier 4	-2.3597**	2.7218**		(0.0534)	
	(1.0500)	(1.2662)	iOS	-0.0496	
				(0.025)	
Dropped Calls	-83.694***	52.389***	Blackberry	-0.2024**	
	(26.028)	(20.107)		(0.0750)	

Notes: Since dropped calls are considered "bad", a *negative* correlation between handset taste and dropped calls indicates that people who prefer that handset also *dislike* dropped calls. Estimates denoted by *, **, and ***, are statistically significant at the 10%, 5% and 1% levels, respectively.

Table 5: Carrier Elasticity Estimates

	Carriers		Handsets
Scenario	Verizon	AT&T	Apple Handsets
1. Base	-1.4077	-1.6506	-0.3946
	(-1.6632, -1.2254)	(-1.935, -1.295)	(-0.4636, -0.3216)
2. Same Carrier Tastes	-1.8192	-1.7569	
	(-2.2479, -1.5049)	(-2.0347,-1.4236)	
3. Also Remove Dropped	-1.9763	-1.8112	
Call Tastes	(-2.1544, -1.7602)	(-2.0896, -1.4449)	
4. Also Offer Same	-2.6282	-2.6120	
Handsets, Monthly Prices	(-2.9768, -2.2326)	(-2.8790, -2.1905)	

Notes: Estimates for carriers are price elasticity of demand of monthly smartphone access price over the dataset time period. Estimates for handsets are the price elasticity of demand of handsets purchased over the dataset time period. Estimates and confidence intervals are computed using 200 simulation draws from the estimated parameter distribution.

Table 6: Counterfactual Estimates of Carrier Willingess-to-Pay for iPhone Exclusivity

	Prices Fixed	
Scenario	Verizon	AT&T
1. Base	\$22.866B	\$19.055B
	(21.390, 24.068)	(17.514, 20.210)
2. Same Carrier Tastes	\$23.607B	\$20.557B
	(21.984, 24.865)	(18.885, 21.739)
3. Also Remove Dropped Call Tastes	\$20.979B	\$20.109B
	(19.591, 22.124)	(18.524, 21.292)
4. Also Offer Same Handsets	\$20.679B	\$20.686B
	(18.885, 21.669)	(19.279, 22.218)
	Prices Recomputed	
	Verizon	AT&T
1. Base	\$11.743B	\$19.072B
	(10.680, 13.656)	(16.104, 21.409)
Monthly Access Price Change	-\$1.550	-\$5.659
	(-2.220, 0.639)	(-6.105, -5.220)

Notes: Table shows each carrier's maximum willingness to pay for exclusivity with Apple, defined as the smartphone service profit difference between exclusivity and rival exclusivity. Estimates are based on 200 simulations drawing from the distribution of the model parameter estimates.

Table 7: Counterfactual: Android Entry Incentives

	Apple Enters on All Carriers (\$)
Change in Android Manufacturer Profits	-1,423.4M
	(-2,130.20M, -931.86M)

Notes: Table shows the simulated change in number of Android handsets sold during the data time period, times the average carrier subsidy during the time period when the iPhone is made available on all carriers as of its initial launch. The estimates are based on 200 simulations drawing from the posterior distribution of the parameter vector, and the confidence interval is constructed as the 5th and 95th percentiles of the simulated outcomes. All prices of handsets and of monthly service are maintained at their observed levels.

Table 8: Counterfactual: Android Entry Incentives

Scenario		Verizon	AT&T
AT&T Exclusivity (Baseline)	Service Plan Months	1.0	1.0
	Monthly Price	1.0	1.0
Verizon Exclusivity	Service Plan Months	1.8224	0.2535
	Monthly Price	0.9828	0.9331
No Exclusivity	Service Plan Months	1.1776	0.5743
	Monthly Price	0.9514	0.9293

Notes: Table shows the simulated change in number of smartphone-plan-months sold by each carrier over the sample period under alternative scenarios, along with the change in equilibrium monthly price.

Appendix

Supplemental Appendix For Online Publication

Empirical Appendix A

Theory Appendix B

A Empirical Appendix

A.1 Representativeness of Demand Survey

Table 9: Comparing Demand Survey to Census

	Main Sample (Weighted)	Census
% Female	51.97%	52.06%
% of Adult Population Age 60+	25.54%	24.37%
% Income $100K+	17.22%	15.73%

Notes: Nielsen Mobile Insights include weights for each respondent. Above are comparisons of the weighted respondents to the 2010 US Census.

A.2 Additional Reduced-Form Evidence

The key source of variation for smartphone tastes comes over time, and so one can look at purchases in each month of the data for the entire US market. A challenge is the endogeneity of prices that is typical in the differentiated-product demand estimation literature. However, handset prices are not set in the same way as the usual differentiated-product oligopoly model used in the industrial organization literature: prices are set by the wireless carriers and include a two-year contract in exchange for a subsidized price. For example, the base models of Apple's iPhone handsets typically start at a price of $200 on a two-year contract at their initial release, and independent estimates of manufacturing costs for their devices at the time of release are just under $200.[82] A standard markup equation would imply that Apple had little market power, which is clearly not the case. Instead, handset pricing appears to follow predictable patterns based on the generation of the device, with a given device's price falling when a newer generation is released.[83]

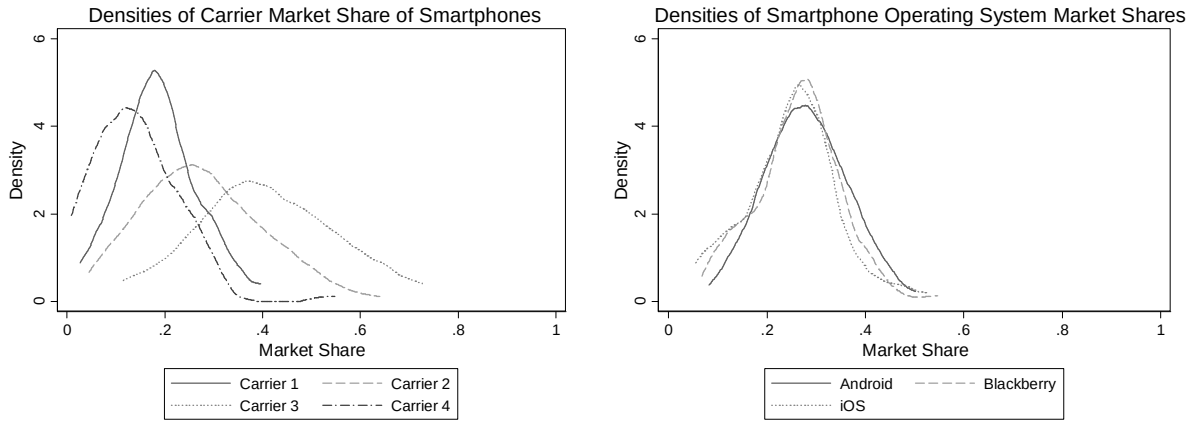
[82] iSuppli Corporation estimated the bill of materials for the entry-level iPhone 3G, 3Gs and 4 at $174.33, $172.46 and $187.51 respectively at their time of release. All three were available from AT&T for $199 on contract at their release.

[83] At the extreme, some older devices are offered free on a two-year contract, although this is not the case for Apple devices during the sample period.

Table 10 shows results from four Logit model specifications examining handsets. The first, a simple OLS estimate, shows a positive coefficient on price, which is typical in a discrete choice setting where one would expect prices to be correlated with unobservable factors that also influence demand. In column 2, prices are instrumented using the average characteristics of competing goods, following BLP (Berry, Levinsohn and Pakes, 1995), and there is a negative coefficient on price, although it is not significant. Column 3 presents an OLS specification but now with fixed effects for smartphone, leveraging the variation over time in introductions of new devices and price decreases of older devices. The price coefficient is reasonable, negative and strongly significant. Finally, in column 4, prices are instrumentd; the estimated coefficient is similar to column 3, but is not precisely estimated.

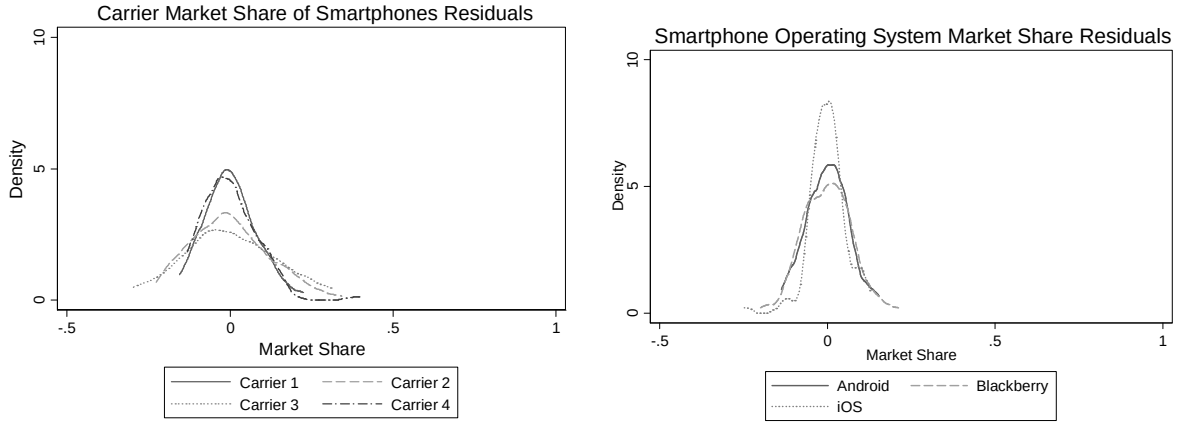
Lastly, there is a question of the relative strength of preferences for networks versus handsets. The data should distinguish whether the market is composed of, say, consumers who want a Blackberry regardless of which carrier it is on, or consumers who want to be on Verizon regardless of what handset they have. Since the data are not a true panel, there are no switching rates between different handset-network bundles to examine. However, treating each market as an independent realization of preferences, the cross-section may contain evidence of substitution. Consider the following: if carriers are good substitutes for one another, one would expect to see wide variance in carrier market shares across markets, relative to the variance in smartphone market shares. Appendix Figure 5 plots these shares across markets in the raw data. There appears to be more variation in carrier market shares than in smartphone market shares across markets. However, there are obvious confounds to this: differences in network quality affect a carrier's market share, as previously discussed. Similarly, since the iPhone is exclusive to AT&T, one would expect AT&T's strength in a market to affect the different smartphone market shares. Appendix Figure 6 plots the residuals from regressions of market shares on controls. Controlling for relevant confounds, there is little variation in smartphone shares across markets, but large variation in carrier shares across markets, lending support to the idea that carriers are good substitutes for one another, but smartphones are poor substitutes for one another.

Figure 5: Across-Market Variance in Shares of Carriers vs Smartphones



Notes: The plots show raw market shares across markets for carriers and smartphones. Shares are averaged over final three months of sample to reduce sample noise in smaller markets.

Figure 6: Across-Market Residuals from Controlled Regressions



Notes: The figures shows residuals from regressions of the market-level shares of carriers and smartphones on a set of controls, including network quality and income distributions. Shares are averaged over final three months of sample to reduce sample noise in smaller markets. Controls include income distributions and network quality (for carriers) and AT&T market share (for smartphones).

A.3 Additional Data and Results

Figure 7: Share of Consumers on Mobile Phone Contracts

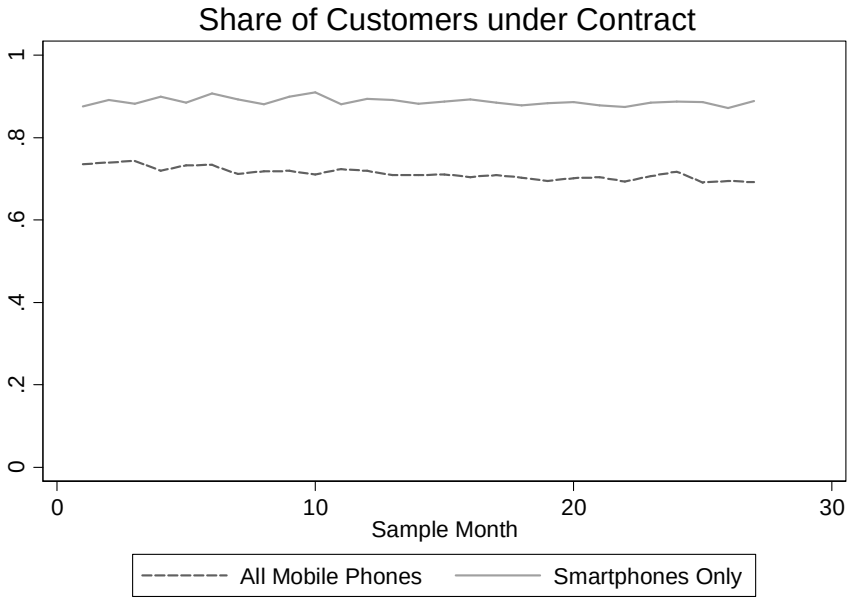


Table 10: Smartphone Choice Logit Model Estimates

	Logit Outcome Variable: Market Share of Purchases			
	OLS	2SLS	OLS-FE	2SLS-FE
	(1)	(2)	(3)	(4)
Price	0.8601^{***}	-0.7101	-0.5526^{***}	-0.4264
	(0.2075)	(0.6541)	(0.1779)	(0.3166)
Ln(Apps+1)	0.0196	0.0708	0.1190^{**}	0.1117^{***}
	(0.0328)	(0.0609)	(0.0305)	(0.0414)
Ln(Processor+1)	0.6646	3.1097^{**}	1.5992	1.2932
	(0.9226)	(1.3836)	(2.5458)	(3.4476)
Month Fixed Effects	**X**	**X**	**X**	**X**
OS Fixed Effects	**X**	**X**	**X**	**X**
OS-Generation Fixed Effects			**X**	**X**
N	257	257	257	257
R^2	0.268	0.045	0.698	0.697

Notes: Standard errors are clustered at the market level for OLS specifications. The dependent variable is $ln\left(\frac{s_j}{s_0}\right)$, where s_j is the share of consumers purchasing smartphone j during the month, and s_0 is the share of consumers purchasing no new smartphone during the time period. Observations are weighted by respondent weights in the Nielsen Mobile Insights survey when computing shares. The symbols *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Table 11: Implied Marginal Cost Estimates

	Estimate ($)
Verizon	25.47
	(16.552, 35.888)
AT&T	32.657
	(19.36, 41.072)

Notes: Estimates are for smartphone plans based on "long term" elasticity over 26 months of sample period. Confidence intervals are based on 200 simulations drawing from the distribution of the parameter estimates.

A.4 Simulation Details

Estimation using the simulation estimator proceeds as follows:

1. For each of the $M = 90$ markets and $N = 7$ income groups, draw a set of S vectors to represent the unobservable types.

2. For each market m, determine a set of weights that, when applied to the N individuals drawn in Step 1, match the observed distributions of the N types in that market. That is, each market

Table 12: Counterfactual Estimates of Carrier Willingess-to-Pay for iPhone Exclusivity

	Prices Fixed, $\beta^c = 0$		Prices Fixed, $MC = 0$	
Scenario	Verizon	AT&T	Verizon	AT&T
Base	\$26.664B	\$22.759B	\$34.299B	\$29.448
	(25.101, 28.032)	(21.088, 24.232)	(32.089, 36.103)	(27.067, 31.234)
Same Carrier Tastes	\$27.393B	\$24.517B	\$35.411B	\$31.770B
	(25.734, 28.813)	(22.693, 25.923)	(32.976, 37.298)	(29.186, 33.597)
Also Remove Dropped Call Tastes	\$24.321B	\$23.806B	\$31.469B	\$31.078B
	(22.971, 25.544)	(22.056, 25.099)	(29.387, 33.186)	(28.628, 32.905)
Also Offer Same Handsets	\$24.472B	\$24.496B	\$31.959B	\$31.970B
	(22.429, 25.646)	(22.995, 26.199)	(29.185, 33.489)	(29.795, 34.336)

Notes: Table shows each carrier's maximum willingness to pay for exclusivity with Apple, defined as difference between the smartphone service revenue margin with exclusivity and with rival exclusivity. Estimates are based on 200 simulations drawing from the distribution of the model parameter estimates.

is expressed as a mixture of finite types of consumers when computing shares. Similarly, determine weights for each market that represent their share of the national market.

3. Search over parameter vectors to minimize an objective function. For each candidate parameter vector,

   (a) Transform a set of S draws to correspond to the random coefficients $\beta_i \sim N\left(\overline{\beta}, \Sigma\right)$ in accordance with the candidate parameter vector.

   (b) For all $N \cdot S$ "drawn individuals" in each of the M markets, simulate the sequence of choices for every month.[84]

   (c) Calculate moments of these sequences that can be matched against observed moments of the dataset.

   (d) Calculate the bias-corrected objective function.

Estimation of the SNLLS parameters was done using Matlab "mex" files to simulate consumer choices and calculate moments and the objective function. I use Halton Sequence draws for random coefficients to improve coverage and reduce spurious correlation. The distribution of random coefficients for dropped calls and for switching costs are truncated at 0, so that no one may get positive utility from dropping calls or switching devices. The MCMC chain constructed has a total length of 100,000 per parameter after a burn-in of 10,000 draws. The variance of the draws for each parameter group is adjusted after every 100 draws per group to maintain an acceptance rate as close as possible to 0.5. I keep track of which markets have only 4 carriers and eliminate the choices from the regional carriers in the market from consumers in those markets when simulating choices. I set $S = 200$, so that the total number of simulated individuals in the nation was 126,000. These individuals each made choices in 26 months plus 8 choices prior to the start of the dataset, for over 4 million choice situations. Each choice situation has nearly 100 options, implying nearly half a billion utility computations per evaluation of the objective function.

A.5 Alternative Logit Approach

The model described in Section 4 is based on the Pure Characteristics model described by Berry & Pakes (2007), which omits i.i.d. Logit draws for each possible good and opts instead for only random coefficients to rationalize tastes. A Logit approach in this setting would consist of adding an i.i.d. Logit errors to each discounted flow utility U_{imnht} and directly estimating a likelihood for each survey respondent. For example, if I observe a survey respondent that owns an iPhone on AT&T which was purchased 5 months ago, then I know that in the survey month, this consumer's

[84] The sequences of choices is begun 5 years prior to the start of the dataset, as discussed in Section 4.1.

state was a 4-month old iPhone on AT&T with 20 months remaining on contract and an early termination fee of, say, $155. I also know that in the survey month, this respondent chose to stay with their iPhone instead of switching to another device or network. I could model the Logit probability of this choice, and maximize the sum of the log likelihoods of these probabilities for all observations. Such an approach has multiple challenges in implementation:

First, such a setup would not easily allow for unobserved tastes (such as random coefficients) beyond the Logit draw. The reason for this is that unobserved taste vectors would have to be drawn from the conditional distribution based on your state. Put simply, our survey respondent's unobserved tastes are not random this month if they chose to purchase an iPhone 5 months ago. Properly drawing from the conditional distribution would be intractable, and imposing that the distribution of random coefficients is state-independent would be unrealistic. This is the "initial conditions problem" of Heckman (1981), and is overcome in this paper as discussed in Section 4.1.

Second, I do not directly observe switching in the dataset. If I observe a survey respondent who purchased an iPhone this month, I do not know what their state was when they arrived in this decision period: they may have been on contract or not, and they may have had a smartphone or not. One approach to measure the likelihood of this observation would be to look at the empirical distribution of states from the previous month for the given market and determine the likelihood of observing an individual purchase an iPhone this month, given the distribution of states in the previous month. This is feasible, although computationally costly, and relies heavily on the quality of the survey sample from that particular market.

Third, direct estimation of each survey respondent would involve maximizing a likelihood over more than 600,000 observations, a non-trivial task. Including random coefficients would increase the computational burden linearly in the number of simulation draws per individual. Even if I were to ignore state-dependence and match aggregate market-level shares for each market and each month, the sample noise is problematic, particularly in smaller markets, and leads to cases of zero shares for some handset-network bundles, whose likelihood is undefined.

Finally, the fact that there are many more models of Android devices than iPhones (see Section 2.3) implies that a Logit approach would likely underestimate the quality of Android devices and skew counterfactuals where the iPhone is made available on additional the carriers. The simple reason is that adding identical products in a Logit model increases welfare, which we know not the be true in reality.

Taken together, this is evidence that this dataset does not lend itself to direct estimation and that serial correlation of tastes is an important aspect of this market to capture. For these reasons, I proceed with the model described in Section 4.

A.6 Bias-Corrected Objective Function, and Inference MCMC Algorithm

The bias-corrected objective function arises form the fact that, as has been noted before, the objective function

$$Q_{LNS}^{naive}(\theta) = \frac{1}{L}\sum_{l=1}^{L}\left\{\left(\psi_l^0 - \psi_l^{NS}(\theta)\right)^2\right\}$$

where moments are indexed by $l = 1..L$ results in a biased estimate when minimized. This is because minimizing the above has as its first order condition

$$H(\theta) \equiv \sum_{l=1}^{L}\left\{\left(\psi_l^0 - \psi_l^{NS}(\theta)\right)\frac{\partial \psi_l^{NS}(\theta)}{\partial \theta}\right\} = 0$$

which, at the true value θ^0, has a non-zero expectation due to correlation between the simulated moment and its derivative; specifically,

$$H\left(\theta^0\right) = -E\left[Var\left(\psi^{NS}\left(\theta^0\right)\right)\right]$$

The bias-corrected objective function obtains a consistent estimate of this above covariance and subtracts it from the naive objective function, resulting in a consistent estimator.

Confidence intervals are obtained using suggestions from Laffont, Ossard and Vuong (1995). Proposition 3 of the former paper establishes a method of estimating confidence intervals that correct for simulation bias (see pp. 964 for estimating equations). I use this suggestion in the construction of the confidence intervals for the point estimates of the parameters. For the confidence intervals of the counterfactuals, I bootstrap 100 draws from the estimated parameter distribution and report the 5th and 95th percentiles of the estimates.[85]

The MCMC estimator uses the method developed by Chernozhukov and Hong (2003), which nests an extremum operator within an MCMC framework. The approach is to construct a quasi-posterior density over the parameter of interest according to

$$p(\theta) = \frac{e^{-Q_{LNS}(\theta)}\pi(\theta)}{\int_\Theta e^{-Q_{LNS}(\theta)}\pi(\theta)\,d\theta}$$

where Θ is a compact convex subset of $\mathbb{R}^k$ that contains θ^0, $\pi(\theta)$ is a prior probability distribution, and Q_{LNS} is the objective function from the SNLLS estimator described above. Inspection of this density reveals that it places most weight in areas of the parameter space where $Q_{LNS}(\theta)$ is small, or where the simulated model closely matches the observed data. In order to compute an es-

[85] For counterfactuals that involve re-computing the price equilibrium, I cannot confirm that the bootstrap method is valid, as I cannot prove that iterating best responses leads to a unique price equilibrium in this model.

timate of θ^0, I can construct a Markov chain whose marginal density is given by $p(\theta)$ and recover our estimates as the mean of the chain. To construct the Markov Chain, I will use the Metropolis-Hastings algorithm with quasi-posteriors suggested by Chernozhukov and Hong (2003), where from a starting value $\theta^{(0)}$, I generate a new candidate vector θ' from a conditional density $q(\theta'|\theta)$, and I update according to

$$\theta^{(j+1)} = \begin{cases} \theta' & w.p. \rho\left(\theta^{(j)}, \theta'\right) \\ \theta^{(j)} & w.p. \left(1 - \rho\left(\theta^{(j)}, \theta'\right)\right) \end{cases}$$

where the transition probability is given by

$$\rho\left(\theta^{(j)}, \theta'\right) = \min\left(\frac{e^{-Q_{LNS}(\theta')}\pi(\theta')q\left(\theta^{(j)}|\theta'\right)}{e^{-Q_{LNS}\left(\theta^{(j)}\right)}\pi\left(\theta^{(j)}\right)q\left(\theta'|\theta^{(j)}\right)}, 1\right)$$

I use a standard normal for $q(\theta'|\theta)$, making the chain a random walk. That is, each candidate vector is centered at the current vector. Further, I specify a flat prior for all terms.[86] This simplifies the transition probabilities for my specification to:

$$\rho\left(\theta^{(j)}, \theta'\right) = \min\left(\frac{e^{-Q_{LNS}(\theta')}}{e^{-Q_{LNS}\left(\theta^{(j)}\right)}}, 1\right)$$

Therefore, if a candidate vector improves the objective function, the chain moves to that point with probability 1. If a candidate vector worsens the objective function, the chain moves to that point with some positive probability that depends on the change in the objective function. Because of this, the chain spends relatively more time in the parameter space where the simulated model fits the observed data. Once the chain reaches a sufficient length, its mean $\bar{\theta}$ can be used to provide a consistent estimate of θ^0.

A.7 Robustness and Exogeneity of Network Quality

A very attractive feature of this setting is that carriers do not charge different prices in different markets. With 90 markets of data, I therefore have prices set at a national level but market-level variation in terms of the product quality (dropped calls). Since price is fixed across markets, I do not need to be concerned about price being correlated with market-level variation in products. However, since carriers are not able to vary prices across markets, it is likely that they may vary

[86] The correlation parameters are constrained to be within the interval $[-0.9, 0.9]$. The handset decay rate is constrained to be non-negative.

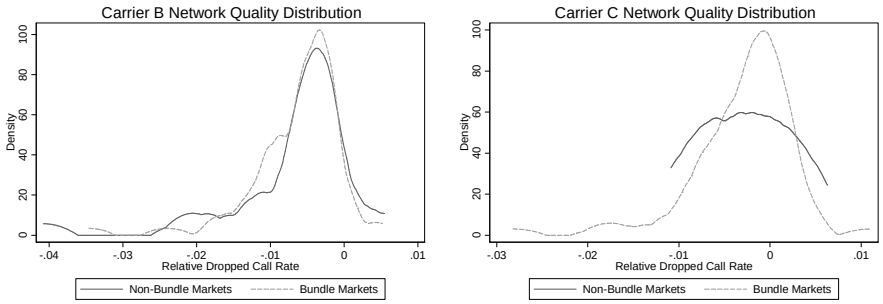
other factors in response to differences in their product quality in a given market. It is for this reason that I explicitly include a carrier's share of advertising spend in the demand for a "flagship" handset. Another concern may be a carrier's retail presence: I regressed the share of a carrier's customers in a market who reported that they purchased their device from one of the carrier's own retail stores (as opposed to a national chain or online) on the carrier's network quality and found no relationship in the data. This leads me to conclude that carriers are not significantly altering their retail presence in response to their network quality.

As shown in Figure 1, network quality does not vary much over time in the data. This is due to the fact that is it difficult for carriers to radically improve their network quality. Erecting new cell sites requires a long permitting process that varies by city and county, and even with sufficient spectrum holdings, it is a challenging engineering task to construct a high performance wireless network. For example, AT&T has the largest specturm holdings of any wireless carrier, but does not have the highest quality network.[87] The fact that network quality varies at all across markets is testament to the fact that, while every carrier would like to have high network quality in every market, there are exogenous factors that affect the quality of a carrier's network across markets.

Another possible source of unobserved demand shocks that could be correlated with a carrier's network quality in a market is the availability of "bundled services", where consumers purchase wireless service in conjunction with any of home television, internet, or landline services and a bundle discount. The survey data contains a question about bundled services, which I use to contruct an indicator variable for markets in which Verizon and AT&T offer such bundles. The concern would be that this may increase demand, and that carriers may invest differently in network quality in such markets. I perform a t-test for each of those carriers to see if the mean network quality in "bundle" and "non-bundle" markets differ, and fail to reject the null hypothesis that the means are identical (I get the same result using a single month's network quality and using the average network quality over all 26 months). Below are non-parametric density plots of each carrier's network quality (relative to market average) for "bundle" and "non-bundle" markets for Survey Month 40 in the data. The plot for Carrier B shows very similar distributions, and while the plot for Carrier C shows less similar distributions, there does not seem to be a systematic difference. I conclude from this that offering bundled services is uncorrelated with network quality.

[87] Sprint Nextel Corporation, "Petition to Deny", briefing filed in the application of AT&T Inc. and Deutsche Telekom AG.

Figure 8: Network Quality in "Bundle" and "Non-Bundle" Markets



Another concern is that unobserved (positive) heterogeneity for a particular carrier in a market could lead simultaneously to increased demand and worse network quality through congestion.[88] More generally, there is a concern that demand for a network would lead to a higher dropped call rate. To investigate this, I use a "long difference" approach, comparing changes from the beginning of the dataset to the end of the dataset. Figure 9 plots differences in market shares and dropped call rates for each carrier in each market using the first and last 3 and 6 months of data. Market shares are measured more precisely for larger markets, and so marker sizes reflect the relative sizes of markets. If unobserved heterogeneity were simultaneously increasing demand and the dropped call rate, we would expect a positive relationship between the two variables. Instead, we see a negative relationship, which although it is not statistically significant, can rule out even small effects of demand on network quality (the corresponding regression results are presented in Table13). This is consistent with the idea that carriers that were able to improve their dropped call rate were able to increase their market share. Market shares evolve slowly, and so Table 14 uses a carrier's share of purchases in late 2010 to show that carriers see increased demand in markets in which they improved their network quality between 2008 and 2010.

[88] Sources in the industry indicate that network congestion is indeed a concern at the ultra-local level, for example during sporting events, but that congestion at the city-wide level is rarely an issue for connectivity, and far less important than tower placement and geography.

Table 13: Long Difference: Changes in Market Shares vs Changes in Network Quality

	Dependent Var: Change in Market Share			
	Using first/last 3 months		Using first/last 6 months	
	(1)	(2)	(3)	(4)
Change in Dropped Call Rate	-0.2612	-0.5084	-0.4786	-0.7028
	(0.4677)	(0.3696)	(0.5084)	(0.4346)
Carrier Fixed Effects	X	X	X	X
Market Fixed Effects		X		X

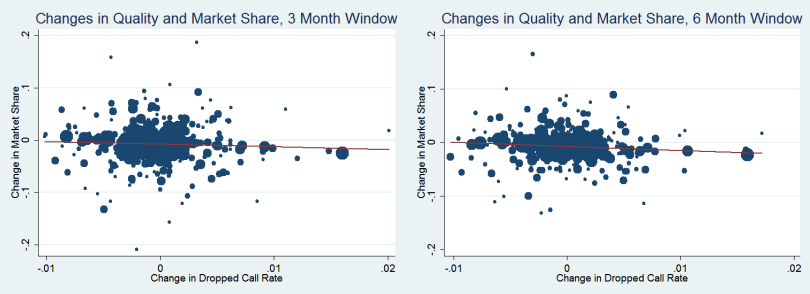
Notes: The number of observations is 356 (one market is dropped as T-Mobile is missing network quality data for the first months of the sample). Regressions use the difference in the average market share over the first and last 3 (6) months of data as the dependent variable, and the same difference in average of the market de-meaned carrier dropped call rate as the independent variable. A higher dropped call rate is considered "worse" in terms of network quality. All standard errors are clustered at the market level. Observations are weighted by respondent weights in the Nielsen Mobile Insights survey. Standard errors are in parentheses. No result is significant at the 10% level; the cofficient in Specification 4 has a p-value of 0.109.

Table 14: Purchases vs Changes in Network Quality

	Dependent Var: Share of Consumers Purchasing in Final 3/6 Months of Data			
	Using first/last 3 months		Using first/last 6 months	
	(1)	(2)	(3)	(4)
Change in Dropped Call Rate	-0.2943^{*}	-0.5715^{*}	-0.7735^{**}	-1.3244^{**}
	(0.1687)	(0.2932)	(0.3536)	(0.5971)
Carrier Fixed Effects	X	X	X	X
Market Fixed Effects		X		X
N	280	280	280	280
R^2	0.1567	0.3341	0.3366	0.4403

Notes: Regressions use the market share of purchases over the last 3 (6) months of data as the dependent variable, and the difference in average of the market de-meaned carrier dropped call rate as the independent variable. A higher dropped call rate is considered "worse" in terms of network quality. All standard errors are clustered at the market level. Observations are weighted by respondent weights in the Nielsen Mobile Insights survey. Results denoted by *, **, and *** are significant at the 10%, 5%, and 1% levels, respectively.

Figure 9: Long Difference in Market Share and Quality



These plots show the difference in market share for a carrier in a market between the last 3 (6) months and the first 3 (6) months of the data, plotted against the analogous difference in dropped call rate. The differences are de-meaned at the carrier and market levels. Sizes of bubbles represent the relative sizes of markets. The fitted line shows the relationship between the two, which is not statistically significant.

Finally, I will argue that any possible bias may well work against my results. If carriers invest *less* in markets where they have positive demand shocks, then my estimate of the tastes for network quality would be biased towards zero, which would work against my findings in Counterfactual 1. It would in fact be optimal for a carrier to invest less in such markets if a positive demand shock reduces the marginal return on investment. This is likely to be the case whenever there are diminishing returns to network quality, a reasonable assumption. Even if a carrier perceived constant returns in network quality, this finding would still hold as long as a carrier's cost function to achieve a given level of network quality were convex, also a reasonable assumption.

B Theory Appendix

B.1 A Hotelling Example of the Effect of Exclusive Contracts

This section begins with an example where one of the goods (wireless services) is homogenous to illustrate the static incentive for exclusive contracts for the non-homogenous good in a simplified setting. Specifically, exclusive contracts lead to steeper reaction functions for the firms producing the non-homogenous goods, resulting in higher prices in equilibrium. The model is then generalized to allow for differentiation of both goods, to match the reality of the US mobile telecommunications industry and establish the theoretical results. The main findings are (1) that an exclusive contract for one of the bundled goods is optimal when that good faces relatively inelastic demand compared to the other good, (2) that such an exclusive contract can increase entry incentives for competitors to the exclusive good; and (3) that the value of the exclusive contract depends on whether consumers are willing to substitute between quality of the two bundled goods. I will refer to the case of non-exclusivity as *common agency* (as though carriers are agents for the handset makers), denoted by C below, the case of single-firm exclusivity as E, and of all handsets

exclusive by EE.

Consider a simplified static setup (see Appendix B.3 for all derivations): Firm A (say, Apple) could invest K to develop a new smartphone. If it enters the market, it would have a smartphone with quality δ_A and marginal cost c, that would compete against Firm B (say, Blackberry) that produces a smartphone with quality δ_B at marginal cost c. Consumer tastes for smartphones are as in a standard Hotelling model where consumers are distributed uniformly over an interval of length 1, with tastes for each smartphone for consumer i at location θ_i given by:

$$\begin{aligned} u_{Ai} &= \delta_A - p_A - \theta_i \\ u_{Bi} &= \delta_B - p_B - (1 - \theta_i) \end{aligned}$$

The smartphones are purchased from the manufacturers at wholesale prices q_A and q_B by N identical wireless carriers. These carriers compete in the downstream market by bundling the devices with their homogenous wireless networks that have marginal cost of zero, and selling the handset-network bundle to consumers at prices p_A and p_B. Appendix B.3, shows the derivation of final consumer demand as a function of prices, $D^A(p_A, p_B)$ and $D^B(p_A, p_B)$, by locating the indifferent consumer and using the properties of the uniform distribution, as is standard for a Hotelling setup.

Firm A could choose to sell its handset to all carriers, or limit itself to a single exclusive carrier. I will first hold Firm B's choice fixed at non-exclusivity for now, but will revisit Firm B's choice later. I begin by analyzing Firm A's expected profits from common-agency, followed by the profits from exclusivity. The order of moves for this full-information setup is (1) upstream firms simultaneously choose wholesale prices, (2) carriers simultaneously choose retail prices, and (3) the market is realized.

If no exclusive contracts are permitted, then all carriers will offer a bundle with each smartphone, and Bertrand competition will ensure that markups are competed to zero. Knowing this, the smartphone firms will choose wholesale prices in equilibrium to maximize their profits given that the downstream firms will not charge a markup:

$$\begin{aligned} \pi_A^c &= (q_A - c) D^A(q_A, q_B) \\ \pi_B^c &= (q_B - c) D^B(q_A, q_B) \end{aligned}$$

Assuming an interior solution,[89] the equilibrium wholesale price and profits for firm A if it enters with no exclusive arrangement are π_A^{C*}, shown in Table 15 with the resulting retail price.

[89] Interior refers to the case where δ^A and δ^B are such that neither firm captures the entire market in equilibrium. Note that if this were not the case, the prices of the two goods would not be strategic complements in a Hotelling model.

This is identical to the level of profits earned if the two smartphone firms competed directly for consumers, due to Bertrand competition among the homogenous carriers.

Now suppose that Firm A could instead sign an agreement with one carrier guaranteeing exclusivity: Firm A could not sell its smartphone to any other carrier, but the carrier would be free to offer smartphone B.[90] In this case, Firm A would expect its exclusive wireless carrier w to choose a retail price to maximize profits, where the carrier's profits and optimal retail price are given by:

$$\begin{aligned} \pi_w^E &= (p_A - q_A) D^A (p_A, q_B) \\ p_A^{E*} &= \left(\frac{1 + \delta_A - \delta_B + p_B + q_A}{2} \right) \end{aligned}$$

The upstream firms choose wholesale prices knowing this markup. Upstream profits[91] are now

$$\begin{aligned} \pi_A^E &= \left(p_A^{E*}(q_A, q_B) - c \right) D^A \left(p_A^{E*}(q_A, q_B), q_B \right) \\ \pi_B^E &= (q_B - c) D^B \left(p_A^{E*}(q_A, q_B), q_B \right) \end{aligned}$$

Solving for equilibrium wholesale prices, we see that Firm B reaction function now takes the downstream optimization into account, and so is more inelastic with respect to Firm A's wholesale price (see Figure 11 for a graph of a numeric example). In other words, for any wholesale price chosen by A, firm B will now pick a higher price; in response, A will raise its price, and so on, until a new equilibrium is found. Consequently, both smartphones have higher prices over the range of interior solutions. Firm A's profit under exclusivity π_A^{E*}, is greater than its profits under common agency. If there are no exclusive contracts, the bundles of the iPhone with each carrier are effectively undifferentiated, and competition reduces markups to zero; the exclusive contract therefore eliminates this "externality" to increase profits from the sale of the iPhone.

If Firm B were also exclusive, both firms would internalize the downstream pricing behavior, and Firm A's profits from exclusivity would rise further. Table 15 summarizes the outcomes of this setup.

Table 15: Equilibrium Outcomes of Hotelling Model

Form of Representation	Retail Price, A	Profits, Firm A
Common Agency (C)	$c + 1 + \frac{1}{3}(\delta_A - \delta_B)$	$\frac{1}{18}(3 + \delta_A - \delta_B)^2$
A Exclusive (E)	$c + \frac{5}{4} + \frac{1}{4}(\delta_A - \delta_B)$	$\frac{1}{32}(5 + \delta_A - \delta_B)^2$
A, B Exclusive (EE)	$c + 2 + \frac{2}{5}(\delta_A - \delta_B)$	$\frac{1}{25}(5 + \delta_A - \delta_B)^2$

[90] This is more closely aligned with the concept of "exclusive territories" than "exclusive contracts" in the literature (Katz, 1989).

[91] Note that Firm A's profits include the downstream firm's markup. It is assumed that when exclusive, upstream firms are able to extract the full surplus via a fixed fee in a two-part tariff.

I may now draw a few conclusions from this model:

1. Firm A will earn greater profits under exclusivity.[92]

2. There exist values of K such that a rational Firm A would choose not to enter in the absence of exclusive contracts. Furthermore, if the incumbent is exclusive, the entry incentive is even greater when exclusive contracts are available.

The second conclusion is a direct result of the first, but is interesting in that it provides evidence that exclusive contracts increase the returns to innovation.

What is driving these result? A major force at work is that downstream Bertrand competition drives markups to zero under common agency, and so exclusivity provides a buffer against price competition. It provides a secondary benefit by altering the response curves of the upstream firms, taking advantage of the fact that prices are strategic complements. Below I will extend the general model to the case of differentiated goods at both upstream and downstream levels and show that under certain conditions, exclusivity is the optimal contract. In many realistic settings, downstream firms are differentiated or contributed a differentiated good to the end product, and so this generalization is relevant.[93]

B.2 General Model

We can think of the case above as a limit case where downstream firms are perfect substitutes to consumers. Another limit case is where downstream firms are not substitutes at all, or where wireless carriers are effectively monopolists over their customers. In that setting, it is clear that exclusivity can not be optimal for an upstream firm, as they could do strictly better selling to 2 or more downstream firms, as each carrier is effectively a separate market. For simplicity, I will assume that the underlying demand system captures downstream "substitutability" with a parameter $\eta \in [0,\infty)$, such that under common agency, when $\eta = 0$, downstream firms are perfect substitutes, but they gain market power as η increases.[94] This allows us to characterize the limit cases of downstream monopolists $(\eta = \infty)$, downstream perfect competition$(\eta = 0)$, and cases

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(a) This result is not particularly novel: Rey and Stiglitz (1995) proved this in the setting of producers and retailers for a general quasi-concave profit function where $\delta_A = \delta_B$ and both upstream firms move simultaneously. Their Proposition 3 states that if retail prices are strategic complements and profit functions are quasi-concave, then both smartphone firms would choose exclusivity. The model described above meets their criteria.

93 Whinston (2006) states with regard to multibuyer/multiseller settings that "developing models that reflect this reality is a high priority."

94 For carrier n, where s_{An} is the share of handset A on carrier n, we have that $\frac{\partial s_{An}}{\partial p_{An}} = -\infty$ when $\eta = 0$. As η increases, so does $\frac{\partial s_{An}}{\partial p_{An}}$, and in the limit $\frac{\partial s_{An}}{\partial p_{An}} \to \frac{\partial s_A}{\partial p_A}$ as $\eta \to \infty$.

in-between.[95] Figure 10 illustrates the profits to the entering upstream firm at different levels of downstream market power, and for different contracts, providing a roadmap to this section. As an example of how such a parameterization could arise, consider a standard Hotelling setup where the transport cost across the unit interval is given by η: when $\eta = 0$, all consumers are equally willing to go to either end of the interval, and as η increases, consumers are less willing to substitute to the firm that is located further from them. Appendix B.4 details additional examples of demand systems with this property.

I will now consider the general case of two upstream firms as before, but now N downstream firms that are imperfect substitutes. Under non-exclusivity for both A and B, the maximum possible profits for firm A under a two-part tariff are given by the profits earned from selling directly to consumers:[96]

$$\pi_A^{C*} = \frac{s_A\left(p_A^{C*}, p_B^{C*}\right)^2}{-\frac{\partial s_A}{\partial p_A}}$$

Under exclusivity, carriers 1 and 2 have exclusivity of products A and B respectively, and choose markups based on the wholesale prices they are charged. It is easy to show that these markups are greater than the markups they choose under common agency at a given wholesale price. Knowing the expected markup functions, the handset makers choose wholesale prices to maximize their joint profits with their exclusive carrier. This yields a best response function for each of the handset makers that is far steeper than the common-agency setting. Let $m_h(q_A, q_B)$ denote the carrier's markup function for handset h, and note that it is decreasing in own wholesale price but increasing in opposite wholesale price. The best response function for Firm A is

$$q_A - c = -m_A + \frac{\left(1 + \frac{\partial m_A}{\partial q_A}\right) s_{A1}}{-\left(\frac{\partial s_{A1}}{\partial p_{A1}}\left(1 + \frac{\partial m_A}{\partial q_A}\right) + \frac{\partial s_{A1}}{\partial p_{B2}}\frac{\partial m_B}{\partial q_A}\right)}$$

We see that the handset maker effectively replaces the carrier's markup with a more optimal one, which is based on a lower elasticity when prices are strategic complements (as captured by $\frac{\partial s_{A1}}{\partial p_{B2}}\frac{\partial m_B}{\partial q_B}$). This results in a higher retail price for both handsets, and profits under exclusivity of π_A^{EE*}.

I can now turn to our first result:

Proposition 1. *In the above model, if (a) prices are strategic complements, (b) shares are smooth and twice continuously differentiable in prices, (c) the price equilibrium exists, is unique, and continuous, then there exists a value η^* such that for all $\eta < \eta^*$, exclusivity is jointly profit maximizing.*

[95] A similar parametrization is used in Rey and Tirole (2013), where the parameter $e \in [0, V]$ indexes the substitutability versus complementarity of two patents.

[96] The details of how this is achieved at any η are in Appendix B.4.

The proof follows from the fact that final retail prices are higher under exclusivity, but market share is lower (except in the case of carriers as perfect substitutes). The formal proof relies on continuity and the Intermediate Value Theorem, since $\pi_A^{EE*}(\eta = 0) > \pi_A^{C*}$, but $\pi_A^{EE*}(\eta = \infty) < \pi_A^{C*}$. From the proof, we can see that the range of downstream elasticity over which exclusivity is optimal is (a) decreasing with N, the number of wireless carriers, (b) increasing with the degree of complementarity of prices, and (c) decreasing with the elasticity of upstream demand. These are all intuitive findings: the first captures the fact that as the number of downstream firms increases, so does the opportunity cost of exclusivity. The second captures the degree of the pricing advantage of exclusive contracting, and the third captures the influence exclusivity will have on downstream market shares.

Corollary. *The existence of exclusive contracts can lead to entry in cases where it would not be profitable otherwise.*

This is a direct consequence of the above proposition. There is a non-empty range of entry costs such that entry is not profitable in the absence of exclusive contracts, but is profitable with exclusivity.

Until now I have considered downstream firms to be identical and horizontally differentiated. Suppose now that for simplicity there are only two downstream firms (carriers) and that they also differ in a vertical characteristic. One example of this for wireless carriers could be the quality of their network (e.g. dropped call rate). Suppose further that a handset maker has decided to enter exclusively. When might we expect one carrier or the other to be the most profitable match for exclusivity? Assume that a carrier would be willing to pay up to its profit difference between exclusivity and rival exclusivity (i.e. AT&T would have been willing to pay Apple up to its profit difference between AT&T-Apple exclusivity and Verizon-Apple exclusivity).

Based on the model above, it seems intuitive that a carrier that faces more elastic demand would have the most to lose from a rival gaining exclusivity, as it would face a larger change in equilibrium price. Assume that consumers observe a vertical characteristic of each carrier n, δ_n, with $\delta_n \neq \delta_{n'}$ and price elasticity at a given price decreasing in δ_n. Further assume that consumer utility for the handset-network bundle (δ_A, δ_n) takes the form $u_{An} = \delta_A + \delta_n + \beta\delta_A\delta_n - p_{An}$. This form is chosen as the interaction term allows consumers to "substitute" between handset and network quality ($\beta < 0$), or it allows a better network to make a handset even better ($\beta > 0$).

Proposition 2. *For the case of two otherwise identical carriers with $\delta_1 < \delta_2$, there exists a β^* such that the carrier 1 is willing to pay more for exclusivity for all $\beta < \beta^*$.*

If consumers are willing to trade-off handset and network quality, then the handset is worth relatively more to the lower quality carrier. Once β gets high enough, its value is sufficiently

augmented by the higher quality carrier for it to be willing to pay more. This tells us that measuring whether or not consumers are willing to substitute between handset and network quality will be a determinant of a carrier's willingness to pay.

This section has established that exclusive contracts can be jointly profit maximizing depending on the relative elasticities of the two markets. The primary mechanism is through an increase in effective elasticity when setting prices, although these contracts can also encourage new entrants. When carriers are also vertically differentiated, we see that consumers' willingness to substitute between handset and network quality will affect which downstream firm values exclusivity more.

Figure 10: Upstream Firm Profits by Contract and Downstream Market Power

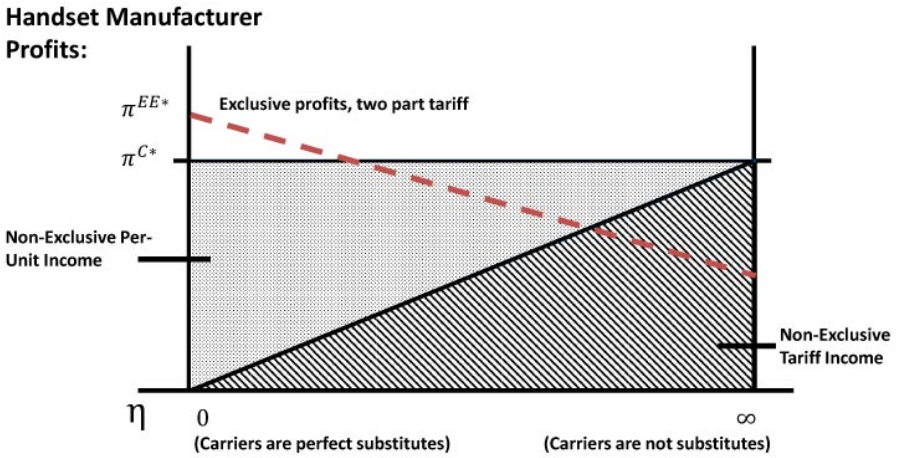
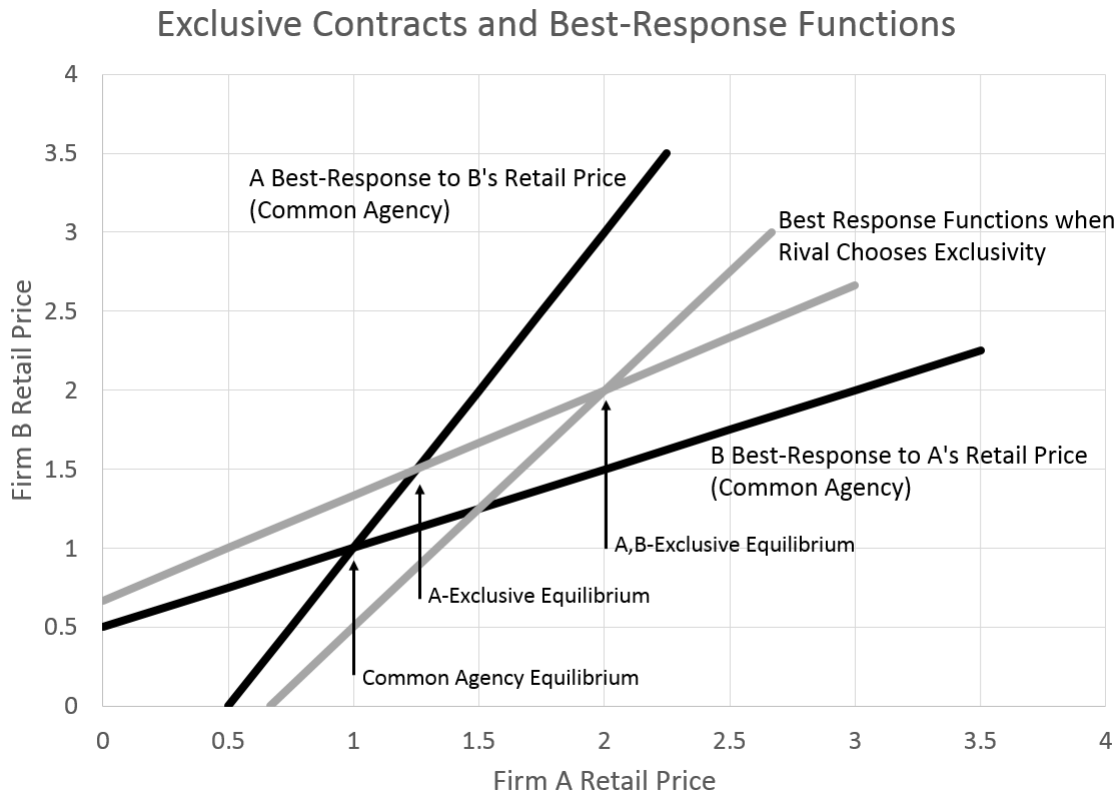


Figure 11: Impact of Exclusivity on Best-Response Functions



The figure shows the best response functions computed for the case where $c = 0$, $\delta_A = \delta_B = 5$.

B.3 Derivation of Hotelling Case

In the Hotelling case, consumer utility from the final good takes the form

$$\begin{aligned} u_{Ai} &= \delta_A - p_A - \theta_i \\ u_{Bi} &= \delta_B - p_B - (1 - \theta_i) \end{aligned}$$

Demand for each good at prices $p_{A,}p_B$ is given by integrating over the uniform distribution of types,

$$\begin{aligned} D_A(p_A, p_B) &= Pr(\delta_A - p_A - \theta_i > \delta_B - p_B - (1 - \theta_i)) \\ &= Pr\left(\theta_i < \frac{\delta_A - \delta_B + p_B - p_A + 1}{2}\right) \\ &= \frac{\delta_A - \delta_B + p_B - p_A + 1}{2} \\ D_B(p_A, p_B) &= \frac{\delta_B - \delta_A + p_A - p_B + 1}{2} \end{aligned}$$

Throughout I will assume that the equilibrium lies in the interior. This is satisfied whenever

$$1 + p_A - p_B > \delta_A - \delta_B \quad > p_A \quad - p_B - 1$$

In the common agency case, downstream firms charge no markups and so upstream firms set the wholesale prices to be the profit-maximizing retail prices:

$$\begin{aligned} \pi_A^C &= (q_A - c) D_A (p_A = q_A, p_B = q_B) \\ \pi_B^C &= (q_B - c) D_B (p_A = q_A, p_B = q_B) \end{aligned}$$

First-order conditions for profit maximization are given by

$$\begin{aligned} q_A &= \frac{\delta_A - \delta_B + q_B + 1 + c}{2} \\ q_B &= \frac{\delta_B - \delta_A + q_A + 1 + c}{2} \end{aligned}$$

The equilibrium is therefore given by wholesale and retail prices of

$$\begin{aligned} q_A^{C*} &= p_A^{C*} = \frac{1}{3}(\delta_A - \delta_B) + 1 + c \\ q_B^{C*} &= p_B^{C*} = \frac{1}{3}(\delta_B - \delta_A) + 1 + c \end{aligned}$$

Profits to the upstream firms in equilibrium are thus

$$\begin{aligned} \pi_A^{C*} &= \frac{1}{18}(\delta_A - \delta_B + 3)^2 \\ \pi_B^{C*} &= \frac{1}{18}(\delta_B - \delta_A + 3)^2 \end{aligned}$$

In the exclusive case, the exclusive carrier chooses a price to maximize profits given the wholesale price q_A:

$$\begin{aligned} \pi_w^E &= (p_A - q_A) D^A (p_A, p_B = q_B) \\ p_A &= \left(\frac{1 + \delta_A - \delta_B + p_B + q_A}{2} \right) \end{aligned}$$

To avoid double marginalization, Firm A will offer a two-part tariff with wholesale price equal to marginal cost and a tariff equal to all of the profits. The two upstream firms profits are given by:

$$\pi_A^E = \left(\frac{1 + \delta_A - \delta_B + p_B + c}{2} - c \right) D^A \left(p_A = \left(\frac{1 + \delta_A - \delta_B + p_B + c}{2} \right), p_B = q_B \right)$$

$$\pi_B^E = (q_B - c) D^B \left(p_A = \left(\frac{1 + \delta_A - \delta_B + p_B + q_A}{2} \right), p_B = q_B \right)$$

Firm B's optimal wholesale price rises now, leading to a higher retail price as well:

$$q_B^{E*} = p_B^{E*} = c + \frac{3}{2} + \frac{1}{2}(\delta_B - \delta_A)$$

Equilibrium profits when A is exclusive and B is not are given by

$$\begin{aligned} \pi_A^{E^*} &= \frac{1}{32}(\delta_A - \delta_B + 5)^2 \\ \pi_B^{E*} &= \frac{1}{16}(\delta_B - \delta_A + 3)^2 \end{aligned}$$

Finally, consider the case when Firm B is also exclusive, which I will denote by EE. Now two carriers set final retail prices to maximize their profits according to

$$\begin{aligned} \pi_{wA}^{EE} &= (p_A - q_A) D^A (p_A, p_B) \\ \pi_{wB}^{EE} &= (p_B - q_B) D^B (p_A, p_B) \end{aligned}$$

Solving, the equilibrium prices they will set as a function of wholesale prices are

$$\begin{aligned} p_A^{EE*} &= \frac{\delta_A - \delta_B + 2q_A + q_B}{3} + 1 \\ p_B^{EE*} &= \frac{\delta_B - \delta_A + 2q_B + q_A}{3} + 1 \end{aligned}$$

Similar to above, we have that both A and B set two-part tariffs to avoid marginalization, and so set wholesale prices to marginal cost and earn tariff profits of

$$\begin{aligned} \pi_A^{EE} &= \left(\frac{\delta_A - \delta_B + 2q_A + q_B}{3} + 1 - c \right) D^A \left(\frac{\delta_A - \delta_B + 2q_A + q_B}{3} + 1, \frac{\delta_B - \delta_A + 2q_B + q_A}{3} + 1 \right) \\ \pi_B^{EE} &= \left(\frac{\delta_B - \delta_A + 2q_B + q_A}{3} + 1 - c \right) D^B \left(\frac{\delta_A - \delta_B + 2q_A + q_B}{3} + 1, \frac{\delta_B - \delta_A + 2q_B + q_A}{3} + 1 \right) \end{aligned}$$

Optimizing, the two firms maximize profits, resulting in the following equilibrium:

$$\begin{aligned} q_A^{EE*} &= c + 1 + \frac{1}{5}(\delta_A - \delta_B) \\ p_A^{EE*} &= c + 2 + \frac{2}{5}(\delta_A - \delta_B) \\ \pi_A^{EE*} &= \frac{1}{25}(\delta_A - \delta_B + 5)^2 \end{aligned}$$

Firm B's outcome is symmetric to this (swapping δ_A and δ_B).

B.4 Proofs for General Case

The following assumptions stand throughout:

1. Tastes for handsets are independent of tastes for carriers.
2. Handsets A and B are substitutes and their prices are strategic complements.
3. The upstream firms set wholesale prices and tariffs independently (i.e. no collusion is possible).
4. Share functions are continuous and differentiable in all prices. Pricing equilibria exist and are unique.
5. For simplicity, I will assume that the underlying demand system captures downstream "market power" with a parameter $\eta \in [0,\infty)$, such that under common agency, when $\eta = 0$, downstream firms are homogenous as in Section 1 so that for carrier n, $\frac{\partial s_{An}}{\partial p_{An}} = -\infty$ when $p_{An} = p_{Bn}$. As η increases, so does $\frac{\partial s_{An}}{\partial p_{An}}$, and in the limit $\frac{\partial s_{An}}{\partial p_{An}} \to \frac{\partial s_A}{\partial p_A}$ as $\eta \to \infty$. This allows us to characterize the limit cases of carrier monopolists $(\eta = \infty)$, carriers as homogenous $(\eta = 0)$, and cases in-between. The analogous values for cross-partials are that $\frac{\partial s_{An}}{\partial p_{An'}}$ goes from ∞ to 0 as η goes from zero to ∞.

An example of a demand system that would satisfy A5: if consumers have taste draws θ_j for each firm $j = 1..J$, drawn from distributions F_j, and utility from the downstream good of firm j were of the form $u_{ij} = \kappa + \eta\theta_j - p_j$ for some constant κ. This is, in effect, a more general version of a Hotelling model. Note that a demand system of the Logit family would not satisfy this assumption, as downstream firms are always imperfect substitutes in that setting, and so the limit cases are not attainable. However, if one were to use a Logit model where utility had the form $u_{ij} = \delta_j + \eta\varepsilon_{ij}$, then this would reproduce the desired qualities except at the exact endpoints.

One challenge is that as downstream firms gain more market power, total market power and the equilibrium prices increase, making direct comparisons of equilibrium prices for different levels of downstream market power difficult. For example, when carriers are monopolists, we would expect the carriers to retain some of the joint surplus; it would be unreasonable to expect that handset firms could extract the complete amount of joint surplus. Therefore, to simplify the comparisons, I will assume that when bargaining over the joint surplus, the outside alternative is to have the upstream firms sell handsets directly to consumers. This allows us to characterize the maximum surplus achievable by the upstream firms as the "direct" profits whenever joint profits are greater than that.

I will first analyze the common-agency case, where each carrier $n = 1..N$ offers both handsets. I will look for a symmetric equilibrium outcome. The upstream firms choose the wholesale prices q_{An} and q_{Bn} (and can further extract surplus from a flat tariff). Downstream firms choose final retail prices p_{An} and p_{Bn}, $n \in \{1,...,N\}$ according to

$$\pi_n = (p_{An} - q_{An})\, s_{An}(p_{An}, p_{-An}) + (p_{Bn} - q_{Bn})\, s_{Bn}(p_{Bn}, p_{-Bn}) \tag{7}$$

Maximizing downstream profits yields two first-order conditions that must be satisfied for both carriers at the optimal retail prices p_A^{C*}, p_B^{C*}:

$$(p_{An} - q_{An}) = \left(-\frac{\partial s_{An}(\mathbf{p})}{\partial p_{An}}\right)^{-1} \left(s_{An}(p_{An}, p_{-An}) + (p_{Bn} - q_{Bn})\frac{\partial s_{Bn}(\mathbf{p})}{\partial p_{An}}\right)$$

$$(p_{Bn} - q_{Bn}) = \left(-\frac{\partial s_{Bn}(\mathbf{p})}{\partial p_{Bn}}\right)^{-1} \left(s_{Bn}(p_{Bn}, p_{-Bn}) + (p_{An} - q_{An})\frac{\partial s_{An}(\mathbf{p})}{\partial p_{Bn}}\right)$$

Notice that the share derivatives must take into account the indirect effect of prices on competing prices, since I have assumed that prices are strategic complements. For example, I have

$$\frac{\partial s_{An}(\mathbf{p})}{\partial p_{An}} = \frac{\partial s_{An}}{\partial p_{An}} + \frac{\partial s_{An}}{\partial p_{Bn}}\frac{\partial p_{Bn}}{\partial p_{An}} + (N-1)\left(\frac{\partial s_{An}}{\partial p_{An'}}\frac{\partial p_{An'}}{\partial p_{An}} + \frac{\partial s_{An}}{\partial p_{Bn'}}\frac{\partial p_{Bn'}}{\partial p_{An}}\right) \tag{8}$$

$$\frac{\partial s_{Bn}(\mathbf{p})}{\partial p_{An}} = \frac{\partial s_{Bn}}{\partial p_{Bn}}\frac{\partial p_{Bn}}{\partial p_{An}} + \frac{\partial s_{Bn}}{\partial p_{An}} + (N-1)\left(\frac{\partial s_{Bn}}{\partial p_{An'}}\frac{\partial p_{An'}}{\partial p_{An}} + \frac{\partial s_{Bn}}{\partial p_{Bn'}}\frac{\partial p_{Bn'}}{\partial p_{An}}\right) \tag{9}$$

where I make use of the fact that I am looking for symmetric equilibria to simplify. Since prices are strategic complements, all derivatives of prices with respect to other prices are positive. I can immediately analyze the limit cases of downstream competition: if carrier demand is perfectly elastic ($\eta = 0$), cross-carrier partial derivatives are infinite, resulting in zero markups. The resulting market outcome is identical to that where the upstream firms compete directly for consumers: handset makers effectively set the final price since q_A and q_B are passed through directly to consumers as p_A and p_B, resulting in equilibrium handset markups under common agency given by

$$\left(q_A^{C*} - c\right) = \left(-\frac{\partial s_A}{\partial p_A}\right)^{-1} s_A\left(\mathbf{p}^{C*}\right)\Big| \; p_A = q_A, p_B = q_B$$

$$\left(q_B^{C*} - c\right) = \left(-\frac{\partial s_B}{\partial p_B}\right)^{-1} s_B\left(\mathbf{p}^{C*}\right)\Big| \; p_A = q_A, p_B = q_B$$

Profits for the upstream firms are then

$$\pi_A^{C*} = \left(-\frac{\partial s_A}{\partial p_A}\right)^{-1} N s_{An}\left(\mathbf{p}^{C*}\right)^2 = \pi_B^{C*}$$

In the other limit case where downstream firms are monopolists (and so each carrier effectively serves a different "market"), we have $\eta = \infty$ and zero cross-carrier effects, and are left with only the first two terms of equations 2 and 3. The carrier then maximizes the joint profits as though the upstream firms were colluding (the carrier effectively vertically integrates with both upstream firms); these profits are maximized when handset manufacturers offer marginal cost pricing to eliminate the double-marginalization ($q_A = q_B = c$) and instead extract surplus through a tariff. Total profits are greater than in the previous limit case, although the upstream firms would not be able to extract the full surplus without actually colluding in setting wholesale prices, which I assume is not possible. Following the bargaining assumption made above, the monopolist carrier retains at least the surplus created from internalizing both upstream firms' profits, the upstream firms are left with maximal profits of π_A^{C*} and π_B^{C*}.

In the intermediate cases, I can assume that upstream firms are effectively able to choose the final retail price as they know the markup function used by carriers and are free to set any wholesale price. The combination of variable profits and tariffs can not exceed π_A^{C*}due to the bargaining assumption (i.e. carriers retain surplus generated by their market power).

Now consider the case of exclusivity: handsets A and B are exclusive to carriers 1 and 2, respectively. The equilibrium first-order conditions for optimal prices p_A^{EE*} and p_B^{EE*} are now

$$\begin{aligned}
(p_{A1} - q_{A1}) &= \left(-\frac{\partial s_{A1}}{\partial p_{A1}}\right)^{-1} (s_{A1}(p_{A1}, p_{B2})) \\
(p_{B2} - q_{B2}) &= \left(-\frac{\partial s_{B2}}{\partial p_{B2}}\right)^{-1} (s_{B2}(p_{A1}, p_{B2}))
\end{aligned}$$

As η goes from zero to ∞, we have that $\frac{\partial s_{A1}}{\partial p_{A1}}$ goes from $\frac{\partial s_A}{\partial p_A}$ to $\frac{\partial s_1}{\partial p_1}$. The handset competition dominates at low η, and the carrier competition dominates at high η.

Define these markup functions as $m(q_{A1}, q_{B2})$ and note that the markup is decreasing in own wholesale price but increasing in opposite wholesale price. Upstream firms, anticipating this markup function, now choose wholesale prices to maximize joint profits, according to

$$\begin{aligned}
\pi_A^{EE} &= (q_{A1} + m_{A1}(q_{A1}, q_{B2}) - c)\, s_{A1}(q_{A1} + m_{A1}(q_{A1}, q_{B2}), q_{B2} + m_{B2}(q_{A1}, q_{B2})) \\
\pi_B^{EE} &= (q_{B2} + m_{B2}(q_{A1}, q_{B2}) - c)\, s_{B2}(q_{A1} + m_{A1}(q_{A1}, q_{B2}), q_{B2} + m_{B2}(q_{A1}, q_{B2}))
\end{aligned}$$

Optimizing, I get Firm A's first-order condition given by

$$q_A - c = -m_A + \frac{\left(1 + \frac{\partial m_A}{\partial q_A}\right) s_{A1}}{-\left(\frac{\partial s_{A1}}{\partial p_{A1}}\left(1 + \frac{\partial m_A}{\partial q_A}\right) + \frac{\partial s_{A1}}{\partial p_{B2}}\frac{\partial m_B}{\partial q_A}\right)}$$

Note that this simplifies to the the first-order condition from the homogenous carrier case if prices are not strategic complements (if there is no positive effect from $\frac{\partial m_B}{\partial q_A}$). Therefore, in the limit case of $\eta = 0$, equilibrium prices are higher when prices are strategic complements. Finally, profits for Firm A in this case are

$$\pi_A^{EE*} = \left(\frac{\left(1 + \frac{\partial m_A}{\partial q_A}\right)}{-\left(\frac{\partial s_{A1}}{\partial p_{A1}}\left(1 + \frac{\partial m_A}{\partial q_A}\right) + \frac{\partial s_{A1}}{\partial p_{B2}}\frac{\partial m_B}{\partial q_A}\right)}\right) s_{A1}\left(p_{A1}^{EE*}, p_{B2}^{EE*}\right)^2$$

Exclusivity is optimal iff

$$\begin{array}{ccc} \pi_A^{EE*} & > & \pi_A^{C*} \\ \left(\frac{\left(1 + \frac{\partial m_A}{\partial q_A}\right)}{-\left(\frac{\partial s_{A1}}{\partial p_{A1}}\left(1 + \frac{\partial m_A}{\partial q_A}\right) + \frac{\partial s_{A1}}{\partial p_{B2}}\frac{\partial m_B}{\partial q_A}\right)}\right) s_{A1}\left(\mathbf{p}^{EE*}\right)^2 & - \left(-\frac{\partial s_A}{\partial p_A}\right)^{-1} N s_{An}\left(\mathbf{p}^{C*}\right)^2 > & 0 \end{array} \qquad (10)$$

I know that

$$\left(\frac{\left(1 + \frac{\partial m_A}{\partial q_A}\right)}{-\left(\frac{\partial s_{A1}}{\partial p_{A1}}\left(1 + \frac{\partial m_A}{\partial q_A}\right) + \frac{\partial s_{A1}}{\partial p_{B2}}\frac{\partial m_B}{\partial q_A}\right)}\right) > \left(-\frac{\partial s_A}{\partial p_A}\right)^{-1}$$

holds for all finite η, and that they are equal in the limit as $\eta \to \infty$ (there is no strategic complementarity of prices "across markets", or $\frac{\partial m_B}{\partial q_A} = 0$ in that limit). Also, for any given price vector $\mathbf{p}$, we have that $s_{A1}(\mathbf{p}) = N s_{An}(\mathbf{p})$ when $\eta = 0$, but $N s_{An}(\mathbf{p}) - s_{A1}(\mathbf{p})$ increases as η increases. That is, the amount of foregone sales from exclusivity increases as consumers are less willing to substitute between downstream goods. We also know that equation 4 holds at $\eta = 0$. Combining these, we have that equation 4 holds at $\eta = 0$, but that the LHS is decreasing as η increases, and that equation 4 does not hold in the limit as $\eta \to \infty$. Under the continuity assumption, I can apply the intermediate value theorem to get that there exists an η^* at which point equation 4 holds with equality. Therefore, for all values of $\eta < \eta^*$, exclusivity is the profit maximizing strategy.

To address Proposition 2, I start with a model of what a carrier's willingness to pay is. For carrier $n \in \{1, 2\}$, the alternative to having handset A exclusively is that carrier n' will have handset

A exclusively (I will assume there is a handset B available to both carriers). The equilibrium outcome will be the one that maximizes the joint profits of the exclusive carrier and Firm A.

I first make a simplifying assumption: each carrier chooses only a network access price; handset prices are fixed across carriers at p_h. This simplifies the analysis, and I do not believe this to be a controversial assumption, as in November 2011 when the iPhone is available on three carriers, the device is priced identically across carriers but monthly access fees differ. The two carriers will have identical marginal costs c, and choose their monthly access prices p_n, which creates a final good price for handset h on carrier n of $p_n + p_h$. Carriers choose their monthly access price in the standard profit maximization framework. From now on, p_1 and p_2 represent equilibrium monthly access prices less marginal cost.

Each carrier's willingness to pay is determined by the difference in profits from having exclusivity versus its rival having exclusivity. I denote carrier 1 having exclusivity of handset A by $\chi = 1$, and carrier 2 having exclusivity with $\chi = 2$. For carrier 1, the willingness to pay to Firm A is therefore

$$p_1(\chi = 1) \cdot (s_{A1}(\chi = 1) + s_{B1}(\chi = 1)) - (p_1(\chi = 2) + p_A) \cdot (s_{B1}(\chi = 2))$$

Similarly, for carrier 2, it is

$$p_2(\chi = 2) \cdot (s_{A2}(\chi = 2) + s_{B2}(\chi = 2)) - (p_2(\chi = 1) + p_A) \cdot (s_{B2}(\chi = 1))$$

Re-arranging, we have each carrier's willingness to pay having two components: a change in profits from B, and the sales potential of A.

$$[p_1(\chi = 1) \cdot s_{B1}(\chi = 1) - p_1(\chi = 2) \cdot s_{B1}(\chi = 2)] + (p_1(\chi = 1) + p_A) \cdot s_{A1}(\chi = 1)$$

$$[p_2(\chi = 2) \cdot s_{B2}(\chi = 2) - p_2(\chi = 1) \cdot s_{B2}(\chi = 1)] + (p_2(\chi = 2) + p_A) \cdot s_{A2}(\chi = 2)$$

I am assuming that carrier 1 faces more elastic demand from its network. Therefore, at $\beta = 0$, I know that the first term for carrier 1 is larger than for carrier 2, and the difference is increasing in β. Further, I know that the second component is larger for carrier 2, since he has a higher quality network, and that this difference is growing in β. Therefore, to establish Proposition 2, I need to show that the 2nd component grows faster in β. This follows form the inclusion of p_A, which is fixed for all β. The price p_A is perfectly inelastic, whereas the equilibrium network prices cannot be, and so there reaches a point at which the limited market achievable by carrier 1 dominates the gains carrier 1 can earn in monthly fees.