The Economic Impact of Wireless Number Portability

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Abstract

This paper examines the price response of wireless carriers to the introduction of number portability. We find that wireless prices decreased in response to number portability, but not uniformly across plans. Average prices for the plans with the fewest minutes decreased by only \$0.19/month (0.97%), but average prices for medium- and high-volume plans decreased by \$3.64/month (4.84%) and \$10.29/month (6.81%), respectively. The results suggest that higher-volume users in the wireless market benefited more from the policy-induced reduction in switching costs.

Keywords: Wireless number portability, Switching costs, Regulation, Market power

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1 Introduction

To reduce consumer switching costs and induce more competition in the wireless telephone industry, the Federal Communications Commission (FCC) required all wireless carriers to offer number portability in the top 100 Metropolitan Statistical Areas (MSAs) by November 24, 2003, and the policy was expanded to the entire US including smaller markets on May 24, 2004. Prior to the implementation of the policy, consumers who wanted to switch service providers had to give up their old phone numbers and get new ones. With the policy in place, consumers have the option of keeping their current phone numbers when they change service providers within the same local geographic area. Therefore, the policy eliminated the switching costs arising from the need to inform one's social network of the phone number change.

This paper examines the response of wireless pricing to the introduction of number portability. Theoretically, it has been shown that the presence of switching costs could confer market power upon firms, leading to higher equilibrium prices (Klemperer, 1987a, 1987b). Empirically, one of the FCC's goals in implementing wireless number portability was to induce more competition by reducing consumer switching costs. Hence it is an interesting question to ask whether the policy indeed led to lower prices for consumers as intended by the regulators. Moreover, since the impact of the policy on the incentive to switch could have been different for different consumers, it is worthwhile to ask whether the price impact of the policy was homogeneous across different consumers. In this paper, we focus on one important, easily observable, dimension along which consumers differ: the size of their plans.

To answer our questions, we compare the prices of wireless plans before and after the introduction of number portability, using the monthly access fee as a measure of price.[1] We use monthly data on wireless plans from Econ One for our analysis. Our empirical investigation of wireless carriers' nonlinear pricing schedule shows that wireless prices decreased when the policy was introduced, but not uniformly across all plans. Average prices for the plans with the fewest minutes decreased by \$0.19/month, but average prices for plans with intermediate and large numbers of minutes decreased by \$3.64/month and \$10.29/month, respectively. In percentage terms, these correspond to 0.97%, 4.84% and 6.81% reduction in monthly prices. We also find that these price changes are not a mere continuation of the pre-existing trend.

Patterns of price dispersion across carriers are also interesting. Since price dispersion across carriers captures carrier premium or discounts that cannot be explained by observable product characteristics, it can be indicative of consumer brand loyalty among other things. If the policy reduced consumers' loyalty

[1] We use the term "price" of a plan rather than "cost" of a plan, because the term cost might be confused with firms' production costs of plans.

to their existing carriers by allowing them to keep phone numbers in case of switching, we would expect a reduction in inter-carrier price dispersion after the policy. We find that the degree of price dispersion decreased overall after number portability and that the decline was larger for higher-volume plans.

Our results thus suggest that the policy-induced reduction in switching costs led to both a decrease in the price level and a decrease in price dispersion across carriers. Moreover, our results indicate that the policy had a larger effect on higher-volume users, as evidenced by the greater reduction in the price level as well as the greater reduction in price dispersion for higher-volume users.

To our knowledge, this paper is the first empirical work to investigate the effects of wireless number portability in the US. With currently 290 million US wireless subscribers, a major regulatory change in the wireless industry could affect more than 94% of the US population. Although our analysis exclusively focuses on one salient feature—price—among many things that might have changed due to the regulation and can only address short-term effects due to data availability, we believe this paper makes a valuable contribution to understanding the impact of this important regulation. Other researchers have investigated the impacts of number portability in different settings. Viard (2007) studies whether the introduction of 800-number portability intensified price competition in the toll-free service market. Shi, Chiang and Rhee (2006) show that mobile number portability led to a higher market concentration in Hong Kong due to on-network pricing. Aoki and Small (1999) and Buehler and Haucap (2004) consider theoretical models to analyze the welfare impacts of wireless number portability.

This paper also relates to the literature on switching costs more generally. Theoretical work on switching costs was pioneered by Klemperer (1987a, 1987b) and his coauthors (Beggs and Klemperer, 1992), and many researchers followed up on it (Farrell and Shapiro, 1988, 1989; Padilla, 1995; Chen, 1997; Taylor, 1999; Cabral and Villas-Boas, 2005). Empirical research on switching costs includes Borenstein (1991), Viard (2007), Knittel (1997), Dubé, Hitsch and Rossi (2009), Calem and Mester (1995), Stango (2002), and Sharpe (1997) among others. Particularly related to this paper is Viard (2007), which finds that prices on larger contracts dropped more after the implementation of 800-number portability in the toll-free service market.

In the next section, we discuss institutional details of the wireless industry, focusing on switching costs in the industry and the introduction of number portability. In Section 3, we describe our data. In Section 4, we present our empirical findings. Section 5 concludes the paper.

2 Switching Costs and Number Portability in Wireless Industry

In the mobile telephone market, consumers face various kinds of switching costs. When they change service providers, they have to incur the time costs of closing their account with one carrier and opening a new account with another. In addition, the inability of end-users to retain their phone numbers when changing service providers forces them to inform their family, friends and business contacts of their new phone numbers. Because consumers in general cannot keep their current handsets when changing service providers, they have to pay for a new handset as well. Finally, many wireless users face contractual switching costs due to a long-term contract. If a wireless user wants to switch carriers before the contract is over, she has to pay an early termination fee of up to $200. Together these amount to a considerable obstacle to switching by wireless users.

Furthermore, switching costs are likely to vary across consumers. A consumer's cost of switching depends on her time costs, how much she values keeping her current phone number, the cost of a new handset she buys, and whether she is under a long-term contract. Regarding switching costs associated with a change in phone numbers, intuitively one would expect that those who heavily use their cell phones, for example, business people, tend to have a lot of contacts they would need to inform of a phone number change in the event of switching carriers, so would highly value keeping their phone numbers. Small users, on the other hand, have only a handful of contacts, such as family members or close friends, so changing a phone number might not be so much of a hassle for them.

The implementation of number portability was first discussed in the 1996 Telecommunications Act. Only local exchange carriers (for landline telephones) were required to provide number portability in the 1996 Telecommunications Act, but the FCC extended number portability requirements to wireless carriers as a way to reduce consumer switching costs and induce more competition in the wireless industry.[2] After a few delays due to the industry's intense resistance, in July 2002 the FCC decided to introduce wireless number portability on November 24, 2003. The Cellular Telecommunications and Internet Association, the trade organization for the wireless telephone industry, and Verizon then filed a petition for forbearance, which was denied by the D.C. Circuit in June 2003 (Kessing, 2004). With no further delay, number portability began in the top 100 MSAs on November 24, 2003 and expanded to the entire country on May 24, 2004.

It is clear that one of the main benefits of wireless number portability envisioned by the FCC was strengthened competition. For instance, John Muleta, a former chief of the FCC's Wireless Telecom-

[2] FCC (2004), Annual Report and Analysis of Competitive Market Conditions with Respect to Commercial Mobile Services

munications Bureau, said in his 2003 speech "To facilitate greater competition in the telecom industry, the FCC allows consumers to keep their phone number when switching wireless carriers."[3] If the policy was indeed effective in enhancing competition, we would observe a decrease in plan prices after the introduction of the policy.

Moreover, it is possible that the impact of the policy differs across consumers in different volume segments. First, switching costs from the inability to keep phone numbers could be higher for higher-volume users as we discussed earlier. Second, even if the magnitudes of policy-induced reduction in switching costs do not differ across consumers, the policy could have generated stronger incentives to switch among high-volume users, since high-volume users have more to gain from switching precisely because of their high volume.[4] Thus, we might expect to observe a greater decrease in plan prices for higher-volume users in response to the implementation of number portability.

These are predictions we will empirically examine in this paper: whether wireless prices fall after the introduction of the policy and whether the decline is larger for higher-volume consumers. This is an empirical question, since despite the general perception that switching costs make markets less competitive, theoretically speaking the effects of switching costs on equilibrium prices are ambiguous. Depending on specifics of the model, such as whether it is possible to charge different prices to new and old consumers, whether consumers are forward-looking, and time horizon of the model, switching costs could make markets more competitive or less competitive (See Farrell and Klemperer (2007) for a nice summary of the literature). Similarly, it is theoretically unclear whom a reduction in switching costs would benefit most. For instance, theoretical literature on models of competition with nonlinear pricing does not provide an unambiguous prediction on who will benefit most from increased competition (e.g., Stole (1995) and Rochet and Stole (2002); see Busse and Rysman (1995) for an empirical application). Therefore, in this paper we attempt to answer the questions empirically.

There are some institutional features of the US wireless market that are noteworthy. First, new consumers and renewing consumers are offered the same menu of plans, and various types of promotions such as a reduction in the monthly access fee are available to both new and renewing customers. Furthermore, there are no penalties to renewing customers such as renewal fees. Hence, a distinction between new and old consumers, a key distinction in the switching costs literature, is not relevant for our analysis.

Second, although the switching costs literature typically compares two extreme cases, one where switching costs are high enough to prevent switching entirely and another in which switching costs are zero, many wireless consumers did switch before the policy introduction and the policy did not reduce

[3] http://wireless.fcc.gov/wlnp/WLNP-video-transcript.pdf

[4] We thank the editor and anonymous referees for pointing this out.

switching costs to zero either.

Third, it is possible that carriers started to change their prices before the actual implementation of the policy. Carriers might have offered lower prices before number portability began so that they could lock in customers with long-term contracts before the policy goes into effect.[5] Moreover, the tendency of contracts to be long term means that price adjustments could take a while to complete. Therefore, we might observe a gradual change in wireless prices around the implementation date, rather than an abrupt one-time shift.

Fourth, many carriers offer incentives, such as a rebate on handset prices and a reduction in activation fees, for consumers to sign up for longer-term contracts. Since consumers optimally choose whether they want to sign up for a longer-term contract and get these benefits in return, switching costs are endogenously determined in our setup. The use of such devices to endogenously create switching costs is a commonly used practice in many industries.

3 Data

The main data for our analysis are cellular and PCS plan data collected by Econ One, a research firm.[6] Econ One collects monthly data on wireless plans that are offered in the 26 largest cities in the US. Plans that a company services but no longer offers are not included in the data. Econ One examines each carrier's web site in order to collect the data. The data cover single-user plans and do not include any pre-paid plans or multiple-line plans. Appendix A lists markets and providers included in the data set. Our Econ One sample runs from January 2003 through June 2004, so we have information both before and after the introduction of number portability.[7] All the markets in the sample implemented number portability in November 2003. There is no new entrant during this time period, which is not surprising given that a new entrant would need to purchase the rights to operate a certain frequency band by participating in an FCC wireless spectrum auction, which is held only very infrequently.

The data set provides information on over 107,000 plans, including providers, markets, monthly access fees, numbers of minutes included in the plans and their composition (anytime minutes, peak minutes and night & weekend minutes),[8] activation fees, lengths of contracts and other relevant information. The

[5] Doing so would reduce demand uncertainty for wireless carriers during the introduction of the policy, since consumers who sign up for a long-term contract a few months before number portability are unlikely to switch for the next year or two. Considering the drastic increase in demand uncertainty due to the policy, a reduction in demand uncertainty through offering lower prices in months ahead of number portability could be valuable to carriers.

[6] Technically, cellular services and PCS (Personal Communications Service) differ in frequency bands they operate in.

[7] The merger between Cingular and AT&T was approved by the government in October 2004.

[8] For a customer whose plan has positive anytime minutes but no N&W minutes, anytime minutes are used whenever she

data set contains almost all relevant information on plan characteristics except information on handset prices.

The sole source of the data is carriers' internet web sites, and hence one might doubt the reliability or relevance of the data. However, the information on wireless plans listed on carriers' web sites appears accurate: we personally compared the lists of plans offered by Palo Alto retailers and lists on the web. Even though the lists did not coincide perfectly, they were very similar.

One potential issue is that since we do not have any data on the purchased quantity of each plan, the Econ One data set might include plans that very few people actually buy. This concern seems valid given the large number of plans each carrier seems to offer in each market/month. The average number of plans for a major carrier (AT&T, Cingular, Sprint, T-Mobile and Verizon) in each market/month is approximately 44 in the data set, which is very high. To partially address this concern, we adjust our estimation sample according to the following criteria. First, we exploit the fact that plan characteristics that are not popular among consumers would not be offered often by carriers, and exclude from our estimation sample plans with infrequently offered characteristics. For instance, voice mail is something that most customers would want, and consequently 98% of all plans offer voice mail. Thus, we exclude plans without voice mail. Similarly, we exclude regional plans[9] and plans that do not have caller id or call waiting function. Second, we try to avoid counting almost identical programs as separate observations. The data set treats two plans that are identical except for the contract length (either 1 year or 2 years) as two separate observations. We exclude plans with a two-year contract if an otherwise identical plan with a one-year contract is also offered. Third, we exclude plans that are strictly dominated by others. If there are two plans offered by the same carrier in the same market in the same month, and these plans have identical features except that one plan charges a lower monthly fee than the other, the second plan is excluded from the sample. Such a case tends to occur when a wireless company offers its regular plan and the same plan with additional benefits such as reduced activation fees under promotion. After these adjustments, the sample contains 51,319 plans, and the average number of plans by a major carrier in each market/month is about 22.[10] Throughout this paper, we will use this refined sample for our

calls, regardless of time. For a customer whose plan includes both anytime minutes and N&W minutes, anytime minutes are the same as peak minutes, except that anytime minutes can be used for N&W calls if she uses up her N&W minutes.

[9] Each plan can be categorized as "local," "regional," "network," or "national," depending on coverage areas. No roaming charge applies to calls made or received within the specified coverage area.

[10] Even this might seem too high given our knowledge about wireless plans these days. However, note that there were a lot more plans available a few years ago because of a lack of consensus on certain plan characteristics. For instance, these days all plans are national plans, but during the sample period, local, network, and national plans were all fairly popular. Such a lack of consensus on plan characteristics resulted in a large number of plans being offered during the sample period.

empirical analysis.[11]

For our analysis of smaller markets that implemented number portability in the second round, May 2004, we use data obtained from MyRatePlan.com, a wireless plan comparison web site. This data set contains, in addition to some of the top 100 MSAs, 4 markets that are outside of the top 100 MSAs—Des Moines (IA), Jackson (MS), Spokane (WA) and Tallahassee (FL). One disadvantage of this data set compared to the Econ One data set is that it does not contain as detailed information on plan characteristics as the Econ One data set does. Hence we perform most of our analysis using the Econ One data and use the MyRatePlan data only for the analysis of smaller markets to exploit different timing of policy introduction.

The FCC does not prohibit carriers from charging fees to recover the costs of implementing number portability as long as the fees do not exceed their porting costs. To our knowledge, there is no carrier who charges one-time porting fees to terminating customers only. However, most carriers have imposed monthly surcharges on their customers to recover the costs of number portability. Different carriers charge different amounts to their customers, but each carrier charges the same amount to all of its customers regardless of their usage levels and whether they switch or not.[12] Neither Econ One data nor MyRatePlan data provide information on those surcharges, and the surcharges are *not* included in the monthly access fee of these data sets, which is the price measure in our empirical analysis. Then, one concern is that wireless carriers might have imposed surcharges that could more than offset any decline in the monthly access fee.

It is difficult to obtain accurate information on how much carriers have charged to consumers to finance number portability. Typically, carriers lump the cost of number portability along with other charges such as "number pooling," and "federal E911 program" under a generic name like "federal recovery fee."[13] The Center for Public Integrity, a nonprofit organization, provides estimates of the federal recovery fees carriers have collected. We will use the estimates provided on its web site,[14] when we later discuss gains to consumers from number portability.

Table 1 shows the summary statistics for the sample that satisfies the aforementioned criteria. Table 1 also reports the summary statistics for the entire Econ One sample to show how our selection criteria affect the distribution of various plan characteristics. For each sample, we report summary statistics

[11] To check the robustness of our results, we also performed our empirical analysis using the entire sample. Our results from the entire sample, not reported, are very similar to the results from the selected sample. All the unreported results in this paper are available from the author upon request.

[12] AT&T is an exception. It charges such fees only on new customers or on existing customers if they change their plan.

[13] Jindrich, Morgan (2004), "Group Wants Truth in Cell Phone Billing," Center for Public Integrity

[14] http://www.public-i.org/telecom/report.aspx?aid=67&sid=200 (October 2003)

http://www.public-i.org/telecom/report.aspx?aid=250&sid=200 (April 2004)

separately for pre-number portability and post-number portability periods. From the table we see that post-NP plans offer more minutes than pre-NP plans on average. The mean price of plans offered after number portability is almost the same as the mean price of plans offered before number portability. More plans require two-year contracts (the longest contract in the data) since the introduction of number portability. Wireless carriers that are worried about more switching due to number portability might try to lock in consumers by requiring longer-term contracts. However, the average cancellation fee drops, so it is unclear whether the contractual switching costs increased or decreased after number portability.

To see if the changes are similar across consumers of different usage levels, Table 2 compares the average numbers of minutes and the average monthly access fees before and after number portability for different user segments. Within each carrier-market-month combination, we rank plans based on the monthly access fee and call the bottom 1/3 "low-price plans," the middle 1/3 "medium-price plans" and the top 1/3 "high-price plans."[15] The table shows that the changes vary across these categories. The average prices for low- and medium-price plans go up, while the average price for high-price plans goes down. The number of included minutes tends to increase, but the changes do not seem uniform across the categories either.

Table 3 shows how the number of included minutes has changed over time for a few selected plans offered by AT&T in Atlanta. For ease of comparison, we chose plans whose monthly access fees as well as other characteristics were constant throughout the sample period so that the number of included minutes is the only dimension that might change over time. Moreover, all plans reported in Table 3 offer unlimited night & weekend minutes and no peak minutes, so we only need to examine how the number of anytime minutes changed over time. A few things are noteworthy in Table 3. First, we see that all plans started to offer more anytime minutes around the time number portability was introduced (October and November 2003). It seems that AT&T started to lower the effective prices of these plans (by offering more minutes at the same price) a month or so prior to the actual implementation, consistent with our discussion in Section 2. Second, we see that the increase in the number of anytime minutes was larger for the higher-volume plan than for the lower-volume plan.

In our empirical analysis, we use the monthly access fee as a measure of price (hence our dependent variable) instead of charges for minutes used in excess of those included in the plan. For our analysis, the access fee, which is a price in an *ex ante* sense, is a more appropriate measure than the price of excess

[15] Here we categorize plans based on the monthly access fee rather than volume, because there are different types of minutes and we are not sure how to define aggregate "volume" based on them. Categorization based on price is less than ideal since price will be our dependent variable in the empirical analysis. In Section 4, we will infer weights given to each type of minutes and define volume as a weighted average of these different types of minutes.

minutes. Since the charges for excess minutes are much higher than the average price of included minutes, we expect consumers to avoid plans with fewer included minutes than they regularly use. Charges for excess minutes are more relevant for those who make mistakes *ex post*, whereas monthly access fees are relevant for any wireless customer. Because we are interested in the impact of number portability on wireless customers in general, the monthly access fee seems to be a more appropriate measure of price for our purpose. Having said that, we recognize that charges for excess minutes make up a significant share of revenues for wireless carriers, and many customers end up paying them. In one of alternative specifications in Section 4, we include charges for excess minutes as one of the RHS variables in order to compare monthly access fees over time holding excess minute charges fixed.

Also note that we use the monthly access fee as our dependent variable instead of per-minute price, which is the monthly access fee divided by the number of minutes. Even if we observe a smaller decrease in the per-minute price for higher-volume users after the policy, the total dollar savings could be larger for them because of their larger volume. Therefore, using the monthly access fee as the dependent variable makes it easier to examine for whom the savings are largest due to the policy.

It is evident in Tables 1-3 that the monthly access fee is not the only dimension that wireless carriers might change in response to number portability. It seems that wireless carriers adjusted other plan characteristics as well, such as the number of minutes. It is then an interesting question whether it is mainly minutes or price or both (or maybe something else) that changed in response to number portability. Tables 1 and 2 seem to suggest that at the aggregate level, more changes occurred on the number of minutes than on the monthly access fee. Unfortunately, this is all we can say using our data. If the data had a unique plan identifier that remains the same over time even when the plan's characteristics change, we would be able to follow the same plan and see which characteristic experienced the most significant change in response to number portability. Our data set does not contain such plan identifiers. What we can instead do is to use a regression framework to translate changes in non-price dimensions to dollar values, in addition to any direct change in prices, so that we can measure how the *effective* price changes due to the policy (i.e., for the exactly same plan, how much less the consumer pays after number portability compared to before). If minutes are the only things that change after number portability, our regression will tell us how much reduction in the effective price is experienced by consumers due to the increase in minutes.

We recognize that welfare implications from an increase in the number of minutes might not be as clear as welfare implications from a reduction in the monthly access fee. For instance, if most consumers do not use all of their minutes, an increase in the number of allowed minutes would not make them better

off.[16] Although this is a very valid concern, we note that this is unlikely to affect our interpretation for most consumers, except for the very bottom consumers, since consumers can downgrade their plans without incurring any penalties (within the same carrier). Suppose that there were three plans before the policy: Plan A ($20 with 400 minutes), Plan B ($30 with 500 minutes) and Plan C ($40 with 600 minutes). Suppose that the plans changed after the policy as follows: Plan A ($20 with 500 minutes), Plan B ($30 with 600 minutes) and Plan C ($40 with 700 minutes). Then a consumer who used to purchase Plan B can now purchase Plan A and a consumer who used to purchase Plan C can now purchase Plan B. The only change in response to the policy was in minutes, but these consumers can now use the same number of minutes and pay a lower price. In this scenario, all consumers other than the very low type can essentially experience a price reduction by moving to a lower plan. If the number of minutes a consumer wants to use on her cell phone increases over time as well, which is likely to be the case in real life as mobile communications become an essential part of business and people's lives, even the very bottom consumers can benefit from the policy. Therefore, although we are aware of subtle differences in welfare implications, we will interpret an increase in the number of minutes as equivalent to a decrease in prices in this paper.

4 Empirical Findings

4.1 Main Results

4.1.1 Price Changes in Major Markets

In this section, we analyze price changes in major MSAs that implemented number portability in the first round, November 2003. We use our main data set from Econ One for analysis. We estimate the monthly access fee for carrier i's plan p in market m at time t as a function of the number of minutes included in the plan, characteristics of the plan such as the coverage area, carrier-specific factors, market-specific factors and number portability. These variables reflect demand, costs of the plan and/or factors that could influence a carrier's market power. We estimate the following pricing equation of wireless carriers:

$$\ln(PRICE_{ipmt}) = (\alpha_1 + \delta_1 NP_t) + (\alpha_2 + \delta_2 NP_t) \times \ln(MINUTES_{ipmt}) + \theta X_{ipmt} + \varepsilon_{ipmt} \qquad (1)$$

The dependent variable $PRICE_{ipmt}$ is the monthly access fee for carrier i's plan p in market m at time t, adjusted for the activation fee and any promotional reduction in the monthly access fee: *PRICE* = (Monthly Access Fee × Length of Contract + Activation Fee – Promotional Access Fee Reduction ×

[16] We are grateful to the editor and an anonymous referee for making this point.

Length of Promotion) / Length of Contract. $MINUTES_{ipmt}$ is the number of minutes included in carrier i's plan p in market m at time t. Each plan offers a bucket of minutes for a fixed monthly access fee. Plans may include "anytime minutes," "peak minutes," and "night & weekend minutes." When a firm sets a plan's price, it must implicitly value each type of minutes included in the plan. Hence, we need to estimate the relative weight given to each type. We define $MINUTES = \beta_1$Anytime Minutes + β_2Peak Minutes + β_3Night & Weekend Minutes.[17] The βs sum to one and we estimate them using nonlinear least squares. The βs reflect both consumers' relative willingness to pay for each type of minutes and the relative costs for each type. We would expect night & weekend minutes to have much lower implicit prices than anytime minutes or peak minutes because consumers value more highly minutes they can use during 6AM-9PM (usual peak hours) on weekdays than those they can use only late at night or on weekends. We also expect higher weights for peak and anytime minutes because wireless carriers may include the marginal cost of capacity in the implicit prices of peak and anytime minutes, but not in the price of night & weekend minutes, since capacity potentially binds only during peak hours.

A dummy variable NP_t is equal to one if numbers were portable at time t and zero otherwise. $NP = 1$ for December 2003 through June 2004 and $NP = 0$ before December 2003.[18] A vector of all other controls that could affect the plan price, such as carrier and market dummies as well as various plan characteristics is represented by X_{ipmt}. The definition of these variables and the economic interpretation of the corresponding coefficients are provided in Appendix B. Finally, we cluster errors by carrier and market to obtain robust standard errors. This allows for serial correlation in the stochastic term ε for a given carrier in a given market. Thus, plans offered by the same carrier in a given market are allowed to have correlated ε across plans as well as over time. Our underlying assumptions are that correlations across carriers in the same market are fully captured by the market fixed effects and correlations across markets for a given carrier are fully captured by the carrier fixed effects.

As we discussed in Section 3, we recognize that the monthly access fee is not the only dimension in which wireless carriers responded to the introduction of number portability. Wireless carriers might have started demanding longer-term contracts from consumers to mitigate the impact of number portability on switching frequency, or they might have changed other features in non-price dimensions. Our empirical approach to deal with these broader changes is to include all these features as explanatory variables so that we can obtain the size of price change due to number portability holding these features constant

[17] If a plan offers unlimited anytime minutes, we set Anytime Minutes = 43200 (total number of minutes in a month). If a plan offers unlimited N&W minutes, we set Night & Weekend Minutes = 23880 (total number of N&W minutes in a month). No plan in our sample offers unlimited peak minutes.

[18] The data are collected at the beginning of each month, so November 2003 data were collected before number portability.

over time. The effect of the policy on price holding all other characteristics constant is what we would like to know an answer to, since it tells us how much less price the consumer needs to pay for the same level of utility from her chosen plan thanks to the policy.

As the discussion makes clear, many of the plan characteristics are choices made by firms and are therefore endogenous. Without taking a more structural approach, it would not be possible to model how firms optimally choose these various dimensions in response to the policy change, and it is beyond the scope of this paper. Thus, we make a compromise and instead examine how the equilibrium relationship between the price and other plan characteristics changes as a result of the policy in a reduced-form way, using our pricing equation (1). Although this makes it difficult for us to attach any structural interpretation to most of the coefficients, our interpretation for coefficients on terms involving *NP* is unlikely to be significantly affected, since the introduction of number portability can be treated as exogenous, as the sequence of events leading to its implementation, discussed in Section 2, show.

The specification of the pricing equation reflects the observation that prices do not increase linearly with included minutes. Optimal screening models, such as in Mussa and Rosen (1978) and Maskin and Riley (1984), predict that for general assumptions about costs, buyers' valuation and the distribution of buyer types, concave tariffs (volume discounts in our case) will be profit-maximizing for a monopolist. Volume discounts could also be due to fixed costs of customer service provision, billing, etc., which reduce the average costs of high-volume plans relative to those of low-volume plans. In real world wireless pricing, volume discounts are common. Hence, we expect α_2 to be less than one. The interaction between $\ln(MINUTES)$ and *NP* allows the curvature of the nonlinear pricing schedule, i.e., the degree of volume discounts, to change with the introduction of number portability.[19]

Table 4 shows the estimation results of the pricing equation. Column A shows the regression results when we restrict δ_2 to be zero. Column B shows the regression results when we free up δ_2. Since Column A does not include the interaction between *NP* and $\ln(MINUTES)$, the coefficient on the NP dummy in Column A represents the average impact of number portability on prices across all plans (as well as general time trend, which we will discuss below). As expected, plan prices are lower after the policy introduction compared to before. The price of a plan offered after number portability is on average 4.7% lower than the price of a plan offered before number portability, when the two plans are identical except for the timing of the offering. Based on Column A of Table 4, Figure 1A shows the fitted pricing schedules before and after number portability. The fitted schedules are obtained by plotting predicted

[19] Defining $MINUTES$ as a weighted average of various types of minutes makes it easier to discuss how the "curvature" of a nonlinear pricing schedule changes with the policy. If we instead included each type of minutes separately in log forms, interpreting the curvatures and drawing the nonlinear pricing schedule would become trickier.

prices for each plan in the data. Column A of Table 4 assumes that number portability affected the prices of all plans by the same proportion.

Column B of Table 4 reports the estimation results when we allow number portability to affect different parts of the pricing schedule by different proportions. The NP dummy in the intercept now has a positive and significant coefficient and the NP dummy in the curvature has a negative and significant coefficient. These results mean that the prices for most plans, except those with the fewest minutes, decreased after number portability,[20] and that the prices of high-volume plans fell proportionally more than the prices of low-volume plans. This pattern is clearly depicted in Figure 1B: the post-NP pricing curve lies below the pre-NP pricing curve, and the difference between the two is much larger at high volume than at low volume.

For concreteness, we provide at the bottom of Table 4 the estimated percentage changes in prices for plans of various volume levels using the results of Column B of Table 4. For example, a low-volume plan whose price was \$20.03 per month before number portability costs \$19.84 after the introduction of number portability, a price reduction of 0.97%. A medium-volume plan whose price was \$75.27 per month before number portability costs \$71.63 after number portability, a price reduction of 4.84%. A high-volume plan whose price was \$151.06 per month before number portability costs \$140.77 after number portability, a price reduction of 6.81%.

Most of the other coefficients in Table 4 are as expected. α_2 is less than 1, which is consistent with the volume discounts common in the wireless market. The magnitude of the βs, the relative weights for each type of minutes in pricing, implies that the number of anytime minutes and peak minutes included in plans mostly determines their prices, whereas night & weekend minutes get almost no weight in determining prices. This is not surprising given our earlier discussion about consumers' willingness to pay and costs for each type of minutes. This might also reflect wireless carriers' strategies of offering huge buckets of night & weekend minutes to catch consumers' attention while pricing does not depend on them since they often go largely unused. Plans in our data offer either anytime minutes or peak minutes, but not both, and the estimated weights β_1 and β_2 suggest that the two types of minutes get almost equal weights.[21]

The coefficients on coverage areas also make sense. National plans are more expensive than network plans, which, in turn, have a higher price than local plans. A push-to-talk feature makes a plan more

[20] Prices decreased for plans with 50 anytime minutes or more. Plans that offer less than 50 anytime minutes per month experienced a slight increase in price—less than 1% increase— after number portability, according to our results. Although we do not know how many users have plans with less than 50 anytime minutes, we see that less than 2% of all plans in our data fall in this category, an indication that these low-volume plans are used by a small number of people.

[21] It is unclear *a priori* which one would have a higher weight. Peak minutes have restrictions on when they can be used. On the other hand, some of anytime minutes might be used during off-peak hours when costs are lower.

attractive, and plans with free long-distance calls are also more attractive. Because some carriers use an activation fee waiver as an incentive for consumers to sign up for longer-term contracts, the coefficient for a two-year contract has a negative sign.

As we mentioned earlier, some wireless carriers have imposed monthly surcharges on their customers to recover the costs of number portability. Since these surcharges are not included in our price measure, one concern is that those surcharges might more than offset the declines in the monthly access fee. According to the Center for Public Integrity, 10 major carriers (ALLTEL, AT&T, Cingular, Leap Wireless, Nextel, Sprint PCS, T-Mobile, US Cellular, Verizon and Western Wireless) were collecting $94 million per month as a "federal recovery fee" as of April 2004. There were about 158,721,981 wireless subscribers at the end of 2003, and 89% of them were served by those 10 major carriers. Assuming that the other smaller carriers charge similar amounts and that 80% of the fees are used for number portability,[22] each consumer pays $0.53 per month as a "price" to have the option of keeping her number when switching carriers.[23] Since low-volume users did not enjoy as large price declines as high-volume users but paid the same "price" to have the option of porting numbers, high-volume users benefited more from the policy. The very low-end users are actually worse off due to number portability since they paid an equal share of number portability costs while there was a slight increase in prices for their plans after number portability. Customers who are not at the very bottom enjoyed net gains from number portability, and the size of the net gains increased with a customer's usage level.[24]

4.1.2 Is the Result Merely a Continuation of the Pre-existing Trend?

To ensure that the observed price changes are not a mere continuation of the existing trend, we check price movements before the policy. If the pre-existing trend was such that prices went down with larger declines for higher-volume plans, we cannot say that the pattern we observe after number portability is due to the policy itself. To check this possibility, we run a regression similar to equation (1) using only pre-number portability data. Since it is possible that number portability started to have an impact on carriers' pricing a few months before its implementation, we use observations between January 2003 and

[22] According to one estimate, the costs for number portability account for 61% of the total federal mandate costs (Lenard and Mast, 2003). Hence, the 80% assumption is a conservative one.

[23] $94 million×100/89×0.8/158721981 = $0.5323. The $94 million/month figure is as of April 2004. The amount of surcharges varies over time and some carriers stopped collecting NP fees since then.

[24] This comparison is made only based on "price effects": we do not attempt to draw conclusions about overall welfare consequences of number portability. For meaningful discussion of welfare, we need to consider many important aspects which are beyond the scope of this paper. For instance, since our data cover only several months after the policy introduction, our results are silent on long-term impacts. Also, one needs to consider the direct benefit of keeping phone numbers and people's frequency of switching. In addition, people might change their choice of plan in response to number portability.

June 2003 only.[25] We then define a new dummy variable, *2ndHalf*, which is equal to one for the second half of this sample (April 2003–June 2003) and is equal to zero for the first half of the sample (January 2003–March 2003). Then we run the same regression as (1), replacing the NP dummy with the new dummy variable *2ndHalf*. If the coefficients on *2ndHalf* have similar patterns as those on *NP*, we cannot interpret the price changes in the previous section as consequences of the policy.

When we estimate the model without the interaction between *2ndHalf* and ln*(MINUTES)* (third column in Panel 1 of Table 5), we find that the coefficient on *2ndHalf* is essentially zero with a p-value of 0.997. This suggests that there was no overall price decline during the pre-NP time period.[26] In contrast, we found a price reduction of 4.7% after number portability (repeated in the first column in Panel 1 of Table 5 for ease of comparison). Furthermore, when we estimate the model with the interaction between *2ndHalf* and ln*(MINUTES)* (fourth column in Panel 1 of Table 5), there was no differential price change between low-volume and high-volume plans, as indicated by the insignificant coefficient on *2ndHalf* in the curvature. In contrast, the corresponding coefficient on *NP* was significant (repeated in the second column in Panel 1 of Table 5). Therefore, we conclude that our results in the previous section are not a mere continuation of the pre-existing time trend.

Alternatively, we can estimate our model with time trends. The short time horizon of the sample makes it difficult to pin down what the existing trend was, but we try estimating equation (1) with time trends (not reported, but available upon request). We use specifications that allow for a linear or quadratic time trend, and our main findings do not change even with the inclusion of time trends.

Another exercise we perform is to use month dummies instead of the NP dummy in order to trace the evolution of price over time. The results are reported in Panel 2 of Table 5. The omitted month in the results is November 2003 (last month with NP = 0 in the data). The first column includes month dummies only in the intercept in order for us to easily see the overall price movements. If a decline in price was a general time trend unrelated to the policy change, we should see all positive numbers for months prior to November 2003 and all negative numbers for months after November 2003. If, on the other hand, prices started to decline due to the introduction of number portability, we would not see all positive numbers for months prior to November 2003 while we would still see all negative numbers for months after November 2003. The results show that not all coefficients are positive for months prior to November 2003 while all coefficients are negative and significant for months since November 2003. Thus, we conclude that the price decline we observe after number portability is not a simple continuation of

[25] Number portability received huge publicity around June 2003, when the D.C. Circuit denied the forbearance petition by Verizon and the Cellular Telecommunications and Internet Association (Kessing, 2004).

[26] This justifies an omission of time trend in our earlier discussion of gains from number portability.

the existing trend.

In the second column of Panel 2 in Table 5, we examine whether we had differential price changes prior to the introduction of number portability, by including month dummies in both the intercept and the curvature. The table shows that since November 2003, prices for high-volume plans started to decline more than prices for low-volume plans, a pattern that did not exist prior to November 2003. Therefore, these results provide evidence that the differential price change is attributable to the policy, rather than the general time trend. The table, however, also shows that the coefficients on the month dummies in the curvature for May and June of 2004 become insignificant after being negative and significant for all other months post NP. This could be either a temporary reversal or an indication that the larger price decline for higher-volume plans might not be long-lived. Unfortunately, we cannot provide a definite answer on the long-term impacts of the policy with the current data.

4.1.3 Price Dispersion

In the previous sections, we found that the impact of number portability on the price level was larger among higher-volume users. In this section, we examine whether the impact of the policy on price dispersion was also larger among higher-volume users. Our motivation for examining price dispersion is as follows. Price dispersion across firms contains information about the degree of consumer brand loyalty.[27] If brand loyalty is strongest among users who choose a certain level of volume, price dispersion across carriers can be largest among those users, other things being equal (this idea was used in Sorensen (2000)). If brand loyalty is not strong, a high level of inter-carrier price dispersion cannot be sustained in equilibrium since carriers would compete away such dispersion. Therefore, if the policy reduced consumers' loyalty to their existing carriers by allowing them to retain phone numbers in case of switching, we might expect a reduction in price dispersion across carriers after the policy introduction. Furthermore, if the policy had a larger impact on higher-volume users, we would expect the reduction in price dispersion to be larger for higher-volume users.

To measure price dispersion across carriers for different volume user segments, we construct a volume for each plan (volume = $\hat{\beta}_1 \times$ Anytime + $\hat{\beta}_2 \times$ Peak + $\hat{\beta}_3 \times$ N&W, where $\hat{\beta}$ is estimated β from Column B of Table 4) and divide plans into three equally-sized categories based on volume (low, medium and high) within each carrier-market-month combination. Then we run 6 separate regressions of equation (1) (excluding the NP dummies in the intercept and in the curvature), for each of the three volume categories

[27] Brand loyalty here is broadly defined as anything that makes a consumer willing to pay a higher price to buy from one carrier than from another when the two firms offer the same product. The degree of brand loyalty might differ between high-volume and low-volume users due to various things like switching costs, search costs, innate brand loyalty, etc.

before and after number portability. For each regression, we then compute standard deviations of the estimated carrier effects.[28] The estimated coefficients for carrier dummies capture a carrier premium or discount which cannot be explained by the observed plan characteristics. If the standard deviation of the estimated carrier effects is high in a particular volume segment, it means a high level of price dispersion in that segment.

We report the standard deviations of the estimated carrier effects in Table 6. Table 6 also reports the standard deviations of the estimated carrier effects when we divide groups in different ways as a robustness check. The second and third panels divide plans into different groups based on their prices rather than volume. For standard errors on the standard deviation estimates, we use bootstrap.

A few patterns emerge from the table. (1) The level of price dispersion is higher for the high-volume user segment than for the low-volume user segment both before and after number portability.[29] (2) Price dispersion tends to decrease in the aftermath of number portability, except for the lowest segment. (3) The decrease in price dispersion after number portability tends to be larger for higher-volume users. These findings nicely complement our earlier findings on the price level. As with the price level, we find that price dispersion decreased after number portability and that the policy had a larger impact on the price dispersion of higher-volume users.[30]

4.1.4 Price Changes in Smaller Markets

Number portability was introduced in two phases. In the first phase, the top 100 MSAs were required to implement number portability in November 2003. In the second phase, all other smaller markets were required to implement number portability in May 2004. In this section, we attempt to exploit this variation in the timing of the policy introduction by comparing price movements between large markets and small markets. For this additional analysis, we use the data obtained from MyRatePlan.com. The data from MyRatePlan.com contain many major markets and 4 smaller markets (Des Moines, IA; Jackson, MS; Spokane, WA; Tallahassee, FL). The set of characteristics reported in the MyRatePlan data differs from, and is not as exhaustive as, that in the Econ One data, and we use the data from MyRatePlan.com for both types of markets in this section to facilitate comparison.[31]

[28] This is conceptually similar to the analysis in Milyo and Waldfogel (1999). We are interested in price dispersion across carriers for a homogeneous product, but plans offered by different carriers differ in various characteristics. Thus, we use the pricing equation where explanatory variables are included to make products as comparable as possible across carriers.

[29] Since our dependent variable is log of price, carrier premium/discounts are in percentage terms. Since this measure of price dispersion is found to increase with volume, it follows that absolute price dispersion also increases with volume.

[30] Sales-weighted price dispersion is probably much lower than what is reported here. However, it seems unlikely that we would have an increase in sales-weighted price dispersion and a decline in unweighted one during the same period.

[31] Due to this difference, we don't expect the results from the two data sets to have the same magnitudes.

Since many carriers have national presence and offer plans in almost all markets, one concern is that a carrier's pricing in smaller markets might be influenced by its pricing in larger markets. If so, we might end up observing price falls in small markets even before number portability is introduced there simply because the policy is in place in large markets. To mitigate this concern, we exclude from our analysis carriers whose presence is mostly in major markets and only focus on carriers who have enough presence in both major markets and smaller markets. Specifically, we use carriers that offer at least 5% of their plans in smaller markets. Our hope is that small markets are important enough to these carriers' revenues to prompt them to tailor their pricing to specifics of small markets. Even for these carriers, however, more than 90% of their plans are offered in major markets, so we might still see pricing in smaller markets comove with pricing in larger markets.

For our analysis, we define three dummy variables for different time periods. *PD1* is equal to 1 for May 2003 through October 2003, 6 months period prior to the first round of the policy implementation, and zero otherwise.[32] *PD2* is equal to 1 for November 2003 through April 2004, 6 months period during which number portability was available in major markets, but not in smaller markets. *PD3* is equal to 1 for May 2004 through October 2004, 6 months period during which numbers were portable in all markets, and zero otherwise. We run separate regressions for major markets and smaller markets and report the results in Table 7. We only report key coefficients to save space.

The first two columns in Table 7 report results from regressions that include the period dummies in the intercept only. They tell us how the overall price level changed during different periods. The results suggest that during *PD2*, when numbers were portable in major markets but not in smaller markets, the two markets experienced different price movements, with prices falling much more in major markets than in smaller markets. During *PD2*, prices fell by 8% in major markets, while prices fell by 4.7% in smaller markets. Our test shows that this difference is statistically different from zero. As a comparison, pre-NP price movements were not statistically different between the two markets (not reported). The fact that we observe price falls in both markets, although numbers are portable in major markets only, might be due to price comovements between small and large markets. The larger fall in larger markets during this time period suggests that the price falls might be a result of the policy. The larger fall in larger markets continues into *PD3*, consistent with a gradual change in wireless prices around the implementation dates.

The last two columns in Table 7 allow for the shape of the nonlinear schedule to change as well. Unfortunately, the difference between the two markets becomes statistically insignificant, although we see that the magnitude of the drop in the curvature is slightly larger for larger markets during *PD2*, which continues till later periods. As a comparison, none of the two markets experienced a reduction in the

[32] The MyRatePlan data for November 2003 were collected after the implementation of the policy in the top 100 MSAs.

curvature prior to number portability (not reported). Given these weak results, we conclude that price movements in smaller markets do not differ significantly from the movements in larger markets. We think this may be partly due to pricing decisions in smaller markets being influenced by more important larger markets, but without data from single-market providers we cannot further investigate this possibility.

4.2 Robustness Checks

In this section, we perform a wide range of robustness checks. First, we investigate whether our main results are driven by a small subset of plans. In constructing our selected sample, we excluded plans that are strictly dominated by others as well as plans that are deemed redundant. Although these steps are helpful in enhancing the validity of the estimation sample, we still give the same weight to each plan included in the estimation sample, and this could be problematic. If prices on popular plans did not change while prices on plans that only a few subscribe to experienced a large change, an estimation with an equal weighting scheme might wrongly indicate that the average price change was large. Unfortunately, we cannot directly address the issue due to the lack of sales data. Instead, we attempt to ensure that our main results are not entirely driven by a small subset of the sample, by grouping plans in various ways and doing a separate regression for each group. We estimate the pricing equation (1) separately for each carrier in the sample, for each coverage area, for various combinations of minutes and for each contract length. Table 8 reports the estimated coefficients. The results in Table 8 clearly show that the pattern of price changes we saw earlier is not driven by a small subset of the sample. Rather, the same pattern is observed for 10 subsets out of 14, and the coefficient is statistically significant for 9 of the 10 subsets.

Table 9 shows estimation results for different specifications. The first specification allows the effects on prices of variables other than minutes to change with the introduction of number portability. The second specification examines whether the curvature of the pricing schedule in our main model was skewed by plans that offer unlimited anytime minutes or unlimited night & weekend minutes by setting Anytime Minutes to 8000 and Night & Weekend Minutes to 7000 if they are unlimited. In the third specification, we check if we obtain similar results once we exclude the plans that cost more than $200/month, because those plans might be bought by a small number of people. The results from these three alternative specifications are similar to the results in Table 4.

The first specification, where we allow the effects on prices of variables other than minutes to change with the policy, is important, because carriers likely have changed other features in response to number portability, and thus the policy may have changed the relationship between various plan features and their

price. The estimation results suggest that there were indeed changes: many of the estimated coefficients on the interactions between the NP dummy and plan features are significant. The direction of the change, however, is not easy to interpret in most cases. For instance, the premium on network plans compared to local plans has increased after the introduction of number portability while the premium on national plans compared to local plans has decreased after the policy. These might be indicative of changes in carriers' market power due to the policy, but the interpretation is not obvious unlike the case for the number of minutes. Despite the difficulty of interpreting these results, it is comforting to note that we still observe differential reductions in prices across different volume of usage even when we allow a potentially changing relationship between price and plan features other than minutes.

Another objection to the pricing equation (1) might be that it is too simple. Although many plan attributes are likely to interact in complex ways in determining price, they enter as separate regressors in the pricing equation. For instance, the impact of coverage area on pricing might depend on the number of included minutes. One way to address this issue would be to examine price changes for the exact same plans over time. This approach is not taken in this paper for two reasons. First, the data do not contain plan identifiers, and as a result one cannot follow the same plans over time. A second, more fundamental issue is the following. Wireless carriers frequently change plan features, introduce new plans and drop some old ones. If carriers responded to the policy by introducing more attractive plans (e.g., plans with more minutes at the same price), in addition to lowering prices on existing plans, we would fail to capture a very important channel through which the policy lowers the effective prices, if we restrict our attention to plans that exist both before and after number portability.

We instead run a specification that is much more flexible than (1) in order to address the misspecification concern. In particular, we interact the number of minutes with all the other plan features. Although this does not fully address the concern about misspecification, if our results are robust to this more flexible specification, it would give more credence to the results. We report our results in the fourth column of Table 9. The magnitudes of the estimated coefficients change, but the main findings remain unchanged.

Figure 2 presents additional robustness checks. Instead of regressing log of price on log of minutes, we try three different functional forms. Depending on specifications, pricing schedules look different, but it still holds that the prices of plans after number portability are lower than the prices of the plans before number portability, and that the price decline was larger for higher-volume plans.[33]

[33] We also estimate an alternative specification that allows potentially non-monotonic price responses. The results, available upon request, show that the effects are indeed monotonic.

5 Conclusion

This paper has examined the price response of wireless carriers to the introduction of number portability. We presented two main empirical findings. First, we find that wireless prices decreased in response to number portability, but not uniformly across all plans. The prices for low-volume plans decreased by 0.97% and the prices for medium- and high-volume plans decreased by 4.84% and 6.81%, respectively. Second, we find that price dispersion across carriers declined after number portability, and that the decline was greater for higher-volume users. These results show that the major regulatory change in the wireless market not only reduced the overall price, as envisioned by policy makers, but also interestingly had differential effects on different consumers.

There are interesting avenues for future research. One avenue is to find consumer-level data and study how consumer switching behavior responded to the policy. Another fruitful avenue would be to explicitly model the dynamics of firm and consumer behavior in order to understand their incentives and behavior in a dynamic setting.

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Appendix A: Markets and Carriers

Market	Carriers
Atlanta	AT&T Wireless, Cingular Wireless, Metro PCS, Sprint PCS, T-Mobile, Verizon Wireless
Boston	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Chicago	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, US Cellular, Verizon Wireless
Cincinnati	Cincinnati Bell Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Cleveland	Alltel, AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Dallas	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Denver	AT&T Wireless, Qwest, Sprint PCS, T-Mobile, Verizon Wireless
Detroit	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Hawaii	AT&T Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Houston	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Kansas City	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Los Angeles	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Miami	AT&T Wireless, Cingular Wireless, MetroPCS, Sprint PCS, T-Mobile, Verizon Wireless
Minneapolis	AT&T Wireless, Qwest, Sprint PCS, T-Mobile, Verizon Wireless
New York	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Philadelphia	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Phoenix	Alltel, AT&T Wireless, Qwest, Sprint PCS, T-Mobile, Verizon Wireless
Pittsburgh	AT&T Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Portland	AT&T Wireless, Qwest, Sprint PCS, T-Mobile, Verizon Wireless
Sacramento	AT&T Wireless, Cingular Wireless, Metro PCS, Sprint PCS, SureWest Wireless, T-Mobile, Verizon Wireless
San Diego	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
San Francisco	AT&T Wireless, Cingular Wireless, Metro PCS, Sprint PCS, T-Mobile, Verizon Wireless
Seattle	AT&T Wireless, Cingular Wireless, Qwest, Sprint PCS, T-Mobile, Verizon Wireless
St. Louis	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Tampa	Alltel, AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless
Washington D.C.	AT&T Wireless, Cingular Wireless, Sprint PCS, T-Mobile, Verizon Wireless

The Econ One data do not include Nextel Communication, Inc., because Nextel primarily offers multiple-user plans.

Appendix B: Definition of Variables

$CONTRACT24_{ipmt}$: $CONTRACT24$ is a dummy variable that is equal to one if the plan requires a two-year contract and zero otherwise.

$NATIONAL_{ipmt}$: $NATIONAL$ is a dummy variable that is equal to one if the plan is a national plan and zero otherwise. $LOCAL$ and $NETWORK$ are similarly defined.

$7PM_{ipmt}$: $7PM$ is a dummy variable that is equal to one if the plan's off-peak hours start at 7PM and zero otherwise. The same number of night & weekend minutes will be more valuable if off-peak hours start at 7PM than if they start at 9PM. The variable $7PM$ is included to account for price differences due to this feature.

$ROLLOVER_{ipmt}$: $ROLLOVER$ is a dummy variable that is equal to one if the plan allows rollover and zero otherwise. With rollover, when a wireless customer doesn't use all the minutes included in the plan, he can rollover the unused minutes to the next month.

$PUSH2TALK_{ipmt}$: $PUSH2TALK$ is a dummy variable that is equal to one if the plan offers walkie-talkie services and zero otherwise. This feature is commonly used by police officers, taxi drivers and construction workers.

PCS_{ipmt}: PCS is a dummy variable that is equal to one if the service operates on PCS frequency (1.9 GHz) and zero if the service operates on cellular frequency (800 MHz). PCS and cellular services are believed to have almost identical qualities from users' point of view, but there might be some differences in costs or consumer's valuations for these two types.

$FREENATIONLD_{ipmt}$: $FREENATIONLD$ is a dummy variable that is equal to one if the plan includes free nationwide long distance calls and zero otherwise.

$FREEINNTWLD_{ipmt}$: $FREEINNTWLD$ is a dummy variable that is equal to one if the plan includes free in-network long distance calls (but not free nationwide long distance calls) and zero otherwise.

$CARRIER_i$: This is a carrier dummy that is equal to one if the plan belongs to carrier i and zero otherwise.

$MARKET_m$: This is a market dummy that is equal to one if the plan belongs to market m and zero otherwise. This variable can capture market-specific characteristics that might affect prices, such as the level of demand or labor costs.

Table 1
Summary Statistics

		Entire Sample		Selected Sample	
		Mean		Mean	
		Before NP	After NP	Before NP	After NP
		Jan-03 – Nov-03	Dec-03 – Jun-04	Jan-03 – Nov-03	Dec-03 – Jun-04
Activation Fee[1]		$27.92	$26.13	$35.17	$34.35
Monthly Access Fee		$98.54	$96.69	$95.99	$96.63
Unlimited Anytime Minutes		0.28%	0.43%	0.12%	0.15%
Unlimited Peak Minutes		0%	0%	0%	0%
Unlimited Night & Weekend Minutes		52.68%	64.19%	45.25%	61.23%
Anytime Minutes[2]		1156.5 min	1086.89 min	1165.94 min	1197.97 min
Peak Minutes		177.38 min	341.54 min	186.80 min	299.34 min
Night & Weekend Minutes[3]		1138.53 min	1516.48 min	1785.98 min	2507.5 min
Coverage	National	25.75%	32.78%	23.04%	29.25%
	Network	45.28%	45.51%	48.36%	48.10%
	Regional	3.63%	2.13%	0%	0%
	Local	25.35%	19.58%	28.60%	22.65%
Contract Length	No Contract	0.06%	0.04%	0%	0%
	1 Year	45.67%	41.34%	68.66%	62.65%
	2 Year	54.26%	58.62%	31.34%	37.35%
Cancellation Fee[4]		$172.84	$168.84	$175.37	$168.88
Availability of Promotion[5]		12.40%	13.31%	9.48%	18.52%
Length of Promotion[6]		11.41 mos	4.45 mos	9.93 mos	5.04 mos
Per-Minute Charge[7]	Peak	$0.35	$0.33	$0.36	$0.35
	N&W	$0.35	$0.33	$0.36	$0.35
Early Nights (7PM)		6.04%	17.08%	11.43%	23.78%
Rollover		11.79%	11.04%	22.81%	20.00%
Push2Talk		1.67%	6.43%	1.88%	5.82%
PCS		47.31%	50.53%	42.96%	49.07%
Free Nationwide Long Distance		37.13%	30.69%	45.20%	36.30%
Free In-Network Long Distance		47.02%	52.41%	40.30%	49.47%
Number of Observations		63979	43034	28278	23041

[1] Some carriers use an activation fee waiver as an incentive for consumers to sign up for longer-term contracts. Since the selected sample does not include plans with a two-year contract if an otherwise identical plan with a one-year contract is also offered, the average activation fee is higher for the selected sample than for the entire sample.

[2] Excluding plans which offer unlimited anytime minutes

[3] Excluding plans which offer unlimited night & weekend minutes

[4] A cancellation fee applies if a customer cancels her service with a carrier before the contract expires.

[5] We say a promotion is available if the plan offers additional minutes and/or an access fee reduction.

[6] Conditional on the availability of a promotion

[7] Additional airtime charges for minutes used in excess of included minutes

Table 2
Heterogeneous Impacts

	Mean					
	Before Number Portability Jan-03 – Nov-03			After Number Portability Dec-03 – Jun-04		
	Low	Medium	High	Low	Medium	High
Monthly Access Fee	$38.79	$75.18	$167.52	$41.95	$76.07	$166.10
Unlimited Anytime Minutes	0.00%	0.25%	0.10%	0.00%	0.00%	0.42%
Unlimited Night & Weekend Minutes	43.13%	46.23%	46.24%	59.14%	64.27%	60.23%
Anytime Minutes[1]	341.7	804.67	2254.85	370.07	875.9	2264.56
Peak Minutes	75.21	160.48	312.8	94.41	220.53	561.38
Night & Weekend Minutes[2]	1700.45	1813.55	1841.81	1767.55	3045.17	2738.42
Number of Observations	8979	9386	9913	7322	7682	8037

[1] Excluding plans which offer unlimited anytime minutes
[2] Excluding plans which offer unlimited night & weekend minutes

Table 3
Changes in Selected AT&T Plans

	Plan 1: $49.99 Anytime minutes	Plan 2: $99.99 Anytime minutes	Plan 3: $149.99 Anytime minutes	Plan 4: $199.99 Anytime minutes
Apr-03	700	1400	2200	3200
May-03	700	1400	2200	3200
Jun-03	700	1400	2200	3200
Jul-03	700	1400	2200	3200
Aug-03	700	1400	2200	3200
Sep-03	700	1400	2200	3200
Oct-03	700	1600	2400	4000
Nov-03	750	1700	2600	4100
Dec-03	750	1700	2600	4100
Jan-04	750	1700	2600	4100
Feb-04	750	1700	2600	4100
Mar-04	750	1700	2600	4100
Apr-04	750	1700	2600	4100

For ease of comparison, we choose plans whose prices and all characteristics (except for the number of anytime minutes) remain the same over time. As a result, the number of anytime minutes is the only dimension that might change over time for the chosen plans.

Table 4
Estimation of Wireless Carriers' Pricing Equation

	A: No Differential Impacts	B: Differential Impacts
NP in Intercept (δ_1)	-0.047 (0.004) ***	0.057 (0.031) *
Curvature (α_2)	0.556 (0.010) ***	0.563 (0.012) ***
NP in Curvature (δ_2)		-0.017 (0.005) ***
Anytime Minutes (β_1)	0.493 (0.005) ***	0.493 (0.005) ***
Peak Minutes (β_2)	0.508 (0.006) ***	0.509 (0.006) ***
CONTRACT24	-0.112 (0.006) ***	-0.111 (0.006) ****
NETWORK	0.088 (0.010) ***	0.090 (0.010) ***
NATIONAL	0.237 (0.013) ***	0.238 (0.013) ***
7PM	0.102 (0.007) ***	0.102 (0.007) ***
ROLLOVER	0.015 (0.014)	0.014 (0.014)
PUSH2TALK	0.202 (0.006) ***	0.203 (0.006) ***
PCS	-0.034 (0.008) ***	-0.034 (0.008) ***
FREENATIONLD	0.137 (0.018) ***	0.135 (0.019) ***
FREEINNTWLD	0.045 (0.012) ***	0.043 (0.012) ***
No. Obs	51319	51319
R-squared	0.8866	0.8868

*** Significant at 1% level ** Significant at 5% level * Significant at 10% level
Inside the parentheses are robust standard errors clustered by carrier and market.
Coefficients for carrier dummies and market dummies are not reported.

Price Changes based on Column B

Weighted Minutes	Pre-NP Price	Post-NP Price	Price Change (%)
50.03	$20.03	$19.84	-0.97%
139.42	$35.44	$34.49	-2.66%
258.77	$50.12	$48.28	-3.67%
533.73	$75.27	$71.63	-4.84%
887.21	$100	$94.53	-5.65%
1839.91	$151.06	$140.77	-6.81%
2426.11	$176.44	$163.66	-7.24%

Based on Column B. Weighted Minutes = B_1 × Anytime Minutes + B_2 × Peak Minutes
+ (1-B_1-B_2) × Night & Weekend Minutes, where the Bs are the estimated βs from Column B

Table 5

Panel 1: Continuation of Existing Trend?

Entire Period (Jan-03 – Jun-04)			Pre-NP Period (Jan-03 – Jun-03)		
	Estimated Coefficient			Estimated Coefficient	
NP in Intercept	-0.047 (0.004) ***	0.057 (0.031) *	*2ndHalf* in Intercept	0.00002 (0.006)	0.042 (0.033)
Curvature	0.556 (0.010) ***	0.563 (0.012) ***	Curvature	0.575 (0.01) ***	0.580 (0.012) ***
NP in Curvature		-0.017 (0.005) ***	*2ndHalf* in Curvature		-0.007 (0.005)
No. Obs	51319	51319	No. Obs	14798	14798

Panel 2: Estimation of Pricing Equation with Month Dummies

	Estimated Coefficient	Estimated Coefficient
1/2003 in Intercept	0.033 (0.007) ***	-0.134 (0.074) *
2/2003 in Intercept	0.042 (0.01) ***	0.009 (0.077)
3/2003 in Intercept	0.075 (0.005) ***	0.183 (0.057) ***
4/2003 in Intercept	0.086 (0.007) ***	0.082 (0.041) **
5/2003 in Intercept	0.042 (0.006) ***	0.141 (0.05) ***
6/2003 in Intercept	-0.003 (0.006)	-0.155 (0.039) ***
7/2003 in Intercept	-0.012 (0.007) *	-0.014 (0.043)
8/2003 in Intercept	-0.01 (0.007)	-0.035 (0.044)
9/2003 in Intercept	0.021 (0.004) ***	-0.028 (0.034)
10/2003 in Intercept	-0.0007 (0.003)	-0.022 (0.023)
12/2003 in Intercept	-0.015 (0.002) ***	0.099 (0.016) ***
1/2004 in Intercept	-0.014 (0.002) ***	0.096 (0.016) ***
2/2004 in Intercept	-0.024 (0.003) ***	0.17 (0.032) ***
3/2004 in Intercept	-0.019 (0.003) ***	0.098 (0.046) **
4/2004 in Intercept	-0.02 (0.003) ***	0.099 (0.047) **
5/2004 in Intercept	-0.043 (0.005) ***	-0.018 (0.053)
6/2004 in Intercept	-0.046 (0.008) ***	-0.048 (0.051)
1/2003 in Curvature		0.028 (0.012) **
2/2003 in Curvature		0.006 (0.012)
3/2003 in Curvature		-0.018 (0.009) **
4/2003 in Curvature		0.0009 (0.007)
5/2003 in Curvature		-0.016 (0.008) *
6/2003 in Curvature		0.025 (0.007) ***
7/2003 in Curvature		0.0002 (0.008)
8/2003 in Curvature		0.004 (0.008)
9/2003 in Curvature		0.008 (0.006)
10/2003 in Curvature		0.003 (0.004)
12/2003 in Curvature		-0.018 (0.003) ***
1/2004 in Curvature		-0.018 (0.003) ***
2/2004 in Curvature		-0.032 (0.006) ***
3/2004 in Curvature		-0.019 (0.008) **
4/2004 in Curvature		-0.019 (0.008) **
5/2004 in Curvature		-0.004 (0.008)
6/2004 in Curvature		0.0002 (0.008)
No. Obs	51319	51319
R-squared	0.8881	0.8887

*** Significant at 1% level ** Significant at 5% level * Significant at 10% level

Inside the parentheses are robust standard errors clustered by carrier and market.

Table 6
Price Dispersion: Standard Deviation of Carrier Effects

		Before NP	After NP
1	Low-Volume Plans	0.025 (0.004)	0.093 (0.006)
	Medium-Volume Plans	0.169 (0.007)	0.108 (0.007)
	High-Volume Plans	0.317 (0.007)	0.229 (0.005)
2	Plans of less than $50	0.051 (0.002)	0.060 (0.002)
	Plans of between $50 and $115	0.097 (0.003)	0.088 (0.004)
	Plans of more than $115	0.370 (0.004)	0.283 (0.002)
3	Plans of less than $55	0.038 (0.002)	0.071 (0.002)
	Plans of between $55 and $110	0.114 (0.003)	0.077 (0.005)
	Plans of more than $110	0.370 (0.003)	0.284 (0.002)

Carriers that have a sufficient number of plans in each category are included in the analysis to make comparison meaningful.
Included carriers are AT&T, Cingular, Sprint, T-Mobile and Verizon.
Inside the parentheses are bootstrapped standard errors.
The number of bootstrap repetitions is 50.

Table 7
Large Markets v. Small Markets

	Large Markets	Small Markets	Large Markets	Small Markets
PD2 in Intercept	-0.080 (0.005) ***	-0.047 (0.018) ***	0.175 (0.022) ***	0.162 (0.107)
PD3 in Intercept	-0.172 (0.018) ***	-0.118 (0.065) *	0.416 (0.025) ***	0.435 (0.087) ***
PD2 in Curvature			-0.027 (0.003) ***	-0.020 (0.008) ***
PD3 in Curvature			-0.058 (0.004) ***	-0.052 (0.015) ***
No. Obs	50812	4297	50812	4297
R-squared	0.7251	0.7386	0.7298	0.743

*** Significant at 1% level ** Significant at 5% level * Significant at 10% level
Inside the parentheses are robust standard errors clustered by carrier and market.

Table 8
Estimation of Pricing Equation for Various Subsets of Sample

	AT&T plans	Cingular plans
NP in Intercept (δ_1)	0.039 (0.011) ***	0.373 (0.083) ***
NP in Curvature (δ_2)	-0.017 (0.002) ***	-0.053 (0.011) ***
No. Obs	11908	13680
	Sprint plans	Verizon plans
NP in Intercept (δ_1)	-0.011 (0.016)	0.028 (0.023)
NP in Curvature (δ_2)	-0.005 (0.002) **	-0.014 (0.004) ***
No. Obs	7100	12281
	T-Mobile	Local plans
NP in Intercept (δ_1)	-0.389 (0.033) ***	0.225 (0.058) ***
NP in Curvature (δ_2)	0.051 (0.005) ***	-0.048 (0.009) ***
No. Obs	4766	13306
	Network plans	National plans
NP in Intercept (δ_1)	-0.161 (0.031) ***	0.348 (0.037) ***
NP in Curvature (δ_2)	0.021 (0.005) ***	-0.066 (0.007) ***
No. Obs	24759	13254
	Plans with Anytime Minutes > 0	Plans with Peak Minutes > 0
NP in Intercept (δ_1)	0.124 (0.036) ***	-0.159 (0.048) ***
NP in Curvature (δ_2)	-0.025 (0.005) ***	0.014 (0.007) *
No. Obs	42525	8735
	Plans with unlimited N&W Minutes	Plans without unlimited N&W Minutes
NP in Intercept (δ_1)	0.096 (0.056) *	0.022 (0.024)
NP in Curvature (δ_2)	-0.028 (0.009) ***	-0.005 (0.004)
No. Obs	26904	24415
	Plans with one-year contracts	Plans with two-year contracts
NP in Intercept (δ_1)	-0.060 (0.030) **	0.367 (0.063) ***
NP in Curvature (δ_2)	0.002 (0.005)	-0.064 (0.009) ***
No. Obs	33852	17467

*** Significant at 1% level ** Significant at 5% level * Significant at 10% level
Inside the parentheses are robust standard errors clustered by carrier and market.

Table 9
Robustness Checks

	Robustness Check 1	Robustness Check 2	Robustness Check 3	Robustness Check 4
NP in Intercept (δ_1)	-0.087 (0.036) **	0.041 (0.030)	0.084 (0.034) **	0.072 (0.03) **
Curvature (α_2)	0.564 (0.012) ***	0.566 (0.010) ***	0.447 (0.010) ***	0.758 (0.067) ***
NP in Curvature (δ_2)	-0.018 (0.005) ***	-0.014 (0.005) ***	-0.024 (0.006) ***	-0.021 (0.005) ***
Anytime Minutes (β_1)	0.485 (0.006) ***	0.498 (0.004) ***	0.464 (0.004) ***	0.489 (0.003) ***
Peak Minutes (β_2)	0.516 (0.007) ***	0.507 (0.005) ***	0.537 (0.004) ***	0.513 (0.003) ***
No. Obs	51319	51319	47795	51319
R-squared	0.8888	0.8935	0.8942	0.9403

Robustness Check 1: We add interactions between NP and all other covariates (carrier dummies, market dummies, coverage dummies, contract length, PUSH2TALK, ROLLOVER, 7PM, PCS, FREENATIONLD and FREEINNTWLD).
Robustness Check 2: We set anytime minutes = 8000 if the plan offers unlimited anytime minutes. Also, we set night & weekend minutes = 7000 if the plan offers unlimited N&W minutes.[1]
Robustness Check 3: We drop plans that cost more than $200 per month. In addition, we include the per-minute charge as a RHS variable.
Robustness Check 4: We include interactions between the minutes and all other plan features.
*** Significant at 1% level ** Significant at 5% level * Significant at 10% level
Inside the parentheses are robust standard errors clustered by carrier and market.

[1] From customers' and firms' perspectives, unlimited minutes might not be different from, say, 8000 minutes, since people don't make full use of unlimited minutes. A person has to talk for four and a half hours per day to use up 8000 minutes. Choices of different numbers (for example, anytime minutes = 10000 if unlimited anytime minutes, night & weekend minutes = 6000 if unlimited night & weekend minutes) don't affect the results.

Figure 1A: No Differential Impacts

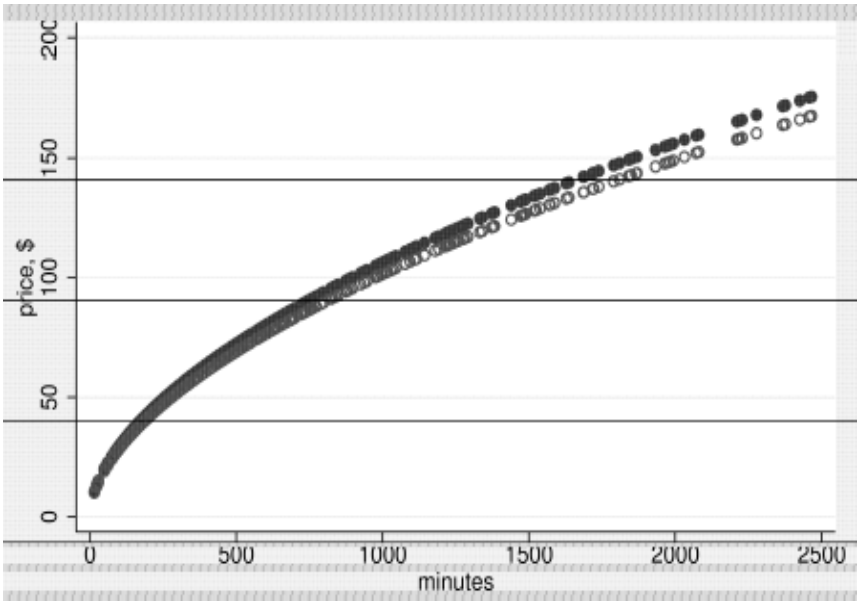
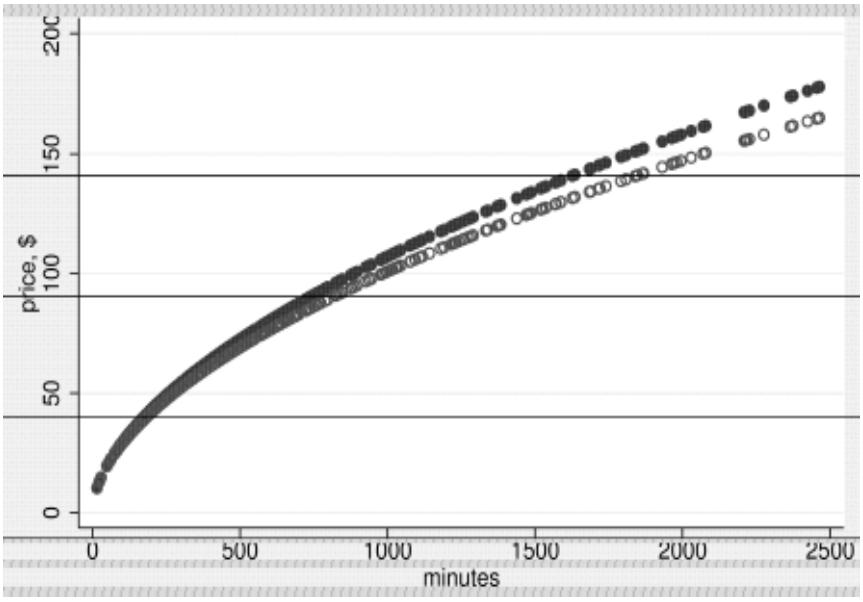


Figure 1B: Differential Impacts

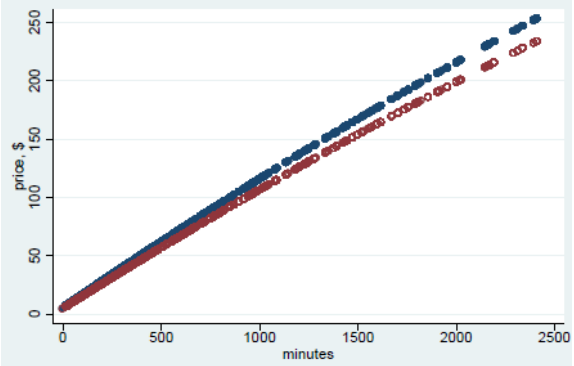


Based on Column A and B of Table 4 respectively. Minutes are the weighted average of anytime, peak and night & weekend minutes, where the weights are the estimated βs. Only about 2% of plans have more than 2500 weighted minutes, so we report the figure only for the range [0, 2500]. The pricing schedule before number portability is denoted with filled circles. The pricing schedule after number portability is denoted with hollow circles

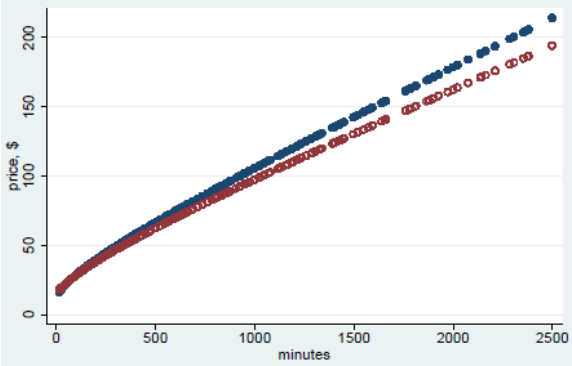
Figure 2

Robustness Checks

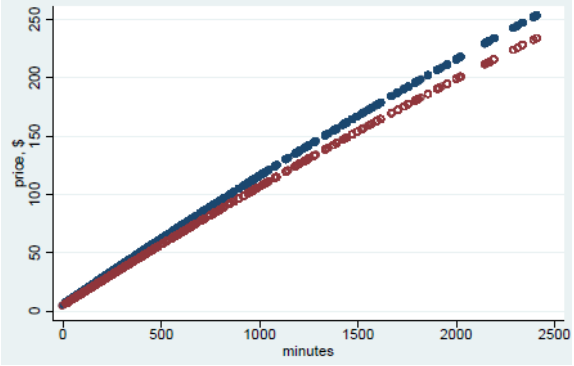
Robustness Check 5



Robustness Check 6



Robustness Check 7



Robustness Check 5: Regress *Price* on *MINUTES* and $MINUTES^2$
Robustness Check 6: Regress *ln(Price)* on *ln(MINUTES)* and $(ln(MINUTES))^2$
Robustness Check 7: Regress *ln(Price)* on *MINUTES* and $MINUTES^2$
The pricing schedule before number portability is denoted with filled circles.
The pricing schedule after number portability is denoted with hollow circles
Plans whose weighted minutes are more than 2500 are not included in graphs (less than 2% of all plans)