The Puzzle of Mistaken Millions: The MTA Surcharge and the Surge of Money onto MetroCards

Meiping (Aggie) Sun *

July 26, 2016

Abstract

Since 1998, the New York City Metropolitan Transportation Authority (MTA) system has used prepaid cards (MetroCards) to collect subway and bus fares. In 2013, the MTA imposed a $1 surcharge on new MetroCard purchases to motivate riders to refill and keep using their existing cards, thereby reducing litter. The Authority’s stated goal was accomplished as the number of new MetroCards sold dropped immediately and stayed low after the surcharge was imposed. Ridership of subways and buses did not change significantly after the surcharge. But, riders who purchased new MetroCards with the surcharge made larger deposits, especially on cards that had no subsequent refill activities. The response to the surcharge was greater in low-income neighborhoods and among riders who used cash or debit cards rather than credit cards. Also, larger changes in new card deposits have been recorded at vending machines than at manned booths (tellers). As a result, the net monthly outstanding balance from transit card deposits increased dramatically, which translates to riders lending an extra $150 million, on an annual basis, to the MTA. Moreover, some of the increased balances were never redeemed and escheated to the MTA after these MetroCards expired. Since the surcharge is a one-time fee, it should have no impact on deposit amounts. I document this puzzle in consumers’ behavior change after the surcharge by constructing a unique novel data set combining transaction-level MetroCard deposit and swipe information. These results suggest that 1) A small penalty may induce unexpected behavior change besides the planned goal. A policy change which meant to reduce waste, while effective in terms of achieving its stated goal, may sometimes lead consumers to make choices that are economically worse and result in more welfare loss. 2) Shrouding add-on fees may sometimes lead consumers to make choices that are economically better.

*Department of Economics, Columbia University (email: ms4196@columbia.edu). I would like to thank Brendan O’Flaherty, Pietro Ortoleva, and Suresh Naidu for invaluable guidance, assistance and advice. I thank Jushan Bai, Alessandra Casella, Donald Davis, Mark Dean, Francois Gerard, Wojciech Kopczuk, Jonah Rockoff, and Miikka Rokkanen for discussions and comments that shaped the content of this paper. I thank Laxman Gurung, Sun Kyoung Lee, Xuan Li, Janis Priede, Tuo Chen, and Danyan Zha for their help. I also thank the participants of seminars at Columbia University and George Washington University for their comments. I thank Tuo Chen for helping with Matlab Codes. I thank Sun Kyoung Lee for providing subway-census-tract data. I am particularly indebted to the staff at Metropolitan Transportation Authority (MTA) who have provided data for my research. All errors are my own.
1 Introduction

Since 1998, the New York City Metropolitan Transportation Authority (MTA) system has used prepaid cards to collect subway and bus fares. Riders load plastic cards (MetroCards) with amounts that they choose and swipe these cards when they ride subways or buses. In 2013, the MTA imposed a $1 "green" surcharge on new MetroCard purchases to motivate riders to refill and keep using their existing cards rather than purchasing new ones, thereby reducing litter. The Authority’s stated goal behind the surcharge was achieved as the number of new MetroCards sold dropped immediately and stayed low after the surcharge was imposed. Before 2013, the Authority, on average, sold about 7 million cards per month. After the surcharge, this number dropped to about 2 million per month.

Surprisingly, after the surcharge, there was a large increase in deposit amounts on new card purchases, especially on cards that had no subsequent refill activities. The increase in deposit amounts was unanticipated: The MTA never said that the goal of this surcharge was to attract more deposits; also, the surcharge on a new MetroCard purchase is a one-time fee, which should have no impact on deposit amounts.

Nevertheless, after the surcharge went into effect, a large portion of riders increased the deposit amounts on new card purchases, yet there was no sizable change in refill amounts. As a result, the monthly outstanding balance that riders carry on their MetroCards, which is defined as the difference between the total amount loaded on the cards in that month and the reductions caused by swipes at turnstiles in the same month\(^1\), increased dramatically after the surcharge. The monthly outstanding balance jumped from less than $35 million to more than $45 million. This translates to riders lending an extra $150 million, on an annual basis, to the MTA. Currently, the MTA is paying 0.37% interest on funds raised from short-term notes. These additional free lending potentially save the MTA hundreds of thousands of dollars in interest payments.

In addition, a portion of the increased balances on MetroCards were never redeemed and escheated to the MTA after these MetroCards expired, which substantially increased the loss to riders. Each MetroCard is valid for 18 months after the initial purchase; inactive cards with pending balances are removed from the liability of MTA as “unredeemed farecard” and become an asset of MTA under the category "expired fare revenue" after the expiration date. The aggregate forgone balance (i.e., expired fare revenue) in 2015, from cards initially purchased in late 2013 and 2014, the first year after the MTA implemented the surcharge, increased to $75 million from $52 million, the aggregate forgone balance in 2014.

I am able to document this puzzle in consumers’ behavior change after the surcharge by constructing a unique novel data set combining transaction-level MetroCard deposit and swipe information. There are five main empirical findings regarding deposits amounts to MetroCards.

---

\(^1\)Mathematically, the net outstanding balance for a specific month is calculated as $\text{Balance} = \sum \text{deposits} \times (1 + \text{bonus}(\%)) - \sum \text{rides} \times \text{basefare}$.
amounts. Meanwhile, there was no significant change in ridership since the imposition of the surcharge.

Second, deposits on new purchases increased tremendously for MetroCards without subsequent refill activities. In contrast, there was only a minor change in the initial deposit amount for MetroCards that showed subsequent refill activities. Consistent with increase in deposit amounts, forgone fare on MetroCards without subsequent refill activities increased significantly while forgone fare on MetroCards with refill activities experienced only a minor increase.

Third, the higher deposit amounts on new purchases mainly came from cash or debit card payments rather than from credit card payments. Agree with the pattern of deposit changes, there was higher forgone fare on MetroCards initially purchased by cash or debit cards rather than from cards initially purchased by credit cards.

Fourth, cash deposits made at vending machines for new card purchases grew in size while cash deposits made at manned booths (tellers) experienced only a minor increase. In line with changes in deposit amounts, forgone fare on MetroCards initially purchased by cash at vending machines increased dramatically while the forgone fare on MetroCards initially purchased by cash at manned booths only increased slightly.

Fifth, by linking deposit data in different subway stations with census tract income data, I found that low-income neighborhoods have a much higher percentage of cash payments compared to high-income neighborhoods. After the MTA imposed the surcharge, there were larger increases in deposit amounts on new MetroCard purchases in low-income neighborhoods than in high-income neighborhoods.

Why did riders increase the deposit amounts on new MetroCard purchases?

One candidate mechanism is that some riders tried harder to reduce the likelihood of losing or forgetting their MetroCards after the surcharge. Once they had a lower probability of losing cards, they started making larger deposits on new card purchases to avoid the hassle of refilling their MetroCards frequently. If this was the case, the change in deposit amounts might improve riders’ welfare as they would lose the deposits on their MetroCards less often.

However, the data do not support this story. Deposits increased mainly on cards that had no subsequent refill activity. In addition, if riders became more careful with their MetroCards and started to make larger deposits, each deposit would last a longer time, and therefore, the total number of deposit transactions (new and refills) would decrease. But there was no decrease in the total number of deposit transactions. Moreover, if riders did become more careful with their MetroCards, the forgone balance on expired cards would decrease after the surcharge. But the forgone balance (i.e., expired fare revenue) increased by about 50% after the surcharge.

I propose a few alternative mechanisms that could explain some aspects of the increased deposit amounts on new card purchases (Table 16). One leading candidate mechanism is that some riders may adopt a quick fix to alleviate the perceived cost of the surcharge on new purchases by making larger deposits. For instance, they may want to compensate for the absolute monetary cost of the surcharge by getting a bonus on pay-per-ride deposits. If a rider makes a $10 deposit to a new MetroCard, the bonus amount is $1.10 (11%*$10), which will offset the $1 surcharge.

---

2Detailed information about the bonus on pay-per-ride deposits appears in section 2.1.3
Likewise, some riders may want to alleviate the perceived average cost of the surcharge per trip. If a rider deposits $5 (fare of a roundtrip) to a new MetroCard after the implementation of the surcharge, the average cost of the surcharge per ride is $0.5 ($1/2=$0.5). But the average cost of the surcharge per ride drops to $0.125 with a $20 deposit (fare of four roundtrips) ($1/8=$0.125).

The existence of a quick fix can largely explain why larger increases on new card purchases were mainly on cards that had no subsequent refill activities: Before the surcharge, more than 60% of the deposits on new cards that had no subsequent refill activities were $4.50 (the fare of a round-trip) while more than 70% of the deposits on new cards with refill transactions were already at least $10 or $20.

This mechanism is consistent with the finding that the increased deposit amounts on new purchases mainly came from cash or debit card payments. Since most credit card payments were already at least $10 or $20 before the surcharge, the perceived cost of the surcharge was relatively small, even when riders were still making the same deposit amounts. In contrast, more than 60% of the cash deposits and more than 30% of the debit card deposits were about $5 (fare of round-trip) before the surcharge. Therefore, riders with cash or debit card payments had more incentive to make larger deposits during new purchases to minimize the perceived cost of the surcharge.

In addition, riders seem to respond more to the surcharge when they learn about it visually before making deposit decisions. This phenomenon is supported by the observation that cash deposits made at vending machines for new card purchases grew in size while the amounts of cash deposits made at booths increased only slightly. At vending machines, riders first learned about the surcharge and then chose the amounts they wanted to put on their cards. In contrast, at booths, riders were likely to first decide how much to put on the card and then learn about the surcharge.

This phenomenon is also supported by the observation that at vending machines, most cash deposits were in amounts of $5, $9, or $19 (i.e. riders paid $6, $10, or $20 in total, respectively, after adding the surcharge) whereas at manned booths, most cash deposits were in amounts of $5, $10, or $20 (i.e. riders paid $6, $11, or $21 in total, respectively, after adding the surcharge). In addition, there was only a small increase in deposit amounts at booth-only stations after the MTA imposed the surcharge in 2013. When the MTA later installed vending machines in some of these stations in 2014, riders who switched from booths to vending machines began to make larger deposits while riders using booths still made similar deposits.

The salience of the surcharge at the vending machines and the larger increase in deposit amounts support the mechanism where some riders may adopt a quick fix to alleviate the perceived cost of the surcharge on new purchases by making larger deposits.

This paper contributes to the existing literature in several distinct ways. First, these findings have implications for consumers behavior changes in response to the introduction of financial incentives such as a penalty or a bonus. Studies have shown that a financial incentive may have no effect on behavior, or have an effect on behavior opposite of that expected (Gneezy and Rustichini, 2000a; Gneezy and Rustichini, 2000b; Ariely et al., 2009; Homonoff, 2015).
For example, Homonoff (2015) found that a five-cent shopping bag tax imposed in the Washington metropolitan area decreased the proportion of customers using disposable bags by a substantial amount. In contrast, a similar policy that offered customers a five-cent bonus for reusable bag use generated virtually no effect on behavior. Gneezy and Rustichini (2000) showed that the introduction of a fine increased the behavior that was fined and that the new higher level was not reduced when the fine was removed. Complementing existing studies on this topic, results in this paper suggest that a small penalty may induce unexpected behavior change besides the planned goal. A policy change which meant to reduce waste, while effective in terms of achieving its stated goal, may sometimes lead consumers to make choices that are economically worse and result in more welfare loss.

Second, this study illustrate a very important process in increasing inequality in the past two decades: Using small decisions by a lot of people to accumulate a large amount of money in one place. These additional deposits to prepaid transit cards could not be done in the token system or before the introduction of the electronic payment system. In this high-tech decade, tiny mistakes can create large transfers.

Third, this paper extends the literature on the “shrouded attributes” of add-on fee. Studies have shown that consumers underreact to fees (or taxes) that are not salient (Allcott, 2011; Chetty et al., 2009; DellaVigna and Pollet, 2009; Masatlioglu et al., 2012). Chetty (2006) found that posting tax-inclusive price tags reduced demand by 8%. Gabaix and Laibson (2006) predicted that shrouded add-on fees are likely to induce myopia in consumers, leading them to make choices that are economically detrimental. In contrast to Gabaix and Laibson (2006), shrouding the surcharge (as at booths) may sometimes lead consumers to make choices that are economically better.

The remainder of the paper is organized as follows. In section 2, I give a brief introduction to MetroCards and the surcharge. In section 3, I present the main features of the MTA dataset. In section 4, I present the main findings about MetroCard sales and deposit patterns. In section 5, I discuss possible explanations for the empirical findings. In section 6, I perform robustness tests. Section 7 concludes the paper.

2 Background

2.1 MetroCard

The MetroCard is a stored ride fare card for the New York City Subway rapid transit system; New York City Transit buses, including routes operated by Atlantic Express under contract to the Metropolitan Transportation Authority (MTA); MTA Bus and Nassau Inter-County Express systems; the PATH subway system; the Roosevelt Island Tram; AirTrain JFK; and Westchester County’s Bee-Line Bus System. It is a thin plastic card on which a rider electronically loads fares. The MTA introduced the card to enhance the technology of the transit system and eliminate the burden of carrying and collecting tokens. The MTA discontinued the use of tokens in the subway on May 3, 2003, and on buses
on December 31, 2003.

2.1.1 Types of MetroCard

Various types of MetroCards are available for purchase. There are two types of value-based cards: pay-per-ride MetroCards and single-ride tickets. Also, there are two types of time-based cards: 7-day-unlimited MetroCards and 30-day-unlimited MetroCards. The pay-per-ride MetroCard is a thin plastic card on which riders can electronically load fares. The new pay-per-ride MetroCard minimum purchase is the fare of a round trip (currently $5.50). No minimum purchase is required for refill transactions. Riders can buy as many trips as they want. When a ride swipes a pay-per-ride MetroCard at a turnstile, the base fare is deducted from the card balance.

A single-ride ticket is a paper card with a magnetic strip on the front and the date and time of purchase stamped on the back. Each ticket is for one subway or one local bus ride with one free bus-to-bus transfer. Single-ride tickets expire two hours from the time of purchase.

A 7-day-unlimited MetroCard is good for unlimited subway and local bus rides until midnight of the seventh day following the first usage. A 30-day-unlimited MetroCard is good for unlimited subway and local bus rides until midnight of the thirtieth day following the first usage.

2.1.2 Purchase Venues

A rider can purchase new or refill existing MetroCards at a subway station MetroCard vending machine (MVM) (Figure 1a) or at a station’s manned booth (teller) (Figure 1b). Manned booths sell all cards, except single-ride tickets, and they accept only cash payments. Station MetroCard vending machines sell all cards, including single-ride tickets. A rider touches the vending machine screen. The screen asks what type of MetroCard a rider wants and takes the rider through the steps to buy it. An illustration showing this process is located at www.antennadesign.com/transit.

There are two types of vending machines. The larger machines accept cash, credit cards, or ATM/debit cards. The small vending machines do not accept cash and are for credit cards or ATM/debit cards only. Single-ride tickets are available for cash only at the large vending machines.

For cash payments, large vending machines accept different types of coins and bills in denomination of $1, $5, $10, $20, and $50. Machines can return no more than $9 in change for cash payments. The change is given only in coins (quarters, dimes, nickels, and dollar coins).

When a rider uses a credit card at a vending machine, the rider is prompted to enter a zip code for verification. However, if the credit card account has a billing address outside of the United States, the rider is not subject to the

---

3 MetroCards can also be purchased out-of-system through the MTA extended sales network (including merchants and tax-benefit providers), which now accounts for the majority of MetroCards sold. Approximately 2.8 million MetroCards are sold out-of-system each month, and this level has not changed noticeably since the introduction of the $1 surcharge (out-of-system sales are not subject to the $1 fee).

4 Quarters, dimes, nickels, and dollar coins, except pennies and half-dollar coins.
zip code verification requirement. Instead, the rider should type in “99999” when prompted for a zip code. This will indicate to the machine that the rider is using an international credit card, and the regular transaction authorization process will still take place. More information is available on MTA’s website: www.mta.info.

Upon the imposition of the surcharge in March 2013, there was no major change in the user interface of vending machine screens, except for the added message about the surcharge (Figure 4).

2.1.3 Bonus Free Ride for Pay-per-ride Purchases

Since January 1, 1998, the MTA has given a "bonus" for pay-per-ride purchases that are at or above a certain threshold amount. For instance, from June 28, 2009, to December 29, 2010, the bonus value for pay-per-ride purchases was 15% of the purchase amount for purchases of $8 or more. For example, when a rider made a deposit of $10 to a pay-per-ride MetroCard, the card balance increased by $11.50 ($10 + $1.50).

This is not a typical bonus since it is always a certain percent of the purchase amount (i.e., linear) while a usual bonus is an increasing percent of the purchase amount (i.e., non-linear). Currently, the bonus value for pay-per-ride MetroCards is 11% of the purchase amount for purchases of $5.50 or more (Table 1 row 6).

2.2 Policy Changes

Table 1 shows the recent history of MTA policy changes. Column 1 presents the fare hike in 2009. On June 28, 2009, the base subway and bus fare rose from $2 to $2.25. The monthly MetroCard rose from $81 to $89. The weekly MetroCard rose from $25 to $27. The pay-per-ride MetroCard bonus remained at 15%, but the threshold for the bonus increased from $7 to $8.

Column 2 lists the fare hike at the end of 2010. On December 30, 2010, the 30-day-unlimited card increased to $104 and the 7-day-unlimited card increased to $29. The bonus value for pay-per-ride cards decreased to 7% for every $10. There was no change in base subway and bus fares, but the cost of a single-ride ticket went from $2.25 to $2.50.

Column 3 shows the fare hike in 2013. On March 3, 2013, the base subway and bus fare increased from $2.25 to $2.50. The cost of a 30-day-unlimited card increased to $112. The cost of a 7-day-unlimited card increased to $30. The bonus for the pay-per-ride MetroCard decreased from 7% to 5%, but the threshold for the bonus decreased from $10 to $5. The price of a single-ride ticket increased from $2.50 to $2.75. The MTA also imposed a $1 fee on new card purchases, the impact of which forms the basis of this study.

Column 4 depicts the fare hike in 2015. On March 22, 2015, the base fare of subway and bus rides rose from $2.50 to $2.75. The cost of a 7-day-unlimited card rose from $30 to $31 and the cost of a 30-day-unlimited card increased from $112 to $116.50. Pay-per-ride bonuses increased from 5% to 11% for purchases greater than or equal to $5.50.
Table 1: Recent History of MTA Policy Changes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Base fare ($)</td>
<td>2.25</td>
<td>2.25</td>
<td>2.50</td>
<td>2.75</td>
</tr>
<tr>
<td>7-day-unlimited ($)</td>
<td>27</td>
<td>29</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>30-day-unlimited ($)</td>
<td>89</td>
<td>104</td>
<td>112</td>
<td>116.50</td>
</tr>
<tr>
<td>Single-ride tickets ($)</td>
<td>2.25</td>
<td>2.50</td>
<td>2.75</td>
<td>3.00</td>
</tr>
<tr>
<td>Surcharge on new MetroCard purchase</td>
<td>No</td>
<td>No</td>
<td>Yes*</td>
<td>Yes</td>
</tr>
<tr>
<td>Bonus for Pay-Per-Ride, % (threshold)</td>
<td>15% ($8)</td>
<td>7% ($10)</td>
<td>5% ($5)</td>
<td>11% ($5.50)</td>
</tr>
</tbody>
</table>

* The main policy change for this paper is the imposition of surcharge on new MetroCard purchases.

2.2.1 Surcharge on New Purchases

The main policy change that concerns this paper is the imposition of a surcharge on new MetroCard purchases. A new MetroCard itself used to be cost-free. A $1 "new card fee", tacked on when someone buys a new MetroCard, went into effect with the fare hikes on March 3, 2013. The fee applies to each new MetroCard purchased at a MetroCard Vending Machine, station booth, or commuter rail station. Riders can avoid this fee by refilling their MetroCards. The MTA will issue a new MetroCard at no charge if a card is expired or damaged. The new $1 charge does not apply to single-ride tickets or to MetroCards bought by reduced fare customers (seniors and customers with disabilities).5

2.3 Environmental Impact

The transportation authority justified the new policy of the $1 surcharge on new MetroCards purchases in environmental terms, arguing that the policy would lead to cleaner subway stations by discouraging people from littering subway stations with their discarded, empty MetroCards. MTA officials mentioned this fee as an environmentally friendly initiative in numerous news reports.6

On average, it costs the agency $20 million a year to print and clean up discarded cards from subway stations. According to MTA, after the imposition of the surcharge, printing fewer MetroCards and trimming cleanup costs was expected to save about $2 million a year.7 Compared to the annual total cost, the saving from the imposition of the surcharge is relatively small. However, it is not unreasonable since MetroCard printing likely requires a huge fixed-cost to set up printing facilities and experience economies of scale.

5 Also, the surcharge does not apply to MetroCards purchased out-of-system through MTA extended sales merchants, users of EasyPayXpress cards, transit benefit organization customers who get their MetroCards directly from employers or their benefit providers, or customers who purchase a combination railroad/MetroCard ticket. Out-of-system MetroCard sales now account for the majority of MetroCards sold. Approximately 2.8 million MetroCards are sold out-of-system each month, and this level has not changed noticeably when comparing MetroCard numbers sold before and after the surcharge went into effect.

6 Some news reports where MTA talked about the surcharge: NY Times, NY Daily News, NBC News

7 Some news reports where MTA mentioned the potential savings from surcharge imposition: NY Daily News-1, NY Daily News-2, NBC New York
3 Data

In this section, I present the main features of the datasets used in this study. The first part of this paper documents the reduction in sales of new MetroCards as well as changes in deposit amounts on MetroCard purchases using two data sets: monthly aggregate MetroCard revenue data and transaction-level deposit data.

3.1 Monthly-Aggregate Revenue Data

First, I use monthly MetroCard revenue data from January 2009 to June 2015. The data set includes information on the number of deposit transactions (new sales versus refills) as well as total in-system MetroCard purchase amounts, broken out for various types of MetroCards.

3.2 Transaction-level Deposit Data

The transaction-level MetroCard deposit data, provided by the New York City Subway Rapid transit system, covers all deposit transactions for the following periods: 1) May 1, 2009 - September 30, 2009; 2) January 1, 2013 - May 1, 2013; and 3) September 1, 2014 - May 31, 2015.

Each observation corresponds to a MetroCard deposit transaction and includes information on the amount of money added to the card, the station at which the card was purchased, the date and time of purchase, the type of deposit, the method of payment, and the balance of the MetroCard before the transaction. The data also include information on whether the transaction took place at a booth station or at a vending machine. These data allow me to calculate daily sales of different types of MetroCards as well as to track changes in the deposit amounts on MetroCards. Therefore, I can compare purchases of new MetroCards before and after the imposition of the surcharge. I can also check the changes in deposit amounts to MetroCards before and after was implementation of the surcharge.

3.3 Transaction-level Swipe Data

The transaction-level swipe data, provided by the New York City Subway Rapid transit system, covers all MetroCard swipe transactions for the time period from January 1, 2013 to May 31, 2015.

Each observation corresponds to a MetroCard swipe transaction and includes information on the amount of money deducted from the card, the station or bus route at which the card was swiped, the date and time of card swipe, and the balance of the MetroCard before the transaction. These data allow me to track changes in the card balance. Therefore,
I can compare changes in foregone balance on MetroCards initially purchased before and after implementation of the surcharge.

3.4 Ride Data

The ride data include the total number of MetroCard swipes riders made each week as they entered each station of the New York City Subway, PATH, AirTrain JFK and Roosevelt Island Tram from January 2011 to June 2015, broken out for various types of MetroCards. I use the rides dataset to investigate whether the differences in behavior I observe in deposit amount and sales of new MetroCards suggest that riders reuse their existing MetroCards more after the surcharge or have decreased their use of the subway system because of the surcharge and/or fare hikes.

4 Main Findings

The main empirical findings are summarized in Table 2. Additional findings are listed in Table 3 as robustness checks. In particular, customers purchased MetroCards - without refill activities - with much larger deposits after the imposition of the surcharge. Consequently, the MTA outstanding balance of deposits jumped up significantly after the surcharge.

4.1 Purchases of New MetroCards Dropped After the Surcharge

Table 4 shows the monthly purchase of new MetroCards from January 2009 to June 2015. After the implementation of the surcharge, the total monthly new MetroCard sales dropped from over 7 million to about 2 million and stayed low, which is very robust across different subgroups: the monthly sales of new pay-per-ride cards decreased from 5.8 million to 1.8 million; the monthly sales of new 30-day-unlimited cards decreased by about 75% to about 0.15 million; and the monthly sales of new 7-day-unlimited cards decreased by over 1.2 million to 0.34 million.

Figure 5 plots the monthly new MetroCard sales from January 2009 to June 2015. This figure shows that new MetroCard sales dropped immediately and stayed low after the surcharge, confirming the summary statistics in Table 4.

I replicated this analysis using transaction-level deposit data in Figure 6. This figure plots the daily new MetroCard sales from January 1, 2013 to April 30, 2013. The MTA sold about 200,000 new MetroCards daily before the surcharge. This estimate dropped immediately to about 130,000 on the first day the surcharge was implemented and further decreased gradually over the next two months. Similar results are observed for all three MetroCard subgroups (Figure 7-9). Figure 7 shows that the MTA sold an average of 150,000 new pay-per-ride MetroCards daily before the implementation of the surcharge. This number dropped by more than half after the surcharge kicked in.
I then used a regression framework to evaluate the effects of the surcharge on new MetroCard sales. The OLS empirical model takes the following forms:

\[ Y = \theta_0 + \theta_1 \text{Surcharge} + \lambda X + \epsilon, \]

where \( Y \) is new MetroCard sales on a daily basis and \( \text{Surcharge} \) is an indicator for observations after the implementation of surcharge. \( X \) is a set of controls including day-of-week and month-of-year fixed effects. The coefficient of interest is \( \theta_1 \), coefficient of \( \text{Surcharge} \), which measures the effect of the surcharge on changes in daily new MetroCard sales.

Table 5 presents the results for the effects of the surcharge on changes in daily new MetroCard sales from January 1, 2013 to April 30, 2013, using different control variables in each specification. The model in column 2 controls for day of week. The results show that the implementation of the surcharge caused a significant decrease of 124,821 in daily new MetroCard purchases. To account for the possibility of variations in MetroCard sales across different months, my preferred specification in column 3 included month-of-year fixed effects. As with the other controls, the addition of month-of-year fixed effects has little impact on the estimated effects of the surcharge.

Using this preferred specification, Table 6 includes measures of changes in daily new card sales for 7-day-unlimited and 30-day-unlimited cards as well as pay-per-ride cards in response to the implementation of the surcharge. The imposition of the surcharge led to a decrease of 120,824 in daily new pay-per-ride MetroCard sales, a decrease of 22,733 in daily new 7-day-unlimited MetroCard sales, and a decrease of 24,304 in daily new 30-day-unlimited MetroCard sales.

4.1.1 Regression-Discontinuity Approach

Since there was no significant sorting of MetroCard purchases around the date when the MTA implemented the surcharge, I also estimated the effect of the surcharge with a sharp regression discontinuity (RD) design. Under some mild regularity conditions, the average causal effect of the surcharge on MetroCard sales just before and just after the surcharge could be identified. There was no discontinuity in ridership or other covariates around the implementation date of the surcharge.

Assuming a homogeneous effect of the surcharge on MetroCard sales with one cutoff date:

\[ Y_t = \beta + \gamma \mathbb{I}\{t \geq t_0\} + a(t) + X_t + u_t, \]

where \( t \) is the indexed date, \( Y_t \) denotes the new MetroCard sales on day \( t \), \( t_0 \) was the distinct cutoff point (i.e., March 3, 2013), \( a(.) \) is a flexible function of date, \( X \) is a set of controls including day-of-week and month-of-year
fixed effects, and \( E(u_t | t) = 0 \).

I present estimates using the analog of the Calonico et al. (2014) bandwidth selectors for sharp RD. Similar estimates are observed under alternative bandwidth selectors based on the Imbens and Kalyanaraman (2012). In the baseline specifications, I used local quadratic regression (a local polynomial of order two) for \( a(.) \). Across specifications, the estimated effect of the surcharge from both local linear and local quadratic regressions corroborate the visual evidence.

Table 18 reports the results of the RD analysis for daily total new card sales and daily new pay-per-ride sales. The imposition of the surcharge led to a decrease in daily total new sales of more than 120,000 and a decrease in daily new pay-per-ride sales of about 110,000.

I replicate this analysis for 7-day-unlimited and 30-day-unlimited cards in Table 19. New pay-per-ride MetroCard sales decreased by 106,985; daily new 7-day-unlimited MetroCard sales decreased by 14,791; and daily new 30-day-unlimited MetroCard sales decreased by 19,626.

The estimates of the RD analysis are smaller than the estimates of the OLS regressions, which is reasonable because new MetroCard sales further decreased gradually over the two months after the implementation of the surcharge (Figure 6 - 9).

### 4.2 Changes in the Outstanding Balance of Deposits

Besides the anticipated drop in new MetroCard sales, the monthly outstanding balance of deposits made to pay-per-ride MetroCards unexpectedly jumped by about one-third, from around $35 million to $45 million after the imposition of the surcharge (Figure 10). In contrast, the net outstanding balance showed no significant increase after the fare hikes in 2009 or 2010, nor after the fare hike in 2015.

The aggregate monthly outstanding balance that riders carried on their MetroCard is defined as the difference between the total amount loaded on the cards and the reductions caused by swipes at turnstiles

This additional outstanding balance translates to riders lending, on an annual basis, an extra $150 million to the MTA. To put this into perspective, currently, the MTA is paying 0.37% interest on funds raised from short-term notes.

---

11Mathematically, the net outstanding balance for month \( i \) is calculated as:

\[
Balance_{mi} = \sum deposits \ast (1 + bonus(\%)) - \sum rides \ast base fare
\]

where base fare is $2.0 for months before February 2008, $2.25 for months from March 2008 to February 2013; $2.5 for months from March 2013 to February 2015.

Theoretically, the net outstanding balance for month \( i \) should be calculated as:

\[
Balance_{mi} = \sum deposits + \sum bonus - \sum rides \ast base fare
\]

However, I only have aggregate monthly deposit amounts data and cannot observe bonus amount for each deposit transaction. Hence, the outstanding balance calculated using equation (1) is the upper bound of the outstanding balance for each month. Since the threshold for bonus free rides was much higher ($10) before the surcharge was imposed, the jump in the outstanding balance from the imposition of the surcharge should be even larger.
4.2.1 No Changes in Ridership

To investigate the reason(s) behind the sharp jump in the outstanding balance on pay-per-ride MetroCards, I first checked whether there were changes in ridership. There has been no jump in ridership since the imposition of the surcharge when looking at weekly ridership (Figure 11a).

I then used an RD regression framework to evaluate the effects of the surcharge on weekly ridership. In the baseline specifications, I used local quadratic regression (a local polynomial of order two) for \( a(.) \). Across specifications, the estimated effect of the surcharge from both local linear and local quadratic regressions corroborate the visual evidence.

Table 7 reports the results of the RD analysis. Consistent with the visual evidence in Figure 11a, there has been no significant jump in ridership since the imposition of the surcharge. These findings confirm that there were minimal changes (i.e., riders did not take fewer trips).

4.2.2 Monthly Deposit Revenue Increased

Since there have been no significant changes in ridership, I then checked whether there have been changes in pay-per-ride deposit revenue. Figure 12a plots the monthly deposit revenue from January 2011 to April 2015. Monthly revenue jumps up by 9.4%, from around $160 million to $175 million after the implementation of the surcharge. This increase in monthly revenue becomes more noticeable when looking at year-by-year monthly revenue (Figure 12b).

From the comparison of ridership versus deposit revenue, it is very likely that the increase in the outstanding balance came from increased deposit amounts by riders rather than from decreased ridership.

4.3 Deposits to MetroCards Show Different Changes: New Purchases Versus Refills

Since the main change came from increased deposit revenue, I turned to transaction-level deposit data to check individual amounts of deposits riders made to MetroCards before and after the implementation of the surcharge.

After the MTA imposed the surcharge, riders who purchased new MetroCards, on average, made larger deposits on new card purchases as shown in Figure 13a. The surcharge caused the average deposit on new purchases to jump by about 22%, from around $9 to $11. In contrast, the average deposit amount changed only slightly following the fare hikes in 2009 and 2010.\(^\text{12}\)

Using transaction-level deposit data, the imposition of the surcharge led to a decrease in the percentage of riders who made deposits of approximately $5 by about 40% and an increase in the percentage of riders who made deposits of approximately $10 and $20 by about 35% (Figure 14a and Figure 15a).

However, the amounts of deposits during refill transactions after the introduction of the surcharge were similar to

\[ \frac{\sum \text{deposit}_a(n)}{\sum \text{new purchases}(n)} \]

\(^{12}\)The average deposit on new purchases is calculated as
the amounts of deposits during refill transactions before the surcharge went into effective (Figure 13b). The same results are observable when looking at transaction-level data (Figures 16a and 17a).

I checked the robustness of the findings by limiting my focus to deposit transactions within one week before and after the imposition of the surcharge. The same changes in deposit amounts are observable for new purchases (Figure 14b and 15b) and refill purchases (Figure 16b and 17b).

I then used a regression framework to evaluate the effects of the surcharge on the amounts of deposits during new purchase and refill transactions. The OLS empirical model takes the following form:

\[ Y = \theta_0 + \theta_1 \text{Surcharge} + \lambda X + \epsilon, \]

where \( Y \) is the deposit amount on pay-per-ride MetroCard purchases, and \( \text{Surcharge} \) is an indicator for observations after the implementation of the surcharge. \( X \) is a set of controls such as time-of-day and station fixed effects. The coefficient of interest is \( \theta_1 \), coefficient of \( \text{Surcharge} \), which measures the effect of the surcharge on changes in deposit amounts on pay-per-ride purchases.

Table 8 presents the results for the effects of the surcharge on changes in deposit amounts on new pay-per-ride purchases from January 1, 2013, to April 30, 2013, using different control variables in each specification. The model in column 3 controls for day-of-week fixed effects. The results show that implementation of the surcharge caused a significant increase of $1.64 in deposit amounts on new pay-per-ride purchases. Riders, on average, made larger deposits during morning and evening rush hours.

To account for the possibility of variations in deposit amounts across different neighborhoods, my preferred specification in column 4 included station fixed effects. The addition of station fixed effects causes the estimated effects of the surcharge to be smaller, which indicates that there is heterogeneity in deposit amounts across different stations.

I replicated this analysis for deposit amounts on pay-per-ride refill transactions. Table 10 reports the results of the regressions. Consistent with the visual evidence in Figure 16a and 17a, the imposition of the surcharge caused only a trivial increase in deposit amounts during pay-per-ride refill transactions.

### 4.3.1 Regression-Discontinuity Approach

I also estimated the effect of the surcharge with a sharp regression discontinuity (RD) design. Table 9 reports the results of the RD analysis, using different control variables in each specification. The model in column 3 controls for day-of-week fixed effects. The results show that the implementation of the surcharge caused a significant increase of $1.07 in deposit amounts on new pay-per-ride purchases. The addition of station fixed effects in column 4 causes the estimated effects of the surcharge to be smaller, which indicates that there is heterogeneity in deposit amounts across

---

13 The average deposit on refill purchases is calculated as \( \frac{\sum \text{deposits}(8)}{\sum \text{refill purchases}(#)} \)
different stations.

The estimates of the RD analysis are again smaller than the estimates of the OLS regressions, which is reasonable because deposit amounts on new purchases were likely to decrease further over the next few months after the surcharge was implemented.

4.4 Deposits to New MetroCards That Would be Held for Different Lengths of Time

In order to further explore the change in deposit patterns, I examined the deposit pattern in MetroCards held for different lengths of time.

Deposits on new pay-per-ride purchases increased tremendously for MetroCards without subsequent refill activities (Figure 18a). Before the surcharge, about 60% of deposits were $5 or less for pay-per-ride MetroCards that had no subsequent refill activities. After the surcharge, this percentage dropped by half to about 30%, while the percentage of $10 or $20 deposits almost doubled. In contrast, there was only a minor change in the initial deposit amount for MetroCards that showed subsequent refill activities (Figure 18b).

4.5 Heterogeneity in Deposits to New Pay-per-ride MetroCards: By Payment Methods

Since the major changes in deposit amounts came from new purchases, I examined the changes in purchase amounts for different payment methods (cash, debit card, versus credit card). Among new purchases, the main changes in the amounts deposited to pay-per-ride cards came from cash or debit-card payments. For credit-card payments, there was only a slight change in deposit amounts (Figure 20c and 21c). In contrast, the percentage of riders who made cash deposits of approximately $10 or $20 increased significantly, from 33% to 63%. The percentage of riders who made cash deposits of approximately $5 dropped by about one-third (Figure 20a and 21a). For debit card payments, the percentage of riders who made deposits of approximately $10 or $20 increased significantly from 46% to 63%. The percentage of riders who made deposits of approximately $5 dropped by about half (Figure 20b and 21b).

4.5.1 Changes in Deposit Amounts Across Different Neighborhoods

The Survey of Consumer Finances (SCF) indicates that it is primarily the poor who use cash in the US (Bricker et al., 2014; Kennickell and Kwast 1997; Klee 2006; Feudner, 2011). To test whether this is true in the case of MetroCards, I linked the deposit amounts in different subway stations to local census tract income data. As shown in Figure 22, low-income neighborhoods have a much higher percentage of cash payments compared to high-income neighborhoods. This finding is in line with other studies on cash usage across different socioeconomic groups (Bricker et al., 2014; Kennickell and Kwast 1997; Klee 2006; Feudner, 2011).

14To minimize measurement errors, I only focused on cards purchased before April 1, 2013 and give each card at least one month to demonstrate refill activities.
Since the increase in the outstanding balance mainly came from cash or debit-card payments, the surcharge may cause a stronger tendency to load more onto their cards among low-income communities.

Controlling for station-level covariates, I used a regression framework to evaluate the effects of surcharge on deposit amounts across different neighborhoods. The empirical model takes the following forms:

\[ Y = \theta_0 + \theta_1 \text{Surcharge} + \theta_2 \text{Income} + \theta_3 \text{Surcharge} \times \text{Income} + \lambda X + \epsilon \]

where \( Y \) is the deposit amount for pay-per-ride MetroCards, and \( \text{Surcharge} \) is an indicator for observations after the implementation of the surcharge. \( \text{Income} \) represents log-income at the census-tract level. \( X \) is a set of controls such as day-of-week fixed effects. The coefficient of interest is \( \theta_3 \), the coefficient on the interaction of \( \text{Surcharge} \) and \( \text{Income} \), which measures the effect of income level on changes in deposit amounts after the surcharge relative to changes in deposit amounts before the surcharge.

Table 11 presents the results for the effect of the surcharge on deposit amounts. After the implementation of the surcharge, the change in deposit amounts was larger in poorer neighborhoods. On the other hand, there are no significant changes in ridership across different neighborhoods before and after the surcharge (Table 12). These results indicate that the surcharge induces poor riders to make larger deposits on new MetroCard purchases, which is not surprising because riders from richer neighborhoods already made larger deposits before the surcharge.

### 4.6 Cash Payments on New Pay-per-ride Purchases: Vending Machines versus Manned Booths

Since riders can purchase MetroCards at both manned booths and vending machines, I checked whether there was any difference in changes in deposit patterns at manned booths versus at vending machines. As manned booths only accept cash payments, Figure 23 plots the cumulative distribution function of cash deposits on new pay-per-ride MetroCard purchases before and after the surcharge went into effect.

Cash deposits made at vending machines for new MetroCard purchases grew in size while cash deposits made at booths for new MetroCard purchases increased only slightly. At vending machines, the percentage of riders who made cash deposits of approximately $10 or $20 almost doubled after the imposition of the surcharge. The percentage of riders who made cash deposits of approximately $5 dropped by about one-third (Figure 23b and 24b). At booths, the percentage of riders who made deposits of approximately $10 or $20 only increased from 20% to 30%, while the percentage of riders who made deposits of approximately $5 dropped from 80% to 70% (Figure 23a and 24a).

What is also interesting to note is that most cash deposits (net of surcharge) are in amounts of $5, $10, or $20 at manned booths, which means that riders pay $6, $11, or $21 in total, respectively. In contrast, most cash deposits (net of surcharge) are in amounts of $5, $9, or $19 at vending machines, indicating that riders pay $6, $10, or $20 in total,
respectively (Figure 23 and 24)

I then used a regression framework to evaluate the effects of the surcharge on cash deposit amounts at vending machines versus at manned booths for new pay-per-ride purchases. The OLS empirical model takes the following form:

\[ Y = \theta_0 + \theta_1 \text{Surcharge} + \theta_2 \text{Machine} + \theta_3 \text{Surcharge} \times \text{Machine} + \lambda X + \epsilon, \]

where \( Y \) is the cash deposit amounts on new pay-per-ride purchases, and \( \text{Surcharge} \) is an indicator for observations after the implementation of the surcharge. \( \text{Machine} \) is an indicator for observations at vending machines. \( X \) is a set of controls such as day-of-week and station fixed effects. The coefficient of interest is \( \theta_3 \), the coefficient on the interaction of \( \text{Surcharge} \) and \( \text{Machine} \), which measure the effect of the surcharge on changes in deposit amounts at vending machines relative to changes in deposit amounts at manned booths.

Table 13 presents the results for the effects of the surcharge on changes in cash deposit amounts on new pay-per-ride purchases from January 1, 2013 to April 30, 2013, using different control variables in each specification. The model in column 3 controls for day-of-week fixed effects. The results show that the implementation of the surcharge caused a significant increase of $1.687 in cash deposit amounts on new pay-per-ride purchases. On top of that, the increase of cash deposit amounts is much larger at vending machines than at manned booths. The cash deposit amounts, on average, increased $0.74 more at vending machines than at manned booths, almost half of the size of the increase in deposit amounts from the imposition of the surcharge.

To account for the possibility of variations in deposit amounts across different neighborhoods, my preferred specification in column 4 included station fixed effects. The addition of station fixed effects causes the estimated effects of the surcharge to be smaller, which indicates that there is heterogeneity in deposit amounts across different stations. However, the increase of cash deposit amounts is still much larger at vending machines than at manned booths.

5 Interpretations

I now consider which assumptions about consumer preferences and beliefs can explain the empirical findings summarized in Table 2. I first introduce a standard model, in which subway and bus rides involve immediate costs (e.g., the cost of waiting in line to add money to the card) and delayed benefits (actually riding the subway or bus). Only three findings are consistent with the results derived from the standard model. First, riders will try to avoid the surcharge by keeping the same MetroCard, which causes a large drop in the number of new MetroCards sold. Second, riders did not change their deposit patterns when refilling cards. Third, there is no change in the total number of deposit transactions. On the other hand, additional findings are hard to reconcile with the standard model.

I then consider whether enriched versions of the standard model can explain the additional findings. Thereafter,
I discuss non-standard preferences and beliefs as possible explanations. In the end, I summarize which explanations rationalize all the empirical findings in Table 16.

5.1 Traditional Model

In each period, a rider is assumed to take a trip. This assumption is introduced to simplify the exposition. The base fare of a ride is $1$, and the fixed cost of each deposit (i.e., the cost of waiting in line to add money to the card, etc) is $c$; $r$ is a known, nonnegative constant representing the marginal utility. The surcharge (or tax) on purchasing new card is $T$, and $d$ is the current balance of the MetroCard (in terms of the number of rides).

When a rider makes a deposit to the MetroCard, the delivery of fares is immediate. When riding the subway or a bus, the rider will make a deposit to the MetroCard with fare for at least one trip: $r$. Hence, assume $r > c + 1$.

Similarly, when the card initial balance $L \in (0, c)$, a rider will refill the card to reach a balance $L' \geq 1$. This statement is easy to verify with $r > c + 1$.

The discount factor is $\beta \in (0, 1)$. A rider’s objective is to choose an ordering policy that maximizes total utility.

A rider is assumed to already have a MetroCard to start with. When the balance of card is zero without a surcharge $T$, the value function $v(0)$ must satisfy the functional equation:

$$v(0) = \sup_n \left( r - c - n + \beta v(n - 1) \right)$$

**Lemma 5.1** Optimal level of deposits, $n^*$, is an increasing function of fixed cost $c$ and discount factor $\beta$.

**Proof** In Appendix

5.1.1 Losing a MetroCard

Suppose that a rider bears a probability $\ell$ of losing a MetroCard. When a rider loses his MetroCard, the balance of the card is assumed to immediately drop back to zero since he forwent all the fare on the card.

With a probability of losing a MetroCard, the new value function $v(0)$ must satisfy the functional equation:

$$v(0) = \max_n \left( r - c - n + \beta(\ell v(0) - T) + (1 - \ell) v(n - 1) \right)$$

**Lemma 5.2** Rider $i$ will make smaller deposits (i.e., smaller $n$) when the probability of losing card $\ell$ is larger. Optimal level of deposits, $n^*$, is independent of surcharge $T$.

**Proof** In Appendix
5.1.2 Predictions of the Standard Model

The standard model predicts that there should be no change in the deposit amount after the introduction of the surcharge since the optimal deposit amount $n^*$ is independent of surcharge $T$. Only three findings are consistent with results derived from the standard model: Riders will try to avoid the surcharge by keeping the same MetroCard and cause a large drop in the number of new MetroCards sold. Riders did not change their deposit patterns when refilling cards. There was also no change in the total number of deposit transactions. The other findings are hard to reconcile with the standard model.

5.2 Enriched Version

In this subsection, I introduce an endogenous probability of losing cards. Riders have idiosyncratic preferences for reusing MetroCards and incur an effort, $e$, for trying to keep the same card.

The probability of losing cards $\ell$ is a convex-decreasing function of effort $e$. The utility cost of $e$ is $\kappa$, which is a convex-increasing function of $e$.

Now a losing-type rider’s utility function becomes:

$$v(0) = \max_{n,e} \left( r - c - n - \kappa(e) + \beta(\ell(e)(v(0) - T) + (1 - \ell(e))v(n - 1)) \right)$$

Lemma 5.3 Rider i will make larger deposits (i.e., larger $n$) when the probability of losing card $\ell$ is smaller (i.e., larger effort $e$). Optimal level of deposits, $n^*$, is an increasing function of $T$.

Proof In Appendix

5.2.1 Predictions of the Enriched Version of Model

The enriched version of the model predicts that there should be larger deposit amount after the introduction of the surcharge since some riders will try harder to keep the same MetroCard.

This enriched model is not likely to justify the larger increase in deposit amounts among new purchases. If riders became more careful with their MetroCards and began making larger deposits, each deposit should last a longer time; hence, the total number of deposit transactions is likely to decrease. Figure 42 shows that there was no decrease in the total number of deposit transactions (new and refills). Also, if riders did become more careful with their MetroCards, the forgone balance on expired cards would decrease after the surcharge. But the forgone balance (i.e., expired fare revenue) increased by about 20% after the surcharge. Therefore, the endogenous probability of losing the card is not likely to account for the observed changes in deposit amounts. Since neither the standard nor the enriched version of the model can explain all the findings, I will discuss alternative preferences and beliefs as possible explanations for the findings.
5.3 Persuasion

The screens of vending machines show three suggested amounts ($10, $20, $40) for deposits, along with bonuses. This could potentially push riders to make higher deposits. However, the screen displayed the same $10 and $20 suggested amounts before and after the surcharge went into effective; only the third suggested amount changed from $50 to $40 (Figure 3). Since the main changes in deposit amounts were switching from $5 to $10 and $20 with no changes of the $10 and $20 suggested amounts, persuasion, solely, is not likely to account for the observed changes in new purchases. If persuasion alone had played a major role, there should also be changes in refill amounts.

5.4 Avoidance of Coins

When riders make deposits to MetroCards using cash at vending machines, they may receive as many as 20 quarters (i.e., $4) as change if they purchase new MetroCards with a $10 bill and only make a deposit of round-trip fare to the card (i.e. $10 - $5 fare cost - $1 surcharge). If some riders prefer not to have a lot of coins as change, they may start making $10 or $20 cash deposits during new pay-per-ride card purchases at vending machines.

However, this explanation, solely, cannot explain the changes observed in debit card payments. Before the surcharge, more than 30% of riders made only $5 deposits (round-trip fare) when they purchased new pay-per-ride MetroCards (Figure 20b). Since $5 has never been one of the suggested deposit amounts on the screen, this means that many riders used to hit the "other amount" option and manually enter $5 as the desired deposit amount. These riders can still choose the "other amount" option and manually enter $6 ($5 fare + $1 surcharge) after the surcharge. But the percentage of $5 deposits dropped to below 20% after the surcharge (Figure 20b).

5.5 Quick Fix

Some riders may want to make larger deposits when purchasing new cards because larger deposits could minimize (or alleviate) the perceived cost of the surcharge. For instance, riders may want to compensate for the absolute monetary cost of the surcharge by bonuses on pay-per-ride deposits.

The existence of a quick fix can largely explain why larger increases on new card purchases were mainly on cards that had no subsequent refill activities: Before the surcharge, more than 60% of the deposits on new cards that had no subsequent refill activities were $4.50 (the fare of a round-trip) while more than 70% of the deposits on new cards with refill transactions were already at least $10 or $20.

The existence of a quick fix can also explain the larger increase in deposits on cash or debit card payments: Since most credit-card payments were already at least $10 or $20 amounts before the surcharge, the cost of the surcharge was relatively small despite riders still making the same deposit amounts. In contrast, more than 60% of the cash deposits were about $5 (round-trip fare) before the surcharge. Therefore, riders with cash or debit card payments have
more incentive to make larger deposits during new purchases to minimize the perceived cost of the surcharge.

This mechanism by itself, nevertheless, is not likely to explain the larger changes in deposits on cash payments at machines than at manned booths (tellers) unless riders who purchased new MetroCards at booths did not know the existence of the surcharge.

When riders try to minimize the cost of the surcharge on a new pay-per-ride purchase, they may justify the changes in deposits by different measures. Some may want to minimize the relative price of the MetroCard itself or the perceived average cost of the surcharge per trip. Others may want to compensate for the absolute monetary cost of the surcharge via bonuses on pay-per-ride deposits. Below I list several possible measures by which riders might justify the increased deposit amounts on new card purchases.

5.5.1 Bonus Effect

Before the surcharge went into effective, many riders used to load only a round-trip fare to the MetroCard, use it, and discard it. Now riders may value the bonus on pay-per-ride deposits more: By making larger deposits on new purchases, the bonus works as a monetary compensation for the $1 surcharge. For instance, if a rider makes a $20 deposit to a new MetroCard, the bonus amount is exactly $1 (5%*$20), which will compensate for the $1 surcharge.

5.5.2 Share of Deposit Amount

Some riders may perceive the surcharge as something like shipping cost or entry fee. Riders may respond to an increased shipping cost by putting more items in the package being shipped (buying an item that costs 10 cents with a shipping cost $1 may seem wasteful to them). Thur, after the introduction of the surcharge, riders may have an incentive to make larger deposits and push down the surcharge’s percent share of total deposit amount. For instance, if a rider deposits $5 to a new MetroCard, the surcharge’s percent share of total deposit amount is 20% ($1/$5=20%). But the surcharge’s percent share of the total deposit amount drops to 5% with a $20 deposit ($1/$20=5%).

5.5.3 Average Cost of the Surcharge per Ride

Some riders may want to minimize the average cost of the surcharge per ride. Before the surcharge went into effective, the average cost of the surcharge per ride was zero. After the introduction of the surcharge, riders may have an incentive to make larger deposits and reduce the average cost of the surcharge per ride. For instance, if a rider deposits $5 (round-trip fare) to a new MetroCard with the surcharge in effect, the average cost of the surcharge per ride is $0.5 ($1/2=$0.5). But the average cost of the surcharge per ride drops to $0.25 with a $10 deposit (fare of two round-trips) ($1/4=$0.25).
5.6  Salience of the Surcharge and Quick Fix

Riders seem to respond more to the surcharge when they learn about the surcharge on pay-per-ride deposits visually before making deposit decisions. This phenomenon is supported by the observation that cash deposits made at vending machines for new card purchases grew in size while the amounts of cash deposits made at booths increased only slightly. At vending machines, riders first learned about the surcharge on pay-per-ride deposits and then chose the amounts they wanted to put on their cards (Figure 4). In contrast, at booths, riders were likely to first decide how much to put on the card and then learn about the surcharge. Thereby, the salience of the surcharge is required - at least moderately — to fit the full pattern of results: riders underreact to a surcharge that is not salient (i.e., easily seen or noticed).

This difference in learning about the surcharge on pay-per-ride deposits at vending machines versus manned booths is highly supported by the observation that most cash deposits at vending machines are in amounts of $5, $9, or $19 (i.e. riders pay $6, $10, or $20 in total, respectively, after adding the surcharge) whereas most cash deposits at manned booths are in amounts of $5, $10, or $20 (i.e. riders pay $6, $11, or $21 in total, respectively, after adding the surcharge).

This mechanism is also supported by the changes in deposit amounts when a booth-only station became a station with both manned-booths and vending machines. There was only small increase in deposit amounts at booth-only stations after the surcharge went into effect in 2013. After vending-machines were installed later in these stations in 2014, riders who switched from booths to vending-machines began to make larger deposits while riders using booths still made similar deposits.

5.6.1  Cash Deposits to MetroCards in Stations Without Booths or Without Vending Machines

A concern that may arise is whether riders who make cash deposits at booth are different from riders who make cash deposits at vending machines. To investigate this issue, I looked at stations without booths or without vending machines. In these stations, riders who make cash deposits have no choice but to use only vending machines or use only booths. In Figure 23a and 23c, similar cash deposit patterns at vending machines are observable among different stations with or without booths. Similar cash deposit patterns are also observed at booths among stations with or without vending machines (Figure 23b and 23d). If there was selection bias in riders who made cash deposits at booths versus at vending machines, cash deposit patterns at booth-only stations or vending-machine-only stations should have looked like the total cash deposit patterns in stations with both manned booths and vending machines.

I performed robustness tests on booth-only stations and the station right before and right after the booth-only station along the same subway line. For instance, the Seneca Avenue station is a booth-only station that serves subway line M. It is located in Queens, New York, and shares the same neighborhood with the next station, Forest Avenue, which
also serves subway line M and has both a manned booth and several vending machines. The cash deposit patterns in these two stations are very different from each other (Figure 26). Another example is from the vending-machine-only 74th-Broadway station which serves subway line 7. It is located in Jackson Heights, Queens, and shares the same station complex with the express station Jackson Heights – Roosevelt Avenue, which serves subway lines E, F, M, and R and has both a manned booth and vending machines. Again, the cash deposit patterns at vending machines in these two stations are very similar to each other, but cash deposit patterns at the manned booth are very different from those at vending machines (Figure 27).

Even in neighborhoods with few tourists such as Riverdale or South Bronx, similar differences in cash deposits are observable at booths versus at vending machines.

Yet another concern is that riders who use booth-only stations or vending-machine-only stations are different from riders using stations with both booths and vending machines. To investigate possible selection effects in station usage, I compared MetroCard transactions that occurred in subway stations that were booth-only stations but later became stations with both booths and vending-machines. For instance, the Seneca station was a booth-only station in early 2013, but vending machines were installed later at this station. There was no change in the total number of deposit transactions (new and refills) in this station (Figure 32), but riders who switched from booths to vending machines began to make larger deposits (Figure 31). These findings suggest that endogenous selection in using booths versus vending machines is not likely to account for the observed differences in deposit amounts.

5.7 Heterogeneity

While other explanations could explain any one result, the salience of surcharge and bonus effect are required – at least moderately – to fit the full pattern of results: riders underreact to a surcharge that is not salient (i.e., easily seen or noticed). At vending machines, riders first learn about the surcharge and then choose the amount they want to put on the card. In contrast, at booths, riders are likely to first decide how much to put on the card, and then learn about the surcharge. If this is the case, and if there is heterogeneity in usage of MetroCards, I expect a correlation between the findings. In particular, new pay-per-ride MetroCards that riders purchased with cash or debit card payments and had no subsequent refill activities should be more likely to have larger increases in deposit amounts since these cards were purchased with much lower deposit amounts before the surcharge, compared to cards that were purchased with credit cards and had no subsequent refill activities.

This is not necessarily the case if the different findings are driven by different phenomena: for example, avoidance of coins for findings 6-7 and persuasion for finding 5.

I tested this prediction by examining deposit amounts on new pay-per-ride MetroCards that were never refilled in the following several months. As shown in Figure 32, larger increases in deposit amounts among cash and debit card...
payments are observable. The percentage of riders paying $5 deposits by cash at vending machines decreased by 30% (from 60% to about 30%), while the percentage of riders depositing $5 by debit card decreased by about 20% (from 40% to 20%). On the other hand, the percentage of riders depositing $5 by credit card decreased by only 10% (20% to 10%)

The larger increase in deposit amounts among cash payments was again observable on new pay-per-ride MetroCards that had subsequent refill activities (Figure 33), suggesting that the correlation is not likely to be spurious.

6 Robustness tests

In this section, I perform several robustness tests to further validate the explanations for the findings.

6.1 Sample

The same results remain no matter whether I use the whole sample or sub-samples (e.g., one week before and after the implementation of the surcharge, or randomly picked stations).

6.2 Cross-type switch in purchases of MetroCards

One concern with interpreting changes in deposit patterns as a response to the surcharge is that there may be cross-type switches from pay-per-ride to unlimited-ride cards or single-ride tickets due to the variations in fare hike across different types of MetroCards.

Table 17 lists monthly revenue before and after the surcharge. There was no significant change in the percent of revenue from pay-per-ride versus that from time-based cards. Table 14 and Table 15 show that the threshold for switching from pay-per-ride to unlimited-ride cards barely changed after the fare hikes in March 2013. This suggests that differences in fare hikes across different types of MetroCards are unlikely to be driving these results. These findings confirm that there is minimal cross-type switching.

6.2.1 Cross-type Switch from Pay-per-ride to Single-ride Tickets

A seemingly reasonable implication from the imposition of the surcharge is that the sales of single-ride tickets are likely to rise since some riders may switch from pay-per-ride to single-ride tickets, especially when they forget their regular MetroCards but need to take a round trip. However, monthly sales of single-ride tickets actually decreased after the surcharge went into effect.
6.2.2 Cross-type Switch from Pay-per-ride to Time-based Cards

Table 14 compares the costs of trips using per-per-ride versus 7-day-unlimited cards. The red oval circles mark the threshold number of trips needed to switch from pay-per-ride to 7-day-unlimited before versus after the surcharge implementation. Before the surcharge, a rider would only save more money buying a 7-day-unlimited than buying a pay-per-ride card if he takes more than 14 trips within one week. After the surcharge, this threshold was 13, only decreasing by one trip.

Table 15 compares the costs of trips using per-per-ride versus 30-day-unlimited cards. The red oval circles mark the threshold number of trips needed to switch from pay-per-ride to 30-day-unlimited before versus after the surcharge implementation. Again, the threshold for switching from pay-per-ride to 30-day-unlimited cards only slightly changed after the fare hikes in March 2013.

6.3 No Jumps (or Discontinuity) in Deposit Amounts Before versus After June 28, 2009

There may be some concern that changes in deposit patterns are solely due to the fare hike in 2009. Figure 38 plots the histogram for deposits on pay-per-ride MetroCard purchases before and after the 2009 fare hike. For both new and refill purchases, there were barely any changes in deposit amounts. Hence, the observed changes in deposit patterns after the surcharge was not likely driven primarily by the $0.25 increase of base fare.

6.4 No jumps (or Discontinuity) in Total Number of Purchases

Perhaps riders became more careful with their MetroCards and thereby started to make larger deposits. If that happened, the total number of deposits (new and refills) would have fallen. However, there was no decrease in the total number of deposit transactions (new and refills), which did not support this hypothesis (Figure 42).

7 Discussions and Conclusions

How do consumers respond to the imposition of a surcharge? In this paper, I examined changes in rider behavior, especially unanticipated changes, in response to the $1 surcharge the MTA imposed upon new MetroCard purchases in 2013. Using a novel panel data set with transaction-level deposit and ride information from the New York City MTA system, I found that the outstanding balance from deposits increased dramatically after the MTA introduced the surcharge, which translates to riders lending an extra $150 million, on an annual basis, to the MTA. Underlying this change in outstanding balance is the fact that riders who purchased MetroCards after the surcharge went into effect on average made larger deposits on new card purchases, especially on cards that had no subsequent refill activities. The response to the surcharge was greater in low-income neighborhoods and among riders who used cash or debit cards.
rather than credit cards. Also, larger changes in new card deposits have been recorded at vending machines than at manned booths (tellers). Moreover, some of the increased balances were never redeemed and escheated to the MTA after these MetroCards expired. This was surprising, because the surcharge is a one-time fee, which should not have changed the deposit behavior of riders.

I document this puzzle in consumers’ behavior change after the surcharge and propose a few mechanisms that could explain some aspects of the increased deposit amounts on new card purchases (Table 16). One leading candidate mechanism is that some riders may adopt a quick fix to alleviate the perceived cost of the surcharge on new purchases by making larger deposits. For instance, they may want to compensate for the absolute monetary cost of the surcharge by getting a bonus on pay-per-ride deposits. If a rider makes a $10 deposit to a new MetroCard, the bonus amount is $1.10 (11%*$10), which will offset the $1 surcharge.

One key mechanism is called for in order to put all the findings together: Riders are likely to respond more to the surcharge when they learn about the surcharge on pay-per-ride deposits visually before making deposit decisions. At vending machines, riders first learn about the surcharge on pay-per-ride deposits and then choose the amount they want to put on the card. In contrast, at booths, riders are likely to first decide the amount to put on the card, and then learn about the surcharge. These results suggest that shrouding the surcharge (as at booths) may sometimes lead consumers to make choices that are economically better.

This paper contributes to the literature on consumers behavior changes in response to the introduction of financial incentives such as a penalty or a bonus. Studies have shown that a financial incentive may have no effect on behavior, or have an effect on behavior opposite of that expected (Gneezy and Rustichini, 2000a; Gneezy and Rustichini, 2000b; Ariely et al., 2009; Homonoff, 2015). Complementing existing studies on this topic, results in this paper suggest that a small penalty may induce unexpected behavior change besides the planned goal; consumers may react to a financial incentive in a fashion not compatible with traditional optimization.

My work thus far suggests that the order of learning about the surcharge versus making deposit decisions matters. A natural follow-up works is to explore in lab settings whether consumers have more incentive to make larger deposits during new purchases to compensate for the surcharge when they learn about the surcharge on pay-per-ride deposits before making deposit decisions. Also, it is imperative that a well-developed detailed survey targeting riders of subways and buses in New York City be carried out to confirm the existence of quick fix and to investigate other possible channels through which riders justify the increased deposit amounts on new pay-per-ride MetroCard purchases after the surcharge.

15Detailed information about the bonus on pay-per-ride deposits appears in section 2.1.3
References


Table 2: Main Empirical Findings

<table>
<thead>
<tr>
<th>Finding</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>After the surcharge: A large drop in number of new MetroCard sold (Figure 5 - 9)</td>
</tr>
<tr>
<td>2</td>
<td>Monthly outstanding balance from pay-per-ride MetroCard deposits jumped by one-third (Figure 10 - 12)</td>
</tr>
<tr>
<td>3</td>
<td>No decrease in the total number of deposit transactions (Figure 42)</td>
</tr>
<tr>
<td>4</td>
<td>Expired fare revenue substantially increased</td>
</tr>
<tr>
<td>5-1</td>
<td>Larger increase in deposits on new purchases (Figure 13a - 15)</td>
</tr>
<tr>
<td>5-2</td>
<td>Trivial change in deposit amounts on refill purchases (Figure 13b - 17)</td>
</tr>
<tr>
<td></td>
<td>Among new purchases,</td>
</tr>
<tr>
<td>6</td>
<td>Larger increase in deposits on cash or debit-card payments (Figure 20 - 21)</td>
</tr>
<tr>
<td></td>
<td>Riders from low-income neighborhoods make larger increase in deposits on new pay-per-ride card purchases (Figure 22 and Table 11)</td>
</tr>
<tr>
<td>7</td>
<td>Larger changes in deposits on cash payments at machines than at manned booths (tellers) (Figure 23 - 24)</td>
</tr>
<tr>
<td>8</td>
<td>Most cash deposits (net of surcharge) in amounts of $5, $10, or $20 at manned booths (Figure 23a and 24a); Most cash deposits (net of surcharge) in amounts of $5, $9, or $19 at vending machines (Figure 23b and 24b).</td>
</tr>
<tr>
<td>9-1</td>
<td>Larger increase in deposits on cards with no subsequent refill activities (Figure 18 - 19)</td>
</tr>
<tr>
<td>9-2</td>
<td>Trivial change in deposit amount on cards with subsequent refill activities (Figure 18 - 19)</td>
</tr>
</tbody>
</table>
Table 3: Robustness Findings

After the surcharge,
Finding 9
No significant changes in ridership (Figure 11)

Finding 10
No significant increase in demand for single-ride tickets (Figure 25)

Finding 11
No significant changes in purchase amounts before versus after the 2009 fare hike (Figure 38)

Finding 12
No significant cross-type changes (unlimited-type versus pay-per-ride) (Figure 36)

Table 4: Monthly Demand for New Cards Before And After the Surcharge (In millions)

<table>
<thead>
<tr>
<th></th>
<th>Before (Jan 2009 to Feb 2013)</th>
<th>After (Mar 2013 to Jun 2015)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number (1)</td>
<td>Percent (2)</td>
<td>Number (3)</td>
</tr>
<tr>
<td>Total</td>
<td>7.70</td>
<td>1</td>
<td>2.32</td>
</tr>
<tr>
<td>(0.55)</td>
<td>(0.39)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pay-per-ride</td>
<td>5.84</td>
<td>0.758</td>
<td>1.826</td>
</tr>
<tr>
<td>(0.47)</td>
<td>(0.28)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-day-unlimited</td>
<td>0.58</td>
<td>0.076</td>
<td>0.15</td>
</tr>
<tr>
<td>(0.055)</td>
<td>(0.042)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-day-unlimited</td>
<td>1.26</td>
<td>0.163</td>
<td>0.339</td>
</tr>
<tr>
<td>(0.079)</td>
<td>(0.076)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>104</td>
<td>104</td>
<td>112</td>
</tr>
</tbody>
</table>

Standard deviations in parentheses
Table reports mean values of each variable
* p-value of mean difference in percent sales before and after the surcharge was implemented.

Table 5: Effect of Surcharge on Daily Total New MetroCard Sales

<table>
<thead>
<tr>
<th></th>
<th>(1) Sales</th>
<th>(2) Sales</th>
<th>(3) Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge</td>
<td>-125286***</td>
<td>-124822***</td>
<td>-163102***</td>
</tr>
<tr>
<td>(6634)</td>
<td>(4975)</td>
<td>(19695)</td>
<td></td>
</tr>
<tr>
<td>Day of Week FE</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Month Fixed Effects (FE)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>R²</td>
<td>0.751</td>
<td>0.868</td>
<td>0.879</td>
</tr>
</tbody>
</table>

Outcome variable: total new card sales on daily basis from January 1, 2013 to April 30, 2013

Note: Robust standard errors in parentheses.
* p < 0.05, ** p < 0.01, *** p < 0.001
<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pay-per-ride</td>
<td>7-day-unlimited</td>
<td>30-day-unlimited</td>
</tr>
<tr>
<td>Surcharge</td>
<td>-120825*** (13076)</td>
<td>-22733*** (4325)</td>
<td>-24305*** (4886)</td>
</tr>
<tr>
<td>Day of Week FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Month Fixed Effects (FE)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.906</td>
<td>0.854</td>
<td>0.554</td>
</tr>
</tbody>
</table>

Outcome variable: new card sales on daily basis from January 1, 2013 to April 30, 2013

Note: Robust standard errors in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

---

Table 7: Effect of Surcharge on Weekly Ridership

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pay-per-ride</td>
<td>30-day-unlimited</td>
<td>7-day-unlimited</td>
</tr>
<tr>
<td>Surcharge</td>
<td>205674 (364673)</td>
<td>1326 (995)</td>
<td>524 (535)</td>
</tr>
<tr>
<td>Month of Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year Fixed Effects</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>120313</td>
<td>120313</td>
<td>120313</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.001</td>
<td>0.003</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Dependent variable is total number of MetroCard swipes at turnstiles made each week, broken out for different types of cards. The coefficients reported here are conventional estimates from default bandwidth with local quadratic described in Calonico et al (2014). The sample is limited to weekly total swipes of MetroCards made from January 2010 to May 2015.

Standard deviations in parentheses and clustered at station-level

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Table 8: Effect of Surcharge on Deposit Amounts at New Purchases: OLS Regressions

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge</td>
<td>1.614***</td>
<td>1.644***</td>
<td>0.933***</td>
</tr>
<tr>
<td></td>
<td>(0.062)</td>
<td>(0.058)</td>
<td>(0.011)</td>
</tr>
<tr>
<td>AM Early Hrs (0:01-6:29am)</td>
<td>–0.697***</td>
<td>–0.755***</td>
<td>–0.235***</td>
</tr>
<tr>
<td></td>
<td>(0.120)</td>
<td>(0.118)</td>
<td>(0.014)</td>
</tr>
<tr>
<td>AM Rush Hrs (6:30-10:00am)</td>
<td>0.736***</td>
<td>0.574***</td>
<td>1.078***</td>
</tr>
<tr>
<td></td>
<td>(0.102)</td>
<td>(0.095)</td>
<td>(0.008)</td>
</tr>
<tr>
<td>AM Late Hrs (10:00-1:00pm)</td>
<td>–0.147***</td>
<td>–0.170***</td>
<td>–0.051***</td>
</tr>
<tr>
<td></td>
<td>(0.031)</td>
<td>(0.031)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>PM Rush Hrs (4:30-8:00pm)</td>
<td>1.174***</td>
<td>1.149***</td>
<td>0.741***</td>
</tr>
<tr>
<td></td>
<td>(0.060)</td>
<td>(0.057)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>PM Late Hrs (8:00-11:59pm)</td>
<td>–0.293***</td>
<td>–0.246***</td>
<td>–0.486***</td>
</tr>
<tr>
<td></td>
<td>(0.055)</td>
<td>(0.054)</td>
<td>(0.011)</td>
</tr>
<tr>
<td>Surcharge * AM Early Hrs</td>
<td>0.494***</td>
<td>0.491***</td>
<td>0.661***</td>
</tr>
<tr>
<td></td>
<td>(0.067)</td>
<td>(0.068)</td>
<td>(0.029)</td>
</tr>
<tr>
<td>Surcharge * AM Rush Hrs</td>
<td>0.379***</td>
<td>0.318***</td>
<td>0.347***</td>
</tr>
<tr>
<td></td>
<td>(0.034)</td>
<td>(0.033)</td>
<td>(0.015)</td>
</tr>
<tr>
<td>Surcharge * AM Late Hrs</td>
<td>0.240***</td>
<td>0.232***</td>
<td>0.117***</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.025)</td>
<td>(0.016)</td>
</tr>
<tr>
<td>Surcharge * PM Rush Hrs</td>
<td>–0.310***</td>
<td>–0.333***</td>
<td>–0.265***</td>
</tr>
<tr>
<td></td>
<td>(0.048)</td>
<td>(0.049)</td>
<td>(0.016)</td>
</tr>
<tr>
<td>Surcharge * PM Late Hrs</td>
<td>–0.058</td>
<td>–0.072*</td>
<td>0.107***</td>
</tr>
<tr>
<td></td>
<td>(0.035)</td>
<td>(0.035)</td>
<td>(0.021)</td>
</tr>
<tr>
<td>Day of Week FE</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Station Fixed Effects (FE)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>13260141</td>
<td>13260141</td>
<td>13260141</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.011</td>
<td>0.015</td>
<td>0.011</td>
</tr>
</tbody>
</table>

Dependent variable: deposit amount at new pay-per-ride purchases. Standard Deviation in parentheses and clustered at station level. The sample is limited to all deposit transactions made to new pay-per-ride MetroCards from January 1, 2013 to April 30, 2013.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
### Table 9: Effect of Surcharge on Deposit Amounts at New Purchases: RD Regressions

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge</td>
<td>1.187***</td>
<td>1.066***</td>
<td>0.925***</td>
</tr>
<tr>
<td>AM Early Hrs</td>
<td>-0.571***</td>
<td>-0.635***</td>
<td>-0.077***</td>
</tr>
<tr>
<td>(0:01-6:29am)</td>
<td>(0.114)</td>
<td>(0.111)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>AM Rush Hrs</td>
<td>0.840***</td>
<td>0.666***</td>
<td>1.177***</td>
</tr>
<tr>
<td>(6:30-10:00am)</td>
<td>(0.106)</td>
<td>(0.099)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>AM Late Hrs</td>
<td>-0.075**</td>
<td>-0.100***</td>
<td>-0.016*</td>
</tr>
<tr>
<td>(10:01-1:00pm)</td>
<td>(0.028)</td>
<td>(0.028)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>PM Rush Hrs</td>
<td>1.086***</td>
<td>1.056***</td>
<td>0.666***</td>
</tr>
<tr>
<td>(4:30-8:00pm)</td>
<td>(0.060)</td>
<td>(0.056)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>PM Late Hrs</td>
<td>-0.314***</td>
<td>-0.267***</td>
<td>-0.458***</td>
</tr>
<tr>
<td>(8:01-11:59pm)</td>
<td>(0.052)</td>
<td>(0.052)</td>
<td>(0.010)</td>
</tr>
<tr>
<td>Day of Week FE</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Station Fixed Effects (FE)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>13195356</td>
<td>13195356</td>
<td>13195356</td>
</tr>
<tr>
<td>R²</td>
<td>0.012</td>
<td>0.015</td>
<td>0.018</td>
</tr>
</tbody>
</table>

Dependent variable: deposit amount at new pay-per-ride purchases.

The sample is limited to all deposit transactions made to new pay-per-ride MetroCards from January 1, 2013 to April 30, 2013. The coefficients reported here are based on default bandwidth with local quadratic described in Calonico et. al (2014). Standard Deviation in parentheses and clustered at station level.

* p < 0.05, ** p < 0.01, *** p < 0.001

### Table 10: Effect of Surcharge on Deposit Amounts at Refills

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge</td>
<td>0.222***</td>
<td>0.211***</td>
<td>0.201***</td>
</tr>
<tr>
<td>(0.004)</td>
<td>(0.004)</td>
<td>(0.008)</td>
<td></td>
</tr>
<tr>
<td>Day of Week FE</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Station Fixed Effects (FE)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>48632976</td>
<td>48632976</td>
<td>48632976</td>
</tr>
<tr>
<td>R²</td>
<td>0.000</td>
<td>0.007</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Dependent variable: deposit amount at refills for pay-per-ride MetroCards. The sample is limited to all deposit transactions at refills for pay-per-ride MetroCards from January 1, 2013 to April 30, 2013. Standard Deviation in parentheses and clustered at station level.

* p < 0.05, ** p < 0.01, *** p < 0.001
Table 11: Median Neighborhood Income and Pay-per-ride Deposit Amounts

<table>
<thead>
<tr>
<th>Total</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Income(log)</td>
<td>0.221***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>Surcharge</td>
<td>0.129***</td>
</tr>
<tr>
<td></td>
<td>(0.012)</td>
</tr>
<tr>
<td>Surcharge_Income(log)</td>
<td>–0.006***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>Day of Week FE</td>
<td>No</td>
</tr>
<tr>
<td>Observations</td>
<td>68632976</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.015</td>
</tr>
</tbody>
</table>

Dependent variable: transaction-level deposit amount for pay-per-ride MetroCards. The sample is limited to all deposit transactions for pay-per-ride MetroCards from January 1, 2013 to April 30, 2013. Standard Deviation in parentheses and clustered at station level.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12: Median Neighborhood Income and Ridership At Station-level

<table>
<thead>
<tr>
<th>Pay-per-ride</th>
<th>7-day</th>
<th>30-day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Income(log)</td>
<td>0.293*</td>
<td>0.293*</td>
</tr>
<tr>
<td></td>
<td>(0.115)</td>
<td>(0.115)</td>
</tr>
<tr>
<td>Surcharge</td>
<td>–0.184</td>
<td>–0.186</td>
</tr>
<tr>
<td></td>
<td>(0.240)</td>
<td>(0.239)</td>
</tr>
<tr>
<td>Surcharge*Income(log)</td>
<td>0.014</td>
<td>0.014</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.024)</td>
</tr>
<tr>
<td>Month of year FE</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>34132</td>
<td>34132</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.040</td>
<td>0.041</td>
</tr>
</tbody>
</table>

Dependent variable: weekly rides from different types of MetroCards. The sample is limited to weekly MetroCard swipes from January 2010 to May 2015. Standard Deviation in parentheses and clustered at station level.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Table 13: Effect of Surcharge on Deposit Amounts at New Pay-per-ride MetroCard Purchases: Cash Payments Only

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge</td>
<td>1.695***</td>
<td>1.687***</td>
<td>1.327***</td>
</tr>
<tr>
<td></td>
<td>(0.012)</td>
<td>(0.012)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>Machine</td>
<td>1.912***</td>
<td>1.914***</td>
<td>1.506***</td>
</tr>
<tr>
<td></td>
<td>(0.005)</td>
<td>(0.005)</td>
<td>(0.005)</td>
</tr>
<tr>
<td>Surcharge*Machine</td>
<td>0.740***</td>
<td>0.741***</td>
<td>0.778***</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
<td>(0.017)</td>
<td>(0.016)</td>
</tr>
<tr>
<td>Day of Week FE</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Station Fixed Effects (FE)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>4689119</td>
<td>4689119</td>
<td>4689119</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.052</td>
<td>0.053</td>
<td>0.083</td>
</tr>
</tbody>
</table>

Dependent variable: deposit amount at new pay-per-ride MetroCards (cash). Standard Deviation in parentheses and clustered at station level. The sample is limited to deposit transactions to new pay-per-ride MetroCards (cash payments only) from January 1, 2013 to April 30, 2013.

* \(p < 0.05\), ** \(p < 0.01\), *** \(p < 0.001\)

Table 14: Comparison of ridership cost Pay-per-ride versus 7-day-unlimited

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7% bonus for every $10</td>
<td>5% bonus for every $5</td>
</tr>
<tr>
<td></td>
<td>Pay-per-ride 7-day-unlimited</td>
<td>Pay-per-ride 7-day-Unlimited</td>
</tr>
<tr>
<td>1</td>
<td>2.25</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>5.0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>12</td>
<td>25.23</td>
<td>28.57</td>
</tr>
<tr>
<td>13</td>
<td>27.34</td>
<td>30.95</td>
</tr>
<tr>
<td>14</td>
<td>29.44</td>
<td>33.33</td>
</tr>
</tbody>
</table>

Table 14 compares the costs of trips using per-per-ride versus 7-day-unlimited cards. The red oval circles mark the threshold number of trips needed to switch from pay-per-ride to 7-day-unlimited before versus after the surcharge was implemented.

Table 15: Comparison of ridership cost Pay-per-ride versus 30-day-unlimited

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7% bonus for every $10</td>
<td>5% bonus for every $5</td>
</tr>
<tr>
<td></td>
<td>Pay-per-ride 30-day-unlimited</td>
<td>Pay-per-ride 30-day-Unlimited</td>
</tr>
<tr>
<td>1</td>
<td>2.25</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>5.0</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>47</td>
<td>98.83</td>
<td>111.90</td>
</tr>
<tr>
<td>48</td>
<td>100.93</td>
<td>114.29</td>
</tr>
<tr>
<td>49</td>
<td>103.04</td>
<td>116.67</td>
</tr>
<tr>
<td>50</td>
<td>105.14</td>
<td>119.05</td>
</tr>
</tbody>
</table>

Table 15 compares the costs of trips using per-per-ride versus 30-day-unlimited cards. The red oval circles mark the threshold number of trips needed to switch from pay-per-ride to 30-day-unlimited before versus after the surcharge was implemented.
<table>
<thead>
<tr>
<th>Finding</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A large drop in number of new MetroCard sold</td>
</tr>
<tr>
<td>2</td>
<td>Monthly outstanding balance from pay-per-ride deposits jumped by 1/3</td>
</tr>
<tr>
<td>3</td>
<td>Increased expired fare revenue</td>
</tr>
<tr>
<td>4</td>
<td>No decrease in the total number of deposit transactions</td>
</tr>
<tr>
<td>5-1</td>
<td>Increase in deposit amount on new purchases</td>
</tr>
<tr>
<td>5-2</td>
<td>Trivial change in deposit amounts during refill transactions</td>
</tr>
<tr>
<td>6</td>
<td>Among new purchases</td>
</tr>
<tr>
<td>7</td>
<td>Larger changes in deposits on cash payments at machines than at booths</td>
</tr>
<tr>
<td>8-1</td>
<td>Most cash deposits in amounts of $5, $10, or $20 at manned booths (net of surcharge)</td>
</tr>
<tr>
<td>8-2</td>
<td>Most cash deposits in amounts of $5, $9, or $19 at vending machines (net of surcharge)</td>
</tr>
<tr>
<td>9-1</td>
<td>Larger increase in deposits on cards with no subsequent refill activities</td>
</tr>
<tr>
<td>9-2</td>
<td>Trivial change in deposit amount on cards with refill activities</td>
</tr>
</tbody>
</table>
Table 17: Monthly Revenue Before and After the Surcharge (In Millions $)

<table>
<thead>
<tr>
<th></th>
<th>Before (Jan 2011 to Feb 2013)</th>
<th>After (Mar 2013 to Jun 2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value (1)</td>
<td>Percent (2)</td>
</tr>
<tr>
<td>Total</td>
<td>269.47</td>
<td>1</td>
</tr>
<tr>
<td>(8.82)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pay-per-ride</td>
<td>159.02</td>
<td>0.59</td>
</tr>
<tr>
<td>(6.92)</td>
<td>(0.012)</td>
<td></td>
</tr>
<tr>
<td>New</td>
<td>53.98</td>
<td>20.68</td>
</tr>
<tr>
<td>(4.04)</td>
<td></td>
<td>(2.94)</td>
</tr>
<tr>
<td>Refill</td>
<td>105.04</td>
<td>30.68</td>
</tr>
<tr>
<td>(4.39)</td>
<td></td>
<td>(7.63)</td>
</tr>
<tr>
<td>30-day-unlimited</td>
<td>64.81</td>
<td>0.241</td>
</tr>
<tr>
<td>(3.78)</td>
<td>(0.015)</td>
<td></td>
</tr>
<tr>
<td>New</td>
<td>60.56</td>
<td>16.68</td>
</tr>
<tr>
<td>(5.67)</td>
<td></td>
<td>(4.64)</td>
</tr>
<tr>
<td>Refill</td>
<td>4.25</td>
<td>15.35</td>
</tr>
<tr>
<td>(3.94)</td>
<td></td>
<td>(5.90)</td>
</tr>
<tr>
<td>7-day-unlimited</td>
<td>38.61</td>
<td>0.143</td>
</tr>
<tr>
<td>(2.18)</td>
<td>(0.005)</td>
<td></td>
</tr>
<tr>
<td>New</td>
<td>36.46</td>
<td>10.17</td>
</tr>
<tr>
<td>(2.28)</td>
<td></td>
<td>(2.26)</td>
</tr>
<tr>
<td>Refill</td>
<td>2.15</td>
<td>4.40</td>
</tr>
<tr>
<td>(2.01)</td>
<td></td>
<td>(4.71)</td>
</tr>
<tr>
<td>Reduced fares</td>
<td>5.63</td>
<td>0.022</td>
</tr>
<tr>
<td>(0.25)</td>
<td>(0.001)</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>104</td>
<td>104</td>
</tr>
</tbody>
</table>

Standard deviations in parentheses
Table reports mean values of each variable
Table 17 shows the monthly revenue from sales of different types of MetroCards before and after the surcharge. There was no significant change in the percent of revenue from pay-per-ride versus that from time-based cards.
Figure 1: MetroCard Purchase Venues

(a) Vending Machine

(b) Manned Booth

Source: Figure 1a www.fastcompany.com; Figure 1b Benjamin Kabak on Flickr

Figure 2: MetroCard Vending Machines

Source: http://web.mta.info/metrocard/mvms/index.htm
Figure 3: Screen Snapshot of the Suggested Purchase Amounts on the Vending Machine Screen Before and After the Surcharge

(a) Before

(b) After

Note: Figure 3a shows the suggested purchase amounts on the vending machine screens before the surcharge went into effective; Figure 3b shows the suggested purchase amounts on the vending machine screens after the surcharge went into effective.

Figure 4: First Screen Snapshot on Vending Machine Purchases Before and After the Surcharge

(a) Before

(b) After

Note: Figure 4a shows the first screen snapshot of the vending machines before the surcharge went into effective; Figure 4b shows the first screen snapshot of the vending machines after the surcharge went into effective.
Figure 5: Monthly New MetroCard Sales From January 2009 to June 2015

(a) Total  
(b) Pay-per-ride  
(c) 30-day-unlimited  
(d) 7-day-unlimited  

Note: Figure 5 plots monthly sales of new MetroCards from January 2009 to June 2015, broken out for different types of MetroCards. The vertical line marks the month when the surcharge was implemented.
Figure 6: Daily Sales of New MetroCards (All Types) from January 1, 2013 to April 30, 2013

(a) Raw  
(b) Adjusted

Figure 6a plots daily sales of new MetroCards (all types) from January 1, 2013 to April 30, 2013. Figure 6b plots residual of daily sales from day of week fixed effect. The vertical line marks the day when the surcharge was implemented.

Figure 7: Daily Sales of New Pay-per-ride MetroCards from January 1, 2013 to April 30, 2013

(a) Raw  
(b) Adjusted

Note: Figure 7a plots daily sales of new pay-per-ride MetroCards from January 1, 2013 to April 30, 2013. Figure 7b plots residual of daily sales from day of week fixed effect. The vertical line marks the day when the surcharge was first imposed.
Figure 8: Daily Sales of New 7-day-unlimited MetroCards from January 1, 2013 to April 30, 2013

(a) Raw                                      (b) Adjusted

Note: Figure 8a plots daily sales of new 7-day-unlimited MetroCards from January 1, 2013 to April 30, 2013. Figure 8b plots residual of daily sales from day of week fixed effect. The vertical line marks the day when the surcharge was first imposed.

Figure 9: Daily Sales of New 30-day-unlimited MetroCards from January 1, 2013 to April 30, 2013

(a) Raw                                      (b) Adjusted

Note: Figure 9a plots daily sales of new 30-day-unlimited MetroCards from January 1, 2013 to April 30, 2013. Figure 9b plots residual of daily sales from day of week fixed effect. The vertical line marks the day when the surcharge was first imposed.
Note: Figure 10 plots monthly outstanding balance from pay-per-ride deposits from January 2008 to April 2015. The aggregate monthly outstanding balance that riders carried on their MetroCard is defined as the difference between the total amount they loaded on the cards and reductions caused by swipes at turnstiles. The first vertical line (purple) marks the month when the 2009 fare hike went into effective, the second vertical line (green) marks the month when the 2010 fare hike went into effective, and the third vertical line (red) marks the month when the surcharge was first imposed (also the month when the 2013 fare hike went into effect). The lines plot fitted values of locally weighted regressions (using Stata’s lowess command) of outstanding balance on time.
Figure 11: Weekly Total Number of MetroCard Swipes from January 2011 to May 2015

(a) Pay-per-ride

(b) 30-day-unlimited

(c) 7-day-unlimited

(d) Senior & disability

Note: Figure 11 plots weekly total number of MetroCard swipes from January 2011 to May 2015. The vertical line (red) marks the week when the surcharge went into effective
Figure 12: Monthly Revenue from Pay-per-ride Deposits from January 1, 2011 to April 30, 2015

(a) 

(b) 

Note: Figure 12a plots monthly revenue of pay-per-ride deposits from January 2011 to April 2015. The vertical line (red) marks the month when the surcharge went into effective. Figure 12b plots year-to-year monthly revenue of pay-per-ride deposits from January 2012 to December 2014.

Figure 13: Average Deposits on Pay-per-ride MetroCard Purchases Before versus After the Surcharge

(a) New 

(b) Refills 

Note: Figure 13a plots average deposits on new pay-per-ride MetroCard purchases before and after the surcharge. Figure 13b plots average deposits on pay-per-ride MetroCard refill purchases before and after the surcharge. The first vertical line (purple) marks the month when the 2009 fare hike went into effective, the second vertical line (green) marks the month when the 2010 fare hike went into effective, the third vertical line (red) marks the month when the surcharge was first imposed (also the month when the 2013 fare hike went into effect), and the fourth vertical line (blue) marks the month when the 2015 fare hike went into effective.
Figure 14: Deposits on New Pay-per-ride MetroCard Purchases Before versus After the Surcharge (From January 1, 2013 To April 30, 2013): Cumulative Distribution Function

Note: Figure 14 plots the cumulative distribution function (CDF) for deposit amounts on new pay-per-ride MetroCard purchases before versus after the surcharge. Figure 14a used all the deposit transactions from January 1, 2013 to April 30, 2013. Figure 14b plots deposits of purchases within one week before and after the surcharge.

Figure 15: Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge (From January 1, 2013 To April 30, 2013): Histogram

Note: Figure 15 plots the histogram of deposit amounts on new pay-per-ride MetroCard purchases before versus after the surcharge. Figure 15a used all the deposit transactions from January 1, 2013 to April 30, 2013. Figure 15b plots deposits of purchases within one week before and after the surcharge.
Figure 16: Deposits on Pay-per-ride MetroCard Refills Before and After the Surcharge (From January 1, 2013 To April 30, 2013): Cumulative Distribution Function

Note: Figure 16 plots the cumulative distribution function (CDF) for deposit amounts on Pay-per-ride MetroCard refill purchases before versus after the surcharge. Figure 16a used all the refill deposit transactions from January 1, 2013 to April 30, 2013. Figure 16b plots deposits of purchases within one week before and after the surcharge.

Figure 17: Deposits on Pay-per-ride MetroCard Refills Before and After the Surcharge (From January 1, 2013 To April 30, 2013): Histogram

Note: Figure 17 plots the histogram of deposit amounts on pay-per-ride MetroCard refill purchases before versus after the surcharge. Figure 17a used all the deposit transactions from January 1, 2013 to April 30, 2013. Figure 17b plots deposits of purchases within one week before and after the surcharge.
Figure 18: Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge (From January 1, 2013 To April 30, 2013): Cumulative Distribution Function

(a) No Refills
(b) With Refills

Note: Figure 18 plots the cumulative distribution function for deposits on new pay-per-ride purchases before and after the surcharge. Figure 18a plots the cumulative distribution function for deposits on new pay-per-ride purchases without subsequent refill activities. Figure 18b plots the cumulative distribution function for deposits on new pay-per-ride purchases with subsequent refill activities.

Figure 19: Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge (From January 1, 2013 To April 30, 2013): Histogram

(a) No Refills
(b) With Refills

Note: Figure 19 plots the histogram for deposits on new pay-per-ride purchases before and after the surcharge (from January 1, 2013 to April 30, 2013). Figure 19a plots the histogram for deposits on new pay-per-ride purchases without subsequent refill activities. Figure 19b plots the histogram for deposits on new pay-per-ride purchases with subsequent refill activities.
Figure 20: Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge by Payment Methods (From January 1, 2013 To April 30, 2013): Cumulative Distribution Function

(a) Cash
(b) Debit
(c) Credit

Note: Figure 20 plots the cumulative distribution function for deposits on new pay-per-ride purchases before and after the surcharge by different payment methods. Figure 20a plots the cumulative distribution function for cash deposits on new pay-per-ride purchases. Figure 20b plots the cumulative distribution function for debit-card payments on new pay-per-ride purchases. Figure 20c plots the cumulative distribution function for credit-card payments on new pay-per-ride purchases.
Figure 21: Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge by Payment Methods (From January 1, 2013 To April 30, 2013): Histogram

(a) Cash

(b) Debit

(c) Credit

Note: Figure 21 plots the histogram for deposits on new pay-per-ride purchases before and after the surcharge by different payment methods. Figure 21a plots the cumulative distribution function for cash deposits on new pay-per-ride purchases. Figure 21b plots the histogram for debit-card payments on new pay-per-ride purchases. Figure 21c plots the histogram for credit-card payments on new pay-per-ride purchases.
Figure 22: Percent of Cash Payments Across Different Subway Stations From January 2013 To April 2013

Note: Figure 22 plots the spatial differences in percent of cash payments for MetroCard purchases across different census tracts. The census-tract level per-capita income data is from American Community Survey (ACS) 2009–2013 (5-Year Estimates)
Figure 23: Total Cash Deposit Amounts (Including the Surcharge) on New Pay-per-ride MetroCard Purchases Before versus After the Surcharge (From January 1, 2013 To April 30, 2013): Cumulative Distribution Function

(a) Manned Booths

(b) Vending Machines

(c) Booth-only Stations

(d) Vending-Machine-Only Stations

Note: Figure 23 plots the cumulative distribution function (CDF) for cash deposit amounts on new pay-per-ride MetroCard purchases before versus after the surcharge. Figure 23a plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths. Figure 23b plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines. Figure 23c plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths in booth-only stations. Figure 23d plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines in vending-machine-only stations.
Figure 24: Cash Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge (From January 1, 2013 To April 30, 2013): Histogram

(a) Manned Booths

(b) Vending Machines

Note: Figure 24 plots the histogram of total cash deposit amounts (including the surcharge) on new pay-per-ride MetroCard purchases before versus after the surcharge. Figure 24a plots the histogram for total cash deposit amounts (including the surcharge) on new pay-per-ride MetroCard purchases at manned booths. Figure 24b plots the histogram for total cash deposit amounts (including the surcharge) on new pay-per-ride MetroCard purchases at vending machines.

Figure 25: Monthly Sales of Single-ride Tickets From January 2011 To June 2015
Figure 26: Total Cash Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge (From January 1, 2013 To April 30, 2013): Forest Avenue Station Versus Seneca Avenue Station

(a) Forest Avenue

(b) Seneca Avenue

Note: Figure 26 plots the cumulative distribution function for cash deposit amounts on new pay-per-ride MetroCard purchases after the surcharge in Forest Avenue station versus Seneca Avenue Station from January 1, 2013 to April 30, 2013. Figure 26a plots the cumulative distribution function for all cash deposit amounts on new pay-per-ride purchases at Forest Avenue station which has both a manned booth and several vending machines. Figure 26b plots the cumulative distribution function for all cash deposit amounts on new pay-per-ride purchases at Seneca Avenue Station which has only a manned booth.

Figure 27: Cash Deposits on New Pay-per-ride MetroCard Purchases After the Surcharge (From January 1, 2013 To April 30, 2013): 74-Broadway Station versus Jackson Height-Roosevelt Avenue Station

(a) Vending Machine

(b) Within Roosevelt Avenue Station

Note: Figure 27 plots the cumulative distribution function for cash deposit amounts on new pay-per-ride MetroCard purchases after the surcharge in 74-Broadway Station versus Jackson Height-Roosevelt Avenue Station from January 1, 2013 to April 30, 2013. Figure 27a plots the cumulative distribution function for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines in 74-Broadway station versus in Jackson Height-Roosevelt Avenue Station. Figure 27b plots the cumulative distribution function for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booth versus at vending machines within Jackson Height-Roosevelt Avenue Station.
Figure 28: Cash Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge in Riverdale Neighborhood (From January 1, 2013 To April 30, 2013): Cumulative Distribution Function

(a) Cash booth  
(b) Cash Vendor

Note: Figure 28 plots the cumulative distribution function (CDF) for cash deposit amounts on new pay-per-ride MetroCard purchases before versus after the surcharge in the Riverdale neighborhood. Figure 28a plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths in Riverdale neighborhood. Figure 28b plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines in Riverdale neighborhood.

Figure 29: Cash Deposits on New Pay-per-ride MetroCard Purchases Before and After the Surcharge in Riverdale Neighborhood (From January 1, 2013 To April 30, 2013): Histogram

(a) Booths  
(b) Machines

Note: Figure 29 plots the histogram of cash deposit amounts on new pay-per-ride MetroCard purchases before versus after the surcharge in Riverdale Neighborhood. Figure 29a plots the histogram for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths. Figure 29b plots the histogram for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines.
Figure 30: Total Number of Daily Deposit Transactions (New and Refills) at Seneca Station: 2013 Versus 2015

(a) 2013
(b) 2015

Note: Figure 30a plots daily total number of MetroCard purchases (new and refills) from January 1, 2013 to April 30, 2013 at Seneca Station. Figure 30b plots daily total number of MetroCard purchases (new and refills) from January 1, 2015 to April 30, 2015 at Seneca Station. The vertical line (red) marks the day when the surcharge went into effective

Figure 31: Cash Deposits at Seneca Avenue Station: 2013 Versus 2015

(a) booth cash
(b) vending machine cash

Note: Figure 31a plots the cumulative distribution function (CDF) for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths of Seneca Station. Figure 31b plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booth versus at vending machines of Seneca Station in 2015. Seneca station was a booth-only station in early 2013. Vending machines were installed at this station in 2014.
Figure 32: Deposits on New Pay-per-ride MetroCard Purchases Before Versus After the Surcharge (From January 1, 2013 To April 30, 2013): No Refill Activities

Note: Figure 32 plots the cumulative distribution function (CDF) for deposit amounts on new pay-per-ride MetroCard that had no subsequent refill activities before versus after the surcharge. Figure 32a plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths. Figure 32b plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines. Figure 32c plots the CDF for debit card payments on new pay-per-ride MetroCard purchases. Figure 32d plots the CDF for credit card payments on new pay-per-ride MetroCard purchases.
Figure 33: Deposits on New Pay-per-ride MetroCard Purchases Before versus After the Surcharge (From January 1, 2013 To April 30, 2013): With Refill Activities

(a) Booth-Cash

(b) Vendor-Cash

(c) Debit

(d) Credit

Note: Figure 33 plots the cumulative distribution function (CDF) for deposit amounts on new pay-per-ride MetroCard purchases at manned booths. Figure 33a plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths. Figure 33b plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines. Figure 33c plots the CDF for debit card payments on new pay-per-ride MetroCard purchases. Figure 33d plots the CDF for credit card payments on new pay-per-ride MetroCard purchases.
Figure 34: Daily Sales of New MetroCard Without Subsequent Refills Before and After Surcharge

(a) 2013
(b) 2014-2015

Note: Figure 34 plots daily sales of new MetroCard without subsequent refills before and after the surcharge. The vertical line marks the day when the surcharge was implemented. Figure 34a plots daily sales of new MetroCard without subsequent refills from January 1, 2013 to April 1, 2013. To minimize measurement errors, I only focused on cards purchased before April 1, 2013 and give each card at least one month to demonstrate refill activities. The vertical line marks the day when the surcharge was implemented. Figure 34b plots daily sales of new MetroCard without subsequent refills from September 1, 2014 to January 1, 2015. To minimize measurement errors, I give each card at least five months to demonstrate refill activities.

Figure 35: Distribution of Deposits to New MetroCards Without Subsequent Refills After the Surcharge: 2013 Versus 2014

Note: Figure 35 plots the cumulative distribution function (CDF) for deposit amounts on new pay-per-ride MetroCard without subsequent refills. The solid line plots the cumulative distribution function (CDF) for deposit amounts on new pay-per-ride MetroCard without subsequent refills, purchased from March 3, 2013 (the day when the $1 surcharge went into effect) to April 30, 2013. The dash line plots the cumulative distribution function (CDF) for deposit amounts on new pay-per-ride MetroCard without subsequent refills, purchased from September 1, 2014 to March 31, 2015.
Figure 36: Daily Total Number of MetroCard Purchases From January 1, 2013 To April 30, 2013: New and Refills

(a) 7-day-unlimited Raw

(b) 7-day-unlimited Adjusted

(c) 30-day-unlimited Raw

(d) 30-day-unlimited Adjusted

Note: Figure 36a plots daily total number of 7-day-unlimited MetroCard purchases (new and refills) from January 1, 2013 to April 30, 2013. Figure 36b plots residual of daily total number of 7-day-unlimited MetroCard purchases (new and refills) from day of week fixed effect. Figure 36c plots daily total number of 30-day-unlimited MetroCard purchases (new and refills) from January 1, 2013 to April 30, 2013. Figure 36d plots residual of daily total number of 30-day-unlimited MetroCard purchases (new and refills) from day of week fixed effect. The vertical line marks the day when the surcharge was implemented.
Figure 37: Deposits on Pay-per-ride MetroCard Purchases Before and After the 2009 Fare Hike (From May 1, 2009 To August 30, 2009): Cumulative Distribution Function

(a) New
(b) Refill

Note: Figure 37 plots the cumulative distribution function for deposits on pay-per-ride MetroCard purchases before and after the 2009 fare hike. Figure 37a plots cumulative distribution function for deposits on new pay-per-ride MetroCard purchases from May 1, 2009 to August 30, 2009. Figure 37b plots the cumulative distribution function for deposits on pay-per-ride refills from May 1, 2009 to August 30, 2009.

Figure 38: Deposits on Pay-per-ride MetroCard Purchases Before and After the 2009 Fare Hike (From May 1, 2009 to August 30, 2009): Histogram

(a) New
(b) Refill

Note: Figure 38 plots the histogram for deposits on pay-per-ride MetroCard purchases before and after the 2009 fare hike. Figure 38a plots the histogram for deposits on new pay-per-ride purchases from May 1, 2009 to August 30, 2009. Figure 38b plots the histogram for deposits on pay-per-ride refills from May 1, 2009 to August 30, 2009.
Figure 39: Cash Deposits on New Pay-per-ride MetroCard Purchases Before and After the 2009 Fare Hike (From May 1, 2009 to August 30, 2009): Cumulative Distribution Function

(a) Manned Booths  (b) Vending Machines

Note: Figure 39 plots the cumulative distribution function (CDF) for cash deposit amounts on new pay-per-ride MetroCard purchases before versus after the 2009 fare hike. Figure 39a plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths. Figure 39b plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines.

Figure 40: Deposits on Pay-per-ride MetroCard Purchases Before and After the 2015 Fare Hike (From January 1, 2015 To May 31, 2015): Cumulative Distribution Function

(a) New  (b) Refill

Note: Figure 40 plots the cumulative distribution function for deposits on pay-per-ride MetroCard purchases before and after the 2015 fare hike. Figure 40a plots cumulative distribution function for deposits on new pay-per-ride MetroCard purchases from January 1, 2015 to May 31, 2015. Figure 40b plots the cumulative distribution function for deposits on pay-per-ride refills from January 1, 2015 to May 31, 2015.
Figure 41: Deposits on New Pay-per-ride MetroCard Purchases Before and After the 2015 Fare Hike by Payment Methods (From January 1, 2015 To May 31, 2015): Cumulative Distribution Function

(a) Manned Booths

(b) Vending Machines

(c) Debit

(d) Credit

Note: Figure 41 plots the cumulative distribution function (CDF) for cash deposit amounts on new pay-per-ride MetroCard purchases before versus after the 2015 fare hike. Figure 41a plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at manned booths. Figure 41b plots the CDF for cash deposit amounts on new pay-per-ride MetroCard purchases at vending machines. Figure 41c plots the cumulative distribution function for debit-card payments on new pay-per-ride purchases. Figure 41d plots the cumulative distribution function for credit-card payments on new pay-per-ride purchases.
Figure 42: Daily Total Number of MetroCard Purchases From January 1, 2013 To April 30, 2013: New and Refills

(a) Pay-per-ride Raw

(b) Pay-per-ride Adjusted

Note: Figure 42a plots daily total number of MetroCard purchases (new and refills) from January 1, 2013 to April 30, 2013. Figure 42b plots residual of daily total number of MetroCard purchases (new and refills) from day of week fixed effect. The vertical line marks the day when the surcharge was implemented.
Figure 43: Daily total number of pay-per-ride MetroCard purchases from January 1, 2013 to April 30, 2013: New and refills

(a) Cash Booth raw
(b) Cash booth adjusted
(c) Cash Vendor Raw
(d) Cash vendor adjusted
(e) Debit raw
(f) Debit adjusted
(g) Credit raw
(h) Credit adjusted

Note: The adjusted plot shows residual from day of week fixed effect
## Appendices

### A  RD Regressions: Alternative Estimators and Bandwidths

Table 18: Effect of Surcharge on Daily New MetroCard Sales (Total and Pay-per-ride): RD Regressions

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th></th>
<th>Pay-per-ride</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bandwidth</td>
<td>Coef*10^5</td>
<td>Bandwidth</td>
<td>Coef*10^5</td>
</tr>
<tr>
<td>Default CCT (with regularization) - Local Linear</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surcharge</td>
<td>25.3</td>
<td>-1.3***</td>
<td>25.4</td>
<td>-1.1***</td>
</tr>
<tr>
<td></td>
<td>(21808)</td>
<td></td>
<td>(13474)</td>
<td></td>
</tr>
<tr>
<td>Default CCT (with regularization) - Local Quadratic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surcharge</td>
<td>23.2</td>
<td>-1.4***</td>
<td>22.8</td>
<td>-1.2***</td>
</tr>
<tr>
<td></td>
<td>(32216)</td>
<td></td>
<td>(20584)</td>
<td></td>
</tr>
<tr>
<td>CCT with no regularization - Local Linear</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surcharge</td>
<td>425.4</td>
<td>-1.2***</td>
<td>50.1</td>
<td>-1.1***</td>
</tr>
<tr>
<td></td>
<td>(13661)</td>
<td></td>
<td>(10106)</td>
<td></td>
</tr>
<tr>
<td>CCT with no regularization - Local Quadratic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surcharge</td>
<td>45.5</td>
<td>-1.4***</td>
<td>42.7</td>
<td>-1.1***</td>
</tr>
<tr>
<td></td>
<td>(23872)</td>
<td></td>
<td>(15171)</td>
<td></td>
</tr>
<tr>
<td>IK with regularization - Local Linear</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surcharge</td>
<td>39.8</td>
<td>-1.2***</td>
<td>37.1</td>
<td>-1.0***</td>
</tr>
<tr>
<td></td>
<td>(17568)</td>
<td></td>
<td>(11588)</td>
<td></td>
</tr>
<tr>
<td>IK with regularization - Local Quadratic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surcharge</td>
<td>33.6</td>
<td>-1.3***</td>
<td>41.9</td>
<td>-1.1***</td>
</tr>
<tr>
<td></td>
<td>(27038)</td>
<td></td>
<td>(16414)</td>
<td></td>
</tr>
</tbody>
</table>

Outcome variable: new card sales on daily basis from January 1, 2013 to April 30, 2013. The default CCT bandwidth and CCT with no regularization are obtained by a variant of the Stata package described in Calonico et al (2014). The coefficients reported here are bias-corrected estimates.

*Note:* Robust standard errors in parentheses.  
*p < 0.05, **p < 0.01, ***p < 0.001*
Table 19: Effect of the Surcharge on Daily New MetroCard Sales (7-day-unlimited and 30-day-unlimited): RD Regressions

<table>
<thead>
<tr>
<th>Bandwidth Coef.</th>
<th>7-day-unlimited</th>
<th>30-day-unlimited</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Default CCT (with regularization) - Local Linear Surcharge</td>
<td>18.1</td>
<td>-10955***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7337)</td>
</tr>
<tr>
<td>Default CCT (with regularization) - Local Quadratic Surcharge</td>
<td>29.3</td>
<td>-9189***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(8176)</td>
</tr>
<tr>
<td>IK with regularization - Local Linear Surcharge</td>
<td>29.2</td>
<td>-14045***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7337)</td>
</tr>
<tr>
<td>IK with regularization - Local Quadratic Surcharge</td>
<td>40.4</td>
<td>-11633***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7392)</td>
</tr>
</tbody>
</table>

Outcome variable: new card sales on daily basis from January 1, 2013 to April 30, 2013. The default CCT bandwidth and IK bandwidth with regularization are obtained by a variant of the Stata package described in Calonico et. al (2014). The coefficients reported here are conventional estimates.

Note: Robust standard errors in parentheses.

*p < 0.05, ** p < 0.01, *** p < 0.001
\section*{B Traditional model}

\begin{align*}
v(0) &= \max_n \left( r - c - n + \beta v(n-1) \right) \\
v(1) &= r + \beta v(0) \\
v(2) &= r + \beta v(1) \\
&= r(1 + \beta) + \beta^2 v(0) \\
\vdots \\
v(n) &= r(1 + \beta + \beta^2 + \ldots + \beta^{n-1}) + \beta^n v(0) \\
\vdots \\
\end{align*}

Hence,

\begin{align*}
v(0) &= \max_n \left( r - c - n + \beta v(n-1) \right) \\
&= \max_n \left( r - c - n + \beta r \left( \frac{1-\beta^{n-1}}{1-\beta} \right) + \beta^n v(0) \right) \\
&= \max_n \left( \frac{r-c-n}{1-\beta} + r \frac{\beta}{1-\beta} - \frac{\beta^{n-1}}{1-\beta^n} \right) \\
&= \max_n \left( r \left( \frac{1}{1-\beta} \right) - \frac{c+n}{1-\beta^n} \right) \\
\end{align*}

**Proof** Proof of Lemma 5.1

Solving Bellman equation,

\begin{align*}
v(0) &= \frac{r}{1-\beta} - \max_n \left( \frac{c+n}{1-\beta^n} \right) \\
\end{align*}

Taking first derivative with respect to \( n \),

\[
\frac{\partial v(0)}{\partial n} = - \frac{(1-\beta^n)-(c+n)(-\beta^n \ln \beta)}{(1-\beta^n)^2} = 0
\]

\[
\iff 1 - \beta^n + (c+n)\beta^n \ln \beta = 0
\]

Therefore,

\[-(c+n) \ln \beta = \beta^{-n} - 1. \text{ Note that both LHS and RHS are continuous and increasing in } n, \text{ also } \lim_{n \to 0} \text{LHS} > \lim_{n \to 0} \text{RHS}, \text{ then } \exists n^* > 0 \text{ s.t. } \forall n > n^*, \text{LHS} < \text{RHS}. \text{ The equality defines } n^*(\beta, c).
\]

\[
\iff (c + n) = \beta^{n-1} \ln \beta. \text{ Since LHS is increasing in } c \text{ and RHS is increasing in } \beta, n^* \text{ is increasing in both arguments.}
\]

Losing of MetroCards

**Exogenous Probability of Losing**

For "losing"-type rider, define \( \ell \) is the probability of losing a MetroCard

\begin{align*}
v(0) &= \max_n \left( r - c - n + \beta (\ell v(0) - T) + (1-\ell)v(n-1) \right) \\
v(1) &= r + \beta (\ell v(0) - T) + (1-\ell)v(0) \\
&= r + \beta v(0) - \beta \ell T
\end{align*}
Endogenous Probability of Losing

\[ v(2) = r + \beta(\ell v(0) - T) + (1 - \ell) v(1) \]
\[ = r + \beta \ell v(0) - \beta \ell T + \beta (1 - \ell) [r + \beta v(0) - \beta \ell T] \]
\[ = [\beta \ell + (1 - \ell) \beta^2] v(0) + r(1 + (1 - \ell) \beta) - \beta \ell T (1 + (1 - \ell) \beta) \]

\[ v(3) = r + \beta (\ell v(0) - T) + (1 - \ell) v(2) \]
\[ = r + \beta \ell v(0) - \beta \ell T + (1 - \ell) v(2) \]
\[ = r + \beta \ell v(0) - \beta \ell T + (1 - \ell) \beta(\ell v(0) + \beta \ell T (1 + (1 - \ell) \beta)) \]
\[ = (1 + (1 - \ell) \beta) \beta \ell v(0) + (1 - \ell)^2 \beta^2 v(0) + \]
\[ r(1 + (1 - \ell) \beta + (1 - \ell)^2 \beta^2) - \beta \ell T (1 + (1 - \ell) \beta + (1 - \ell)^2 \beta^2) \]

\[ v(n - 1) = (1 - \ell)^{n-2} \beta^n - (1 - \ell) + (1 - \ell)^2 \beta^2 + \ldots + (1 - \ell)^n \beta^n - \beta \ell T (1 - \ell) \beta + (1 - \ell)^2 \beta^2 \]
\[ = (1 - \ell)^{n-2} \beta^n - \beta \ell T (1 - \ell) \beta + (1 - \ell)^2 \beta^2 \]
\[ + r \frac{(1 - \ell)^{n-1} \beta^{n-1}}{1 - (1 - \ell) \beta} - \beta \ell T (1 - \ell)^{n-1} \beta^{n-1} \]

**Proof** Proof of Lemma 5.2

Solving Bellman equation,

\[ v(0) = r - \frac{\beta \ell T}{1 - \beta} - \max_n ((c + n) \frac{1 - (1 - \ell) \beta}{(1 - \beta)(1 - (1 - \ell)^n)}) \]

Taking first-order derivative with respect to \(n\),

\[ \frac{\partial v(0)}{\partial n} = - \frac{(1 - \beta)(1 - (1 - \ell)^n)(1 - \beta (1 - \ell) + (c + n) (1 - \beta) (1 - \ell)^n \ln(\beta (1 - \ell))}{((1 - \beta)(1 - (1 - \ell)^n))^2} \]
\[ = 0 \]
\[ \iff 1 - (\beta (1 - \ell))^n + (c + n) (\beta (1 - \ell))^n \ln(\beta (1 - \ell)) = 0 \]

Therefore,

\[- \ln(\beta (1 - \ell)) (c + n) = (\beta (1 - \ell))^{-n} - 1.\]

Note that both LHS and RHS are continuous and increasing in \(n\),

\[ \lim_{n \to 0} LHS > \lim_{n \to 0} RHS \quad \exists n^* > 0 s.t. \forall n > n^*, \quad LHS < RHS. \]

The equality defines \(n^*(\beta, \ell, c)\).

\[ \iff (c + n) = \frac{(\beta (1 - \ell))^{-n} - 1}{\ln(\beta (1 - \ell))} \]

Since LHS is increasing in \(c\) and RHS is increasing in \(\beta\) and decreasing in \(\ell\), \(n^*\) is increasing in \(\beta\) and \(c\) and decreasing in \(\ell\). Also, \(n^*\) is independent of \(T\).

**Endogenous Probability of Losing**

\[ v(0) = \max_{n,e} (r - c - n - \kappa(e) + \beta(\ell c)(v(0) - T) + (1 - \ell(e))v(n - 1)) \]

\[ v(1) = r - \kappa(e) + \beta(\ell c)(v(0) - T) + (1 - \ell(e))v(0) \]
\[ = r - \kappa(e) + \beta v(0) - \beta \ell c T \]
\[ v(2) = r - \kappa(e) + \beta(\ell(e)(v(0) - T) + (1 - \ell(e))v(1)) \]
\[ = r - \kappa(e) + \beta(\ell(e)v(0) - \beta \ell(e)T + \beta(1 - \ell(e))v(2)) \]
\[ = r - \kappa(e) + \beta(\ell(e)v(0) - \beta \ell(e)T + \beta(1 - \ell(e))(\beta(1 - \ell(e))v(0) - \beta \ell(e)T(1 + (1 - \ell(e))\beta) + r(1 + (1 - \ell(e))\beta - \kappa(e)(1 + (1 - \ell(e))\beta) \]
\[ v(3) = = r - \kappa(e) + \beta(\ell(e)(v(0) - T) + (1 - \ell(e))v(2)) \]
\[ = r - \kappa(e) + \beta(\ell(e)v(0) - \beta \ell(e)T + \beta(1 - \ell(e))v(2) \]
\[ = r - \kappa(e) + \beta(\ell(e)v(0) - \beta \ell(e)T + \beta(1 - \ell(e))(\beta(1 - \ell(e))v(0) - \beta \ell(e)T(1 + (1 - \ell(e))\beta) + r(1 + (1 - \ell(e))\beta - \kappa(e)(1 + (1 - \ell(e))\beta) \]
\[ v(n - 1) = [1 + (1 - \ell(e))\beta + ... + (1 - \ell(e))^{n-3}\beta^{n-3}]\beta(\ell(e)v(0) + (1 - \ell(e))v(n - 1)) \]
\[ = \frac{r}{1 - \beta} - \max\left(\frac{\kappa(e)}{1 - \beta} + \frac{\beta(\ell(e)T}{1 - \beta} + (c + n)\frac{1 - (1 - \ell(e))\beta}{1 - \beta(1 - \beta(1 - \ell(e)))^n} \right) \]

Taking first-order derivative with respect to \( e \),
\[ \frac{\partial v(0)}{\partial e} = -\kappa'(e) \frac{1}{1 - \beta} - \beta(\ell(e))T \]
\[ = -\frac{\kappa'(e)}{1 - \beta} - \beta(\ell(e))T \]
\[ - (1 - \beta)(1 - (1 - \ell(e)))^n(c + n)(\beta(\ell(e)) - (c + n)(1 - \beta(1 - \ell(e)))(1 - \beta)(\beta(1 - \ell(e)))^{n-1}\beta(\ell(e)) \]
\[ = -\frac{\kappa'(e)}{1 - \beta} - \beta(\ell(e))T \]
\[ - \frac{(c + n)(\beta(\ell(e)) - (c + n)(1 - \beta(1 - \ell(e)))(1 - \beta)(\beta(1 - \ell(e)))^{n-1}\beta(\ell(e))}{(1 - \beta)(1 - \beta(1 - \ell(e)))^n} \]
\[ \iff \kappa'(e)(1 - (1 - \ell(e)))^n = -\beta(\ell(e))T (1 - (1 - \ell(e)))^n \]
\[ + (c + n)(\beta(\ell(e)) - (c + n)(1 - \beta(1 - \ell(e)))(1 - \beta)(\beta(1 - \ell(e)))^{n-1}\beta(\ell(e)) \]
\[ - (c + n)(1 - (1 - \ell(e)))^n(1 - (1 - \ell(e)))^n \]

Let \( M = \beta(1 - \ell(e)) \),
\[ \kappa'(e) = -\beta \ell'(e) T - (c + n) \beta \ell'(e) (1 - M^n - (1 - M)nM^{n-1})(1 - M^n)^{-2}. \]

Note that LHS is continuous and increasing in \(e\) and RHS is continuous and decreasing in \(e\), \(\lim_{e \to 0} LHS < \lim_{e \to 0} RHS\) and \(\exists e > 0 \text{ s.t. } \forall e > e^*, LHS > RHS\). The equality defines \(e(\beta, T, c)\). This is increasing in \(\beta, c\), and \(T\), since RHS is increasing in \(\beta, T\), and \(c\).

Taking first-order derivative with respect to \(n\),
\[ \frac{\partial e(0)}{\partial n} = -\frac{(1-\beta)(1-(\beta(1-\ell(e)))^n)(1-\beta(1-\ell(e)))(\beta(1-\ell(e)))^n \ln(\beta(1-\ell(e)))}{((1-\beta)(1-(\beta(1-\ell(e)))^n))^2} \]
\[ = 0 \]
\[ \iff 1 - (\beta(1 - \ell(e)))^n + (c + n)(\beta(1 - \ell(e)))^n \ln(\beta(1 - \ell(e))) = 0 \]
Therefore,
\[ -\ln(\beta(1 - \ell(e)))(c + n) = (\beta(1 - \ell(e)))^{-n} - 1. \]
Note that both LHS and RHS are continuous and increasing in \(n\), \(\lim_{n \to 0} LHS > \lim_{n \to 0} RHS\) and \(\exists n^* > 0 \text{ s.t. } \forall n > n^*, LHS < RHS\). The equality defines \(n^*(\beta, \ell, c)\).
\[ \iff (c + n) = \frac{1}{\ln(\beta(1 - \ell(e)))} \]
Since LHS is increasing in \(c\) and RHS is decreasing in \(\ell\) and increasing in \(\beta\), \(n^*\) is increasing in \(\beta\) and \(c\) and decreasing in \(\ell\). Consequently, \(n^*\) is increasing in surcharge \(T\).