

# Endogenous ATM Networks and Pricing\*

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## **Abstract**

### **Endogenous ATM Networks and Pricing**

We develop a novel spatial model in which we endogenize the choice by banks of both (i) how to price banking services, and (ii) how many ATMs to provide. The feature of the spatial model that makes it possible to solve for equilibrium pricing and location choices is that consumers receive bank-specific location shocks. Consistent with the recent proliferations of ATMs, we find that in equilibrium, banks over-provide ATMs. Banks do so because they extract profits more efficiently from bank members and a more developed ATM network raises the attraction of establishing an account with the bank.

# 1 Introduction

Perhaps the most important recent technological advancement in the banking industry is the rapid diffusion of Automated Teller Machines (ATMs). The number of ATMs has exploded from 83,000 in 1991 to 227,000 in 1999; consumers can obtain basic banking services at anytime from far more locations than ever before. At the same time, average transactions per machine per month have fallen sharply from 6,403 in 1991 to 3,985 in 1999 (American Bankers Association: ATM facts sheet, 1999).

This raises the following fundamental questions: Does competition among banks give rise to too many or too few ATMs from a social perspective? Do the benefits from increased consumer convenience exceed the costs associated with greater ATM provision?

To answer these questions, we develop a novel spatial model formulation that permits us to endogenize the ATM network and service prices; and the bank account and ATM use choices by consumers. This is a significant methodological contribution, because solving for equilibrium outcomes when both location and pricing is endogenous is infeasible in standard spatial models. The key feature of our spatial model is that consumers receive *bank-specific* location shocks. An equilibrium consequence is that for a given number of ATMs, the optimal locations of one bank's ATMs are unaffected by the other bank's ATM network.

The other features of our economy are as follows. Banks choose ATM prices for members and non-members, bank fees and ATM locations to maximize profits, recognizing the consequences for consumer choice of where to establish bank accounts and where to obtain bank services. Consumers, who differ in their ex-ante valuation of each bank (e.g., due to initial spatial locations), first choose a bank at which to establish an account. Then given bank membership, ATM prices for members and non-members, and bank-specific location shocks, individuals choose which bank's ATM to use.

We first consider equilibrium outcomes when banks simultaneously choose ATM networks and prices. We show that in equilibrium, banks over-provide ATMs relative to the social optimum, a finding consistent with the recent proliferation of ATMs. The other features of the equilibrium also accord with the empirical regularities: banks set high account fees for members but do not charge them for ATM use; and they impose high ATM surcharges on non-member users.

The driving force underlying the over-provision of ATMs is that banks efficiently extract profits

only from their own members. That is, banks avoid inefficiently distorting ATM choice by their own members by two-part pricing, setting high account fees, and marginal cost pricing ATM services. In contrast, banks can extract profits from non-members only by pricing the ATM service above marginal cost, which introduces distortions (from the bank's perspective) in their ATM use. In particular, members patronize their own bank's ATM only when the bank finds it optimal, but non-members sometimes use their own bank's ATM when the foreign bank could serve them at mutually-agreeable prices. This leads banks to compete aggressively for greater bank account market shares by over-providing ATMs, and setting high ATM surcharges that discourage non-membership.

We document the competitive over-provision of ATMs in two ways. We first contrast the competitive ATM provision with that which a social planner would choose *given* that banks compete on service prices. We show that a social planner would choose a less extensive ATM network. Because greater ATM concentrations imply lower prices for bank services, it *immediately* follows that bank profits are lower and consumer surplus is higher in the competitive equilibrium than they would be were the ATM network chosen by a social planner.

We then consider how outcomes are affected when banks first invest strategically in ATM networks and then price banking services. When ATM networks are chosen prior to pricing, banks internalize the effects of their ATM network on both their market shares and the *ex-post* intensity of price competition. We show that this leads banks to *increase* their provision of ATMs, despite the fact that greater ATM concentrations compete bank service prices down, reinforcing the decline in bank profits due to the greater costly ATM provision.

That is, the strategic incentives to over-develop an ATM network are *raised* when ATM networks are chosen *before* prices. At first glance, this result seems counter-intuitive. Indeed, for the general problem of duopolist choosing product ranges, the only known analysis of equilibrium location and pricing is Anderson et al. (1992), and there the opposite finding obtains. Anderson et al. (1992) consider a logit specification of consumer demand, in which firms first choose the product range, and then select prices. They find that firms choose product ranges that are too short from a social perspective, as firms internalize the fact that longer product ranges intensify price competition.

Why then do banks choose more extensive ATM networks if ATM networks are chosen before prices? Surprisingly, the economic reasoning is almost identical to that in Anderson et al. The

difference is that, in contrast to standard duopoly contexts, inducing the other bank  $B$  to lower its ATM surcharge *raises* bank  $A$ 's profits: bank  $B$ 's reduced surcharge on non-members lowers the cost of establishing a bank account at Bank  $A$  rather than  $B$ , thereby *raising* bank  $A$ 's profit.

When ATM locations are chosen before prices, each bank recognizes the benefits from having a relatively larger ATM network for the impacts on bank account base and pricing by the other bank. In equilibrium, both banks have the same dynamic incentive to increase ATM provision. As a result, banks spend more resources providing ATMs *and* fiercer price competition results; but, in equilibrium, they of course fail to steal greater shares of the bank account market.

Similar reasoning underlies why the competitive equilibrium provision of ATMs exceeds that the social optimum. A social planner ignores the private benefits that accrue to a bank from added ATMs that increase its bank account base at the expense of the other bank. In equilibrium, banks are hurt by pursuing this private benefit, both because building a more extensive ATM network is costly and because it leads to fiercer price competition.

To summarize, banks over-provide ATMs as they compete to increase their bank account bases. The incentives to over-provide ATMs are especially strong if prices are chosen after ATM locations, so that banks internalize the effect of ATM location on pricing. In equilibrium, banks' efforts to steal bank account market share from each other are unsuccessful; and by over-providing ATMs, banks reduce their profit below the level that a social planner would provide, but raise consumer surplus.

**Methodology and Related Research.** To place our methodological contribution, it helps to understand what makes endogenizing prices and location so difficult in existing spatial models. To ensure that a posited set of (price, location) strategies is indeed an equilibrium, one must verify that *no* deviation in location or prices raises profits. In standard spatial models this is infeasible: One must calculate pricing and profits for all possible numbers of branches and branch locations, which necessarily demands consideration of asymmetries across local markets, and hence pricing. As a result, one cannot solve for equilibrium location and pricing when firms provide multiple products.

More importantly, even if one *could* solve standard spatial models for equilibrium pricing and location, they would seemingly generate the wrong predictions. Simple observation suggests that a bank's choice of ATM locations depends on its *own* network, and not the specific locations of ATMs of other banks. In practice, a bank spaces out its own ATMs—as our theory predicts—and

this sometimes, but not always, results in ATMs of competing banks being located side-by-side. This pattern could not be generated in standard spatial models—competing banks would never locate ATMs side-by-side—but this outcome arises naturally when only a bank’s own network is relevant for determining location. This point is quite general—fast food franchises of the same firm are invariably separated, but competing franchises are sometimes located next to each other.

Standard spatial models also predict that pricing at any given location is sensitive to specific locations of competing franchises. This is because these models collapse the spatial environment into a single dimension so that the optimal local pricing depends on the relative locations of competing franchises. But, in practice, pricing quite generally is insensitive to the locations of competing franchises/branches, and varies little across a given firm’s franchises. For example, Citybank’s ATM surcharges do not vary across locations in New York, and specifically do not vary with the specific locations of JP Morgan Chase’s ATMs. In sharp contrast, our model generates precisely such a prediction because pricing does not depend on the fine details of the competing bank’s network design.

That is, it is precisely the innovative feature of our spatial structure that lets us match real world phenomena, while the standard spatial design is precisely what underlies why it generates the wrong predictions. In particular, our spatial model delivers the correct predictions for the banking industry. Not only do we find that competition among banks gives rise to excessive ATM concentrations, high surcharges for ATM use by non-members, and the high bank fees and bank profits that characterize the industry, but our model also predicts that ATM service prices will not vary with location. More generally, our model captures well those industries in which the specific locations of one firm’s branches do not significantly impact on another firm’s price choices.

Massoud and Bernhardt (2002) consider a standard circular spatial banking model in which branch location is exogenous and endogenizes both the pricing of bank services and consumer choice of where to establish bank accounts and ATM use<sup>1</sup>. Our current paper endogenizes ATM location, in order to address how competition affects ATM provision, bank profit and consumer surplus.

Matutes and Padilla (1993) take an ATM network as exogenous and study the incentive of banks to employ compatible ATM technologies when banks compete for deposits and cannot price

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<sup>1</sup>Our paper also extends Croft and Spencer (2003) study in which they develop a spatial model of ATM networks to explore the implications for banks and nonbanks of interchange fees, foreign fees and surcharges applied to transactions by customers at other than an own-bank ATM.

discriminate among consumers. Chiappori et al. (1995) develop a spatial model with exogenous bank location, in which banks compete on deposits and loans and do not discriminate across customer types. In contrast, we focus on price discrimination according to membership when the ATM network is *endogenous* and ATM technologies are compatible.

Laffont et al. (1998a, b, 1997) and Economides et al. (1997) developed related spatial models of competition between telecommunication networks. In Laffont et al. (1998a, b) foreign networks charge access fees to the other network for calls between networks. The networks price discriminate, setting prices equal to the perceived marginal cost to avoid distorting consumer choice. In contrast, in our economy, banks set high ATM surcharges to distort customer choice of where to establish bank accounts toward them, and our focus is on the consequences of bank competition for the endogenous ATM network structure.

Our paper extends the intermediation literature by examining the provision and pricing of ATM services. As such it differs from existing research into bank service pricing which has focused on the balance-sheet and, in particular, the pricing of deposits and loans. For example, Ho and Saunders (1981) and Allen (1988) look at how a bank should set its deposit rate fees when there is uncertainty about the timing of arrival of deposit and loan demands. Allen, Saunders and Udell (1992) analyze the pricing and provision of deposit services, while Sharpe (1990) among others examine loan pricing. Berlin and Mester (1999) and Mester and Saunders (1995) explore macro and systematic impacts on loan pricing. To date, however, little research has focused on the pricing and provision of the real service and production side of banks, such as that with ATMs<sup>2</sup>.

## 2 The Economy

We consider a spatial game with two banks,  $A$  and  $B$ . Banks compete to provide ATM services both to bank-members and to non-members.<sup>3</sup> The marginal cost of providing the ATM service to a customer is  $c$ . Bank  $j$  is associated with its own spatial line  $J$  of length  $Q$ , on which it locates its ATMs. This spatial line is illustrated in Figure 1 and is described below. The cost of installing an ATM machine is  $C_\alpha > 0$ .

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<sup>2</sup>This paper is also related to the literature on the payment system, e.g. Berger et al (1996).

<sup>3</sup>In Bernhardt and Massoud (2002) qualitative outcomes are unchanged if consumers sometimes require in-branch services such as a review of past check payments that only their bank can provide.

There is a measure  $n$  of bank consumers. Ex ante, consumers are distinguished by their intrinsic valuation of each bank. Economy wide, the relative valuation for bank  $A$  is uniformly distributed on  $[-m, m]$ , where  $m > 0$ : a consumer with relative valuation  $z$  gains an extra (in dollar terms) value of  $z$  from establishing an account at bank  $A$  (if  $z < 0$ , he prefers bank  $B$ ).<sup>4</sup>

Each consumer must establish a bank account at some bank to use an ATM. Consumers then receive bank-specific location shocks and a ‘need’ to use an ATM. Each customer receives incremental utility  $M$  from using an ATM; we assume that  $M$  is large enough that in equilibrium, all consumers use an ATM. A consumer must travel to an ATM to use it. Each consumer receives a bank-specific location shock for each bank that is uniformly distributed on the bank’s spatial line. A consumer’s spatial location,  $\ell_A$ , for bank  $A$  is independently distributed from her bank  $B$  location,  $\ell_B$ . Hence, the distance she must travel to the nearest bank  $A$  ATM is independently distributed from the distance that she must travel to the nearest bank  $B$  ATM. The cost of traveling distance  $d$  is  $Td$ . Each consumer, given her bank-specific location shocks, the pricing and location of ATMs by each bank (detailed below), and bank membership, chooses which ATM to patronize.

Banks charge customers fees to maintain accounts. Let  $F^j$  be the bank account fee that bank  $j$  charges. This fee captures such non-discretionary charges as standard account fees, fees for checks, the value of the difference between the bank and market interest rates offered on accounts, etc. Let  $\delta_j \in \{0, 1\}$  denote whether a customer is a bank member;  $\delta_j$  is equal to one if the consumer establishes an account with bank  $j$ , and  $\delta_j$  is equal to zero if the consumer does not. The ATM service price that bank  $j$  charges a customer with bank membership status  $\delta_j$  is  $p^j(\delta_j)$ .

In equilibrium, the uniform distribution of location shocks leads banks to space their ATM locations equally, so that a bank with  $\alpha$  ATMs will locate them at  $\frac{Q(2i-1)}{2\alpha}$ ,  $i = 1, \dots, \alpha$ . Exploiting this, we reduce notation and refer to  $\alpha$  as the bank’s ATM network. As a result, the distance a customer must travel to bank  $j$ ’s ATM is uniformly distributed on  $[0, \frac{Q}{2\alpha_j}]$ . Let  $V^j = [\alpha_j, p^j(0), p^j(1), F^j]$  denote the vector of ATM network and service prices set by bank  $j$ . Our analysis treats the ATM network,  $\alpha_j$ , as a continuous variable. This eases the analysis by smoothing out discontinuities, and generating symmetric equilibrium behavior.

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<sup>4</sup>It is important for our analysis that individuals differ ex ante in their preferences for each bank. It eases the analysis to build this heterogeneity directly into preferences. Bernhardt and Massoud (2002) introduce this heterogeneity by assuming that an individual is distinguished by her initial spatial location. In the current model, endogenizing the ex ante heterogeneity in consumers in this way needlessly complicates the analysis.

The timing of the game is as follows. First banks choose both their ATM locations and the prices for their bank services. Then, given their relative valuations for bank  $A$  and the strategic choices by banks, customers choose where to establish their bank accounts. Finally, customers receive bank-specific location shocks and must choose which ATM to use.

An equilibrium to this game is a collection of

1. A vector of ATM networks and service prices for each bank,  $V^{A*} = [\alpha_A^*, p^{A*}(1), p^{A*}(0), F^{A*}]$  and  $V^{B*} = [\alpha_B^*, p^{B*}(1), p^{B*}(0), F^{B*}]$ ;
2. A set of bank account choice functions,  $\delta_j^*(z, V^A, V^B)$ , for each consumer given relative bank valuation  $z$  and bank strategic choices  $V^A$  and  $V^B$ ; and
3. A set of ATM use functions  $\rho^*(d_A, d_B, \delta_j, V^A, V^B) \in \{0, 1\}$  for each consumer, where  $\rho = 1$  if and only if she uses an ATM of the bank where she has an account.

such that

1. Almost every consumer's choice of ATM service maximizes utility: for almost all  $(d_A, d_B, \delta_j)$ ,  $\rho^*(d_A, d_B, \delta_j, V^A, V^B) = 1$  if and only if

$$0 \leq M - p^A(1) - Td_A \geq M - p^B(0) - Td_B; \quad (1)$$

2. Almost every consumer chooses bank membership to maximize expected utility: for almost all  $z$ ,  $\delta_j^*(z, V^A, V^B) = 1$  if and only if

$$z - F^A + E[u^A(d_A, d_B, V^A, V^B)] \geq -F^B + E[u^B(d_A, d_B, V^A, V^B)], \quad (2)$$

where  $E[u^j(d_A, d_B, V^A, V^B)]$  is the maximized utility of a consumer who has bank affiliation  $j$ , and bank-specific location shocks  $d_A, d_B$ , facing bank strategies  $V^A$  and  $V^B$ ;

3. Banks choose ATM networks and service prices to maximize profits:

$$\pi^j(V^j, V^{-j}) \geq \pi^j(\hat{V}^j, V^{-j}) \quad \forall \hat{V}^j, j \in \{A, B\}, \quad (3)$$

where  $\pi^j(V^j, V^{-j})$  are bank  $j$ 's profits given the vector of ATM and pricing choices, and subsequent optimization by almost all consumers.

**Equilibrium solution:** To solve for the equilibrium, we recursively set up and solve the optimization problems for agents at each stage.

**Stage three:** At this last stage, banks have made their location and pricing decisions, and customers have established their bank accounts. Then customers receive bank-specific location shocks and must choose which ATM to use. The utility of a customer with an account at bank  $j$  who must travel  $d_j$  to use bank  $j$ 's ATM, and  $d_{-j}$  to use the other bank's ATM is

$$u(0 | d_j, d_{-j}) = \left( M - \min \left[ \left( p^j(1) + Td_j \right), \left( p^{-j}(0) + Td_{-j} \right) \right] \right). \quad (4)$$

Accordingly, a consumer uses her own bank's ATM if and only if

$$M - p^j(1) - Td_j \geq M - p^{-j}(0) - Td_{-j}. \quad (5)$$

Letting  $Y_j = d_j - d_{-j}$ , we solve for the location of the consumer who is indifferent between traveling to her own bank's ATM and the nearest ATM of the other bank,

$$Y_j = \frac{-p^j(1) + p^{-j}(0)}{T}. \quad (6)$$

The ex-ante probability that a consumer will use her own bank's ATM is:

$$\begin{aligned} y^j(1) &= \text{Prob}(d_j - d_{-j} \leq Y_j) \\ &= \frac{4}{Q^2} \left\{ \int_0^{Y_j} \int_0^{\frac{Q}{2\alpha_j}} \alpha_j \alpha_{-j} d(d_{-j}) d(d_j) + \int_{Y_j}^{\frac{Q}{2\alpha_j}} \int_{d_j - Y_j}^{\frac{Q}{2\alpha_{-j}}} \alpha_j \alpha_{-j} d(d_{-j}) d(d_j) \right\}. \end{aligned} \quad (7)$$

Thus, the ex-ante probability the consumer obtains ATM services from the other bank is

$$y^{-j}(0) = \frac{4}{Q^2} \int_{Y_j}^{\frac{Q}{2\alpha_j}} \int_0^{d_j - Y_j} \alpha_j \alpha_{-j} d(d_{-j}) d(d_j). \quad (8)$$

**Stage two:** At this stage, banks have made their location and pricing decisions. Then each customer, given her relative valuation  $z$  for bank  $A$  chooses where to establish a bank account. A customer establishes an account with bank  $A$  if and only if

$$z - F^A + K_A \geq -F^B + K_B, \quad (9)$$

where  $K_j$  is the expected utility of a consumer affiliated with bank  $j$  who obtains ATM services when we integrate over her possible spatial locations,

$$K_j = \frac{4\alpha_j\alpha_{-j}}{Q^2} \left\{ \begin{array}{l} \int_0^{Y_j} \int_0^{\frac{Q}{2\alpha_{-j}}} (M - p^j(1) - Td_j) d(d_{-j})d(d_j) \\ + \int_{Y_j}^{\frac{Q}{2\alpha_j}} \int_{d_j - Y_j}^{\frac{Q}{2\alpha_{-j}}} (M - p^j(1) - Td_j) d(d_{-j})d(d_j) \\ + \int_{Y_j}^{\frac{Q}{2\alpha_j}} \int_0^{d_j - Y_j} (M - p^{-j}(0) - Td_{-j}) d(d_{-j})d(d_j) \end{array} \right\}. \quad (10)$$

Solving equation (9) at equality yields the location  $\bar{z}$  of the consumer who is indifferent to where she has her bank account,

$$\bar{z}(F^A, p^j(\delta), \alpha_j, T) = F^A - F^B - (K_A - K_B). \quad (11)$$

Consumers with stronger preferences for bank  $A$  establish accounts with  $A$ , while all others choose  $B$ . Hence, the measure of consumers who establish accounts at bank  $A$  is:

$$N_A = n \int_{\bar{z}}^m \frac{1}{2m} d(z) = \frac{n}{2} \left( 1 - \frac{\bar{z}}{m} \right), \quad (12)$$

and the measure that establishes accounts at bank  $B$  is:

$$N_B = n \int_{-m}^{\bar{z}} \frac{1}{2m} d(z) = \frac{n}{2} \left( 1 + \frac{\bar{z}}{m} \right), \quad (13)$$

where  $n$  is the measure of consumers in the economy.

**Stage one:** At this stage each bank chooses both the location of its ATMs and the prices of its banking services taking the subsequent optimization by (almost all) consumers as given. The expected profit function of bank  $j$  is:

$$\pi_j = N_j F^j + N_j y^j(1) [p^j(1) - c] + N_{-j} y^j(0) [p^j(0) - c] - \alpha_j C_\alpha. \quad (14)$$

The first two terms are the bank's profit from members; the third term is the profit from non-members who use the ATM service; and the last term is the cost of the ATM network.

**Equilibrium solution:** Banks simultaneously choose bank service prices and ATM networks to maximize profits, equation (14). If a pure strategy equilibrium exists, then it features symmetric strategies,  $F^A = F^B$ ,  $p^A(0) = p^B(0)$ ,  $p^A(1) = p^B(1)$  and  $\alpha_A = \alpha_B$ . To solve for equilibrium outcomes, we derive the first-order conditions for profit maximization by the banks. We then impose

symmetry and solve for our posited equilibrium. Next we verify that the necessary second order conditions for profit maximization hold. Finally, to ensure that we have an equilibrium, we verify numerically that non-local strategy deviations are not optimal. In fact, if consumer preferences over which bank to patronize are weak enough (i.e.,  $m$  is small), then the banks compete so aggressively on pricing that they cannot cover their ATM construction costs in the posited equilibrium, in which case a pure strategy equilibrium does not exist.

While our calculations were done in Maple, we can sketch out the derivations of the first-order conditions, exploiting the fact that banks charge members the marginal cost of the ATM service,  $p^j(1) = c$ . To see why banks do this, recognize that marginal cost pricing induces customers to use the service if and only if doing so raises total (consumer plus producer) surplus. Banks want a member to use their ATM service if and only if there is surplus that the bank can claim. There is surplus from supplying the ATM service whenever the value exceeds the marginal cost; and the bank can extract this surplus from members, ex ante, by a commensurate increase in the bank account fee,  $F^j$ .

Exploiting this observation and considering a simple case where the marginal cost of providing the ATM service to customers is  $c = 0$ , bank  $A$ 's profits simplify to

$$\pi_A = N_A F^A + N_B y^A(0) p^A(0) - \alpha_A C_\alpha. \quad (15)$$

The first-order conditions are:

$$\frac{\partial \pi^A}{\partial F^A} = N_A + \frac{\partial N_A}{\partial F^A} F^A + \frac{\partial N_B}{\partial F^A} y^A(0) p^A(0) = 0 \quad (16)$$

$$\frac{\partial \pi^A}{\partial p^A(0)} = \frac{\partial N_A}{\partial p^A(0)} F^A + \left( \frac{\partial N_B}{\partial p^A(0)} y^A(0) + \frac{\partial y^A(0)}{\partial p^A(0)} N_B \right) p^A(0) + N_B y^A(0) = 0 \quad (17)$$

$$\frac{\partial \pi^A}{\partial \alpha_A} = \frac{\partial N_A}{\partial \alpha_A} F^A + \left( \frac{\partial N_B}{\partial \alpha_A} y^A(0) + \frac{\partial y^A(0)}{\partial \alpha_A} N_B \right) p^A(0) - C_\alpha = 0. \quad (18)$$

The appendix contains a detailed derivation of the first-order conditions. The key point to observe in each first-order condition is that the bank internalizes the impact on its bank-account membership, and the consequent revenue gain from that membership. For example, in equation (17),  $\frac{\partial N_A}{\partial p^A(0)} F^A$  is the increase in bank-account membership due to a marginally higher surcharge times the bank account fee extracted;  $\frac{\partial N_B}{\partial p^A(0)} y^A(0) p^A(0)$  is the loss in surcharge revenues from these consumers who switch bank-membership to bank  $A$  due to the increase in  $p^A(0)$ ; and  $N_B y^A(0) + \frac{\partial y^A(0)}{\partial p^A(0)} N_B p^A(0)$  is the impact on surcharge revenues from consumers who still establish accounts at bank  $B$ .

To solve for an equilibrium, we impose symmetry and then solve equations (16)–(18) for the equilibrium values of  $\alpha^*$ ,  $F^*$  and  $p^*(0)$ . We then verify that neither bank can raise its profits by deviating non-locally. We also verify that there is no asymmetric solution to the first order conditions. Proposition 1 summarizes equilibrium outcomes.

**Proposition 1** *In equilibrium,*

- *Banks' choice of the extent of their ATM network is:  $\alpha^* = \frac{\sqrt{7}}{8} \sqrt{\frac{nQT}{C_\alpha}}$ .*
- *Banks charge affiliated ATM users the marginal cost of the service,  $p^*(1) = c$ , but impose higher surcharges on non-affiliated ATM users,  $p^*(0) = c + \frac{QT}{4\alpha^*} = c + 2\sqrt{\frac{C_\alpha QT}{7n}}$ .*
- *Bank account fees are:  $F^* = m + \frac{QT}{32\alpha^*} = m + \frac{1}{4} \sqrt{\frac{QTC_\alpha}{7n}}$ .*
- *Bank profits are:  $\pi^* = \frac{nm}{2} + \frac{nQT}{\alpha^*} - 32C_\alpha\alpha^* = n \left( \frac{m}{2} - \frac{5}{8} \sqrt{\frac{C_\alpha QT}{7n}} \right)$ .*
- *Consumer surplus is:  $CS = Mn + \frac{nm}{4} - \frac{5nQT}{24\alpha^*} - 2C_\alpha\alpha^* = Mn + \frac{nm}{4} - \frac{41\sqrt{\frac{nQTC_\alpha}{7}}}{12}$ .*

*An equilibrium exists if and only if  $m \geq m^* = \frac{5}{4} \sqrt{\frac{C_\alpha QT}{7n}}$ , i.e., if and only if the bank profits associated with these strategies are non-negative.*

To verify the equilibrium, we first checked that the necessary second-order conditions for profit maximization hold for  $m \geq m^*$ ; i.e., the Hessian matrix is negative semi-definite, implying that the profit function is locally concave. This still admits the possibility that non-local strategy deviations are optimal. In particular, the concern is that if customers do not have strong preferences regarding which bank to patronize—i.e.,  $m$  is small—then first-order conditions may not characterize the optimal ATM surcharge. Specifically, in order to increase its bank account customer base, a bank, say Bank  $A$ , may prefer to set an ATM surcharge that is so high that no non-member uses  $A$ 's ATMs. Their associated profit function becomes  $\pi_A = N_A F^A - \alpha_A C_\alpha$ . First-order conditions then characterize the optimal  $\alpha_A$  and  $F^A$ . Using a fine grid for exogenous model parameters, we then verify that for  $m \geq m^*$ , bank  $A$  earned higher profits in the symmetric equilibrium, and for  $m < m^*$ , profits from this non-local deviation are negative. We conclude that for  $m \geq m^*$ , the local symmetric equilibrium is a global equilibrium.

The key comparative statics predictions of the equilibrium are the following:

**Cost of ATM installation.** As the cost of installing an ATM rises, banks provide fewer ATMs,  $\frac{\partial \alpha^*}{\partial C_\alpha} < 0$ . In turn, the price elasticity of ATM demand falls, causing banks to raise both ATM surcharges and bank account fees,  $\frac{\partial p^*(0)}{\partial C_\alpha} > 0$  and  $\frac{\partial F^*}{\partial C_\alpha} > 0$ . The direct impact of higher ATM costs on profits exceeds the offsetting reduction in price competition,  $\frac{\partial \pi^*}{\partial C_\alpha} < 0$ .

**Travel costs.** Increased consumer travel costs cause banks to increase ATM networks,  $\frac{\partial \alpha^*}{\partial T} > 0$ . A larger ATM network raises the price elasticity of demand; while higher traveling costs reduce the elasticity. For pricing, the latter effect dominates:  $\frac{\partial p^*(0)}{\partial T} > 0$  and  $\frac{\partial F^*}{\partial T} > 0$ . Surprisingly, bank profits fall as consumer travel costs rise,  $\frac{\partial \pi^*}{\partial T} < 0$ : the revenue gains from the higher prices set as  $T$  rises are *more* than offset by the costs of the more extensive ATM network supplied. This result is the opposite of what happens when ATM networks are exogenously specified, in which case higher travel costs serve only to reduce demand elasticities, which raises equilibrium prices and hence bank profits. This result thus highlights the importance of endogenizing ATM location.

The qualitative predictions match the facts: banks develop large ATM networks, and impose high surcharges on non-members. Banks create large ATM networks and impose high surcharges as they seek to steal bank account business from the other bank. Because banks extract surplus more efficiently from their own customers, they compete for a greater customer-account base by over-providing ATM services and set a higher surcharge than they would set were customer-account base exogenous. Massoud, Saunders and Scholnick (2003) document this strategic surcharging, showing that after controlling for other bank factors, higher ATM surcharges and ATM networks result in a higher market share of deposits. Hannan et al. (2000) provide additional empirical support.

To show how competition gives rise to excessive ATM networks we maintain the assumption that banks compete on service prices and compare the equilibrium network with the social optimum. The social planner chooses ATM networks to maximize total consumer plus producer surplus:

$$\max_{\alpha^j} \left\{ n \int_{\bar{z}}^m \frac{z - F^A + K^A}{2m} d(z) + n \int_{-m}^z \frac{-F^B + K^B}{2m} d(z) + \pi^A + \pi^B \right\}, \quad (19)$$

while bank  $j$  chooses bank account fee  $F^j$  and ATM surcharge  $p^j(0)$  to maximize profits given correct conjectures about the social planner's ATM network choice, and the other bank's service prices. The first-order conditions characterizing a bank's price choices remain the same (see equations (16)

and (17)), and the social planner's first-order condition is:

$$\frac{\partial CS}{\partial \alpha_A} = n \int_{\bar{z}}^m \frac{\partial K^A}{\partial \alpha_A} \frac{d(z)}{2m} + n \int_{-m}^{\bar{z}} \frac{\partial K^B}{\partial \alpha_A} \frac{d(z)}{2m} + \frac{\partial \pi^A}{\partial \alpha_A} + \frac{\partial \pi^B}{\partial \alpha_A} = 0. \quad (20)$$

Comparing the first-order condition for the ATM network, equation (20), with that chosen by banks in the competitive equilibrium, equation (18), the key feature is that the social planner internalizes the (negative) effect of a greater ATM provision on the profitability of the other bank,  $\frac{\partial \pi^B}{\partial \alpha_A}$ , causing the social planner to choose a less extensive ATM network.

Proposition 2 contrasts the competitive and social planner outcomes:

**Proposition 2** *Relative to when a social planner chooses ATM networks, in the competitive equilibrium,*

- *Banks choose greater ATM networks:*  $\alpha^s = \frac{\sqrt{7}}{4\sqrt{6}} \sqrt{\frac{nQT}{C_\alpha}} < \alpha^* = \sqrt{\frac{3}{2}} \alpha^s$ .
- *Banks set lower fixed fees:*  $F^s - m = \sqrt{\frac{3}{2}} (F^* - m)$ .
- *Banks impose lower ATM surcharges:*  $p^s(0) = \sqrt{\frac{3}{2}} p^*(0)$ .
- *Bank earn lower profits:*  $\pi^s - \pi^* = \left(\frac{5}{8} - \frac{1}{\sqrt{6}}\right) \sqrt{\frac{QTC_\alpha}{7n}}$ .
- *Expected consumer surplus is higher:*  $CS^s - CS^* = \left(\frac{41-17\sqrt{6}}{12}\right) \sqrt{\frac{QTC_\alpha}{7n}} < 0$ .

*An equilibrium exists if and only if  $m \geq \sqrt{\frac{2}{3}} \sqrt{\frac{C_\alpha QT}{7n}}$ .*

**Proof:** If an equilibrium exists, it is given by the simultaneous solution to the three first-order conditions. This solution was done in Maple. The appendix provides the solution when  $c = 0$ , incorporating the equilibrium result that banks charge their members the marginal cost of the ATM service.

Proposition 2 shows that competition gives rise to more extensive ATM networks than is socially optimal. This is because a social planner internalizes the incentives to enlarge ATM networks in order to steal bank-account membership from the other bank.

Another way to document how competition for greater account bases induces banks to over-develop ATM networks is to contrast the competitive equilibrium network with that which would

arise were bank account choices and bank account fees exogenously fixed at their competitive equilibrium levels. Fixing bank account choices eliminates the incentive to overprovide ATM networks in order to increase bank account base. Then, the only endogenous variables are the banks' choices of ATM surcharges on non-members and ATM networks. Bank A's profits are:

$$\pi_A(ex) = R + N_B y^A(0|ex) p^A(0|ex) - \alpha_A(ex) C_\alpha, \quad (21)$$

where  $R$  is the profit from providing services to members, the second term is the revenue generated from non-members, and  $\alpha_A(ex) C_\alpha$  is the cost of the ATM network. Since profits from bank members are fixed, bank  $A$  chooses the extent of its ATM network,  $\alpha_A(ex)$ , and ATM surcharges,  $p^A(0|ex)$ , to maximize profits from non-members. The first-order conditions are:

$$\frac{\partial \pi^A(ex)}{\partial p^A(0|ex)} = \frac{\partial y^A(0|ex)}{\partial p^A(0|ex)} N_B p^A(0|ex) + N_B y^A(0|ex) = 0 \quad (22)$$

$$\frac{\partial \pi^A(ex)}{\partial \alpha_A} = \frac{\partial y^A(0|ex)}{\partial \alpha_A} N_B p^A(0|ex) - C_\alpha = 0. \quad (23)$$

These first-order conditions are similar to those from the competitive economy, equations (17) and (18), except that  $\frac{\partial N_j(0)}{\partial(\cdot)} = 0$ , because bank membership is fixed. Proposition 3 summarizes equilibrium outcomes. The solution is presented in the appendix.

**Proposition 3** *Suppose that both bank account memberships and bank account fees are exogenously fixed to correspond to their competitive equilibrium levels. When banks choose ATM networks and surcharges, then relative to the competitive equilibrium counterparts:*

- *The extent of the ATM network falls:  $\alpha(ex) = \frac{1}{3\sqrt{6}} \sqrt{\frac{nQT}{C_\alpha}} < \alpha^* = \frac{\sqrt{7}}{8} \sqrt{\frac{nQT}{C_\alpha}}$ .*
- *ATM surcharges on non-members rise:  $p(0|ex) = \sqrt{\frac{3}{2}} \sqrt{\frac{QTC_\alpha}{n}} > p^*(0) = \frac{2}{\sqrt{7}} \sqrt{\frac{QTC_\alpha}{n}}$ .*

Now a bank's choices of ATM network and surcharge do not impact membership. As a result, banks compete less aggressively and the optimal extent of the ATM network is reduced. In turn, the reduced ATM network gives rise to higher ATM surcharges.

The intuition can be uncovered by comparing the first-order conditions with their competitive equilibrium counterparts. The competitive first-order condition for  $\alpha$ , equation (18), has two extra terms not present in the first-order condition when bank membership is fixed, equation (23):

$\frac{\partial N_A}{\partial \alpha_A} F_A$ , the marginal increase in bank account-membership induced by a marginal increase in ATM provision multiplied by the fixed fees, and  $\frac{\partial N_B}{\partial \alpha_A} y^A(0)p^A(0)$ , the loss in surcharge revenue due to members who switch bank membership due to the greater ATM provision. The net impact of these two strategic effects is to cause competitive banks to increase the extent of their ATM networks.

The sharply-reduced ATM network encourages banks to impose *higher* ATM surcharges than in the competitive equilibrium. This is because ATM demand is less price elastic when potential customers must travel further to a competing ATM. This surcharge result is the *opposite* of what happens when ATM networks are exogenous (Massoud and Bernhardt (2002)). When ATM location is exogenous, fixing bank membership eliminates a bank's incentives to set high ATM surcharges in order to increase bank membership. This countervailing incentive exists here as well, but it is swamped by the impact of the reduced ATM network. This result further highlights the importance of endogenizing ATM networks.

### 3 Strategic investment in ATM networks

We next explore how outcomes are affected when banks make strategic investments in their ATM networks before setting prices. Now banks internalize how their ATM networks affect both consumer choices *and* the intensity of price competition—and hence bank account market shares and ATM use. The other features of the model remain the same.

#### **Timing of the game:**

Stage 1. Each bank chooses its ATM network.

Stage 2. Banks price their services.

Stage 3. Consumers make bank account choices.

Stage 4. Customers receive location shocks and choose where to obtain ATM services.

The analysis of the sub-game perfect equilibrium mirrors what we have done, except for that of stage 1. In particular, given the stage 1 ATM network choices, banks will set  $p(0) = \frac{QT}{4\alpha}$ , and  $F = m + \frac{QT}{32\alpha}$ . To avoid redundancy, we focus attention on the stage one choice of the ATM network. Each bank chooses its ATM network taking into consideration how its choice affects market shares

and the *ex post* price competition. Bank  $j$ 's profit function is:

$$\pi_j \left( F^j, p^j(0), F^{-j}, p^{-j}(0), \alpha_j \right) = \left\{ N_j F^j(\alpha_j, \alpha_{-j}) + N_{-j} y^j(0) p^j(0; \alpha_j, \alpha_{-j}) - \alpha_j C_\alpha \right\} \quad (24)$$

Using the envelope theorem, bank  $j$ 's optimal choice of its ATM network solves:

$$\frac{\partial \pi^j(\cdot)}{\partial \alpha_j} + \frac{\partial \pi^j(\cdot)}{\partial F^{-j}(\alpha_j)} \frac{\partial F^{-j}(\alpha_j)}{\partial \alpha_j} + \frac{\partial \pi^j(\cdot)}{\partial p^{-j}(0; \alpha_j)} \frac{\partial p^{-j}(0; \alpha_j)}{\partial \alpha_j} = 0. \quad (25)$$

We decompose the first-order condition into the sum of two components. First, there is a direct effect on market shares and network provision,

$$\frac{\partial \pi^j(\cdot)}{\partial \alpha_j} = \frac{\partial N_A}{\partial \alpha_A} F^A + \left( \frac{\partial N_B}{\partial \alpha_A} y^A(0) + \frac{\partial y^A(0)}{\partial \alpha_A} N_B \right) p^A(0) - C_\alpha,$$

which corresponds exactly with its analogue when ATM networks and prices are chosen simultaneously, equation (18). In addition, there is a strategic effect,

$$\frac{\partial \pi^j(\cdot)}{\partial F^{-j}(\alpha_j)} \frac{\partial F^{-j}(\alpha_j)}{\partial \alpha_j} + \frac{\partial \pi^j(\cdot)}{\partial p^{-j}(0; \alpha_j)} \frac{\partial p^{-j}(0; \alpha_j)}{\partial \alpha_j},$$

that details the influence of a bank's ATM network on the other bank's price choices. This strategic effect is absent when banks choose ATM networks and prices simultaneously.

Let  $F^m = F^A(\alpha_A, \alpha_B) = F^B(\alpha_A, \alpha_B)$ ,  $p^m = p^A(0; \alpha_A, \alpha_B) = p^B(0; \alpha_A, \alpha_B)$  and  $\alpha^m = \alpha_A = \alpha_B$  denote the symmetric equilibrium outcome. Equilibrium outcomes are given by the solution to the first-order condition, which is a high order polynomial. Although no closed-form solution exists, we can solve the polynomial numerically to obtain equilibrium outcomes. Figures 2 to 5 graph how the cost of installing a new ATM machine,  $C_\alpha$  affects the equilibrium ATM network. The other parameters are set to  $Q = 8$ ,  $M = 1000$ ,  $n = 250,000$ ,  $T = 6$  and  $m = 200$ .

The central observation to make is that equilibrium ATM networks are greater when banks choose ATM networks before prices than when banks choose networks and prices simultaneously. It follows immediately that bank service prices and bank profits are all lower when banks choose ATM location first (Proposition 1 details that each of these equilibrium values are declining functions of  $\alpha$ ). The underlying economic force is that increasing the extent of ATM networks raises demand elasticities, which heightens price competition.

To understand why the strategic incentives to over-develop ATM networks are higher when networks are chosen before prices, consider the equilibrium network when prices and network are

chosen simultaneously. Now augment one bank's ATM network slightly. Consumers have a relative preference for that bank, *ceteris paribus*. As a result, the larger bank can profitably exploit its customers more by setting higher prices than the smaller bank because it provides a more valued-service to both members and non-members—on average most consumers are located closer to the larger bank's ATMs. When ATM locations are chosen before prices, each bank internalizes the effects of a relatively larger ATM network on bank membership and pricing. This leads banks to increase further their ATM networks.

To highlight the competitive over-provision of ATMs, we next compare competitive outcomes with their counterparts when a social planner chooses the ATM networks. Here, the social planner chooses ATM networks to maximize total consumer plus producer surplus, and then banks choose prices. The formulation differs from the previous social planner formulation only in the timing of the ATM network choice. Figure 6 illustrates that the social planner always chooses a smaller ATM network. Intuitively, the social planner does not value the market share stealing effect associated with a greater ATM network. It again follows immediately that the competitive economy features lower bank service prices, lower bank profits, and higher consumer surplus.

In summary, the incentives that banks have to over-provide ATMs are reinforced when banks choose ATM networks before setting prices. Bank profits are reduced both by the costs of the ATM provision, and by their subsequent more intense price competition.

## 4 Conclusion

This paper develops a novel spatial model formulation that permits us to endogenize both ATM networks and the pricing of bank services. We prove that competition among banks generates *excessive* ATM networks relative to the social optimum. Surprisingly, banks' incentives to over-provide ATMs are reinforced when banks first choose ATM networks taking into account the subsequent impact on equilibrium prices. These findings can reconcile the explosive growth in ATMs in the past two decades, as ATM supply has almost tripled even though demand has far less than doubled.

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## Appendix

**Equilibrium of the competitive economy.** The first-order conditions for bank  $A$  are,

$$\frac{\partial \pi^A}{\partial F^A} = N_A + \frac{\partial N_A}{\partial F^A} F^A + \frac{\partial N_B}{\partial F^A} y^A(0) p^A(0) = 0, \quad (26)$$

$$\frac{\partial \pi^A}{\partial p^A(0)} = \frac{\partial N_A}{\partial p^A(0)} F^A + \left( \frac{\partial N_B}{\partial p^A(0)} y^A(0) + \frac{\partial y^A(0)}{\partial p^A(0)} N_B \right) p^A(0) + N_B y^A(0) = 0, \quad (27)$$

and

$$\frac{\partial \pi^A}{\partial \alpha_A} = \frac{\partial N_A}{\partial \alpha_A} F^A + \left( \frac{\partial N_B}{\partial \alpha_A} y^A(0) + \frac{\partial y^A(0)}{\partial \alpha_A} N_B \right) p^A(0) - C_\alpha = 0, \quad (28)$$

Imposing symmetry,  $p^A(0) = p^B(0) = p(0)$ ,  $F^A = F^B = F$  and  $\alpha_A = \alpha_B = \alpha$ , terms simplify to,

$$N_A = N_B = \frac{n}{2}, \quad (29)$$

$$y^A(0) = \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2}, \quad (30)$$

$$\frac{\partial N_A}{\partial F^A} = -\frac{\partial N_B}{\partial F^A} = \frac{-n}{2m}, \quad (31)$$

$$\frac{\partial N_A}{\partial p^A(0)} = -\frac{\partial N_B}{\partial p^A(0)} = \frac{n}{4mQ^2 T^2} (2\alpha p(0) - QT)^2, \quad (32)$$

$$\frac{\partial N_A}{\partial \alpha_A} = -\frac{\partial N_B}{\partial \alpha_A} = \frac{-np(0)}{2\alpha m QT} (\alpha p(0) - QT), \quad (33)$$

$$\frac{\partial y^A(0)}{\partial p^A(0)} = \frac{2\alpha (2\alpha p(0) - QT)}{Q^2 T^2}, \quad (34)$$

$$\frac{\partial y^A(0)}{\partial \alpha_A} = \frac{(2\alpha p(0) - QT)^2}{2\alpha Q^2 T^2}. \quad (35)$$

Substituting (30) for  $y^A(0)$  and (31) for  $\frac{\partial N_A}{\partial F^A}$  into (26) yields

$$\frac{\partial \pi^A}{\partial F^A} = \frac{n}{2} + \frac{-n}{2m} F + \frac{n}{2m} p(0) \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2} = 0. \quad (36)$$

Solving, we obtain

$$F = m + p(0) \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2}. \quad (37)$$

Similar substitutions into the first-order condition for  $p^A(0)$ , equation (27), yield

$$\begin{aligned} F \frac{n}{4mQ^2 T^2} (2\alpha p(0) - QT)^2 + p(0) \frac{-n}{4mQ^2 T^2} (2\alpha p(0) - QT)^2 \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2} \\ + p(0) \frac{n}{2} \frac{2\alpha (2\alpha p(0) - QT)}{Q^2 T^2} + \frac{n}{2} \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2} = 0. \end{aligned} \quad (38)$$

Multiplying both sides by  $\frac{Q^2 T^2}{2\alpha p(0) - QT}$  and substituting for  $F$  from equation (37), we get

$$0 = \left(m + p(0) \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2}\right) \frac{n}{4m} (2\alpha p(0) - QT) - p(0) \frac{n}{4m} (2\alpha p(0) - QT) \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2} + \alpha n p(0) + \frac{n}{4} (2\alpha p(0) - QT) \quad (39)$$

$$= \frac{n}{4} (2\alpha p(0) - QT) + p(0) \frac{n}{8m Q^2 T^2} (2\alpha p(0) - QT)^3 - p(0) \frac{n}{8m Q^2 T^2} (2\alpha p(0) - QT)^3 + \alpha n p(0) + \frac{n}{4} (2\alpha p(0) - QT). \quad (40)$$

The second and third terms cancel. Solving for  $p(0)$  yields

$$p(0) = \frac{QT}{4\alpha}. \quad (41)$$

In turn, substituting this solution for  $p(0)$  into  $F$ , equation (37), we get,

$$F = m + \frac{QT}{32\alpha}. \quad (42)$$

Finally, we consider the first-order condition for  $\alpha_A$ , equation (28). Substituting the appropriate expressions, the first-order condition becomes

$$\begin{aligned} \frac{\partial \pi^A}{\partial \alpha_A} &= \frac{-np(0)}{2\alpha m QT} (\alpha p(0) - QT) F + \frac{np(0)}{2\alpha m QT} (\alpha p(0) - QT) \frac{(2\alpha p(0) - QT)^2}{2Q^2 T^2} p(0) \\ &\quad + \frac{(2\alpha p(0) - QT)^2}{2\alpha Q^2 T^2} \frac{n}{2} p(0) - C_\alpha = 0. \end{aligned} \quad (43)$$

We next substitute our solutions for  $p(0)$  and  $F$  from equations (41) and (42) to obtain

$$0 = \left(m + \frac{QT}{32\alpha}\right) \frac{3nQT}{32m\alpha^2} - \frac{3nQ^2 T^2}{32^2 m \alpha^3} + \frac{nQT}{64\alpha^2} - C_\alpha \quad (44)$$

$$= \frac{3nQT}{32\alpha^2} + \frac{nQT}{64\alpha^2} - C_\alpha. \quad (45)$$

Finally, solving for  $\alpha$ , we get,

$$\alpha = \frac{\sqrt{7nQT}}{8\sqrt{C_\alpha}}. \quad (46)$$

Finally, substituting (46) for  $\alpha$  into our solutions for  $p(0)$  and  $F$  in equations (41) and (42) yields the expressions in Proposition 1.

**Equilibrium with a social planner.** The first-order conditions are:

$$\frac{\partial CS}{\partial \alpha_A} = n \int_{\bar{z}}^m \frac{\partial K^A}{\partial \alpha_A} \frac{d(z)}{2m} + n \int_{-m}^z \frac{\partial K^B}{\partial \alpha_A} \frac{d(z)}{2m} + \frac{\partial \pi^A}{\partial \alpha_A} + \frac{\partial \pi^B}{\partial \alpha_A} = 0. \quad (47)$$

$$\frac{\partial \pi^A}{\partial F^A} = N_A + \frac{\partial N_A}{\partial F^A} F^A + \frac{\partial N_B}{\partial F^A} y^A(0) p^A(0) = 0. \quad (48)$$

$$\frac{\partial \pi^A}{\partial p^A(0)} = \frac{\partial N_A}{\partial p^A(0)} F^A + \left( \frac{\partial N_B}{\partial p^A(0)} y^A(0) + \frac{\partial y^A(0)}{\partial p^A(0)} N_B \right) p^A(0) + N_B y^A(0) = 0, \quad (49)$$

where

$$\frac{\partial \pi^A}{\partial \alpha_A} = \frac{\partial N_A}{\partial \alpha_A} F^A + \left( \frac{\partial N_B}{\partial \alpha_A} y^A(0) + \frac{\partial y^A(0)}{\partial \alpha_A} N_B \right) p^A(0) - C_\alpha = 0, \quad (50)$$

and

$$\frac{\partial \pi^B}{\partial \alpha_A} = \frac{\partial N_B}{\partial \alpha_A} F^B + \left( \frac{\partial N_A}{\partial \alpha_A} y^B(0) + \frac{\partial y^B(0)}{\partial \alpha_A} N_B \right) p^B(0) = 0. \quad (51)$$

Impose symmetry,  $p^A(0) = p^B(0) = p(0)$ ,  $F^A = F^B = F$  and  $\alpha_A = \alpha_B = \alpha$  to solve for:

$$\frac{\partial K^A}{\partial \alpha_A} = \frac{1}{12\alpha^2 Q^2 T^2} \left( Q^3 T^3 - 8\alpha^3 p(0)^3 + 6\alpha p(0) Q^2 T^2 \right), \quad (52)$$

$$\frac{\partial K^B}{\partial \alpha_A} = \frac{1}{12\alpha^2 Q^2 T^2} \left( Q^3 T^3 - 8\alpha^3 p(0)^3 - 6\alpha p(0) Q^2 T^2 + 12QT\alpha^2 p(0)^2 \right), \quad (53)$$

$$\frac{\partial N_A}{\partial \alpha_A} = \frac{-\partial N_B}{\partial \alpha_A} = \frac{np(0)}{2\alpha m QT} (QT - \alpha p(0)), \quad (54)$$

$$\frac{\partial y^A(0)}{\partial \alpha_A} = \frac{1}{2\alpha Q^2 T^2} (2\alpha p(0) - QT)^2, \quad (55)$$

$$\frac{\partial y^B(0)}{\partial \alpha_A} = \frac{1}{2\alpha Q^2 T^2} (4\alpha^2 p(0)^2 - Q^2 T^2). \quad (56)$$

Substituting these expressions into the first-order condition for  $\alpha$ , equation (47), yields

$$\frac{1}{12\alpha^2 Q^2 T^2} \left( -12\alpha^2 Q^2 T^2 C_\alpha + 16n\alpha^3 p(0)^3 - 6n\alpha^2 p(0)^2 QT + nQ^3 T^3 \right) = 0. \quad (57)$$

The first-order conditions for  $F^A$  and  $p^A(0)$ , (48) and (49), are the same as the ones from the competitive equilibrium. Hence, their solution as a function of  $\alpha$  is the same:

$$F = m + \frac{QT}{32\alpha} \quad \text{and} \quad p(0) = \frac{QT}{4\alpha}. \quad (58)$$

Substituting for  $F$  and  $p(0)$  into the first-order condition for  $\alpha$ , equation (57), yields

$$\frac{1}{96\alpha^2} \left( 96\alpha^2 C_\alpha - 7nQT \right) = 0. \quad (59)$$

Solving for  $\alpha$ , we get:

$$\alpha = \frac{\sqrt{42}}{24} \sqrt{\frac{nQT}{C_\alpha}} = 0. \quad (60)$$

Substituting for the values of  $\alpha$ ,  $F$  and  $p(0)$  into consumer surplus, equation (19), and bank profits, equation (15), yields

$$\pi^s = n \left( \frac{m}{2} - \frac{1}{\sqrt{6}} \sqrt{\frac{QT C_\alpha}{7n}} \right) \quad \text{and} \quad CS^s = n \left( M + \frac{m}{4} - \frac{17\sqrt{6}}{12} \sqrt{\frac{QT C_\alpha}{7n}} \right). \quad (61)$$

**Equilibrium with exogenous affiliation.** If affiliations are exogenously set equal to their competitive equilibrium level, the first-order conditions become

$$\frac{\partial \pi^A(ex)}{\partial p^A(0|ex)} = N_B y^A(0|ex) + N_B p^A(0|ex) \frac{\partial y^A(0|ex)}{\partial p^A(0|ex)} = 0 \quad (62)$$

$$\frac{\partial \pi^A(ex)}{\partial \alpha_A(ex)} = N_B p^A(0|ex) \frac{\partial y^A(0|ex)}{\partial \alpha_A(ex)} - C_\alpha = 0. \quad (63)$$

Imposing symmetry and substituting for  $y^A(0|ex)$ ,  $\frac{\partial y^A(0|ex)}{\partial p^A(0|ex)}$  and  $\frac{\partial y^A(0|ex)}{\partial \alpha_A}$  from equations (30)–(35), respectively, the first-order conditions simplify to,

$$0 = \frac{\partial \pi^A(ex)}{\partial p^A(0|ex)} = n \left( \frac{3\alpha^2(ex)p^2(0|ex)}{Q^2 T^2} - \frac{2\alpha(ex)p(0|ex)}{QT} + \frac{1}{4} \right) \quad (64)$$

$$0 = \frac{\partial \pi^A(ex)}{\partial \alpha_A} = \frac{1}{4\alpha(ex)Q^2 T^2} \times \left( np(0|ex)Q^2 T^2 + 4n\alpha^2(ex)p^3(0|ex) - 4n\alpha(ex)p^2(0|ex)QT - 4\alpha(ex)C_\alpha Q^2 T^2 \right). \quad (65)$$

Completing the square, equation (64) simplifies to

$$\left( \frac{3\alpha(ex)p(0|ex)}{QT} - \frac{1}{2} \right) \left( \frac{\alpha(ex)p(0|ex)}{QT} - \frac{1}{2} \right) = 0. \quad (66)$$

Solving for  $p(0|ex)$ , we obtain  $pa(0|ex) \in \left\{ \frac{QT}{6\alpha(ex)}, \frac{QT}{2\alpha(ex)} \right\}$ . The relevant root is  $pa(0|ex) = \frac{QT}{6\alpha(ex)}$ .

Substituting into the first-order condition for  $\alpha$ , equation (65), yields

$$54\alpha^2(ex)C_\alpha - nQT = 0. \quad (67)$$

Solving for  $\alpha(ex)$ , we get,

$$\alpha(ex) = \sqrt{\frac{nQT}{54C_\alpha}} = \frac{1}{3\sqrt{6}} \sqrt{\frac{nQT}{C_\alpha}}. \quad (68)$$

Substituting this solution into  $p(0|ex)$  yields

$$p(0|ex) = \sqrt{\frac{3}{2}} \sqrt{\frac{QT C_\alpha}{n}}. \quad (69)$$

Figure 1: Banks' spatial lines

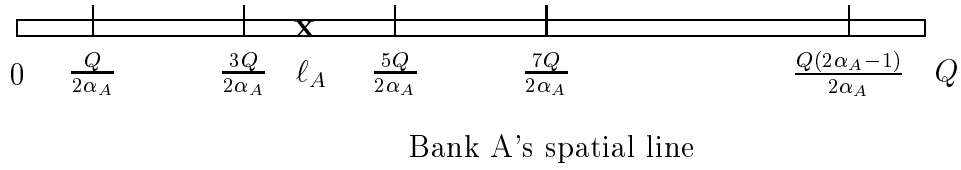
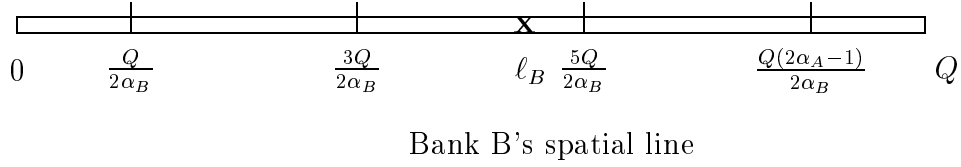


Figure 2: ATM network: Simultaneous price/location vs. sequential strategic ATM investment.

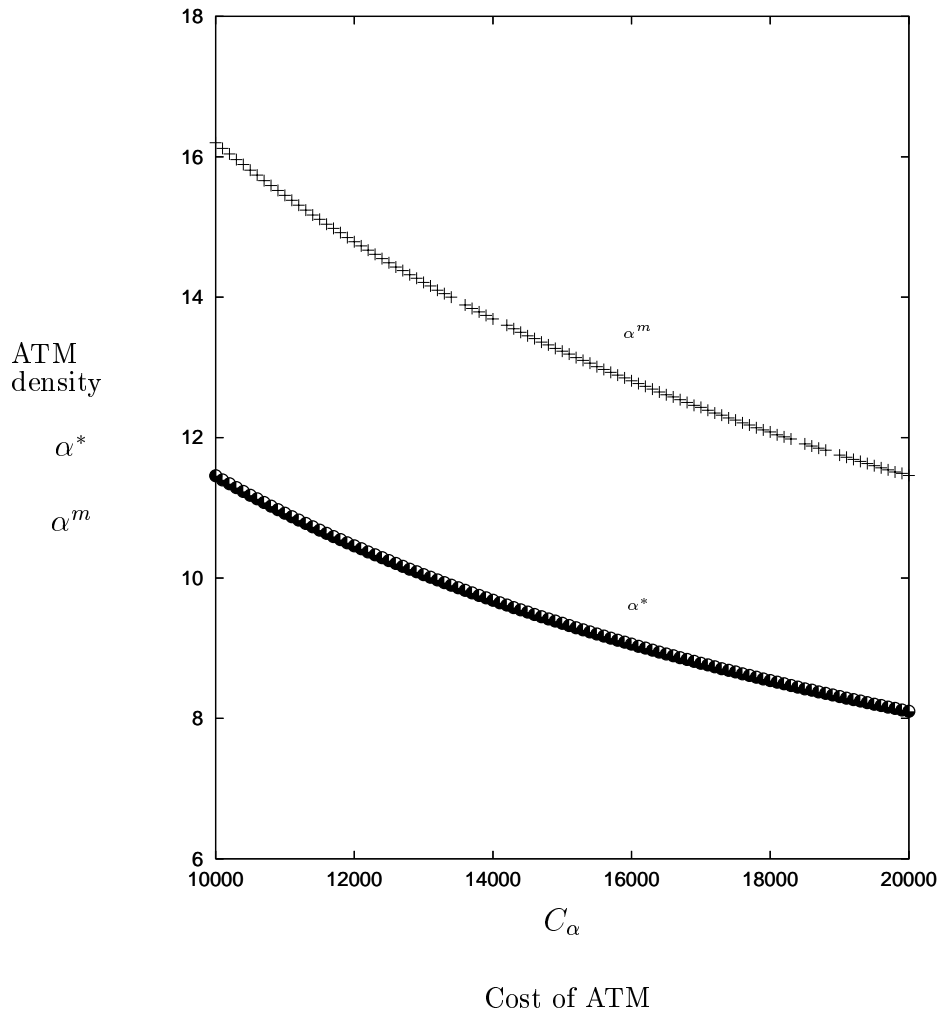


Figure 3: ATM surcharges: Simultaneous price/location vs. sequential strategic ATM investment.

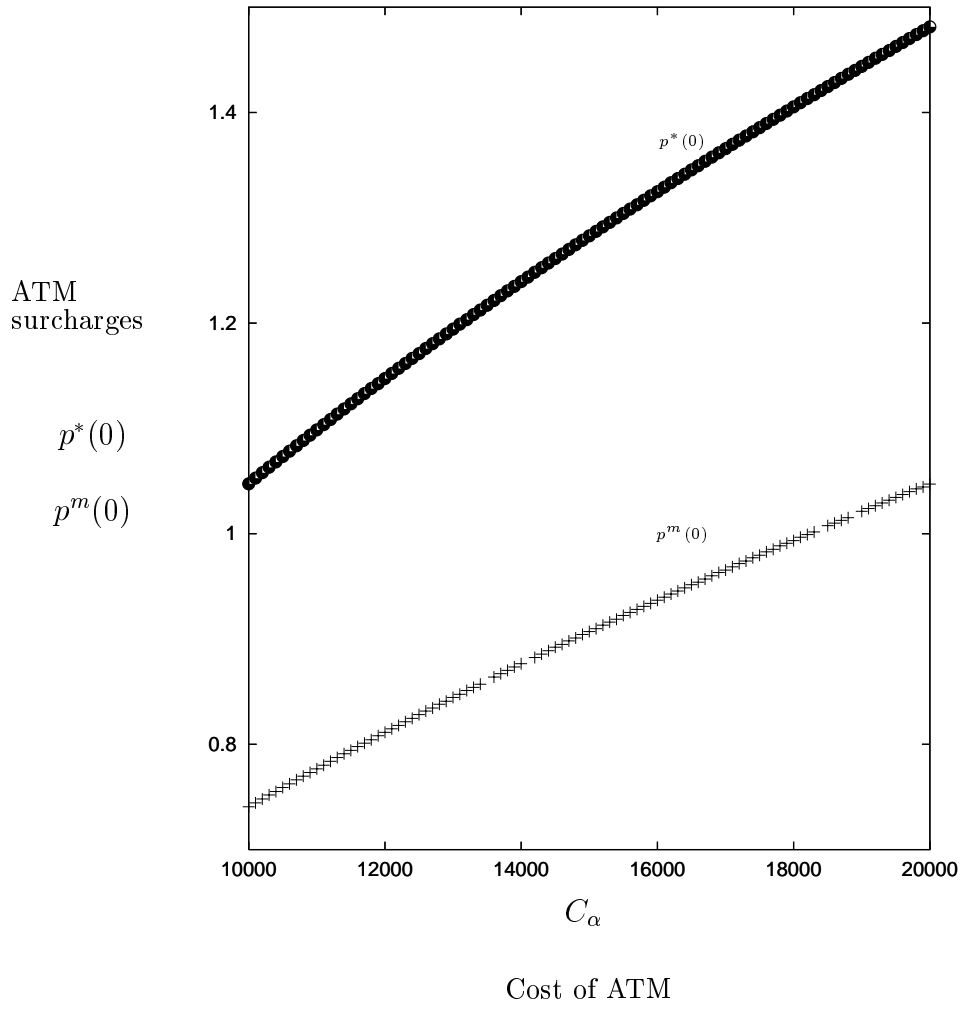


Figure 4: Bank Account Fees: Simultaneous price/location vs. sequential strategic ATM investment.

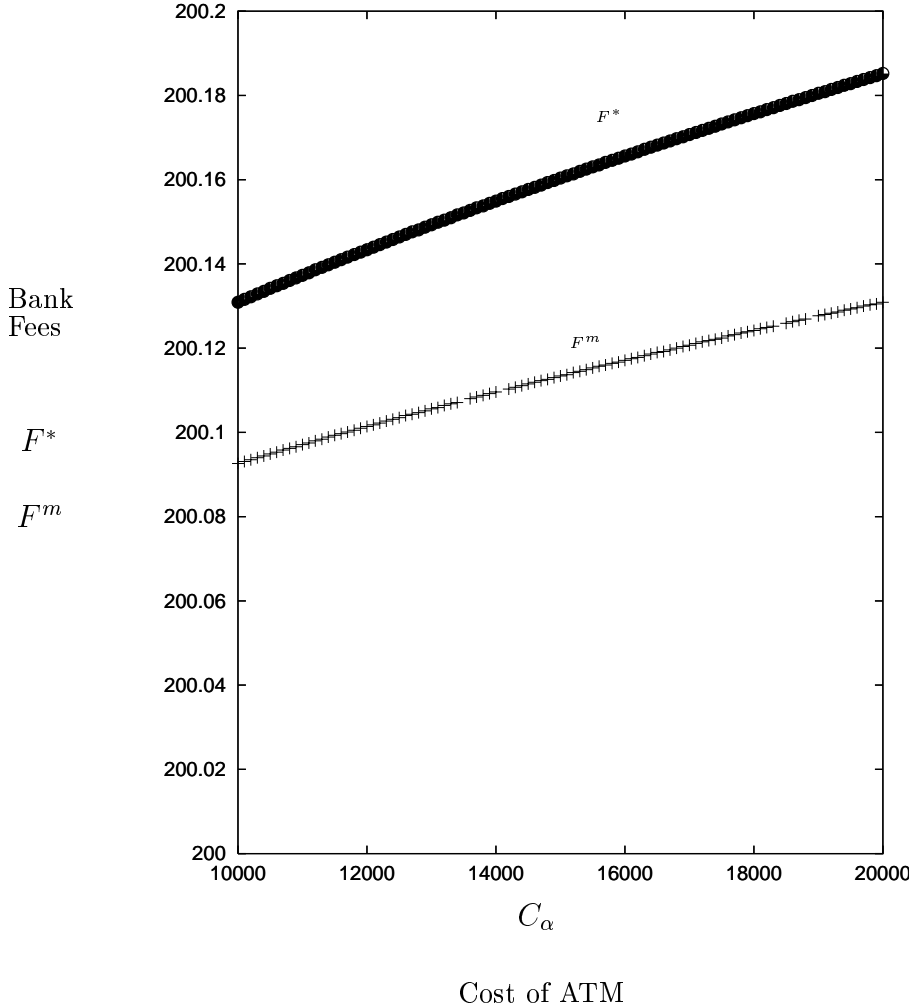


Figure 5: Bank Profits: Simultaneous price/location vs. sequential strategic ATM investment.

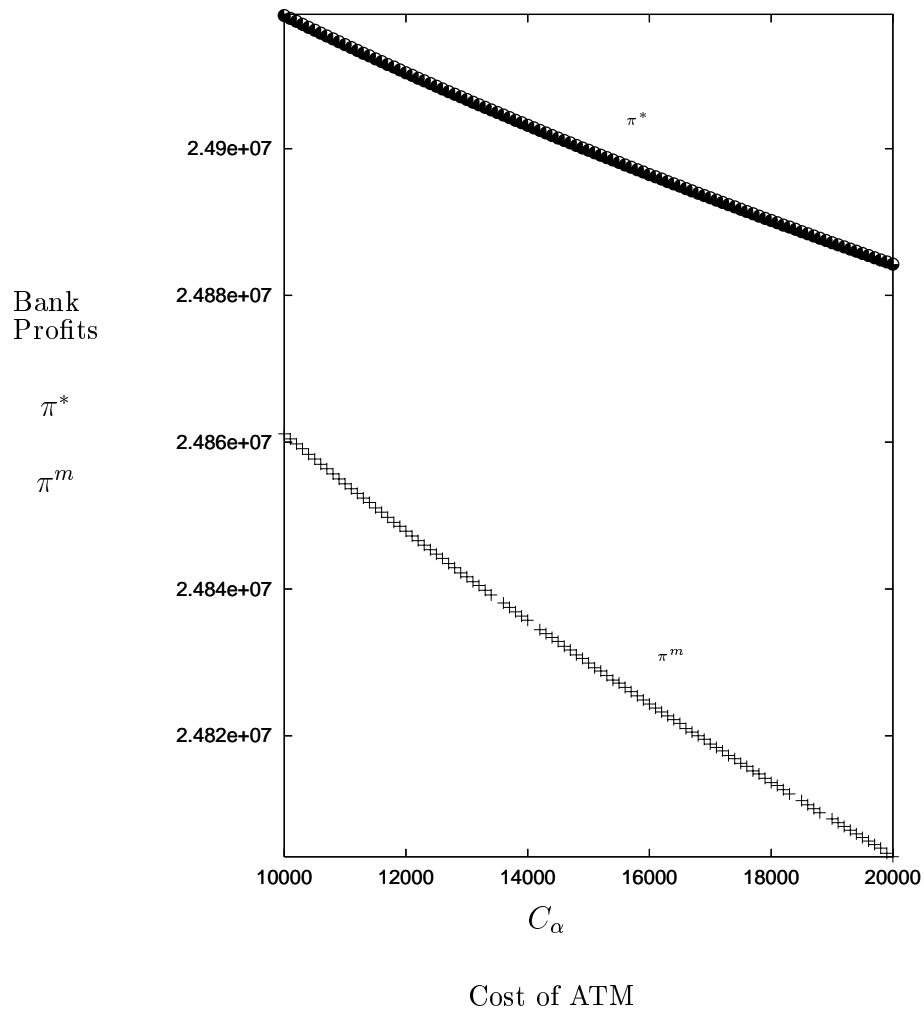


Figure 6: ATM network: Sequential strategic ATM investment model: Competitive equilibrium vs. social planner.

