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Innovation, Deregulation, and the Life Cycle of a Financial Service Industry

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Innovation, Deregulation, and the Life Cycle of a Financial Service Industry*

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Abstract

We construct a dynamic equilibrium model to study how a major product innovation (introducing the debit card function) interacted with banking deregulation and drove the shakeout of the U.S. ATM and debit card industry. The model matches the quantitative pattern of the industry well and allows us to conduct counterfactual analyses to evaluate the roles that innovation and deregulation each played in the industry evolution. The findings show that debit innovation was the main driving force for the decline in ATM network numbers, but deregulation added an important impact on the industry's welfare gains.

JEL classification: L10; O30; G2

Keywords: ATM; Banking Deregulation; Industry Dynamics; Shakeout

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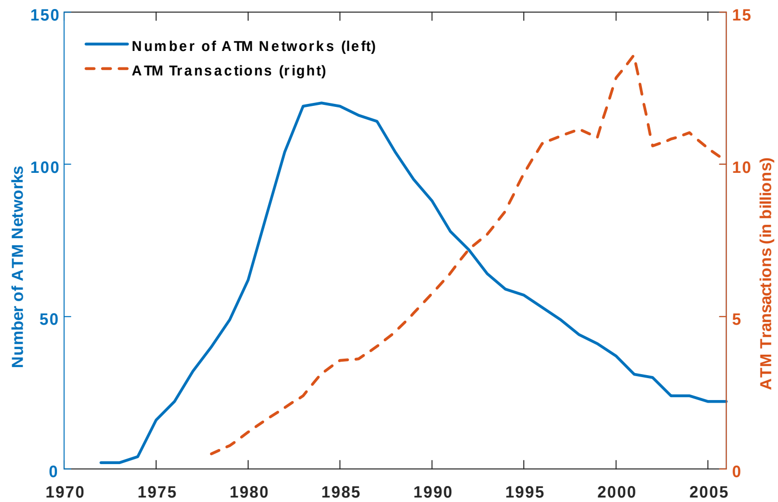
I. Introduction

As new industries evolve from birth to maturity, it is typically observed that price falls, output rises, and firm numbers initially rise and later fall (Gort and Klepper, 1982; Klepper and Graddy, 1990; Agarwal and Gort, 1996). Eventually, only a small number of firms survive, and the industry becomes concentrated. Many recent studies of industrial economics have been interested in explaining this profound life-cycle pattern of industry evolution, particularly the significant decline in firm numbers that takes place during periods of market expansion, termed as "shakeout."

Most existing theories, motivated by evidence from manufacturing industries, have focused on the role of technological innovations (e.g., Hopenhayn, 1994; Jovanovic and MacDonald, 1994; Klepper, 1996; Wang, 2008). They show that as an industry evolves, innovations tend to drive down production costs and increase the technology gap between firms. A shakeout then results when market demand turns inelastic or the inter-firm technology gap becomes sufficiently large. The literature has also debated the relative importance of different types of innovations. A commonly expressed view is that product innovations tend to dominate at the early stage of the industry life cycle while process innovations take over later on, but the pattern can vary considerably across industries (Utterback and Suarez, 1993; Filson, 2001, 2002; Klepper and Simons, 2000, 2005; Cabral, 2012).

While this literature has greatly advanced our understanding of industry evolution, few studies have looked at nonmanufacturing service industries, some of which may also experience shakeouts.[1] One notable difference between manufacturing and services is that the latter are often under extensive government regulations. A strand of industrial organization literature has long been interested in the impact of deregulation on industry development. For instance, Winston (1998) provides a comprehensive survey of the literature that studies industry responses to deregulation in airlines, motor carriers, railroads, banking, and utilities. Those studies showed that deregulation could also have important impact on industry prices, outputs, and firm dynamics.

[1]For example, shakeouts have been documented in the wholesale drug industry (Fein, 1998), the internet industry (Demers and Lev, 2001; Wang, 2007), and the telecommunication industry (Barbarino and Jovanovic, 2007).



Data source: Hayashi, Sullivan, and Weiner (2006).

Figure 1. Number of Shared Networks and ATM Transaction Volumes

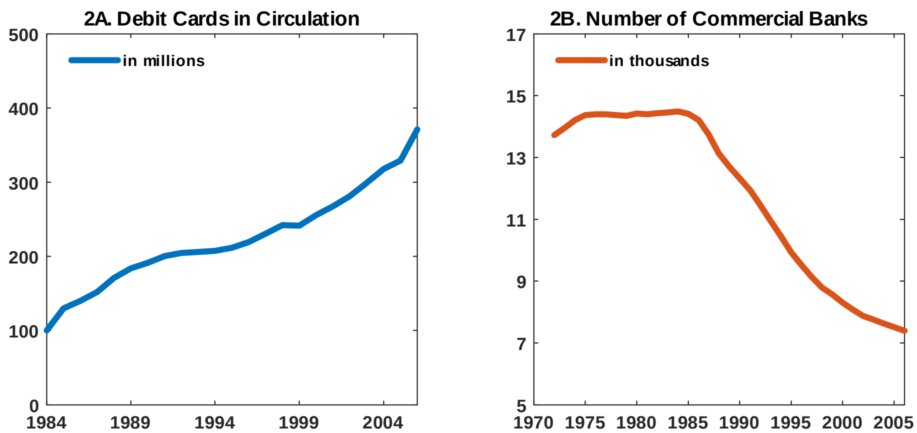
In this paper, we study the life cycle of a financial service industry – the U.S. automated teller machine (ATM) and debit card industry, where both technological innovation and deregulation played important roles. The industry started in the early 1970s, and the firms we refer to are shared ATM networks, which deploy ATM machines and provide ATM services to cardholders from multiple financial institutions. As shown in Figure 1, the number of networks grew rapidly to a peak in the mid-1980s but declined sharply afterward in spite of the continuing growth of ATM transaction volumes.[2]

We identify two major shocks at the outset of the shakeout. One was a product innovation — introducing the debit card function in the mid-1980s.[3] The debit innovation enhances the function of ATM cards, allowing cardholders to use them not only at ATMs (i.e., as ATM cards), but also at retail locations to pay for goods and services (i.e., as debit cards). The synergies between ATM and debit services greatly increased the optimal size of networks and spurred a race of adopting the debit innovation among networks. Over time, the joint ATM-debit technology became increasingly efficient and

[2]Note that the ATM transaction volumes reported after the 2000s exclude certain categories in the pre-2000 data, so the seeming decline of the ATM transactions in the early 2000s is an artifact of changing data definition.

[3]The debit innovation can be traced back to the early 1980s, when the point of sale debit function was first tested in a large scale at some gas station chains (Hayashi, Sullivan, and Weiner, 2003). In our dataset, 1984 was the first year that debit networks were reported.

intensified the competition between networks that adopted the debit innovation and those that did not. Figure 2A plots the increasing number of ATM cards that have enabled the debit function since the mid-1980s.



Data source: 2A – Hayashi, Sullivan, and Weiner (2006); 2B – FDIC.

Figure 2. Debit Growth and Banking Development

Another major shock to the industry was the banking deregulation that started taking effect around the same time.[4] As shown in Figure 2B, the U.S. banking industry had maintained an almost constant number of commercial banks until the mid-1980s, after which the number of banks continued to decline. The deregulation relaxed the size constraints on banks, and larger banks facilitated larger ATM networks. In addition, as a part of the deregulation, an important legal development took place in the mid-1980s when the Supreme Court ruled in 1985 to uphold a federal appeals court's decision (i.e., the *Marine Midland* case in 1984) that national banks' use of shared ATM networks did not violate the federal branching restrictions. This removed a major legal ambiguity that could limit networks' size and operation.[5]

In this paper, we construct a dynamic equilibrium model to explain how the two major shocks interacted with each other and drove the shakeout in the ATM and debit card industry. The model matches the quantitative pattern of the industry well and

[4]In the mid-1970s, no state allowed out-of-state bank holding companies to buy in-state banks, and most states had intrastate branching restrictions. Starting in the late 1970s and early 1980s, most states began relaxing restrictions on both statewide and interstate banking (Jayaratne and Strahan, 1997).

[5]Tibbals (1985) provides a detailed discussion on the court decisions in the *Marine Midland* case.

allows us to conduct counterfactual analyses to evaluate the roles that innovation and deregulation each played in the industry evolution.

Motivated by the industry facts, we introduce several novel features into our model framework. First, unlike traditional shakeout theories focusing on a single process innovation in a homogenous goods industry (e.g., Jovanovic and MacDonald 1994), we consider both product and process innovations in a differentiated goods industry. The model aligns well with the rich ATM network dataset we collected, which allows us to distinguish a major product innovation (i.e., introducing the debit card function) from the subsequent process innovations (reflected by the continuing increase of network sizes). Second and more importantly, we incorporate deregulation in our industry evolution model and consider both general banking deregulation (i.e., interstate banking/mergers) and ATM-specific deregulation (i.e., the *Marine Midland* case). The two types of deregulation enhance industry productivity through different channels: the former helps reducing ATM networks' operating costs by allowing them to serve card users through fewer but larger banks, while the latter removes an explicit size restriction on ATM networks.

Our analysis yields the following findings. On the one hand, we find debit innovation to be the main driving force for the decline in network numbers. Intuitively speaking, debit innovation introduces an adoption race among otherwise identical ATM networks. Over time, the technological gap between debit adopters and nonadopters widens, which discourages network entry and late debit adoption. The falling network numbers then result from the endogenous collapse of entry and eventually voluntary exit of nonadopters. On the other hand, while deregulation explains little of the decline in network numbers, it does generate substantial welfare gains through cost and price reduction, and the effects magnify when interacting with the debit innovation. According to our quantitative exercises, the industry's welfare increases from 100 to 253 measured at the 25th year after the two shocks, with the pre-shock welfare normalized to 100. Among that, the welfare gain of deregulation without debit innovation is 45 (100 to 145), but it rises to 83 with debit innovation (170 to 253). In comparison, the welfare gain due to debit innovation is 70 without deregulation (100 to 170), and it rises to 108 with deregulation (145 to 253).

Considering deregulation in the industry evolution framework is a major novelty of the paper. The finding that deregulation could have substantial welfare impact through cost and price reduction is consistent with observations from other industries. Winston (1998) surveys studies of a variety of service industries that experienced more than 20 years of deregulation from 1970s to 1990s, and points out that "The evidence to date suggests that since deregulation, each industry has substantially improved its productivity and reduced its real operating costs from 25 to 75 percent....and reduced its real average prices from 30 to 75 percent." These numbers are in line with our quantitative findings. However, without a structural model, it was difficult for the early studies to disentangle the effects between deregulation and technology progress, and it was speculated that "one can attribute most but not all of the decline in prices (and operating costs) to deregulation."

Our paper is also related to a recent empirical literature on ATMs, most of which studies ATM surcharge and incompatibility within a shared network. In particular, Ishii (2005), Ferrari et al. (2010), and Gowrisankaran and Krainer (2011) develop structural models and focus on banks' strategic motives for investing in ATMs. In contrast, our model simplifies banks' and consumers' decisions within a shared network, but rather focuses on the dynamic competition among networks. We also take a nonstrategic approach, which provides a convenient framework to study the broad picture of industry evolution and the roles played by innovation and deregulation.

The paper is organized as follows. Section II summarizes key features of the industry evolution. Section III presents a model that characterizes the industry dynamics. Section IV calibrates the model to our dataset on network entry, exit, size, and product offerings. Section V conducts counterfactual and welfare analysis. Section VI discusses extensions of anticipated shocks and heterogeneous networks. Section VII concludes.

II. Industry Background

The late 1960s marked the beginning of modern ATM services. The first ATMs were basically cash-dispensing machines.[6] By the early 1970s, ATM technology had advanced

[6] In 1967, England's Barclays Bank installed the first cash dispenser. In 1968, Don Wetzel developed the first ATM in the United States using modern magnetic stripe access cards.

to the system we know today. ATMs were developed to take deposits, transfer money between checking and savings accounts, provide cash advances from credit cards, and take payments. ATMs were also connected to computers, allowing real-time access to cardholder account information. By connecting ATMs of multiple financial institutions (banks) to a centralized system, shared networks began to emerge in the early 1970s (Felgran, 1984, 1985).[7]

Shared ATM networks generally take one of two forms of organization. First, a bank with a proprietary network can share with franchisees who purchase access to an entire system of terminals and computers. In this case, the proprietary network drives all the ATMs and does all the processing for the franchisees. Second, several banks can share a network through a joint venture, and the ownership of the network is divided by arrangement. In some cases, a third party such as a data processing company may retain an interest in the network.

A shared network allows cardholders to use any ATMs of participating banks in the network. This extends the geographic service area of banks and enhances consumer convenience. In the early years of the industry, most shared ATM networks were regional in scope.[8] In return for providing the ATM service, networks charge fees to participating banks, which then pass the charges to their customers (McAndrews, 2003).[9]

The 1970s saw steady growth of shared ATM networks and the number of networks peaked around 120 in the mid-1980s. However, the industry went through a striking shakeout afterward. Half of the networks had exited by the mid-1990s and less than 30 networks survived to 2006 (cf. Figure 1). As we discussed above, debit innovation and banking deregulation could be the two major shocks that drove the shakeout.

To study the industry evolution closely, we collect a novel dataset. The data are drawn from various issues of the EFT Network Data Book, which provides annual lists of regional ATM networks between 1984 and 2006.[10] In total, we have 144 networks

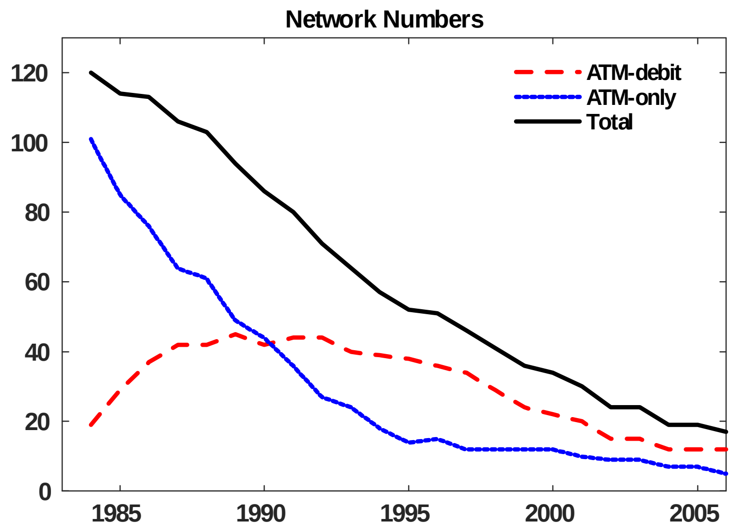
[7] In addition to the shared networks, some exclusive networks serving a single financial institution also existed in the early times. However, the data of exclusive networks are not available for analysis.

[8] In some cases, a regional network might establish sharing agreements allowing its cardholders to access another network's ATMs under certain conditions and fees, but the network would maintain its separate identity and revenue.

[9] In reality, a bank either charges its customers explicit fees for card services (e.g., per-transaction fees or annual fees) or bundles the fees with other banking services.

[10] *ATM&Debit News* (formerly, *Bank Network News*) publishes the *EFT Network Data Book* annually

that existed at some point of time during the period. We then exclude 12 networks serving exclusively credit unions and/or savings and loan banks.[11] For the remaining 132 networks in the sample, we also collect the number of cards in circulation and ATM transactions up to the year 2000. The dataset provides us great details on network entry, exit, size, and product offerings.



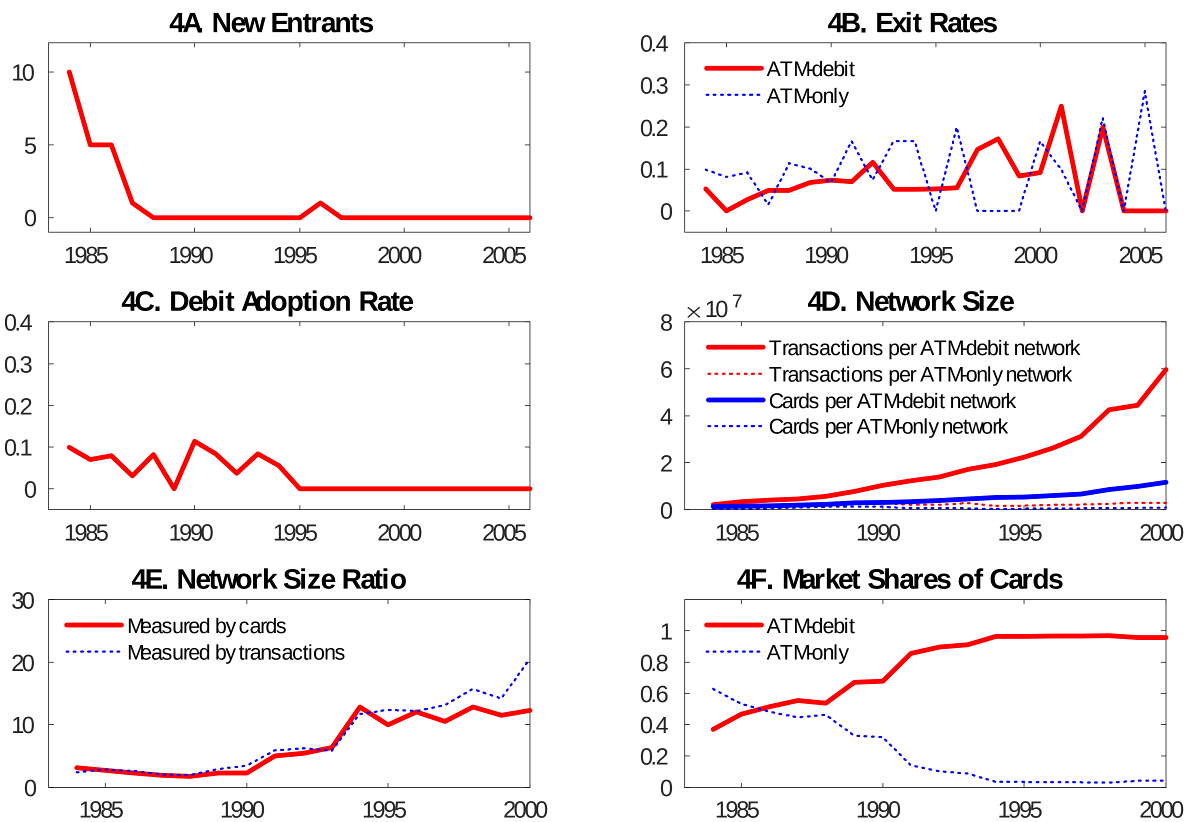
Data source: *EFT Network Data Book*, 1984-2006.

Figure 3. Number of Networks by Type

We first summarize the key facts of the industry evolution, which will later serve as target moments for our model calibration. Figure 3 plots the number of networks by network type in our sample from 1984-2006. While the total number of networks continued to decline in this period, the pattern was quite different between networks that adopted the debit innovation (denoted as "ATM-debit networks") and those that did not (denoted as "ATM-only networks"): the number of ATM-only networks declined monotonically, but the number of ATM-debit networks initially rose before later falling.

(EFT stands for "Electronic Funds Transfer"). The dataset does not include national networks, such as Cirrus and Plus, because national networks used to play a different role than regional networks. They offered a "bridge" between regional networks. See Hayashi, Sullivan, and Weiner (2003) for details.

[11] Because our analysis considers the impact of commercial banking deregulation on ATM networks, it is necessary to exclude networks serving exclusively credit unions and/or savings and loan banks. Credit unions and savings and loan banks serve special groups of customers and were subject to different regulatory regimes, so the networks they used could have behaved differently than those serving commercial banks.



Data source: *EFT Network Data Book*, 1984-2006. Definition: "New Entrants" – the number of new network entrants each year; "Exit Rates" – annual exit rate of networks by type; "Debit Adoption Rate" – annual debit adoption rate by ATM-only networks; "Network Size" – cards in circulation or ATM transaction volumes per network; "Network Size Ratio" – average size of an ATM-debit network over that of an ATM-only network; "Market Shares of Cards" – the fraction of each type of cards over all cards in circulation.

Figure 4: Empirical Facts of ATM Industry Evolution

Figures 4A-4F present additional facts of the industry evolution:

- Figure 4A shows a short entry wave following the debit innovation and banking deregulation, but the entry essentially stopped after 1987 (with only one exception in 1996).

- Figure 4B shows similar annual exit rates for different networks over time, with the ATM-only networks' exit rate being more volatile than the ATM-debit networks.

- Figure 4C shows the annual debit adoption rate by ATM-only networks. The adoption rate stayed positive until 1994 but fell to zero afterward.

- Figure 4D plots the average network size by type (measured either by cards in circulation or ATM transaction volumes per network). The ATM-debit networks saw a dramatic size increase over time, which suggests rapid technological progress. In contrast, the size of ATM-only networks remained relatively stable.

- Figure 4E reports the size ratio between an average ATM-debit network and an average ATM-only network based on either cards in circulation or ATM transaction volumes. The two measures show similar rising ratios over time.[12]

- Figure 4F plots the market shares of ATM-debit cards and ATM-only cards in terms of cards in circulation. The share of ATM-debit cards increased sharply and exceeded 95 percent after the mid-1990s.

III. Theory

In this section, we construct an industry evolution model in the context of ATM and debit card services, in which forward-looking networks make optimal decisions on entry, exit, firm size, and product offerings in a competitive market. We then study how the industry evolution responds to the shocks of debit innovation and deregulation. Appendix A provides an illustration of the timeline of the model.

A. Model Basics

The model is cast in discrete time and infinite horizon. The environment is a competitive market for ATM and debit card services. Two generations of cards appear in the market subsequently. The first one is ATM-only cards, which cardholders can use exclusively at ATMs. The second generation is new ATM-debit cards, which cardholders can use not only at ATMs, but also to pay at the point of sale.

[12] In the data, some banks belong to multiple networks. This raises a concern of double counting when we measure networks' sizes based on their numbers of cards in circulation. To address this issue, we collect data on each network's ATM transactions. As shown in Figures 4D-4E, the two network size measures deliver largely consistent patterns.

On the supply side, card services are provided by networks. During the first generation of cards, there are ATM-only networks in the market, denoted as a. After the debit innovation arrives, ATM-debit networks emerge, denoted as d. Each network charges a fee P^i per card according to the network type $i = \{a, d\}$ and incurs a sunk cost as well as variable costs to operate.[13]

On the demand side, consumers use card services provided by a network through their banks. To offer card services to its customers, a bank needs to participate in a network and pays a fee P^i per card to the network. When banks decide which network to join, they consider the quality of the card services provided by networks. Naturally, an ATM-debit card is more beneficial to the cardholder than an ATM-only card because of the additional debit function. Let ω^i denote the quality of card services, and we assume $\omega^d > \omega^a > 0$.

For a bank, offering ATM or ATM-debit services raises its customers' willingness to pay for banking services and increases its revenue per customer by $\omega^i\theta$. Here θ is a bank-specific factor, which reflects its customers' preference for card services. We assume θ is distributed across banks according to a cumulative distribution function G, independent with bank size.[14] For each bank, the net revenue per card is expressed as

$$R(\theta; \omega^i, P^i) = \omega^i\theta - P^i, \qquad i = \{a, d\}. \tag{1}$$

B. Emergence of ATM Networks

The market starts at time 0 when the ATM service becomes available. Given the historical context, we consider the banking industry under regulations that result in a restricted average bank size z_0. There is also legal ambiguity on whether ATMs are subject to branching restrictions so that ATM networks, if growing above certain size $\overline{q}$, could be challenged by regulators or courts. However, given that ATM networks were small at the time, we assume that the size restriction is barely binding.

[13]Note that assuming networks charge per transaction fees instead of per card fees would not affect our analysis if the number of card transactions is closely related to the number of cards.

[14]The independence assumption is made for simplicity, which serves as a good benchmark. If we instead consider the distribution of θ being correlated with bank size, we then need to model a joint distribution of θ and bank size, which can be arbitrary and cumbersome but does not affect the intuition of our analysis.

Potential network entrants, denoted by ϕ, are of an infinite measure. Each period, a potential entrant may choose to enter the market or take an outside option for a payoff π^{ϕ}.[15] A new entrant pays a sunk cost K to set up an ATM network, which takes one period to start operation.[16] An existing network, however, may receive an exogenous exit shock each period with a probability γ and exit at the end of the period. Exiting does not incur additional costs, but the initial sunk cost cannot be recovered.

An ATM network a earns a profit π_t^a at time t, which depends on price P_t^a and cost $C(q_t^a; z_t)$, i.e., $\pi_t^a = \max_{q_t^a}\{P_t^a q_t^a - C(q_t^a; z_t)\}$. Here, C is a convex cost function in q_t^a, the network's output measured by cards in circulation. Conditional on q_t^a, C decreases in z_t, the average bank size in terms of customers per bank. The idea is that a network's costs would be lower if it could serve the same number of card users through fewer banks.

For simplicity, we assume the chance of future innovations or market changes is too small to affect a network's decision.[17] Hence, at each time $t \geq 0$, we have the following value functions:

$$U_t^{\phi} = \pi^{\phi} + \max\{\beta U_{t+1}^{\phi}, \beta U_{t+1}^{a} - K\}, \tag{2}$$

$$U_t^{a} = \max\{\pi^{\phi} + \beta U_{t+1}^{\phi}, \pi_t^a + \gamma\beta U_{t+1}^{\phi} + (1-\gamma)\beta U_{t+1}^{a}\}, \tag{3}$$

where U_t^{ϕ} and U_t^a are the value of a potential entrant ϕ and an ATM network a at time t, respectively, and β is the discount factor.

Given a restricted average bank size $z_t = z_0$, the industry has a steady state. Due to free entry, there exists a price P^{a^*} at which potential network entrants are indifferent between entering the industry and staying outside, so that Eq (2) implies that

$$U^{\phi} = \frac{\pi^{\phi}}{1-\beta} = U^a - \frac{K}{\beta}. \tag{4}$$

Also, an incumbent network would strictly prefer staying in the industry because of the

[15] We can interpret π^{ϕ} as the foregone income of the network owner/manager for participating in the industry. For instance, it may equal the income he or she could have earned in the banking or other comparable financial service sectors.

[16] This assumption follows the convention of the literature (e.g., Jovanovic and MacDonald, 1994), which is motivated by the empirical evidence of "time-to-build" found in many industries (Koeva, 2000).

[17] We will relax this assumption and consider anticipated shocks in Section VI.

sunk cost paid. Accordingly, Eq (3) implies that

$$U^a = \pi^a + \gamma\beta U^\phi + (1-\gamma)\beta U^a. \tag{5}$$

Using (4) and (5), we can solve explicitly for U^a:

$$U^a = \frac{\pi^a - \gamma K}{1-\beta}. \tag{6}$$

Equations (4) and (6) then imply that

$$\pi^a(P^{a^*}; z_0) = \pi^\phi + (\gamma + \frac{1-\beta}{\beta})K, \tag{7}$$

which pins down the industry price P^{a^*}. Because $(\gamma + \frac{1-\beta}{\beta})K > 0$, Eq (7) suggests that $\pi^a(P^{a^*}; z_0) > \pi^\phi$.

On the demand side, banks choose whether to participate in an ATM network. At equilibrium, banks with a high value of θ ($\theta \geq \frac{P^{a^*}}{\omega^a}$) would do so because

$$\omega^a\theta - P^{a^*} \geq 0 \Longrightarrow \theta \geq \frac{P^{a^*}}{\omega^a}.$$

In contrast, banks with a low value of θ ($\theta < \frac{P^{a^*}}{\omega^a}$) would forgo card services. Therefore, given that the distribution of θ is independent with bank size, the total market demand for ATM cards is $1 - G(\frac{P^{a^*}}{\omega^a})$.

The market demand equals supply at the equilibrium. Hence,

$$1 - G(\frac{P^{a^*}}{\omega^a}) = N^a q^a(P^{a^*}; z_0), \tag{8}$$

where N^a is the number of ATM networks, and $q^a(P^{a^*}; z_0)$ is output per network. Under the assumption that networks barely met the size restriction at the time, we will later use $\overline{q} = q^a(P^{a^*}; z_0)$ to infer the potential network size restriction in our counterfactual analysis.

Equations (7) and (8) describe a simple industry equilibrium path: at time 0, N^a entrants choose to invest in the ATM technology and it takes one period to build the network. Thereafter, for any time $t \geq 1$, there are N^a networks operating in the market each having $q^a(P^{a^*}; z_0)$ cards in circulation, and the flows of network entry and exit balance out (i.e., at the end of each period, γN^a networks exit and get replaced by the same number of new entrants at the beginning of the next period). As a result, the total card supply $q^a(P^{a^*}; z_0)N^a$ equates the demand $1 - G(\frac{P^{a^*}}{\omega^a})$ in each period.

C. Twin Shocks: Debit Innovation and Banking Deregulation

At time T, the debit innovation and banking deregulation arrive as unexpected shocks. Because of the debit innovation, networks now have a chance to offer a superior product, the ATM-debit card d. To adopt the innovation, an ATM-only network needs to make a risky investment I_t^r for learning the new technology and recruiting merchants to accept its cards. We assume that the investment may succeed with probability λ or the network may fail and will have to try next period.[18] Once it succeeds, the network then pays a fixed cost I_t^{nr} to implement the new technology, which takes one period to start operation. Potential entrants may also enter, but they need to first build an ATM-only network before they can try adopting the debit innovation in subsequent periods.[19]

For an ATM-debit network, the profit π_t^d depends on the price P_t^d and cost $g_t C(q_t^d, z_t)$, i.e., $\pi_t^d = \max_{q_t^d}\{P_t^d q_t^d - g_t C(q_t^d, z_t)\}$, where C stands for the same cost function for ATM-only networks and g_t is a cost-efficiency measure specific to ATM-debit. Because an ATM-debit card provides a better service than an ATM-only card (i.e., $\omega^d > \omega^a$), it charges a higher price at the equilibrium (i.e., $P_t^d > P_t^a$).[20] ATM-debit networks also enjoy an increasing cost efficiency, so $\partial g_t / \partial t < 0$.[21] The costs of adopting debit innovation I_t^r and I_t^{nr} increase over time, reflecting that as the technology gap between debit adopters and nonadopters widens, it becomes increasingly costly to adopt the

[18] The "failure" captures the uncertainties involved in adopting the debit innovation. For example, industry evidence shows that it was not easy for networks to recruit merchants to accept debit cards due to the conflicts between merchants and banks over payment of transaction fees and the cost of POS terminals, and by the existence of multiple technical standards (Hayashi, Sullivan, and Weiner, 2003).

[19] The data show that almost all the new entrants entered as ATM-only networks.

[20] Note that if a low-quality card charges a higher price, it would have no demand.

[21] There are several sources of the increasing cost efficiency of ATM-debit networks. For instance, providing debit services allows networks to learn about their customers' shopping patterns so that they can better allocate the ATM machines and services. Moreover, providing debit services allows networks to bring another user group, the merchants, on board. Over time, the increasing merchant sponsorship for debit services (e.g., merchant fees) helps offset the network costs. Finally, the debit service itself enjoys rapid technological progress in terms of falling operational costs and fraud rates.

innovation.[22]

Meanwhile, banking deregulation results in an increasing average bank size z_t over time, which benefits both ATM-only and ATM-debit networks by reducing their card service costs. Moreover, because of the Supreme Court decision, networks are freed from the potential size restriction $\overline{q}$.

Therefore, upon the arrival of the debit innovation and banking deregulation, networks reconsider their entry, exit, and product offerings. At each time $t \geq T$, we have the following value functions for networks by type:

$$\begin{aligned} V_t^{\phi} &= \pi^{\phi} + \max\{\beta V_{t+1}^{\phi}, \beta V_{t+1}^{a} - K\}, & (9) \\ V_t^{a} &= \max\{\pi^{\phi} + \beta V_{t+1}^{\phi}, \pi_t^{a} + \gamma \beta V_{t+1}^{\phi} + (1-\gamma)\max[\beta V_{t+1}^{a}, & (10) \\ & \quad \lambda(\beta V_{t+1}^{d} - I_t^{nr}) + (1-\lambda)\beta V_{t+1}^{a} - I_t^{r}]\}, \\ V_t^{d} &= \max\{\pi^{\phi} + \beta V_{t+1}^{\phi}, \pi_t^{d} + \gamma \beta V_{t+1}^{\phi} + (1-\gamma)\beta V_{t+1}^{d}\}. & (11) \end{aligned}$$

Equations (9)-(11) say the following. In (9), at each time $t \geq T$, a potential entrant ϕ may choose whether or not to enter as an ATM-only network (with the option of adopting the debit innovation later). In (10), an incumbent ATM-only network a has following options: at the beginning of each period, it may decide whether to voluntarily exit the industry. If it chooses to stay, it can earn a profit π_t^a, but there is a chance γ that the network will receive an exogenous exit shock and exit at the end of the period. If it survives the exogenous shock, it will then plan for the next period by choosing to either stay as it is or try adopting the debit innovation at a success rate λ. Equation (11) has the analogous interpretation for an ATM-debit network d.

D. Post-Shock Industry Dynamics: Characterization

We denote the mass of the two types of active networks at time t to be $n_t \equiv (n_t^a, n_t^d)$ and characterize the post-shock industry dynamics. Note that networks' entry and adoption decisions depend on the tradeoff between investment costs and future profits,

[22] The increasing adoption costs I_t^r and I_t^{nr} reflect the increasing difficulties for a new debit entrant to recruit merchants and the higher sunk costs associated with larger entry size of ATM-debit networks over time. They help explain why ATM-only networks eventually stopped adopting the debit innovation.

so the industry evolution pattern could vary by model parameter values.[23] Our analysis will focus on the evolution patterns that are most empirically relevant, and we will show our model calibration matches the data well.

At time T, provided that the entry cost K can be justified by future profits, a number N^{ϕ} of new entrants enter as ATM-only networks. As suggested by Eq (9), a positive entry requires

$$\beta V_{T+1}^{\phi} = \beta V_{T+1}^{a} - K \Longrightarrow V_{T+1}^{a} = \frac{\pi^{\phi}}{1-\beta} + \frac{K}{\beta}. \tag{12}$$

Meanwhile, all existing ATM-only networks (except the fraction γ that receive an exogenous exit shock) attempt to adopt the debit innovation if that is profitable. We define the value of adopting debit to be $\Psi_t \equiv \lambda(\beta V_{t+1}^{d} - I_t^{nr}) + (1-\lambda)\beta V_{t+1}^{a} - I_t^{r} - \beta V_{t+1}^{a}$ as suggested by Eq (10). Therefore, networks will attempt to adopt if the following condition holds at time T that

$$\Psi_t > 0 \Longrightarrow V_{t+1}^{d} > V_{t+1}^{a} + \frac{I_t}{\lambda\beta}, \tag{13}$$

where we define $I_t = I_t^{r} + \lambda I_t^{nr}$ as networks' expected costs of debit adoption. Since it takes one period for the adoption to take effect and all exogenous exits occur at the end of the period, there is no change in price and output in this period.

At time $T+1$, N^{ϕ} new ATM-only networks appear in the market. There are also $(1-\gamma)N^{a}$ incumbent ATM-only networks that survive the exogenous exit shock last period, of which a fraction λ succeed in adopting the debit innovation. From then on, as long as the value of Ψ_t stays positive (i.e., $V_{t+1}^{d} > V_{t+1}^{a} + \frac{I_t}{\lambda\beta}$), incumbent ATM-only networks will continue to try adopting the debit innovation. However, provided that the adoption cost I_t increases sufficiently fast over time, Ψ_t decreases in t.

Meanwhile, despite a fraction γ of networks exogenously exiting every period, we assume that the increasing supply of ATM-debit cards through network conversion (i.e., an increasing n_t^{d}) and cost reduction (i.e., an increasing z_t and a decreasing g_t) is large enough to continue pushing down the prices P_t^{a} and P_t^{d}, so an increasing number of consumers use ATM and/or debit services. Also, as Ψ_t and P_t^{a} fall over time, the value

[23] For example, paths with no entry are possible (e.g., when the technological progress associated with the debit innovation is too slow or the investment costs are too high). In the counterfactual analyses in Section V, we show how the number of entrants is affected by model environment and parameters.

of V_t^a declines despite cost reduction via an increasing z_t. As a result, there would be no further entry from outside the industry after time $T+1$.

At time T', the value of adopting debit Ψ_t falls below zero so that ATM-only networks no longer find it profitable to try adopting the debit innovation. Hence, for the time period $T+1 \leq t \leq T'-1$, the number of each type of networks is given by the following equations

$$n_t^a = [(1-\gamma)(1-\lambda)]^{t-T-1}[N^\phi + N^a(1-\gamma)(1-\lambda)], \tag{14}$$

$$n_t^d = (1-\gamma)^{t-T-1}[N^\phi + N^a(1-\gamma)] - n_t^a. \tag{15}$$

However, from time T' and afterward, the supply of cards continues to increase due to cost reduction (due to an increasing z_t and/or a decreasing g_t) and drives down the card prices P_t^a and P_t^d. Eventually, ATM-only networks may choose to exit voluntarily, but the exit pattern could vary by parameter values.

Consider that at some point $t > T'$, the cost reduction due to an increasing z_t vanishes as the average bank size eventually reaches a new steady state $\bar{z}$. Thereafter, the price of ATM-only cards continues to decline because the increasing supply of ATM-debit cards due to the decreasing g_t. P_t^a eventually reaches a critical value $\bar{P}^a$ at time T'', for which $\pi^a(\bar{P}^a; \bar{z}) = \pi^\phi$, so some ATM-only networks become indifferent between staying and exiting the market.

Note that for $T' \leq t \leq T'' - 1$, the number of each type of networks is

$$n_t^a = (1-\gamma)^{t-T'+1} n_{T'-1}^a, \tag{16}$$

$$n_t^d = (1-\gamma)^{t-T'+1} n_{T'-1}^d, \tag{17}$$

where $n_{T'-1}^a$ and $n_{T'-1}^d$ are given by Eqs (14) and (15). During the time period $T+1 \leq t \leq T'' - 1$, market demand meets the supply for the ATM-debit cards:

$$1 - G\left(\frac{P_t^d - P_t^a}{\omega^d - \omega^a}\right) = n_t^d q_t^d(P_t^d; z_t), \tag{18}$$

and for the ATM-only cards:

$$G(\frac{P_t^d - P_t^a}{\omega^d - \omega^a}) - G(\frac{P_t^a}{\omega^a}) = n_t^a q^a(P_t^a; z_t). \tag{19}$$

From time T'' and afterward, some (but not all) ATM-only networks may exit voluntarily. As long as there are voluntary exits of ATM-only networks, the industry equilibrium requires that $P_t^a = \bar{P}^a$ and

$$1 - G(\frac{P_t^d - \bar{P}^a}{\omega^d - \omega^a}) = n_t^d q_t^d(P_t^d; \bar{z}), \tag{20}$$

$$1 - G(\frac{\bar{P}^a}{\omega^a}) = n_t^d q_t^d(P_t^d; \bar{z}) + n_t^a q^a(\bar{P}^a; \bar{z}),$$

where

$$n_t^d = (1-\gamma)^{t-T''+1} n_{T''-1}^d. \tag{21}$$

This yields that

$$n_t^a = \frac{1 - G(\frac{\bar{P}^a}{\omega^a}) - n_t^d q_t^d(P_t^d; \bar{z})}{q^a(\bar{P}^a; \bar{z})}. \tag{22}$$

Hence, the number of ATM-only networks that voluntarily exit in each period is

$$x_t^a = (1-\gamma) n_{t-1}^a - n_t^a.$$

There could also exist another scenario. Consider that, for certain parameter values, we obtain $n_t^a < 0$ from Eq (22) at time T''. In this case, all the ATM-only networks have to exit at T'', and the only cards remaining in circulation would be the ATM-debit ones. If the price $P_{T''}^d$, determined by

$$1 - G(\frac{P_{T''}^d}{\omega^d}) = n_{T''}^d q_{T''}^d(P_{T''}^d; \bar{z}), \tag{23}$$

yields a profit $\pi_{T''}^d(P_{T''}^d; \bar{z}) > \pi^\phi$, then no ATM-debit network would exit voluntarily. Thereafter, while a fraction γ of remaining ATM-debit networks exit each period exogenously, no ATM-debit network would want to voluntarily exit. In fact, given the card demand implied by the distribution G is price elastic (as considered in our calibration), an improving technology (due to the decreasing g_t) together with the falling network numbers (due to the exit rate γ) will always raise network profit π_t^d. Therefore, $\pi_t^d > \pi^\phi$ for any $t > T''$, so no ATM-debit network will voluntarily exit.

More generally, for some other parameter values we may obtain $n_t^a > 0$ for T'' from (22) but $n_t^a < 0$ for some $t > T''$, a similar analysis can apply.

IV. Model Calibration

Our theory characterizes the process by which the twin shocks, debit innovation and banking deregulation, drove the evolution of the ATM and debit card industry. In this section, we calibrate the model to the dataset introduced in Section II and show that our theory matches the quantitative pattern of the industry well.

A. Parameterization

For the model calibration, we first specify the convex cost function for an ATM-only network to be

$$C(q_t^a; z_t) = c_0 \left(q_t^a\right)^{c_1} z_t^{c_2} \quad \text{where } c_0 > 0,\ c_1 > 1 \text{ and } c_2 < 0.$$

The corresponding profit function is

$$\pi_t^a(P_t^a; z_t) = (c_1 - 1) c_1^{\frac{c_1}{1-c_1}} (c_0 z_t^{c_2})^{\frac{1}{1-c_1}} (P_t^a)^{\frac{c_1}{c_1-1}},$$

and the output function is

$$q_t^a(P_t^a; z_t) = \left(\frac{P_t^a}{c_0 z_t^{c_2} c_1}\right)^{\frac{1}{c_1-1}}.$$

Similarly, we specify the cost function for an ATM-debit network to be $g_t c_0 \left(q_t^d\right)^{c_1} z_t^{c_2}$, so the profit function is

$$\pi_t^d(P_t^d; z_t) = (g_t)^{\frac{1}{1-c_1}} (c_1 - 1) c_1^{\frac{c_1}{1-c_1}} (c_0 z_t^{c_2})^{\frac{1}{1-c_1}} \left(P_t^d\right)^{\frac{c_1}{c_1-1}},$$

and the output function is

$$q_t^d(P_t^d; z_t) = (g_t)^{\frac{1}{1-c_1}} \left(\frac{P_t^d}{c_0 z_t^{c_2} c_1} \right)^{\frac{1}{c_1-1}}.$$

On the demand side, we assume that the heterogeneity of banks θ follows a Pareto distribution

$$G(\theta) = 1 - d_0 \theta^{-d_1} \quad \text{where } d_0 > 0 \text{ and } d_1 > 1. \tag{24}$$

Accordingly, when there is only one type of cards in the market (e.g., before debit function is introduced or after the ATM-only networks have all exited), the demand for card services has a constant elasticity

$$Q_t^i = d_0 \left(\frac{P_t^i}{\omega^i} \right)^{-d_1}, \quad i = \{a, d\}.$$

Or, when both types of cards are in the market, the demand for ATM-debit cards is

$$Q_t^d = d_0 \left(\frac{P_t^d - P_t^a}{\omega^d - \omega^a} \right)^{-d_1}, \tag{25}$$

and the demand for ATM-only cards is

$$Q_t^a = d_0 \left(\frac{P_t^a}{\omega^a} \right)^{-d_1} - d_0 \left(\frac{P_t^d - P_t^a}{\omega^d - \omega^a} \right)^{-d_1}. \tag{26}$$

Eqs (25) and (26) show that ATM-debit and ATM-only cards are substitute goods, so their demands depend on each other's prices.

Given the parameterization, the equilibrium path for the model industry is obtained as follows. Prior to the twin shocks, the industry steady state (P^{a^*}, N^a) is determined by two equations:

$$N^a \left(\frac{P^{a^*}}{c_0 z_0^{c_2} c_1} \right)^{\frac{1}{c_1-1}} = d_0 \left(\frac{P^{a^*}}{\omega^a} \right)^{-d_1},$$

$$\text{and} \quad \pi^\phi = (c_1 - 1) c_1^{\frac{c_1}{1-c_1}} (c_0 z_0^{c_2})^{\frac{1}{1-c_1}} \left(P^{a^*} \right)^{\frac{c_1}{c_1-1}} - (\gamma + \frac{1-\beta}{\beta}) K,$$

where the first one requires that supply equates demand, and the second one reflects the free entry of networks.

After the twin shocks arrive, industry players then reconsider their entry, exit, and product decisions by taking into account the debit adoption success rate λ, the changing average bank size

$$z_t = z_0(1+z_1)^{t-T}, \text{ where } z_0 > 0,\ z_1 > 0,$$

the debit adoption cost

$$I_t = I_0(1+I_1)^{t-T}, \quad \text{where } I_0 > 0,\ I_1 > 0,$$

and the debit technological progress

$$g_t = g_0(1-g_1)^{t-T}, \qquad \text{where } 0 < g_0,\ 0 < g_1 < 1.$$

In the calibration exercise, we normalize $z_0 = 1$ and assume that the average bank size increases at 3 percent annually (i.e., $z_1 = 0.03$) for 25 years before reaching the new steady state.[24] This is consistent with the fact that the annual growth rate of transaction deposits per bank post deregulation (1983-2005) was 3 percent higher compared with the pre-deregulation era (1970-1983), and the trend started to return in the 2000s.[25] To ensure a stationary equilibrium, we also assume that g_t and I_t reach constant levels and γ goes to zero after t gets sufficiently large.[26]

The model equilibrium can be solved using backward induction to pin down the number of entrants N^ϕ at time T, the final time of debit adoption T', the time T'' when the voluntary exit starts, and the time paths of other endogenous variables, including prices (P_t^a, P_t^d), outputs per network (q_t^a, q_t^d), profits per network (π_t^a, π_t^d), network numbers (n_t^a, n_t^d), value functions (V_t^a, V_t^d), and voluntary exits x_t^a. Appendix B provides technical details of the numerical solution to the model.

[24] In our model context, this implies that the average bank size (in terms of customers per bank) would double and the number of banks would fall by half in 25 years after deregulation, which is consistent with the empirical change of bank numbers between mid-1980s and late 2000s (cf. Figure 2B).

[25] Because ATM/debit usage is tied to transaction deposits, transaction deposits per bank is a natural measure of average bank size in our context. A similar pattern is found by Janicki and Prescott (2006), who compare bank size changes from 1960-2005 using various measures, including assets, deposits, and loans. They conclude that "It appears that the 1960s and 1970s were relatively stationary periods, but the 1980s and 1990s were a long transition period, no doubt due to the legal, regulatory, and technological changes of the period. Finally, the 2000–2005 period appears to be the end of the transition, as the size dynamics seem to be returning slowly to the numbers of the 1960s and 1970s."

[26] In the calibration, we assume g_t and I_t reach constant levels and γ goes to zero after 120 periods.

B. Parameter Values and Model Fit

Given the above calibration setup, we choose parameter values to fit the data. Based on the data, we consider that the twin shocks arrived in 1983 and debit technology was first used in production in 1984. We then calibrate the model to match the following data moments. Parameter values used for the calibration are reported in Table 1.

- Pre-shock steady state in 1983: (1) the number of networks, and (2) the number of cards in circulation per network.[27]
- Post-shock equilibrium path since 1984: (1) the numbers of ATM-only networks and ATM-debit networks each year, (2) the number of new entrants each year, (3) network debit adoption rate each year, and (4) the output of an ATM-only network and that of an ATM-debit network each year.

Table 1. Parameter Values for Model Calibration

Parameter Definition		Value	Parameter Definition		Value
Constant in cost function	c_0	4	Constant in demand function	d_0	570
Cost elasticity to cards in circulation	c_1	2	Demand elasticity	d_1	1.5
Cost elasticity to average bank size	c_2	-2	Quality of ATM-only cards	ω^a	1
Debit cost efficiency (initial level)	g_0	0.75	Quality of ATM-debit cards	ω^d	1.5
Debit cost efficiency (growth rate)	g_1	0.115	Average bank size (initial level)	z_0	1
Debit adoption cost (initial level)	I_0	4.77	Average bank size (growth rate)	z_1	0.03
Debit adoption cost (growth rate)	I_1	0.12	Exogenous network exit rate	γ	0.08
Sunk cost of network entry	K	8	Debit adoption success rate	λ	0.07
Outside option	π^ϕ	0.1	Discount factor	β	0.95

Our calibrated model fits the data very well. Basically, we assume that the networks have a quadratic cost function and face elastic industry demands. We also assume that networks have an exogenous annual exit rate of 8 percent. With the parameter values

[27] While we do not have direct observations, we derive the network numbers in 1983 using the network numbers and new entrants in 1984 together with the network exit rate in 1983 (i.e., $\gamma = 0.08$). Also, we estimate the number of cards per network in 1983 based on the average size of the ATM-only network in 1984.

we choose, our model calibration matches the pre-shock steady state in 1983: there were 118 networks in the industry and each network had a half million cards in circulation. The latter will also be used to proxy for the size restriction $\overline{q}$ that networks might face if there were no ATM deregulation in our counterfactual exercises.

We then introduce the twin shocks. The debit innovation creates a superior product (i.e., $\omega^d > \omega^a$). It also generates continuing technological progress for ATM-debit networks (i.e., a decreasing g_t), but the adoption is random (i.e., $1 > \lambda > 0$) and becomes increasingly costly over time (i.e., an increasing I_t). At the same time, the banking deregulation increases the average bank size (i.e., an increasing z_t), which reduces the costs for all networks. Moreover, as a part of banking deregulation, a potential size restriction on networks, $\overline{q}$, is removed.

Figures 5A-5F compare our calibrated results with the data for the post-1984 era, which show a good match.

1. Our model fits well with the total number of networks over time. Also, the calibrated number of ATM-only networks declines monotonically, while the number of ATM-debit networks initially rises before it later falls.

2. A short wave of entry occurs right after the shocks. Specifically, our calibrated model generates 22 new entrants in 1984, which equals the total number of new entrants that occurred after the shocks in the data.

3. The calibrated sample period 1984-2006 falls into the time range $t < T''$, so the model has an exogenous network exit rate of 8 percent, which matches the average of the data.[28]

4. Our calibration endogenously determines an 11-year window of debit adoption ending in 1994, the same as the data. The model's annual debit adoption rate before 1994 is 7 percent, which matches the average of the data.

5. Our calibration generates a rising output ratio over time between an ATM-debit network and an ATM-only network. The magnitude is consistent with those in the data measured either by cards in circulation or ATM transaction volumes.

[28] Our baseline calibration yields $T'' = T + 91$, and all remaining ATM-only networks exit at T''.

6. The evolution of market shares of different cards generated by our calibration closely matches those of the data.

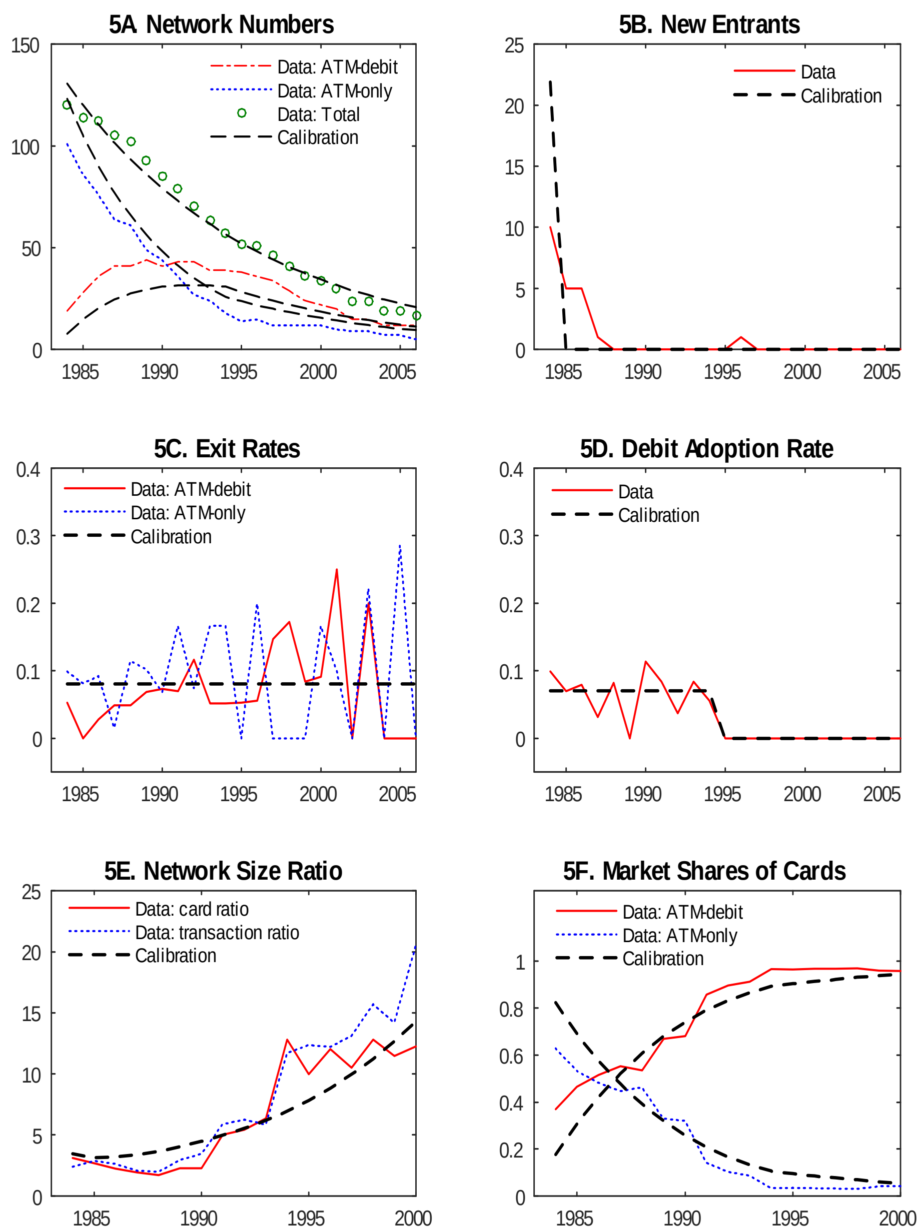


Figure 5. Model Fit — Baseline Calibration

Our calibrated model also delivers useful results for the untargeted moments, such as prices, profits, and value functions. Although we do not have data for those, the calibration results confirm the predictions of our theory in Section III. We show in Figures 6 that along the equilibrium time path, both prices of ATM-only and ATM-debit cards decrease.[29] As a result, the profit of an ATM-only network falls, but the profit of an ATM-debit network rises because technological progress dominates the price decline. Also, the calibration verifies that after the arrival of shocks, the value of an ATM-debit network increases over time, but that of an ATM-only network decreases. The latter explains why entry can only occur for one period right after the twin shocks.

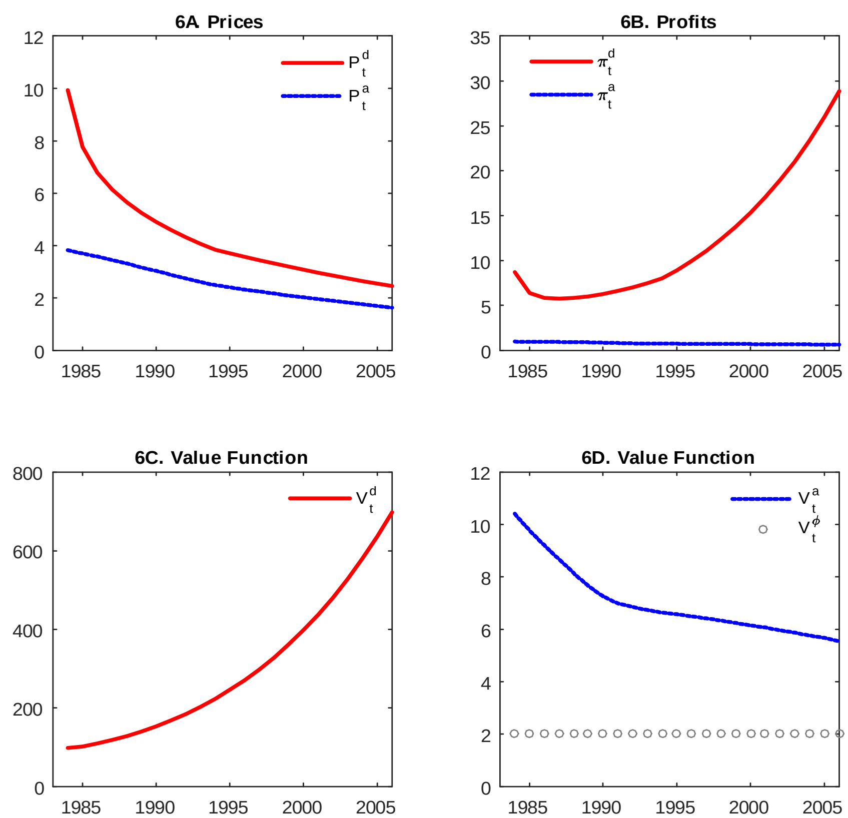


Figure 6. Model Fit — Baseline Calibration (continued)

[29] The decline in prices is in line with observations from other industries. Winston (1998) surveys studies of a variety of service industries that experienced deregulation from 1970s to 1990s. The results show that after more than 20 years since deregulation, each industry had "reduced its real average prices from 30 to 75 percent."

V. Counterfactual Analysis

Our model considers the joint effects of debit innovation and banking deregulation on the ATM industry evolution. In this section, we evaluate the roles that innovation and deregulation each played by conducting counterfactual exercises. In each exercise, we shut off one factor of interest at a time and re-simulate the model. The difference between the counterfactual simulation and the baseline model is then used to measure the impact of that factor.

A. The Role of Debit Innovation

In our model, technological innovation is the main driving force for the shakeout (i.e., the secular decline in network numbers). The intuition is as follows: the debit innovation introduces heterogeneity among otherwise identical ATM networks and drives down industry prices. Over time, the technological gap between debit adopters and non-adopters widens, which discourages entry and late debit adoption. The falling network numbers then result from the endogenous collapse of entry and eventually voluntary exit of nonadopters.

The role of debit innovation can be seen more clearly by a counterfactual exercise, referred to as **Case 1** hereafter, where we re-simulate the model but assume no debit innovation. In this case, deregulation is the only shock to the industry, which removes the potential size restriction $\overline{q}$ on ATM-only networks and reduces networks' costs through an increasing average bank size z_t. Along the industry evolution path, price falls, network size rises, and because card demand is elastic, the number of networks increases (rather than decreases) until z_t reaches the new steady state. Given entry being positive every period, the free entry condition requires network profit and value stay constant during the entire process. The simulation results are plotted in Figure 11 in Appendix C.

This counterfactual exercise suggests that in our model framework, deregulation alone would not cause the shakeout of network numbers if there were no debit innovation. This result hinges on the assumption of debit adoption being the only source of heterogeneity among networks. In the following Section VI B, we will provide further discussions on this.

B. The Role of Deregulation

Our model also allows us to evaluate the role played by deregulation. As we will see, while deregulation is not a primary force driving the decline in network numbers, it does add an important impact on the industry's welfare gains.

General Banking Deregulation.—We first evaluate the role played by the "general banking deregulation." We consider a scenario where there is debit innovation but no general banking deregulation even though the Supreme Court allows ATMs to be exempt from the branching restrictions. This corresponds to a counterfactual exercise, in which we re-simulate the model but set $z_t = z_0$ for any time t. We hereafter refer to this exercise as **Case 2,** and the results are plotted in Figure 7.

Compared with the baseline model, Case 2 has a much smaller number of entrants following the shocks (i.e., 3 versus 22), and entry lasts for one period as well. Along the industry evolution path, network profits are not much different than the baseline model because network profits have to satisfy the same conditions of free entry and debit adoption in both cases. However, absent the general banking deregulation, debit adoption would stop two years earlier than the baseline, and industry prices become substantially higher. This yields important welfare implications, which we will explore further in the following subsection C.

ATM-Specific Deregulation.—Similarly, we can assess the additional role played by the "ATM-specific deregulation." We consider a scenario where there is neither general banking deregulation nor the Supreme Court's decision on ATM status.[30] In this case, it would remain ambiguous whether ATMs in a shared network should be subject to branching restrictions, and the related decision would be at the discretion of bank regulators and local courts on a case-by-case basis.[31] This would create substantial

[30]Note that given that the ATM-specific deregulation is a part of the broader bank branching deregulation, it would not be meaningful to consider a case where branching restrictions are removed for banks but not for ATMs.

[31]The regulation on ATMs varied by state and by bank charter at the time. Particularly, the legal status of ATMs in shared ATM networks was ambiguous. In the *Marine Midland* case, the defendant argued that ATMs in a shared network should be exempt from the branching restrictions according to the view of the national bank regulator (the Comptroller of Currency) as well as the ruling of the District of Columbia Circuit Court on a similar case. However, the arguments were rejected by the Western District Court of New York, which ruled in favor of the plaintiffs. Later, the case was overturned by the Appeals Court of the Second Circuit.

uncertainties about whether the size of an ATM network would be restricted.

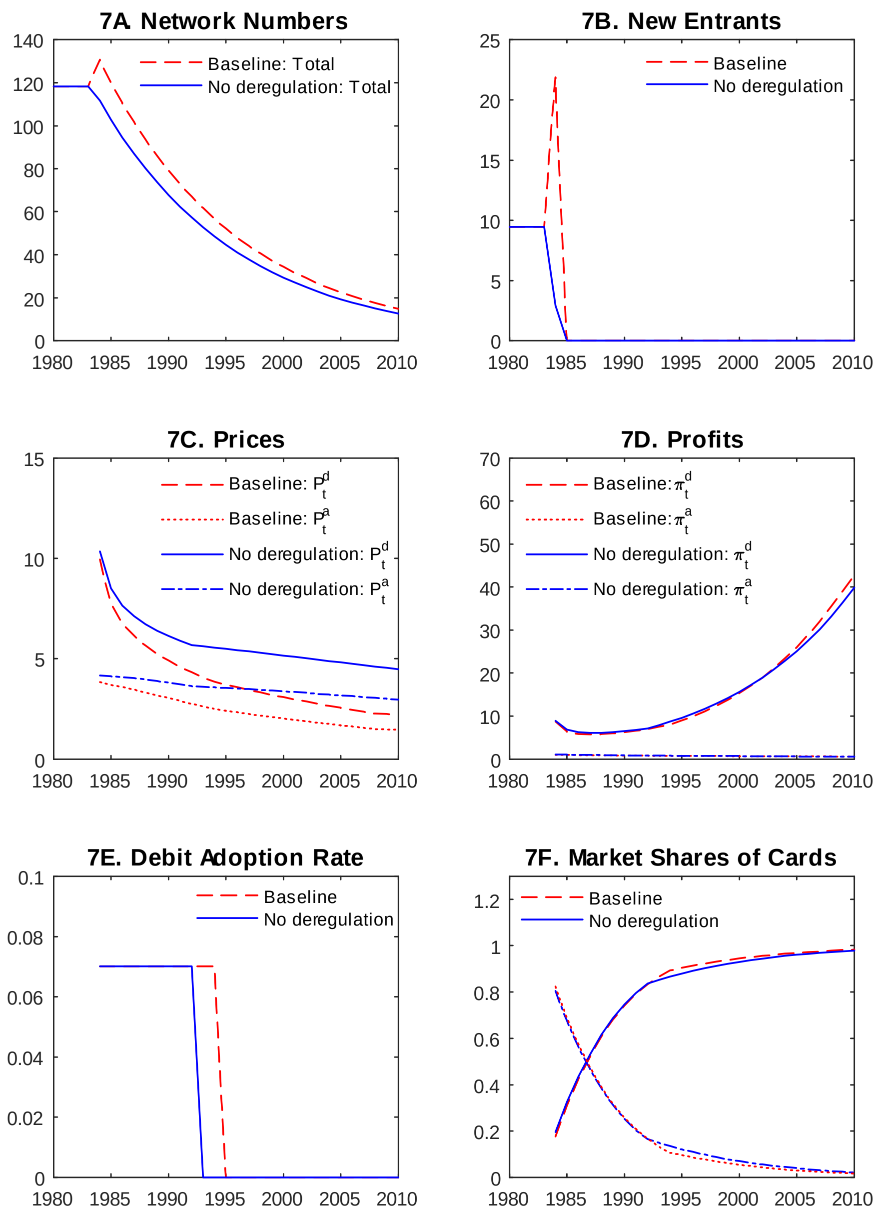


Figure 7. Counterfactual Case 2 – No General Banking Deregulation

In the counterfactual exercise, we model the ambiguity as a random size restriction: if a network expands beyond the size $\overline{q}$, with a probability α, the network will be challenged and restricted to the size $\overline{q}$; otherwise, the network is unrestricted. We proxy the value of $\overline{q}$ using the average network size prior to the shocks. Note that in this counterfactual world, the cost function of an ATM-only network is time invariant given $z_t = z_0$, so the size of an ATM-only network is declining over time as price falls and the size constraint $\overline{q}$ would not bind for them. In contrast, due to technological progress (i.e., a decreasing g_t), an ATM-debit network would have to deal with this random size restriction. Because networks make entry and debit adoption decisions before the uncertainties resolve, the industry-level outcomes are equivalent whether we model α as a one-time permanent shock or a recurrent i.i.d. shock hitting a network every period.

Figure 8 plots the results assuming $\alpha = 0.2$, and we refer to this exercise as **Case 3** hereafter. The results are similar to Case 2 above but stronger. We again have a smaller number of entrants than the baseline model, but the number is higher than Case 2 (i.e., 8 versus 3). Along the industry evolution path, the profit of an unrestricted (restricted) ATM-debit network is higher (lower) than the baseline, but if we calculate the expected profits weighted by α, the time path would not be much different from the baseline. This is again due to the fact that the expected network profits need to satisfy the same conditions of free entry and debit adoption as in the baseline model. Moreover, debit adoption stops three years earlier than the baseline and one year earlier than Case 2. The industry prices become even higher, which we will discuss further in the following welfare analysis.

We also rerun the counterfactual exercise by setting $\alpha = 0.4$ and report the results in Figure 12 in Appendix C, which we refer to as **Case 4** hereafter. As expected, the results of Case 4 are similar to Case 3 but stronger.

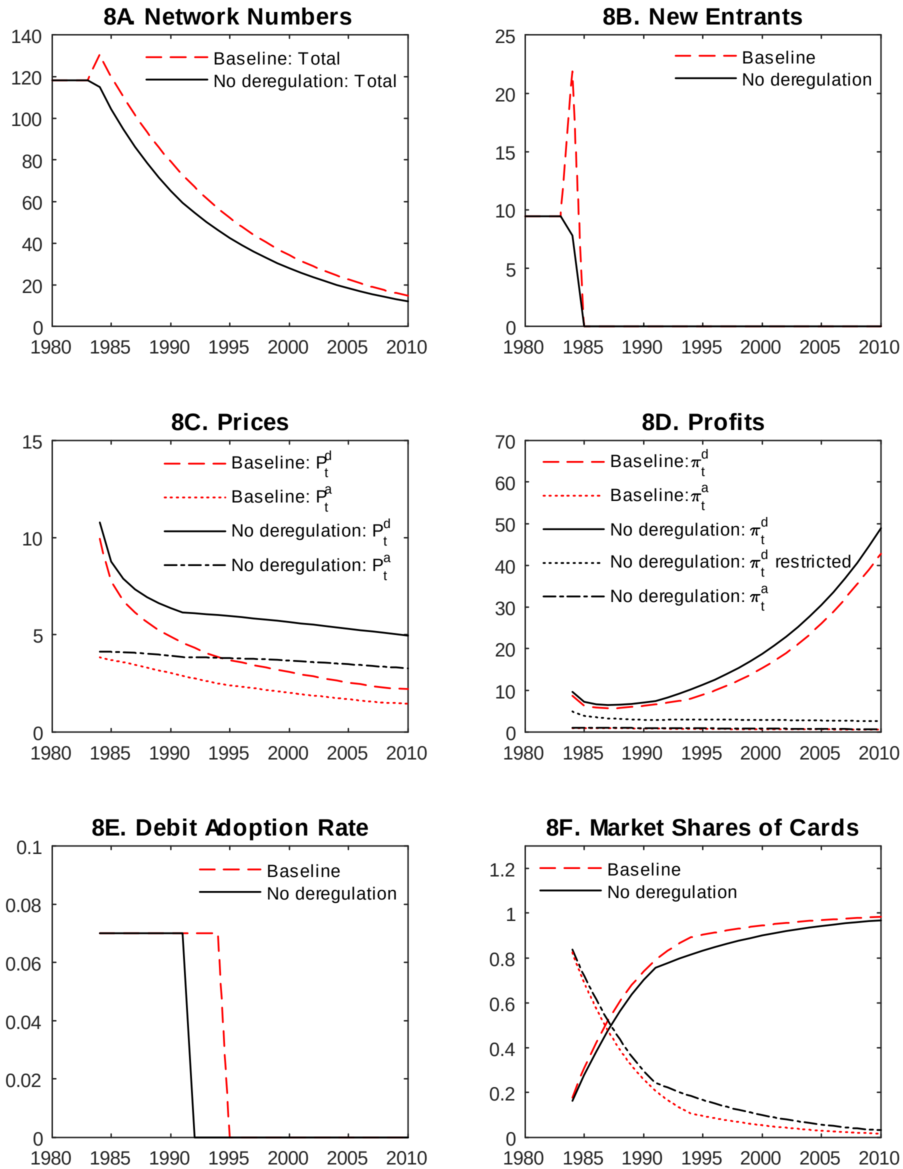


Figure 8. Counterfactual Case 3— No Banking or ATM Deregulation ($\alpha = 0.2$)

C. Innovation and Deregulation: A Welfare Comparison

Our counterfactual Cases 2-4 show that deregulation does not affect much the declining trend of total network numbers (cf. Figures 7A, 8A, and 12A), though it appears to affect the number of entrants in the short entry wave right after the shocks (cf. Figures 7B, 8B, and 12B). However, the number of networks does not directly tell industry performance in our model given that networks as a whole break even under the free entry condition. Moreover, the finding that the number of entrants varies with deregulation is driven by the market clearing condition: networks operating under regulations would require higher industry prices to break even, so the number of entrants has to balance out the reduced market demand and the constrained network size.

On the other hand, industry performance is reflected by prices and outputs, which determine social welfare. On that regard, we find that deregulation does have important positive impact, mainly through cost and price reduction. To quantify that, note that our model allows us to calculate welfare (captured by banks' net revenue gain in our model context) according to the demand specification (1), where θ follows a Pareto distribution given by (25).[32] Denote W as the total welfare generated by card services, and W^a, W^d as welfare associated with ATM-only cards and ATM-debit cards respectively. When there is only one type of cards in the market (e.g., before debit function is introduced or after the ATM-only networks have all exited), the total welfare $W_t = W_t^i$, where

$$W_t^i = \omega^i d_0 \frac{d_1}{d_1 - 1} \left(\frac{P_t^i}{\omega^i} \right)^{1-d_1} - P_t^i Q_t^i \ , \quad i = \{a, d\};$$

when there are two types of cards in the market, the total welfare $W_t = W_t^a + W_t^d$, where

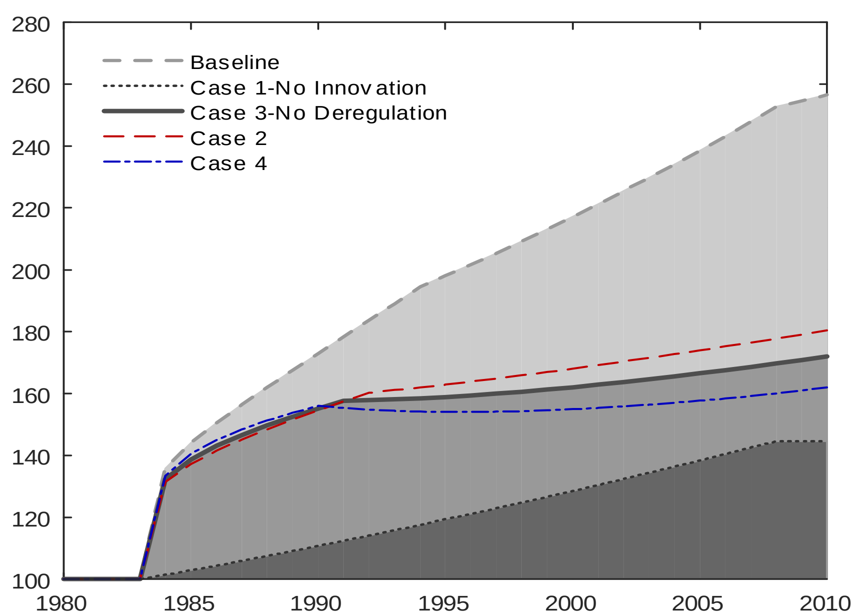
$$W_t^a = \omega^a d_0 \frac{d_1}{d_1 - 1} \left[\left(\frac{P_t^a}{\omega^a} \right)^{1-d_1} - \left(\frac{P_t^d - P_t^a}{\omega^d - \omega^a} \right)^{1-d_1} \right] - P_t^a Q_t^a$$

and

$$W_t^d = \omega^d d_0 \frac{d_1}{d_1 - 1} \left(\frac{P_t^d - P_t^a}{\omega^d - \omega^a} \right)^{1-d_1} - P_t^d Q_t^d.$$

[32] Here we assume that banks extract all the consumer surplus from card users. However, our analysis would equally hold if we instead assume that banks and card users split the total surplus so that banks' net revenue gain is a fraction of the total surplus.

Figure 9 plots the total welfare for the baseline model and for all the counterfactual Cases 1-4, with the welfare at the pre-shock steady state being normalized to 100. Take the baseline model for example. We see an immediate jump of welfare following the introduction of the new product, the ATM-debit cards. Welfare continues to increase over time as prices of card services fall, though the slope of the increase changes slightly at some turning points, for instance, when debit adoption stops after the 11th year and when the average bank size z_t reaches the new steady state at the 25th year. The similar pattern can be found in the counterfactual Cases 2, 3, and 4, though in those cases welfare is lower and debit adoption stops earlier. In contrast, the counterfactual Case 1 assumes deregulation but no debit innovation, so there is no initial jump of welfare. Instead, welfare increases gradually as deregulation reduces costs for ATM-only networks until the average bank size z_t reaches the new steady state.



Note: The welfare at the pre-shock steady state is normalized to 100. Baseline refers to the calibrated model with both deregulation and debit innovation. Case 1 refers to the counterfactual scenario with deregulation but no debit innovation. Case 2 refers to the counterfactual scenario with debit innovation but no general banking deregulation even though ATMs in a shared network are exempt from the branching restrictions. Case 3 refers to the counterfactual scenario with neither debit innovation nor deregulation, assuming α=0.2. Case 4 repeats Case 3 except assuming α=0.4.

Figure 9. Welfare Comparison

There are different ways to quantify the welfare contribution of debit innovation and deregulation. We first consider a single year 2008, the 25th year post-shocks (i.e., when z_t is assumed to reach the new steady state). Figure 9 shows that absent the twin shocks, welfare would be at the pre-shock steady state level, normalized to 100. But with the twin shock (i.e., the baseline), welfare increases to 253, two and half times higher. If there were deregulation but no debit innovation (i.e., Case 1), welfare would increase from 100 to 145; or if there were debit innovation but no deregulation (i.e., Case 3), welfare would increase from 100 to 170. Therefore, the total welfare increase is larger under the twin shocks than under two stand-alone shocks (i.e., $153 > 45+70$), which suggests important interaction effects between debit innovation and deregulation.

Taking the interaction effects into account, we compare the relative welfare contribution between debit innovation and deregulation as follows. Note that given debit innovation in place, deregulation would increase welfare by 83 (from 170 to 253). On the other hand, given deregulation in place, debit innovation would increase welfare by 108 (from 145 to 253). Therefore, the relative contribution between debit innovation and deregulation is 43 percent versus 57 percent.

Alternatively, we could redo the exercise using cumulative welfare gains for a range of years, for example, the discounted sum of welfare gains from the first year post-shocks to 25 years later. The results show that compared with the pre-shock steady state, the baseline welfare would be 1.87 times higher. In terms of relative welfare contribution, debit innovation counts for 68 percent and deregulation counts for 32 percent.

For robustness checks, we repeat the exercises above using Case 4 instead of Case 3 (that is, we assume $\alpha = 0.4$ instead of $\alpha = 0.2$). The results are similar: for the 25th year alone, debit innovation counts for 54 percent and deregulation counts for 46 percent in terms of relative welfare contribution. For the first 25 years all together, debit innovation counts for 66 percent and deregulation counts for 34 percent.[33]

[33] Considering that our model allows ATM-debit networks to enjoy technological progress beyond the first 25 years, we also do the welfare comparison at the 50th year mark post-shocks. The results are not much different. Compared with the pre-shock steady state, the baseline model has welfare tripled in the 50th year alone or doubled for the first 50 years all together. In terms of relative welfare contribution, debit innovation and deregulation count for 61 percent and 39 percent respectively for the 50th year alone or the shares become 65 percent and 35 percent for the first 50 years all together. If we use Case 4 instead of Case 3 to compute the relative welfare contribution, the shares for debit innovation and deregulation are 58 percent and 42 percent respectively for the 50th year alone, and 62 percent and 38

Figure 9 is also informative on welfare changes associated with each type of deregulation. Note that the difference between the baseline and Case 2 reflects the welfare gain due to the general banking deregulation. Evaluated at the 25th year mark, this accounts for 90 percent of the total welfare gain due to deregulation for that year (i.e., the difference between baseline and Case 3 in 2008). The additional ATM-specific deregulation (i.e., the difference between Case 2 and Case 3) counts for the other 10 percent. If we use Case 4 instead of Case 3 in the exercise, we get 80 percent and 20 percent respectively. These numbers help illustrate the working of the model, but unlike the exercises above, they do not fully reveal the relative contribution of the two types of deregulation. The reason is that in Cases 3 and 4, ATM-specific deregulation is considered in addition to (rather than instead of) the general banking deregulation, so all the interaction effects are attributed to the latter. Therefore, these estimates may be taken as upper and lower bounds for the relative welfare contribution between the general banking deregulation and the ATM-specific deregulation in our model context.

VI. Further Discussions

A. Anticipated Shocks

Our model assumes that debit innovation and banking deregulation arrived as unexpected shocks. This is mainly a simplifying assumption given that our data do not provide information to identify whether (or to what extent) the shocks were anticipated. However, it is possible to extend our analysis to incorporate anticipated shocks if data on market expectation become available. Formally, let μ denote the possibility that the shocks will arrive in any period. We can then rewrite the pre-shock value functions as

$$\begin{aligned} U_t^{\phi} &= \pi^{\phi} + \max\{\beta[\mu V_{t+1}^{\phi} + (1-\mu)U_{t+1}^{\phi}], \\ &\quad \beta[\mu V_{t+1}^{a} + (1-\mu)U_{t+1}^{a}] - K\}, \end{aligned} \tag{27}$$

$$\begin{aligned} U_t^{a} &= \max\{\pi^{\phi} + \beta[\mu V_{t+1}^{\phi} + (1-\mu)U_{t+1}^{\phi}], \\ &\quad \pi^{a} + \beta\mu[\gamma V_{t+1}^{\phi} + (1-\gamma)V_{t+1}^{a}] \\ &\quad +\beta(1-\mu)[\gamma U_{t+1}^{\phi} + (1-\gamma)U_{t+1}^{a}]\}, \end{aligned} \tag{28}$$

percent for the first 50 years all together.

where V_{t+1}^{ϕ} and V_{t+1}^{a} are post-shock value functions defined in Eqs (9) and (10).

Compared with our baseline calibration, the anticipated arrival of the shocks would increase the option value of entering as an ATM-only network. As a result, we would have a larger number of ATM networks and hence a lower price and a higher industry output in the pre-shock equilibrium. This would also lead to lower prices and higher industry outputs than the baseline along the post-shock equilibrium path since incumbents can try the debit adoption one period ahead of the new entrants. Appendix D provides the technical details for solving the pre-shock equilibrium with anticipated shocks.

B. Network Heterogeneity

In our model, networks are assumed identical if they provide the same product or service. This is a theoretical simplification, but in reality networks could be heterogenous. In fact, before the debit innovation arrived, ATM-only networks did differ in size. Then, a natural question is whether the observed network growth could have been driven by something other than debit adoption. For instance, large ATM networks may have enjoyed some other advantages (e.g., inherent efficiency) allowing them to grow faster and they happened to adopt the debit innovation on the way. If so, deregulation could have played a bigger role in driving the shakeout because it would help large networks to expand at the expense of small ones.

To address this question, we group the ATM-only networks by size in 1984. We name the networks that ranked in the top one-third in terms of cards in circulation as "large ATM-only networks," and the rest as "small ATM-only networks." We then keep track of their performance over time. Figures 10A-10D report the results.

- Figure 10A shows that "large" and "small" ATM-only networks, as long as they hadn't adopted the debit innovation, had similar exit rates in most time periods.
- Figure 10B shows that "large ATM-only networks" had a higher annual debit adoption rate than the "small" ones.
- Figures 10C-10D show that both "large" and "small" networks enjoyed faster size growth only after they had adopted the debit innovation. Otherwise, they had similar low growth rates.

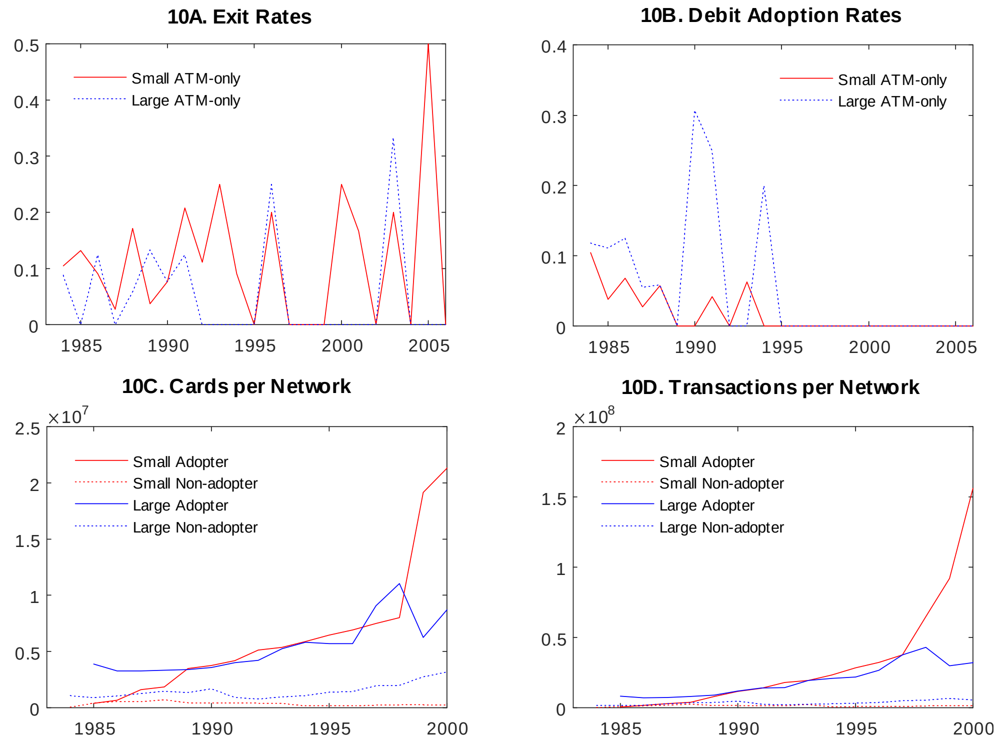


Figure 10. Network Size and Performance

These findings are informative. Figure 10B suggests the presence of some firm size advantages: large networks may perform better in terms of debit adoption. This could be explained by some possible network effects, for example, large networks might be more likely to convince merchants to accept their debit cards due to their large cardholder base and better infrastructure in place.

Figures 10C-10D suggest that debit adoption was a necessary condition for network growth. Regardless of initial size differences, networks expanded only after they had adopted debit. This lends support to our finding that debit innovation was the primary driving force for network growth and shakeout.

It is possible to extend our model to incorporate heterogenous network sizes prior to the shocks. However, given that our baseline model has explained the data quite well, the gains of making that extension might be limited compared with the greater complexity added to the analysis.

VII. Conclusion

The U.S. ATM and debit card industry is an intriguing example of the broader debate on industrial evolution. Unlike many manufacturing industries studied in the literature, this financial service industry experienced both technological innovation and deregulation over its life cycle.

In this paper, we construct a dynamic equilibrium model to study how a major product innovation (introducing the debit card function) interacted with banking deregulation and drove the industry shakeout. Calibrating the model to a novel dataset on network entry, exit, size, and product offerings shows that our theory matches the quantitative pattern of the industry well. The model also allows us to conduct counterfactual analyses to evaluate the roles that innovation and deregulation each played in the industry evolution. We find that the debit innovation was the main driving force for the decline in network numbers, but deregulation added an important impact on the industry's welfare gains.

There are several directions for future research. First, one may consider exploring the role that entry cohorts play in the industry evolution. Some studies (e.g., Klepper, 1996; Klepper and Simons, 2000) find that early entrants tend to enjoy first-mover advantages during industry evolution. On the other hand, a large literature establishes that late entrants can perform better under certain conditions.[34] While we did not detect a significant cohort effect in the ATM and debit card industry, it would be interesting to explore this further.[35]

Second, one may study different firm exit modes. Our model assumes that networks are subject to random exit risk and no scrap value would be recovered upon exit. This is a simplifying assumption. In our dataset, about 35 percent of networks exited through merger or acquisition. Presumably, some of those networks may not necessarily have

[34] For example, late entrants may enjoy advantages because they come with newer and better capital (Jovanovic and Lach, 1989; Mitchell, 2002), or because innovations are competence destroying (Tushman and Anderson, 1986), architectural (Henderson and Clark, 1990), disruptive (Christensen and Bower, 1996), reduce the value of complementary assets (Tripsas, 1997), or involve new product generations (Filson and Gretz, 2004; Franco and Filson, 2006).

[35] For example, Agarwal and Gort (1996) and Agarwal, Sarkar, and Echambadi (2002) examine the relationship between firm entry by industry life cycle stage and subsequent performance using data from dozens of industries.

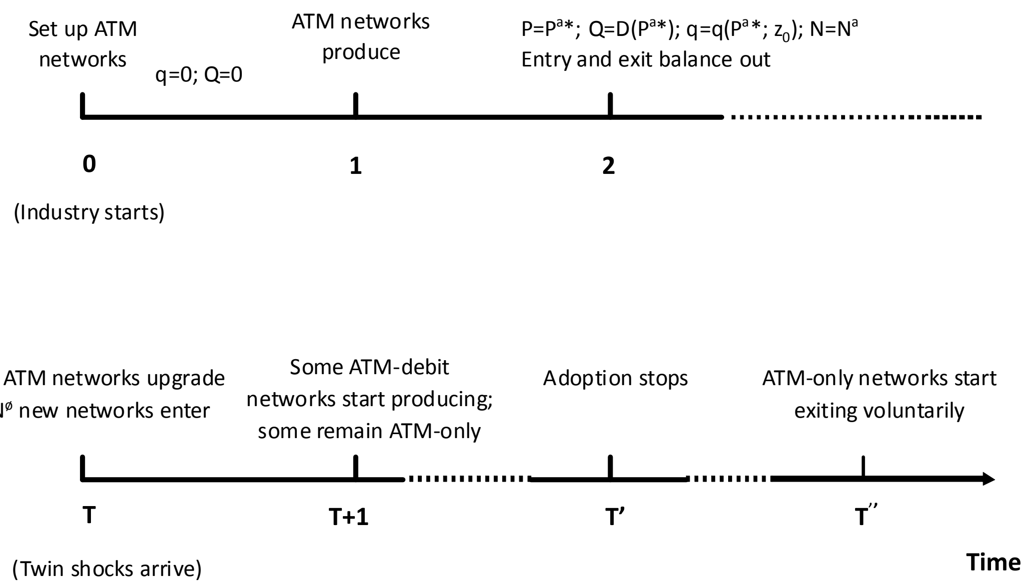
failed, but could be merged or acquired for other reasons. An extension of our model may accommodate those cases by allowing exiting networks to recover a scrap value. It would be interesting to investigate those cases provided related information becomes available.

Third, our study assumes that bank size is determined outside the model and banking deregulation arrives as an exogenous shock. However, it is possible that bank size and banking deregulation could be endogenously influenced by ATMs to some extent (Kroszner and Strahan, 1999). Therefore, it would be interesting to explore the potential feedback channel. Moreover, our model separates network decisions from bank decisions by treating networks as independent entities from banks. However, real-world networks are typically owned by either a single bank or a group of banks. It is possible that without modeling deeper bank-network connections, we may understate the impact of deregulation on the industry shakeout. For instance, independent of the debit adoption effect, deregulation resulted in fewer but larger banks, which may have favored the growth of networks affiliated with those banks. Examining this possibility would require a more complete structural model as well as more detailed data on bank-network connections, which we leave for future research.

Fourth, one may look further into the early stages of industry life cycle. Our model implies that an industry quickly reaches the steady state in the pre-shakeout stage, which deviates from the slow buildup of firm numbers observed in the data. One possible way to address the discrepancy is to consider external adjustment costs at the industry level (e.g., Mussa, 1977), for which firms may want to smooth entries over time.

Finally, our analysis focuses on the binary quality of networks: ATM-only or ATM-debit services. In reality, network differentiation could also have a strong horizontal component because consumers may want to use ATMs close to where they live, work, shop, etc. It could be that shrinking the number of ATM networks nationally coincides with more availability locally. Provided richer data become available, future studies could incorporate local competition of networks into the analysis.

Appendix A: Timeline of the Industry Evolution



Appendix B: Model Solution

This appendix provides additional details and the procedure of numerically solving the model. Recall in our model, the exogenous parameters are (β, d_0, d_1, c_0, c_1, c_2, π^ϕ, K, ω^a, ω^d, z_0, z_1, I_0, I_1, g_0, g_1, λ, γ). The endogenous variables are the number of new entrants N^ϕ at time T, the final time of debit adoption T', the starting time of voluntary exit T'', and the sequences of prices (P_t^a, P_t^d), outputs per network (q_t^a, q_t^d), profits per network (π_t^a, π_t^d), network numbers (n_t^a, n_t^d), value functions (V_t^a, V_t^d), and voluntary exits x_t^a.

As we have characterized in the paper, the dynamics of prices, outputs per network, profits per network, network numbers, value functions, and voluntary exits will be determined by the number of new entrants N^ϕ and the timing of endogenous final adoption and voluntary exit T' and T''. Among them, T'' ($> T'$) will be determined by the outside option value π^ϕ. So we can use the following algorithm to solve for the model solution with two-dimensional grid search over control space of N^{ϕ} and T', and in the meantime we derive the dynamics of all other endogenous variables.

- Step 1: Define the grid points by discretizing the control space of the numbers of entrants N^{ϕ} and the endogenous time T'. Make an initial guess of the numbers of entrants N^{ϕ}.

- Step 2: Take N^{ϕ} as given, and make a guess of the final adoption time T'. We can characterize the dynamics of the solution for three time ranges — from T to T', from T' to T'', and from T'' and onward. Given the initial numbers of entrants and the final adoption time, we first obtain the sequences of prices, network outputs, network profits, network numbers, voluntary exits until T'. As $T'' > T'$, we then derive the voluntary exit time T'' with the condition that the profits of ATM-only networks equate the outside option value π^{ϕ}. With the known T'', we then solve the full paths of all other endogenous variables (P_t^a, P_t^d, q_t^a, q_t^d, π_t^a, π_t^d, n_t^a, n_t^d, x_t^a). Applying the backward induction based on 400 periods, we also derive the sequences of value functions (V_t^a, V_t^d) from equations (9)–(11) given N^{ϕ} and T'.

- Step 3: Given N^{ϕ}, we now verify whether the guess of time T' satisfies the condition $\Psi_t \geq 0$ for all $t < T'$ and $\Psi_t < 0$ for $t \geq T'$ shown in equation (13). If the condition is not satisfied, we then make another guess of T' and repeat Step 2 until we derive the consistent final adoption time T' and other variable values for the given N^{ϕ}.

- Step 4: We then verify whether the guess of the number of entrants N^{ϕ} satisfies the condition shown in equation (12). Check the discrepancy of equation (12) given N^{ϕ} and the derived T' from Step 3. If it is above the desired tolerance, go back and repeat Step 2 and 3 until both conditions in equations (12) and (13) are satisfied within the desired tolerance level. Finally, we check the time path of V_t^a to verify that entry only occurs in the period right after shocks but not afterward. Thus, we have solved for the dynamics of all endogenous variables.

Appendix C: Counterfactual Exercises

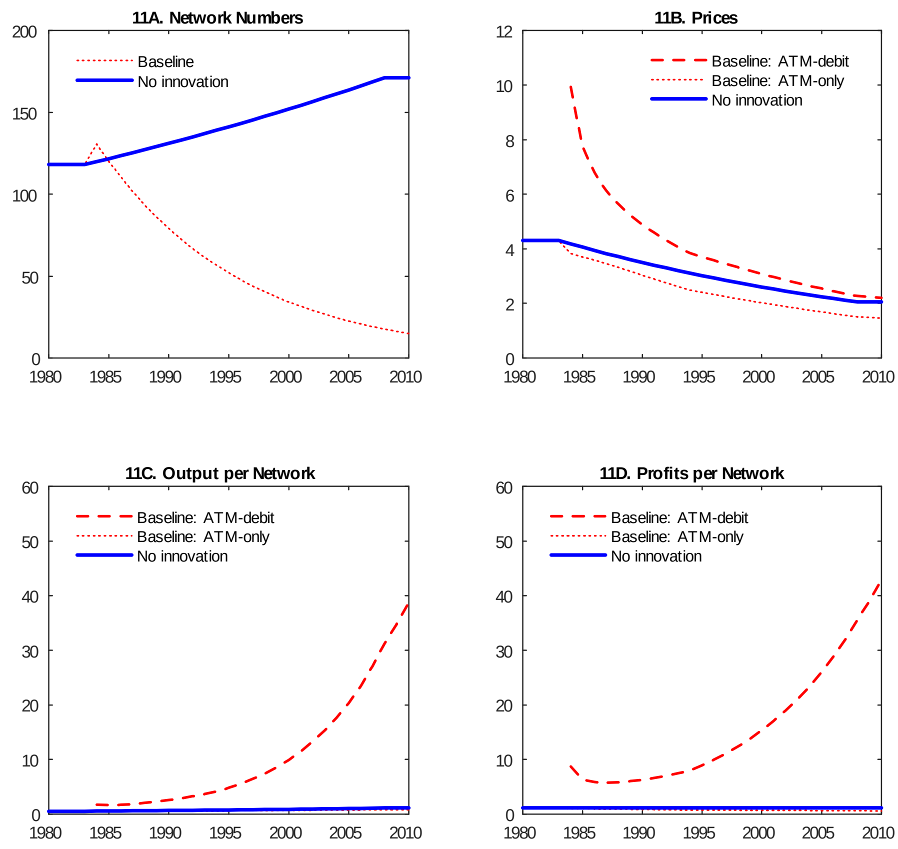


Figure 11. Counterfactual Case 1 – No Debit Innovation

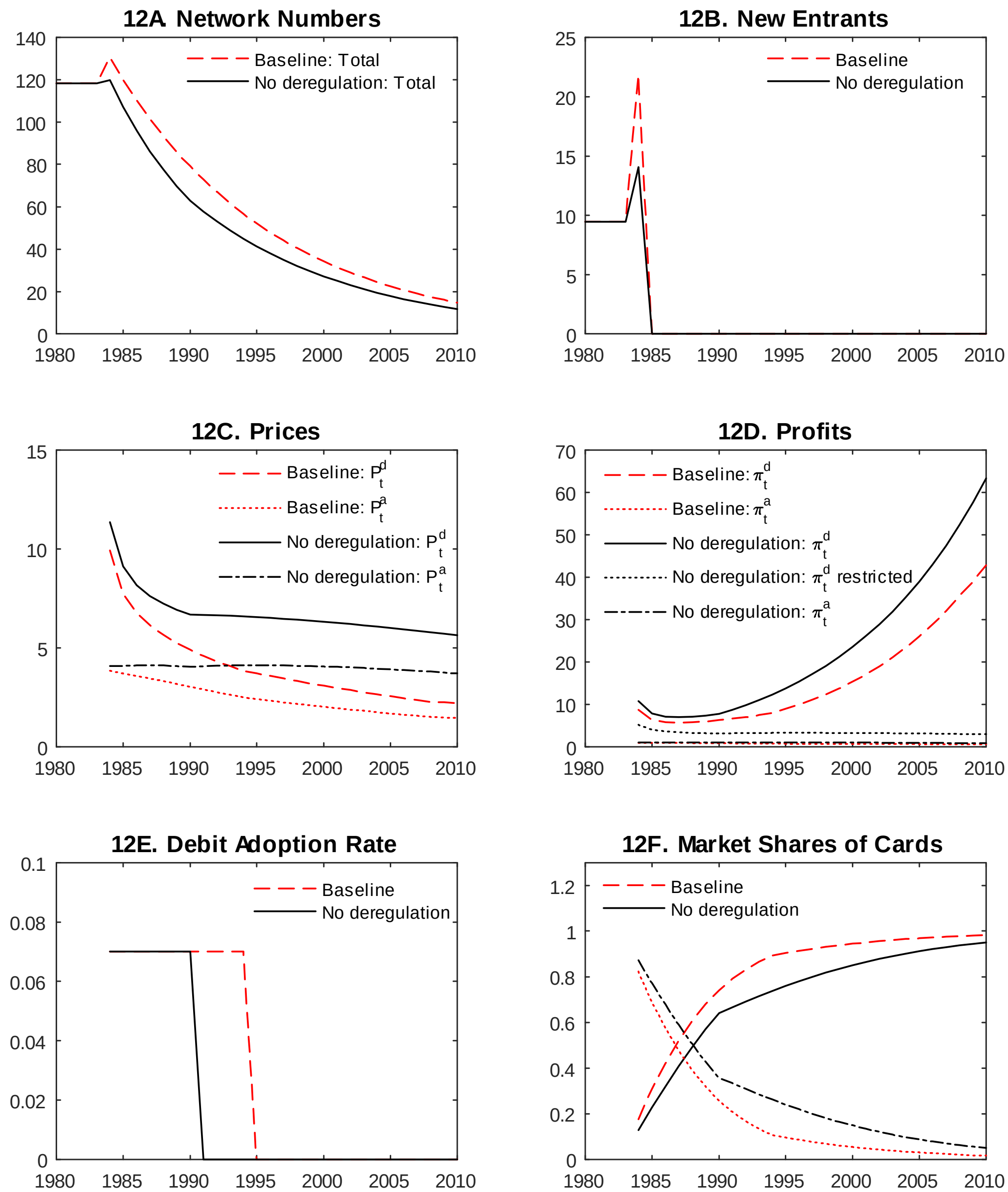


Figure 12. Counterfactual Case 4 — No Banking or ATM Deregulation ($\alpha = 0.4$)

Appendix D: Anticipated Shocks

This appendix provides details for solving the pre-shock steady-state equilibrium with anticipated shocks.

Under the free entry condition, we can rewrite Eq (27) as

$$U^{\phi} = \pi^{\phi} + \max\{\beta U^{\phi}, \beta[\mu V^{a} + (1-\mu)U^{a}] - K\}. \tag{29}$$

This implies that

$$U^{\phi} = \pi^{\phi} + \beta U^{\phi} \Longrightarrow U^{\phi} = \frac{\pi^{\phi}}{1-\beta}, \tag{30}$$

$$\text{and} \qquad U^{\phi} = \pi^{\phi} + \beta[\mu V^{a} + (1-\mu)U^{a}] - K. \tag{31}$$

Therefore,

$$\frac{\pi^{\phi}}{1-\beta} = [\mu V^{a} + (1-\mu)U^{a}] - \frac{K}{\beta}. \tag{32}$$

Because of the sunk cost paid, an incumbent network would strictly prefer staying in the industry. Hence, we can rewrite Eq (28) as

$$\begin{aligned} U^{a} \quad = \quad & \pi^{a} + \beta\mu[\gamma V^{\phi} + (1-\gamma)V^{a}] \\ & + \beta(1-\mu)[\gamma U^{\phi} + (1-\gamma)U^{a}]\}, \end{aligned} \tag{33}$$

which implies

$$[1 - \beta(1-\mu)(1-\gamma)]U^{a} = \pi^{a} + \beta\gamma U^{\phi} + \beta\mu(1-\gamma)V^{a}. \tag{34}$$

In addition, at the equilibrium, we have

$$1 - G(\frac{P^{a^*}}{\omega^{a}}) = N^{a} q^{a}(P^{a^*};\ z_0), \tag{35}$$

and the network profit π^{a} is determined by P^{a^*}. Under our parameterization, this means that

$$\pi^{a}(P^{a^*};\ z_0) = (c_1 - 1) c_1^{\frac{c_1}{1-c_1}} (c_0 z_0^{c_2})^{\frac{1}{1-c_1}} \left(P^{a^*}\right)^{\frac{c_1}{c_1 - 1}}, \tag{36}$$

$$d_0 \left(\frac{P^{a^*}}{\omega^a} \right)^{-d_1} = N^a \left(\frac{P^{a^*}}{c_0 z_0^{c_2} c_1} \right)^{\frac{1}{c_1 - 1}}. \tag{37}$$

The pre-shock steady-state equilibrium is then pinned down by Eqs (32), (34), (36), and (37). Note that V^a is the value function of being an ATM-only network in the period when the shocks indeed arrive and the number of existing networks is N^a, and $V^a(N^a)$ can be numerically solved using the algorithm described in Appendix B above.

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