Timing Is Everything: How a U.S. Payment Regulation Helped Overcome a Network Barrier without a Mandate

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DRAFT

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I have to change. It's like a curse.

--Miles Davis

Extended Abstract

Despite the rise of competing payment instruments over the last fifty years, checks remain a major component of the U.S. payments system: In 2015, checks held a 16 percent share by number and a 17 percent share by value. Because of coordination problems for the large number and broadly diverse array of independent banks, legal barriers, and limited government powers or political will to mandate clearing methods, checks were the last major noncash payment instrument to switch to electronic payment and settlement. Nevertheless, the transition to the new technology was achieved in a surprisingly short amount of time. Banks were able to choose the timing of technology adoption based on their own self-interest. Those that had most to gain took on more of the costs, creating a positive spillover to bring along the rest. The transition to virtually universal adoption of the new technology was made possible by regulation that did not mandate an outcome or set a deadline, but, instead, merely helped to overcome the network holdup problem by creating a bridge between the old and new technologies. That bridge allowed a kind of Pareto optimal adjustment to the new and better equilibrium. The experience provides an example where government effectively encouraged technology adoption by using a light touch, and may provide lessons for regulators faced with myriad technology choices and a desire to avoid the pitfalls of picking winners, often a politically fraught exercise undertaken in industries with network economies like payments and financial market infrastructures.

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A service with network economies can provide large benefits to providers and users, but network economies can also make efforts to replace old technology difficult. An innovation will be preferred to the existing technology only if sufficient numbers of providers and users adopt it. In such cases, there may be a role for market intervention to facilitate a transition. However, a regulation mandating the use of new technology may impose high costs on some market participants, but alternatively, if the intervention has too light a touch the transition may be delayed or postponed indefinitely, foregoing its benefits. Where possible, providing for interoperability of the old and new technologies can ease a transition by lowering the cost of adoption and enhancing the network economies of using the new rather than the old technology. Agents with the largest net benefits adopt first, and as more agents adopt, more network economies transfer to the new technology, increasing incentives for non-adopters to switch, accelerating adoption.

By law, the default method of check clearing was based on an old technology: physical presentment of the original paper at the paying bank's address. By allowing agents, in this case banks, to choose to use the old or new technology through the use of a replacement object—the substitute check, a mechanism that bridged the compatibility gap between paper and electronics—the law known as "Check 21" and its resulting regulation struck a balance between encouraging the adoption of new technology and ensuring that the benefits of doing so outweighed the costs. We find banks' response to the regulation is consistent with a dynamic Pareto optimal adjustment to the new equilibrium. The transition, which occurred in a surprisingly short period of time, was also encouraged by incentive-based pricing policies of the central bank and other competing central clearinghouses. These incentives allowed network economies to develop in the new technology more quickly than otherwise might have happened. The experience demonstrates a regulatory pathway from a suboptimal equilibrium to a superior one by a careful lifting of a constraint without imposing high adjustment costs on agents with low benefits of using it and without providing a direct subsidy.

In this paper, we examine the market and regulatory barriers that inhibited this conversion, construct an empirical model of a bank's decision of when to adopt once a major barrier was lifted, and estimate the magnitude of the network economies of this intervention. In particular, we identify a clear path for network economies to affect the benefits of switching to electronic processing, thus affecting banks' adoption decisions.

Our model is most similar to that used by Saloner and Shepard (1995) to study the adoption of ATMs. The fundamental similarity is that we are interested in the dynamics of the network externality and how it influences the *timing* of adoption. Behind this choice is the practical recognition that by 2012 almost all checks were cleared by electronic image, with only the smallest of banks still making use of Federal Reserve paper check clearing services. This setup implicitly assumes that adoption of the new technology is inevitable.

Using monthly billing data from the Federal Reserve's check clearing service provided to banks, we are able to examine the technology adoption "S curves" of Federal Reserve check processing regions that evolve from negligible adoption in November 2004 to nearly universal adoption by mid-2012. We show that while some banks were early adopters, a positive network externality is also present that helps to accelerate the adoption of laggards. We are able to quantify the network effect by measuring the influence of the relative proportion of local banks that have adopted on the probability of a bank's own adoption. We estimate that a 1 percent increase in the proportion of local adopters increases the probability of adopting by more than 2 percent, as averaged over all banks over the entire time period. This network effect is large, especially when observing the cumulative adoption pattern in the regional cross section, which displays extremely wide variation in adoption proportions during some time periods. The network effect generates rapid and substantial feedback over time, leading the regions with highest relative adoption proportions to have even higher relative proportions later. The differential spread of adoption proportions peaks, not surprisingly, at the same time that the number of substitute checks in the market peaks (about 2006). Of course, because of the boundary of 100 percent adoption, this feedback effect is naturally pared down once the peak is passed.

In short, because of Check 21, banks were able to adopt at their own pace. The banks with greatest benefits from adopting had incentives to bear the costs of learning by doing and to share their knowledge with other banks. Allowing the demand for the new technology to be based on economic decision-making and accelerated by the network spillover, avoided a variety of pitfalls that might have occurred if a more disruptive regulatory method had been chosen.

1. Introduction

A service with network economies can provide large benefits to providers and users, but network economies can also make efforts to replace old technology difficult. An innovation will be preferred to the existing technology only if sufficient numbers of providers and users adopt it. In such cases, there may be a role for market intervention to facilitate a transition. However, imposing regulations mandating the use of new technology may impose high costs on some market participants, but alternatively, if the intervention has too light a touch the transition may be delayed or postponed indefinitely, foregoing its benefits. Where possible, providing for interoperability of the old and new technologies can ease the transition by lowering the cost of adoption. Agents with the largest net benefits adopt first, and as more agents adopt, more network economies transfer to the new technology, increasing incentives for non-adopters to switch, accelerating adoption.

By law, the default method of check clearing was based on an old technology: presentment of the original paper. By allowing agents, in this case banks, to choose to use the old or new technology through the use of an object—a substitute check—that bridged the compatibility gap between paper and electronics, the Check 21 legislation struck a balance between encouraging the adoption of new technology and ensuring that the benefits of doing so outweighed the costs. We find banks' response to the Check 21 legislation is consistent with a dynamic Pareto optimal adjustment to the new equilibrium. The transition, which occurred in a surprisingly short period of time, was also encouraged by incentive-based pricing policies of Reserve Bank and other competing central clearinghouses. These incentives allowed network economies to develop in the new technology more quickly than otherwise might have happened. The experience demonstrates a regulatory pathway from a suboptimal equilibrium to a superior one by a careful lifting of a constraint without undue imposition of high adjustment costs on agents with relatively low value of using the new technology and without providing a direct subsidy.

In this paper, we examine the market and regulatory barriers that inhibited this conversion, construct an empirical model of banks decision of when to adopt once a major barrier was lifted, and estimate the magnitude of the network economies of this intervention. In particular, we identify a clear path for network economies to affect the benefits of switching to electronic processing, thus affecting banks' adoption decisions. Despite this, identifying its magnitude is a challenge because there likely were other technology related learning-by-doing spillovers present that also influenced banks' adoption decisions.

Networks exhibit two types of externalities that are likely present for banks in the case of check clearing (Katz & Shapiro, 1986). First, like learning-by-doing, networks exhibit "demand-side economies of scale," where the benefits of adopting increase as others adopt the product or service. Second, network adoption decisions are influenced by expectations about the future success of a product or service: As more of a bank's check-clearing counterparties adopt, its expectations of the future success of the technology increase, and so do its perceived benefits of adopting. Furthermore, the network effect will look very similar over time to internal (operations within the bank) and external (operations of a clearinghouse, in this case) scale economies, learning-by-doing, and learning-by-doing spillovers, technical change over time, and differing intensities of local competition. While all of these phenomena may result in a bank being more likely to adopt over time, the network effect and possibly learning-by-doing spillovers will be positively related to the adoption by its peers. Having data across regions and over time and controlling for banks' market power across regions can help us identify the network economies effect, but in particular cost savings from external scale economies and network economies will look very similar.

A few empirical papers have attempted to measure or identify network or learning-by-doing spillover effects in a technology adoption setting. Saloner and Shepard (1995) studied the adoption of Automated Teller Machines (ATMs), a technology in which banks can benefit from offering the service to users who obtain greater network effects the greater the number of ATMs installed (Saloner & Shepard, 1995). They focus on the timing of the adoption decision, but, unlike our paper, spillovers and learning by doing were not featured. Goolsbee and Klenow (2002) found evidence of learning by doing and network spillovers in the diffusion and adoption of home computers, and measured them in the cross-section at a single point in time (Goolsbee & Klenow, 2002). Gowrisankaran and Stavins (2004) studied network externalities in the adoption of automated clearinghouse (ACH) payments technology over eleven quarters (two and three-quarters years) (Gowrisankaran & Stavins, 2004). In that paper, the network externality is indirectly realized by banks through the benefits that accrue to users playing a Nash game between the check and ACH technologies as in (Farrell & Saloner, 1985). Our study differs from the two banking studies in that the network effects we study are spillovers directly experienced by the banks, and differs from all of these studies because we study the technology adoption experience in a ninety-two month (seven and two-thirds year) panel that spans almost the entire technology adoption experience from when no bank used the new technology to when virtually all banks used it.

Our model is most similar to that used by Saloner and Shepard (1995) to study the adoption of ATMs. The fundamental similarity is that we are interested in the dynamics of the network externality and how it influences the *timing* of adoption. Behind this choice of approach is the practical recognition that by 2012 almost all checks were cleared by electronic image, with only the smallest of banks still making use of Federal Reserve paper check clearing services. This setup implicitly assumes that adoption of the new technology is inevitable. We recognize the fact that, as is shown in Farrell and Saloner (1985) and others, multiple stable equilibria can arise in technology adoption settings. While acknowledging that the outcome could have been different under various conditions, with multiple possible pathways or intermediate equilibria, our purpose is to empirically analyze the national transformation of check clearing that actually occurred from the pre-Check 21 paper equilibrium to the post-Check 21 electronic image equilibrium. Also, we focus on timing because, in the presence of learning by doing and knowledge spillovers, timing of adoption plays a central role in sorting out the network users that create the knowledge spillover and those who benefit from it.

Although the number of checks written has been declining since the mid-1990s, they have remained a significant part of the payments system. In 2009 check's share of everyday noncash payments was 22 percent by number and 44 percent by value (Federal Reserve System, 2011). The Reserve Banks processed a significant share of interbank checks. Although the checks they processed were declining, the Reserve Banks held a steady market share of an estimated 44 percent of interbank checks in 2007 and 2010.

Using monthly billing data from the Federal Reserve's check clearing service provided to banks, we are able to examine the technology adoption "S curves" of Federal Reserve check processing regions that evolved from negligible adoption in November 2004 to nearly universal adoption by mid-2012. We show that while some banks were early adopters, a positive network externality was also present that helped to accelerate the adoption of laggards. We are able to quantify the network effect by measuring the influence of the relative proportion of local banks that have adopted on the probability of a bank's own adoption. We estimate that a 1 percent increase in the proportion of local adopters increased the probability of adopting by more than 2 percent, as averaged over all banks over the entire time period. We argue that this network effect was large, especially when observing the cumulative adoption pattern in the regional cross section, which had extremely wide variation in adoption proportions during some time periods. The network effect generates rapid and substantial feedback over time, leading the regions with highest relative adoption proportions to have even higher relative proportions later. The differential spread of adoption proportions peaked, not surprisingly, at the same time that the number of substitute checks in the market peaked (about 2006). Of course, because of the boundary of 100 percent adoption, this feedback effect was naturally pared down once the peak was passed.

The paper proceeds as follows. First we outline the legislative and legal steps that enabled electronic processing of checks. Next we develop a dynamic optimization model for banks' adoption decisions. Network economies organically arise from this model. We then describe our data and employ it to explore the transition to electronic processing and to estimate the magnitude of the network economies.

2. Steps to Electronic Processing

By the new millennium, banks had adopted electronic clearing methods for all types of noncash payment instruments except checks. Paper clearing of checks persisted partly because of state regulations which allowed a check writer's bank (the paying bank) to require physical delivery of the original paper check before settling with the check depositor's bank (the collecting bank). Prior to Check 21, to compete for customers, to comply with federal regulations, and to minimize risks associated with delay, collecting banks sought to make funds available to the depositors quickly, and thus strived to present checks to the paying bank quickly. Consequently, most inter-regional checks were flown on dedicated airplanes, and schedules for collection involved multiple courier pickup times throughout the day. Although costly, the system made sense given the incentives and regulations then in place.

Banks and industry observers recognized that electronic transmission of the check information would benefit the collecting bank in several ways. First, it would reduce the often substantial collection costs of expedited physical shipping of the original paper. Further, moving the information and funds sooner allowed more freedom to control risk or to pass on faster funds availability to depositors. On the other hand, from the perspective of paying checks, banks did not incur any collection costs, and would stand to lose some of the float benefits, particularly in a high-interest rate environment, if funds were moved sooner. For a particular check, therefore, there was a clear incentive for the collecting bank to reduce shipping costs, but also a zero-sum game to divide the benefits of any float between the collecting and paying banks. Paying banks, however, must return some, albeit typically a very small fraction, of their checks because of insufficient funds, fraud, closed accounts, etc. Although the percentage of returned checks is small, the cost of returning a check can be substantially greater than collecting a check, in part because of the need to sort through and return the original. Thus, cost reductions can also be obtained from the paying side as well. Of course, most banks pay some checks and collect other checks, so mutual benefits were possible if somehow the system could be restructured to allow electronic collection.

In the decade prior to passage of Check 21, some bilateral agreements between banks were negotiated to allow for the substitution of electronic presentment in place of the original paper check, but such agreements were rare. Because of scale efficiencies, paper check clearing was reasonably cheap, (less than 2 cents per item (Bauer & Ferrier, 1996)) in most cases banks just paid to deliver paper on an expedited schedule. Because of the scale economies associated with both presentment modes, a substantial coalition of banks switching to electronic checks would have been required to affect the relative cost of paper compared with electronics to tip the scales toward electronics enough to make a switch attractive to the majority of banks.

While many banks might have chosen the electronic route, legal and regulatory hurdles had to be overcome before check processing banks could shed the paper and go all electronic. A fundamental change that set in motion the possibility of electronic checks was the Electronic Signatures Act (E-Sign), which went into effect October 1, 2000. This law allowed electronic contracts, such as signed documents sent over fax machines, to carry the same force in legal disputes as a paper version. Even with this in place, however, checks could not be freed from the need to ultimately deliver the original paper.[1]

The key insight for what ultimately became the substitute check, the catalyst to electronic adoption in check processing provided by the Check 21 law, may have come from similar ideas discussed with Federal Reserve Board staff by two depository institutions looking to reduce their internal check processing costs, not their external check collection costs. Both of these ideas proposed creating a substitute paper copy of original checks using the ordinary paper check collection system. One large national bank wanted to be able to acquire check images and send them over a network from its widely disbursed ATM network, avoiding costly periodic (daily or

[1] E-Sign includes a special provision for checks and other negotiable instruments for record retention requirements and for rules of evidence or other laws requiring the production of an "original" document, so long as the electronic record meets requirements for accuracy and accessibility. That law might have made electronic clearing possible except that it explicitly excluded from its coverage the use of checks as a payment device "in part out of deference to concerns of bank regulators over the impact that the sudden recognition of electronic checks as a new payment device might have on the stability and security of U.S. payment systems" (Wittie & Winn, 2000). The E-Sign drafting committee determined that inclusion of electronic checks as a payment device would be a formidable task, and more properly taken on by the National Conference of Commissioners on Uniform State Laws (NCCUSL). For their part, the NCCUSL determined that the topic of electronic checks was too controversial and would delay its other work. Some other approach was clearly needed if something was to be done to overcome the barrier.

sometimes several times a day) physical armored carrier retrievals from each location. This approach would allow immediate transmission of the images to a central processing location, avoiding the risks and costs of internal delay. The bank would then print out paper copies of the images, essentially image replacement documents, and collect the paper copies of the checks as substitutes for the checks in their cash letters, just as with original paper checks.

A corporate credit union had a different cost-saving idea using image replacement documents based on a modification to the routine check image archiving it undertook for a large number of credit union customers. As was typical for credit unions, which had never as a matter of routine provided cancelled checks to customers, this corporate credit union would transmit magnetic ink character recognition (MICR) data from the checks as part of its operations. Inevitably some of these checks would have to be returned after they were reviewed. The *status quo* processing routine required an additional passes through the same stack of physical checks later when the customer credit unions needed one of those checks to be culled out and returned. The idea was that substantial savings could be achieved by just printing out as-needed copies of the checks from the archived images and, as with the large national bank, submitting those substitute image replacement documents as part of their normal check returns processing.

Both of these ideas would reduce physical processing costs, but, importantly, expedite the process of collecting or returning checks, thus helping to reduce risks inherent in delay. These banks wanted the Federal Reserve Board to make revisions to Regulation CC to allow them to implement their ideas but such a change was beyond its authority. Only the Congress could make such a change.

Working with the industry, the Federal Reserve Board developed and eventually proposed a new draft federal law called the Check Truncation Act, which was a compromise between mandating electronics and retaining the *status quo*. The Check Truncation Act was designed to allow banks to adopt electronic processing methods for checks like the depository institution's internal cost saving ideas above, even when other banks did not. That aspect of the proposed law was key to getting support, because while some banks, particularly large banks with extensive national networks of ATMs or branches, third-party check processors and banks that used their services might expect to see substantial cost reductions from cutting paper out of their internal processes, other banks—without their own business case for doing so—might have resisted a mandate because of the cost of switching from the status quo to new electronic processing methods on day one. The use of the substitute check idea rather than mandating electronic processing was the central element that made the Check 21 law different from the way that many other developed countries had replaced their paper-based check clearing systems.

The Check Truncation Act was designed to allow banks to adopt electronic processing methods for checks even when other banks did not. That aspect of the proposed law was key to getting support, because while some banks, particularly large banks with extensive national networks of ATMs or branches expected to see substantial cost reductions from cutting paper out of their internal processes, smaller banks resisted because of the perceived cost of switching from the status quo to new electronic processing methods. The substitute check was the central element that made the Check 21 law different from the way that many other developed countries had replaced their paper-based check clearing systems.

A version of the Check Truncation Act, called the Check Clearing for the Twenty-First Century Act (Check 21), was eventually passed unanimously in committee and by both houses of

Congress, and enacted into law on October 2003. In the end, all of the banking trade associations supported passage of the law, although some consumer interest groups continued to raise objections and did not support the law because of a variety of concerns, including costs associated with not getting physical checks back, fears of increased errors such as double debiting, increased check bouncing risk due to faster electronic clearing, and increased fees (Eubanks, 2004) (Credit Union Times, 2002). The experience of credit unions, which generally did not return checks to customers routinely and which had a good track record of customer satisfaction was held up as a counterpoint to these objections. While these fears were given a hearing, consumer's groups continued to be able to pursue specific concerns about banks through other legislation.

Check 21, which took effect October 28, 2004, allows a collecting bank to present a legally equivalent paper copy of an original check—called a "substitute check"—if the paying bank requires a check to be presented for payment in paper form. By permitting the use of substitute checks, Check 21 removed a key legal impediment to the replacement, during the collection process, of paper checks with electronic information ("check truncation"). This federal law overrode state laws based on U.C.C. standards which only required payment upon presentation of the original check. The substitute check innovation was the method by which a compromise was reached, and was the mechanism which provided banks the ability to make self-interested adjustments to electronic processing without making other banks worse off: essentially a Pareto improvement.

Banks could create paper facsimiles of original paper checks and present them to banks that required paper for the first time in the United States. Substitute checks were essentially photocopies that met a certain standard, and the paying bank had to treat them as if they were the original paper check. More to the point, however, was the fact that banks could replace their own internal paper-based processes with electronic processes from the initial receipt of the original check up to the actual presentment of the check to the paying bank.

With Check 21 in effect, a bank with a large network of branches and ATMs might realize substantial cost reductions by replacing its distributed paper-based internal check processing networks—which included daily armored carrier trips to all ATMs and bank branches to cull check deposits—with a centralized electronic hub. Such banks could further extend cost reductions out to check depositing customers by allowing remote depositing, avoiding special trips to the bank to collect the check. All these changes could pile up and give the collecting bank a real timing advantage for collecting checks. The only remaining extra cost would be to print out and deliver paper at the end if necessary, but at least in theory a bank could deliver a check to the paying bank in record time by enlisting the help of a nearby printing facility. If the paying bank was willing to receive the check electronically, then the timing would be even faster, and the marginal cost would be very low.

A law like Check 21 was required before a fuller potential of electronic processing was possible for banks that wanted to do so. But Check 21 did not require all banks to begin electronic check processing. The size of the benefit of switching from the existing paper check processing network to a faster electronic check processing system, on net, would depend on a bank's own particular balance between the number and value of checks it collects relative to checks it pays. Furthermore, some banks might simply choose to process paper as usual if the costs of switching—at least in the short run—outweigh the benefits.

There was a concern: If checks were dying off, why bother? A Federal Reserve study published in August 2002 by Walton and Gerdes had found that national volumes of checks peaked in the mid-1990s, and were declining at about 4 percent a year (Walton & Gerdes, 2002). In light of the declining market, the Federal Reserve Banks were already engaged in efforts to consolidate excess paper processing capacity. The conversion of checks to ACH payments, which directly replaced the check with an electronic ACH payment for many checks written by consumers had come online by 2003. It was possible that any cost-saving payoff from replacing banks' paper-based check clearing operations with electronic systems would be limited by rapidly shrinking demand for check services (Capachin, 2004).

Some supporters of Check 21 saw it as a catalyst for convincing banks and users to move away from checks and start using other payment methods such as debit cards or automated clearinghouse (ACH), but also thought that a dual check clearing system that included significant numbers of electronic, paper, and substitute checks would exist for a decade or more. Many believed that most banks, especially small ones, would wait a very long time before switching to the electronic technology (Murphy, 2004). The Federal Reserve Banks, committed to supporting the check clearing system, built up a large capacity for substitute check processing and planned for an extended transition.

Less than a decade later, however, banks have almost universally adopted the new processing method, although some banks with very low volumes have not. By mid-2012, almost all checks are now cleared electronically. Eliminating paper from the check clearing process has resulted in substantial cost reductions: One study estimated that Check 21 has reduced check clearing costs by $3.2 billion annually (Humphrey & Hunt, 2012).

3. The Model

Given their early support, some banks expected to realize immediate and significant positive net benefits from adopting Check 21. These banks were poised to implement internal cost reducing measures, and to offer new products to their check depositing customers that were expected to generate new revenues or provide a competitive edge compared with other banks that were slower to adopt the technology. In addition, because some aspects of image processing under Check 21 was new technology, through learning by doing banks generally would be able to reduce their internal costs over time. Some of these cost reductions would also result in indirect cost-reducing knowledge spillovers through various mechanisms, such as communications between personnel across nearby banks, through intermediaries such as the Federal Reserve Banks and other check processors, through industry conferences and workshops, and through consulting firms and solution marketers.

Banks that adopted electronic image processing may have had a strong motivation to communicate their knowledge and help reduce the cost of check processing for other banks: Printing substitute checks, required when collecting checks from a bank that had not adopted Check 21, were expensive relative to electronic images, and often more expensive than presenting the original paper. A bank could reduce its check collection expenditures by convincing banks within its own check clearing network to accept electronic images. Likewise, as the number of adopting banks in an as yet non-adoptive bank's network increased, the relative cost of adopting would decline.

A network externality arises when an increase in the users adopting the technology, or equivalently joining the network, increases the value (and therefore the probability) of other users also adopting. Banks would have directly and perhaps indirectly benefited from an increase in the proportion of banks in their networks that adopted Check 21, and that would have increased the probability of adoption. At the same time, declines in the relative prices of collecting checks via electronic images compared with paper or internal cost declines, and internal benefit increases based on offering remote deposit capture and other Check 21 derivative products would have also increased the probability of adoption.

Here we develop a model of Check 21 adoption by banks to set up a framework to identify whether a check-image-processing externality and/or knowledge spillover existed, and, if so, measure its size. The optimization problem we develop here is similar to that developed by Saloner and Shepard (1995) in their study of the influence of an end-user network effect on banks' decisions to adopt ATMs. Our model differs from that study, however, because the nature of the network externality is different, and the available data are different.

Let the adoption decision of bank i be

$$a_{it} = \begin{cases} 1 & \text{if bank } i \text{ adopts at } t, \\ 0 & \text{otherwise.} \end{cases} \quad (3.1)$$

The bank's decision will be based on maximizing the expected discounted sum of net benefits of adopting f_{it} less q_{it} the one-time cost of adopting:

$$\text{NPV}(t) = \sum_{s=0}^{\infty} \delta^s f_{it+s} - q_{it}. \quad (3.2)$$

In each time period the bank must decide whether to adopt or wait. With adoption inevitable, the date of adoption is the earliest time period in which $\text{NPV}(t) > \delta \text{NPV}(t+1)$. Thus, the bank will adopt if

$$\sum_{s=0}^{\infty}\delta^s f_{iT+s} - q_{iT} > \delta(\sum_{s=0}^{\infty}\delta^s f_{iT+1+s} - q_{iT+1}) \quad (3.3)$$

which reduces to

$$f_{it} > q_{it} - \delta q_{it+1}. \quad (3.4)$$

This inequality says that the bank will adopt once current net benefits exceed any (discounted) switching costs a bank can expect to avoid by waiting one more period.

We want to test whether the rate at which other banks in a given bank's network have adopted affects the probability of adopting. Let the number of other banks in the network of bank i be N_i and let the number of these banks that adopted in the previous period be $A_{it-1} = \sum_{j \in N_i} a_{jt-1}$. (In this paper, we assume that a bank's network consists of the other banks in its own Fed processing region, which will be developed in the data section below.)

There could be a variety of potential pathways through which a bank receives the Check 21 network externality. One particularly obvious path is the direct change in a bank's check processing expenditures charged by intermediaries caused by the adoption of electronic image processing of other banks in its network.

Let v_{it} be the total number of checks for which bank i collects payment from the other banks in its network. Let s_t, p_t, and e_t be the prices paid for clearing substitute checks, paper checks, and electronic image checks, respectively. Assuming that an equal number of checks are collected from each bank in the network[2], the expenditure from clearing checks for bank i at t is

$$c_{it}(a_{it}) = \left(\frac{v_{it}}{N_i}\right)\left(e_t a_{it} A_{it-1} + s_t a_{it}(N_i - A_{it-1}) + p_t(1-a_{it})N_i\right). \quad (3.5)$$

Considering only these expenditures, the net benefits from adopting would equal the expenditure savings from adopting electronic image processing (joining the Check 21 network), i.e.

$$\begin{aligned} f_{it} &\equiv c_{it}(0) - c_{it}(1) \\ &= \left(\frac{v_{it}}{N_i}\right)\left(p_t N_i - e_t A_{it-1} - s_t(N_i - A_{it-1})\right) \quad (3.6) \\ &= v_{it}\left(p_t - e_t\left(\frac{A_{it-1}}{N_i}\right) - s_t\left(\frac{N_i - A_{it-1}}{N_i}\right)\right). \end{aligned}$$

Intuitively, there is a benefit to switching as long as the weighted average of items processed electronically and by substitute check is smaller than not switching (continuing to process paper).

Now let $r = A/N$. Note the network economies effect is thus

$$\frac{\mathrm{d}f(r)}{\mathrm{d}r} = v(s-e). \quad (3.7)$$

Again this expression has a nice intuitive interpretation, as long as price paid for substitute checks exceeds that of electronic images ($s > e$) the bank's net benefits increase as other banks adopt. Equations (3.6) and (3.6) also show that the net benefits and the intensity and direction

[2] This assumption simplifies the mathematics but is not essential.

of the network effect will evolve over time based on how prices change. This reveals one way in which the effects of the network can be dependent on prices.

Note that processors can increase net benefits by increasing the price of depositing paper checks or decreasing the prices of depositing electronic images. Pricing of the intermediate technology, the substitute check is more complex. If the price of substitute checks is raised, the network spillover caused by the adoption of counterparties is intensified through equation (3.7) but the net benefit declines. These considerations suggest that strategic pricing by processors should have an effect on adoption decisions, but the optimal strategy would vary over time based on a variety of factors.

For banks, the net benefits function and switching costs will likely depend on these expenditures as well as a variety of other costs and benefits dependent on r, other characteristics of the bank that can be measured, and characteristics that are idiosyncratic to the specific bank that cannot be measured.

Let $g_{iT} = f_{iT} + \delta q_{iT+1} - q_{iT}$. Then the cumulative distribution for the random variable T, the date of adoption, is $\Omega(t) = \Pr(T \leq t) = \Pr(g_{iT} > 0)$. The corresponding density is $\omega(t) = d\Omega(t)/dt$. The "risk" or "hazard" of adopting at time t conditional on having waited until t is

$$a(t) = \Pr(t < T < t+1 \mid T \geq t) = \frac{\omega(t)}{1-\Omega(t)}. \quad (3.8)$$

We can now estimate the effect of the network externality and other factors on the risk of adopting electronic image processing conditional on having survived by using the standard duration or hazard regression framework which outlines techniques for estimating the effect of a set of explanatory variables, such as $v_{it}, N_k, A_{kT-1}, s_T, p_T, e_T$ on the hazard rate, or rate of adoption.

4. The Data

The Federal Reserve Banks process checks for a large number of depository institutions. Bank customers pay the Reserve Banks per-item and per-transaction fees for checks they deposit and collect for them, and the volumes of checks and the cost by the type of deposit are reported in monthly billing statements. During the period we study, there were three basic methods of depositing and collecting checks through the Reserve Banks. First there was the collection and presentment of checks deposited in paper, usually original paper, form. This is the traditional check collection product, and there is no pricing difference based on whether the paying bank requires paper or is willing to accept an image. Alternatively, checks could be deposited in electronic image form and collected by printing a substitute check for presentment to banks that require paper. Finally, the whole process can be handled electronically by forwarding deposited electronic images for presentment to banks that agree to receive electronic images. (These three deposit methods are reflected in the model above which has one price for the paper deposit product, but a weighted average of prices for the image deposit product.)

Our billing dataset consists of a monthly volume and fee record by category of service for each customer "endpoint" that was billed for any kind of Reserve Bank check processing. These endpoints are offices of chartered depository institutions (commercial banks, savings institutions, and credit unions) that are identified by their ABA or routing number. Some of these chartered institutions (banks) are independent and some are affiliated with other banks that are also "endpoints" in the data. The Federal Reserve Banks began offering electronic check payment services, called "Fed forward," in November, 2004, the same month that Check 21 went into effect. From that time on, banks could subscribe to either a paper deposit service, or an electronic image deposit service. Our analysis will focus on the banks that were using Federal Reserve check services in November 2004, the first month that regulations allowed banks to create, collect and present substitute checks to other banks, and the first month that Check 21-based products were offered. We follow these banks from that point until our last observation 92 months later in June 2012.

Check processing volumes and prices over time

Total volumes calculated from the Reserve Bank billing database show how the overall use of paper, substitute checks, and images in the collection process changed from November 2004 through June 2012 (Figure 1). As noted above, the total volume of checks fell over the period. The total volume of the November 2004 cohort fell faster than Reserve Bank total volume, reflecting occasional switching of service providers both *to* and *from* Reserve Bank check processing competitors (other clearinghouses and correspondent banks). Paper check deposit volume dropped steadily until 2009 when the volume of checks deposited in paper form began to drop off at a slower rate. Substitute checks, the bridge between paper and image technology, initially gained in volume, as the banks that adopted image deposit early were forced to have substitute checks printed to deal with the large number of other banks that had not yet adopted. The volume of substitute checks peaked in 2008 and had virtually disappeared by 2011 when nearly all banks had adopted. By 2008 the number of image checks was larger than either paper or substitute checks, and by 2010 image checks exceeded paper and substitute checks combined.

The detailed data on Reserve Bank check processing allows us to study bank's technology adoption decisions and network effects. While the billing database provides great detail on checks processed by the Reserve Banks, clearing volumes from the entire interbank check market must be estimated from surveys. We can compare the Reserve Bank volumes of these different types of checks to aggregate survey estimates of checks received by banks for 2007 and 2010 using data described variously in (Gerdes, 2008) and (Federal Reserve System, 2011). During both periods, the Reserve Banks processed about 44 percent of all commercial interbank checks (Table 1). We can also compare the proportions of different types of checks received by form of presentment from the national survey estimates to the proportions of different types of checks by deposit product type. Because these measures are from different perspectives (presented-received versus deposited-sent), they will differ not only because of the size of the markets they represent, but also because some checks that were deposited as paper would have been received as images by banks that paid for the privilege.[3] The most striking difference in the proportions occured in 2007 where the national survey presentment figures had a greater proportion of check images and the Reserve Bank deposit figures had a greater proportion of paper checks, particularly substitute checks.

In fact, the above comparison suggests that during this period the Reserve Bank's market share of substitute checks was 89 percent. This is consistent with the anectdote that the Reserve Banks were committed to promoting the adoption of check clearing by standing ready to print substitute checks wherever required. The fact that the Reserve Banks had such a large share of substitute checks leading up to their peak in 2008 despite having less than half of the interbank check market suggests that private clearinghouses were concentrating their efforts on clearing check images from end-to-end and either were not offering substitute check services universally or at

[3] The Reserve Banks and other intermediaries provide such "payor bank" services. In future, we may find a way to bring some or all of Reserve Bank payor bank volume into our analysis.

competitive prices. Traditionally, banks collected checks through the most cost-effective route possible. For example, a bank might clear local checks with some of its largest partners in a private clearinghouse, splitting volumes and giving the rest of its checks to the Reserve Banks. The Reserve Banks are required to serve all endpoints, while competitors generally do not. Just as the largest banks were directly clearing some of their checks in original paper form with their largest partners, they began to split image volume as well, clearing an increasing number of check images outside the Reserve Bank services. By 2010 and as the need for substitute checks wound down Reserve Bank proportions were much more closely in line with the entire market.

As the volume of paper checks declined, the fees associated with depositing paper checks with the Reserve Banks began to rise (Figure 2). Because of the loss of scale economies and the fixed cost of maintaining paper processing infrastructure at the Reserve Banks, fees began to rise substantially by 2010, and began to rise by hundreds of percentage points beginning in 2011. At the same time, as electronic image and substitute processing ramped up, the cost per item fell.

The Reserve Banks are required to recover long-run check processing costs plus imputed costs designed to approximate taxes, return on investment, and other costs or profits that would have been incurred or required by a private firm. The Reserve Banks face competitive pressure that motivates them to keep check processing costs low. Thus, we conclude that overall the fees charged are similar fees for similar services charged by their competitors. While the Reserve Banks must recover overall costs in check processing, the fees within the service line may vary so as to create incentives for desired customer choices. The Reserve Banks recognized from the beginning that, for image deposits, the cost of presenting substitute checks would be greater than presenting images. It was not possible to charge banks for insisting on receiving paper. To help spur the positive externality favoring image deposit, however, the Federal Reserve strategically raised paper deposit prices and offered partial discounts on other check services (such as image deposits) to customers that agreed to accept images for presentment (Federal Reserve System, 2005).[4] The discounts increased from 2006 through at least 2008 but became less relevant later as paper presentment became a less attractive product. While we do not claim that fees always reflected the true costs of each method, these pricing policies had meaningful effects on the cost of choosing paper or image deposit.

Check 21 Adoption

Over 7500 banks were using Reserve Bank check services in November 2004. We begin our empirical analysis by first examining the unconditional distribution of t, the number of months that passed before each of these banks adopted. Note that adoption by some of the banks in the dataset is unobserved, or censored, because they either had not adopted by June 2012 or exited the dataset early meaning they either merged with another bank, switched to another check processing service provider or correspondent bank, or (unlikely) simply stopped processing checks. We assume, and alternative specifications discussed later suggest, that the censored observations are ignorable. An empirical estimate of the probability density $\omega(t)$ shows that adoption peaked in early 2006 (Figure 3). The corresponding cumulative density displays the expected "S-curve" shape predicted by the technology adoption literature, with the steepest portion of the curve located around the same time that adoption peaked.

[4]The Federal Reserve System considers pricing strategies for Reserve Bank priced services, including check, in the fall of each year. High level strategies and fee schedules are published in Federal Register notices in early November of each year. For example, in 2005, the notice announced the introduction of per-check discounts on checks received for 2006. The notice also anticipated that in the long run paper prices might be strategically increased to encourage further Check 21 adoption.

The national adoption "hazard" function $a(t)$ displays the odds of adopting at t conditional on having survived until t (Equation 3.8). A nonparametric estimate of $a(t)$ shows a peak in the national hazard rate at roughly 18 months after Check 21 went into effect (Figure 4). At that point, the risk of adopting Check 21, conditional on having not adopted up to that point, was just under 0.07 percent. Note that these hazards are conditional. Therefore, the decline in the hazard rate is not simply due to a decline in the number of banks that have not yet adopted. The pattern suggests that the longer a bank resists adopting, the less likely adoption becomes for that bank.

5. Estimation

To estimate the effect of network spillovers, we need information about the technology adoption decision of a bank's own network. Such detailed data are unavailable, and so we use information about the adoption of other banks within a local region as a proxy. We argue this proxy is a good one based on a few empirical observations about check processing.

There are 47 local Federal Reserve regions spread across the lower 48 states, defined by historical check processing offices. These offices don't represent a one-to-one mapping to states but correspond very closely to reasonably cohesive economic areas as defined, for example, by the Bureau of Economic Analysis. With the advent of Reserve Bank office consolidation and Check 21, the Reserve Bank operations for these regions have merged over time. By law and regulation, the definition of what makes a check local or nonlocal for purposes of making funds available was tied to the Reserve Bank offices themselves. Funds from local checks have to be made available within two days compared with five days for nonlocal checks. Therefore, the mergers motivated faster methods of check collection for checks outside the local area. Such changes created greater bank demand for electronic images or substitute checks, especially when collecting them from banks in other regions or remote areas where paper check transportation is more expensive. But the behavior of check users for the most part has not been affected.

Most checks (roughly 80 percent) collected through the Reserve Banks were paid by a bank in the same region (Figure 5). This percentage was, for the most part, very consistent over the time period we study. There was a steady decline from 85 percent in 2004 to about 72 percent in 2008. Then the proportion began to rise again and leveled out at about 80 percent through 2011.

We exploit the fact that the preponderance of checks is cleared locally within regions to study regional differences in the adoption of electronic check image processing, and argue that while these are imperfect representations they are reasonable proxies of the typical banks' most relevant "network nodes." We cannot observe the specific network of banks that each bank trades checks with. That network and its adoption rate would have the most direct effect on the check clearing expenditures of a bank, a direct network externality. We assume, however, that banks are part of a broader local network of banks where closely competing banks learn from and respond to each other's behavior. If a growing number of banks begin offering desirable check deposit services to customers derived from the use of electronic images, a bank that has not yet adopted might feel more pressure to adopt than otherwise. While such pressure might be affected by the concentration of banking within the region, this effect may also legitimately be considered another externality of the network that increases the net benefit of adopting electronic images.

When we examine the pattern of the technology adoption "S-curves" by creating separate cumulative densities for each region, it becomes apparent that some regions experienced relatively rapid adoption starting in 2006 while other regions showed much slower adoption

(Figure 6). Banks in some regions quickly adopted, reaching 100 percent adoption in just over a year. By August, 2006 half of the regions had reached an adoption rate of at least 50 percent. Banks in other regions adopted more slowly: By August, 2008, two years later, the last region finally reached at least an adoption rate of 50 percent.

Empirical Model Specification

To estimate the existence and size of the network effect we need to specify a model for the adoption risk in Equation (3.8). We begin our analysis with the Cox proportional hazard model which takes the form

$$a(t) = a_0(t)\exp(\beta X) \quad (4.1)$$

where $a_0(t)$ is called the baseline adoption, X is a matrix of observed characteristics of the banks we study, and β is a set of parameters that describe how the characteristics of the banks shift adoption from the baseline. The Cox approach is a semi-parametric partial maximum likelihood method, a product of likelihoods of all the events that are observed, where the baseline adoption, the nonparametric part, can be derived after the parameters are estimated.[5] The likelihood function takes the following form:

$$PL = \prod_{k=1}^{K} L_k = \prod_{k=1}^{K} \frac{a_k(t_k)}{\sum_{j \in R(t_k)} a_j(t_k)} = \prod_{K=1}^{K} \frac{a_0(t_k)\exp(\beta X_{(k)})}{\sum_{j \in R(t_k)} a_0(t_k)\exp(\beta X_{(j)})}, \quad (4.2)$$

where $R(t_k)$ is the risk set, the banks for which $t_j \geq t_k$, i.e. the banks that adopted later (or not at all). At each point in time that an adoption is observed, the bank or banks that adopted are

[5] The partial likelihood function, a product of likelihoods of events, differs from the usual likelihood function, which is a product of likelihoods across individuals.

compared with the banks that did not. This allows our baseline hazard function to vary over time unfettered by a specific parametric form.

We have national prices, which change over time, but do not vary extensively by bank or by region. The proportional hazards model does not have a way to distinguish prices from time, and therefore from the advance of technology. In spite of this shortcoming, their influence is embedded in the baseline adoption rate that comes out of the model. The network effect does vary by region and is hypothesized to affect the probability of adoption. As noted above, we proxy for the banks' own network by using the regional adoption rate

$$\mathrm{RAR}_{kt-1} = \frac{\sum_{j \in k} a_{jt}}{N_k}. \quad (4.3)$$

Because this ratio increases over time, albeit at different rates in each region, inclusion of this variable in the regression would confound the network effect with time, technological change, prices and other effects correlated with time. To avoid this problem, we define the relative regional adoption rate as the difference of the region's adoption rate from the mean adoption rate at each point in time

$$\mathrm{RRAR}_{kt-1} = \mathrm{RAR}_{kt-1} - \frac{\sum_{j=1,\ldots,M} \mathrm{RAR}_{jt-1}}{M}, \quad (4.4)$$

where M is the number of regions. We begin with an estimate of a simple model of the effect of the relative regional adoption rate on a banks' decision to adopt:

$$a_i^1(t) = a_0^1(t)\exp(\beta \mathrm{RRAR}_{it}). \quad (4.5)$$

The estimated coefficient on RRAR in hazard ratio form is 3.91 (Table 2). The hazard ratio interpretation of the estimated coefficient β is that a one-unit increase in the exogenous variable (RRAR) increases the hazard by $100(\beta - 1)$ percent. Since RRAR is a difference in percents, the hazard in a region where the proportion of banks that have adopted was one percent above the average in the previous month would have an increased adoption hazard of 3.91-1=2.91 percent. This is a quantitatively large network spillover, in part because the RRAR spread between regions differed by tens of percentage points during some time periods.

Next we look at whether the size of the bank, as measured by the relative amount of check volume processed through the Reserve Banks around the time of adoption, has an important influence on the decision to adopt. To do this we estimate a quadratic function of both the relative regional adoption rate and bank size. To remove the influence of units on the estimated coefficients, we define VOL as the logarithm of the estimated six-month check volume for the bank minus the logarithm of the mean overall check volume across all banks at the time they adopted. Then we define and estimate a simple quadratic function of the two variables.

$$a^2(t) = a_0^{\,2}(t)\exp(\beta_1 \text{RRAR} + \beta_{11}\text{RRAR}^2 + \beta_{12}\text{RRAR} * \text{VOL} + \beta_2 \text{VOL} + \beta_{22}\text{VOL}^2).$$

Model 2 has a much better fit than Model 1 as evidenced by the LR chi2 statistic (Table 3). In addition, we find that the network externality remains significant after allowing for increasing or diminishing effects of the relative regional adoption rate and controlling for banks' check operations size. The estimated coefficients on $RRAR$ and $RRAR^2$ support the same conclusions about the positive network externality in the previous simpler model, but show that the strength of the externality tends to diminish as the relative regional adoption rate increases. The coefficients on *VOL* and VOL^2 show that banks with larger check operations had higher adoption hazards, but the coefficient on the squared term shows that effect diminished as size increased. Finally, the interaction between RRAR and VOL suggests that the combination of a high RRAR and a high VOL diminishes the risk of adoption, suggesting a negative correlation between the risk factors. It is hard to be sure what this means, but possibilities include the idea that a larger bank may be more likely to reach a decision to adopt based on internal factors, while smaller banks may be more influenced by the network spillover.

Examination of the estimated baseline adoption rate $\hat{a}_0^2(t)$ after accounting for how the relative regional adoption rate (RRAR) and check operations size (VOL) of a bank help to discern how changes over time, particularly prices, influenced the adoption rate of banks (Figure 7). There is a hump in the middle of the baseline adoption rate corresponding roughly to the rise and fall in the volume of substitute checks. This suggests that when the volume of substitute checks was high, there were slightly greater pressures on banks to adopt Check 21 (including a price discount on electronic check deposits for banks that accepted electronic checks as well). The baseline hazard shoots higher in the last year and a half of the analysis period. This corresponds to a rapidly rising price of paper checks. By June of 2012, the cost of depositing checks in paper form was greater than $2.00 per check, already100 times the $0.002 cost of processing a paper check during the heyday of paper check processing. This is where the parametric portion of Model 2 does least well at explaining the hazard, and where price likely had the greatest independent influence on the adoption decision of remaining banks.

6. Conclusions

The Check Clearing for the Twenty-First Century Act (Check 21) created a new paper payment instrument called the substitute check. While the substitute check was never the end purpose of the law, it was the means to the end purpose of electronic check clearing. The substitute check embodies the essential compromise necessary to obtain passage of the law. In this paper, we looked at the transition from paper to electronic processing of checks. While legal and regulatory reforms were necessary for this to occur, correctly aligning banks' incentives was also necessary for the transition to occur efficiently. By striking a balance between encouraging the adoption of new technology and ensuring that the benefits of doing so outweigh the costs, the Check 21 legislation smoothed the transition.

We constructed an empirical model of banks' adoption decision that contains a clear path for network economies to affect this decision. A straightforward nonparametric application of the model to cross-regional differences in adoption rates showed that the network spillovers were large.

It is well understood that holdup problems can occur when network effects are large. We find that the combination of judicious regulation, a bridge technology and price incentives combined with a strong network externality allowed for the transformation of check processing technology from paper to electronics in an unexpectedly short time. The experience suggests that in network industries regulations and policies can be designed that encourage technology adoption without mandating the use of the new technology and without creating winners and losers or large transformation costs. In the case of Check 21, banks were able to adopt at their own pace. The banks with greatest benefits from adopting had incentives to bear the costs of learning by doing and to share their knowledge with other banks.

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8. Figures and Tables

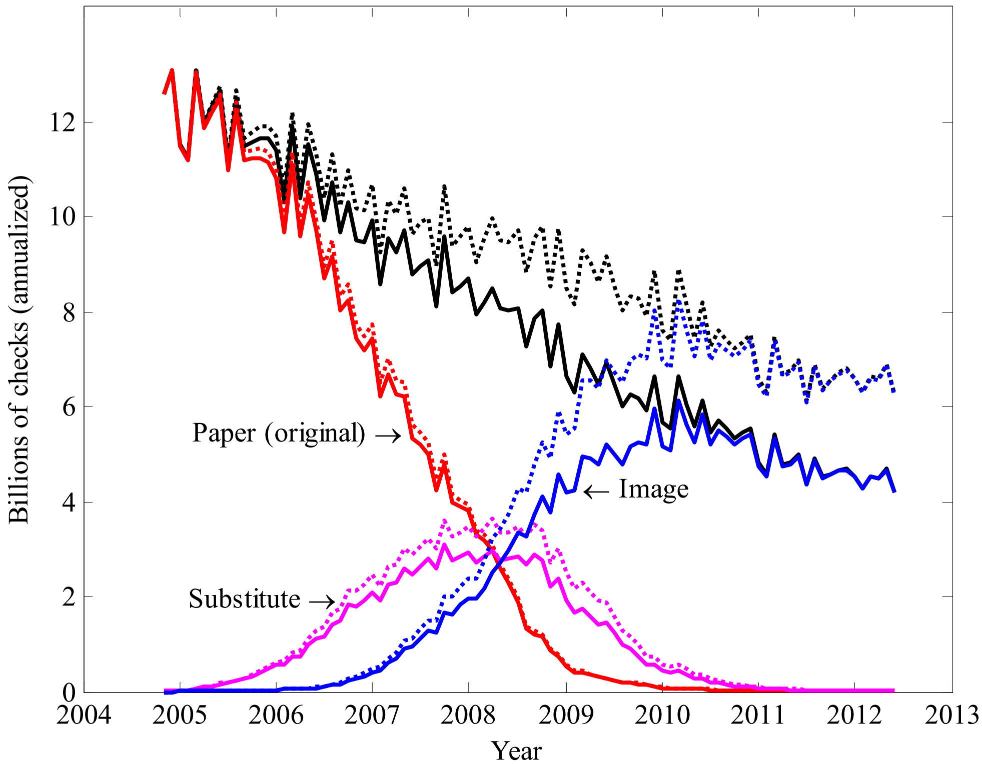

Figure 1: TOTAL CHECK VOLUME OF RESERVE BANK CUSTOMERS BY DEPOSIT PRODUCT TYPE, ALL CUSTOMERS (DOTTED LINES) AND NOV 2004 CUSTOMERS (SOLID LINES). Paper (original) refers to checks that were deposited in paper form (typically the original check), Image refers to checks that were deposited and presented as electronic images, and Substitute refers to checks that were deposited as images and presented in paper form as substitute checks. The paper deposit product type does not distinguish whether the deposited check is an original check or a substitute check, nor does it distinguish between the electronic or image presentment types.

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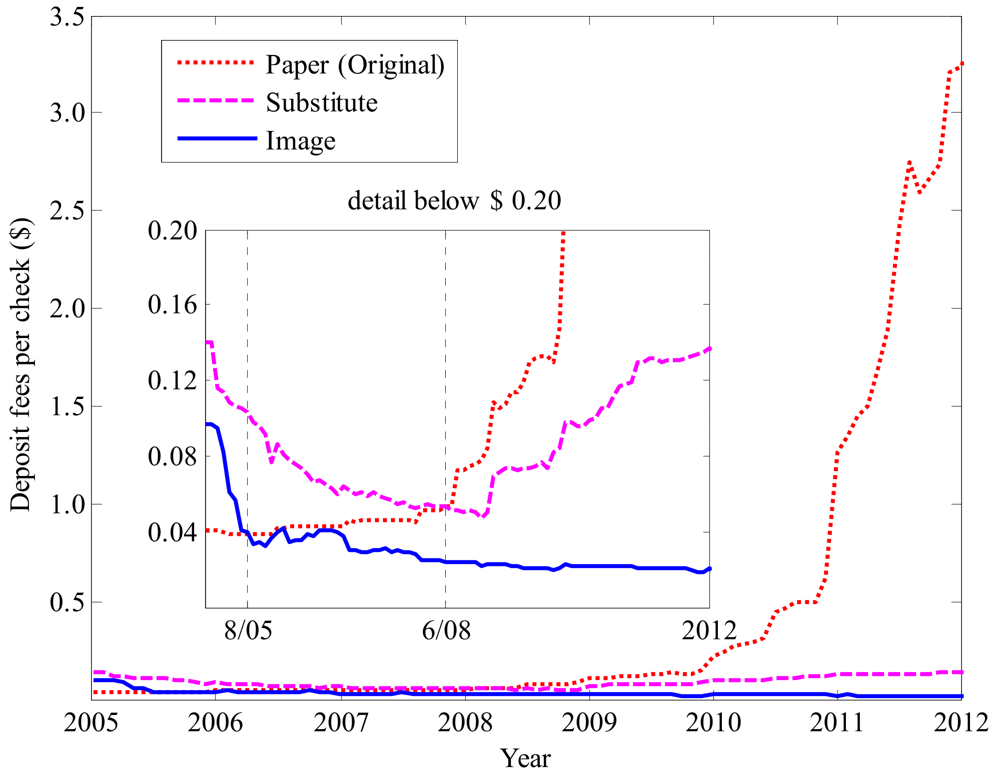

Figure 2: AVERAGE DEPOSIT FEES PER CHECK BY TYPE OF DEPOSIT. The figure shows how the deposit fees billed to Reserve Bank customers changed from November 2004 to June 2012. Deposit fees are broken down by type of deposit into a monthly service charge, a per transaction (deposit or "cash letter") fee, and a per item fee. There was a substantial rise in the average cost of depositing checks in paper form starting around 2010, coinciding with the loss of scale economies due to the shrinking of paper processing volume to negligible levels. The insert is a version of the plot with the y-axis rescaled to display the detail at average fees below $0.20. The average cost of depositing paper began to exceed the cost of depositing by image and presenting by image around August 2005, and began to exceed the cost of depositing by image and presenting by substitute check around June 2008. The cost of presenting by substitute check began to rise after the peak volume because of loss of scale economies, but has stayed below the cost of depositing paper.

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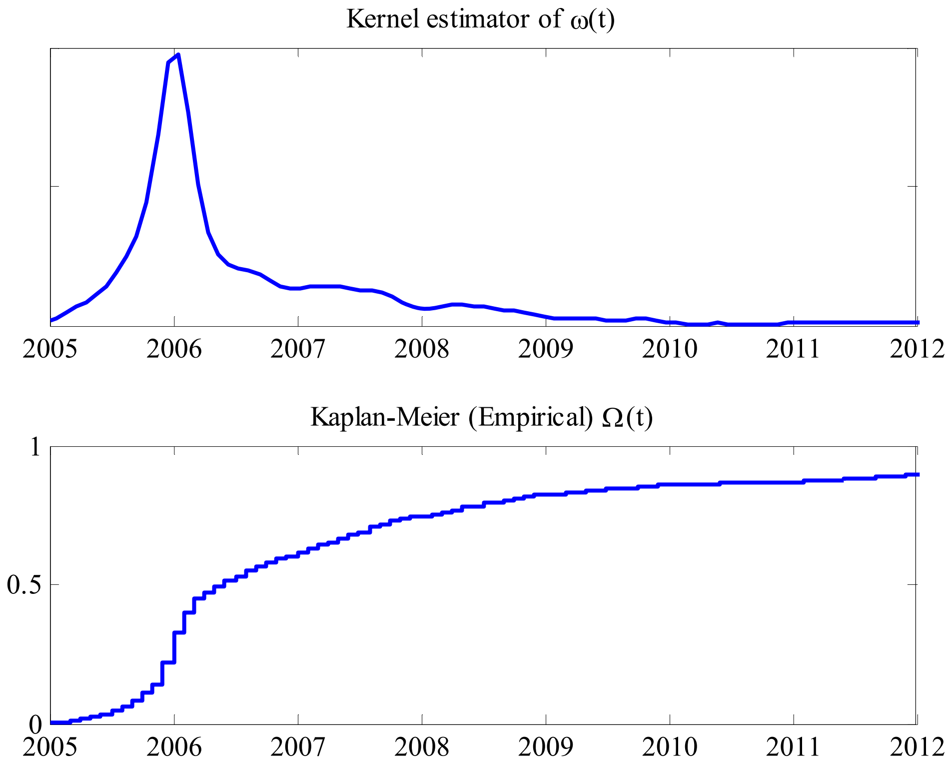

Figure 3: KERNEL ESTIMATOR OF THE UNCONDITIONAL PROBABILITY DENSITY $\omega(t)$ AND THE KAPLAN MEIER ESTIMATE OF THE UNCONDITIONAL CUMULATIVE DENSITY $\Omega(t)$. The figures show the nationwide distribution of adoption over time. The rate of adoption peaked in early 2006 and then dropped suddenly midyear, as shown in the probability density plot above. The probability density is skewed to the left, indicating intensive early action followed by a gradual tailing off of adoption by 2010. The cumulative density displays the technology adoption "S-curve". The curve shows that by mid-2006 half of the banks that were using Reserve Bank check services had adopted check image deposit.

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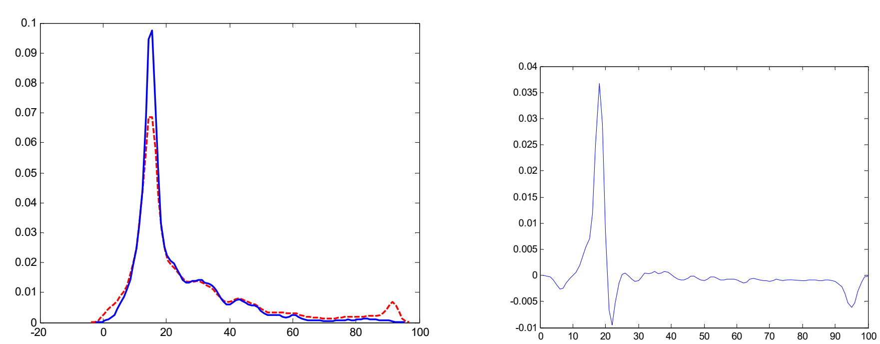

Note: Plot overlaying pdf if the censored observations were treated as adopters, and the diff. (Not cited in text.)

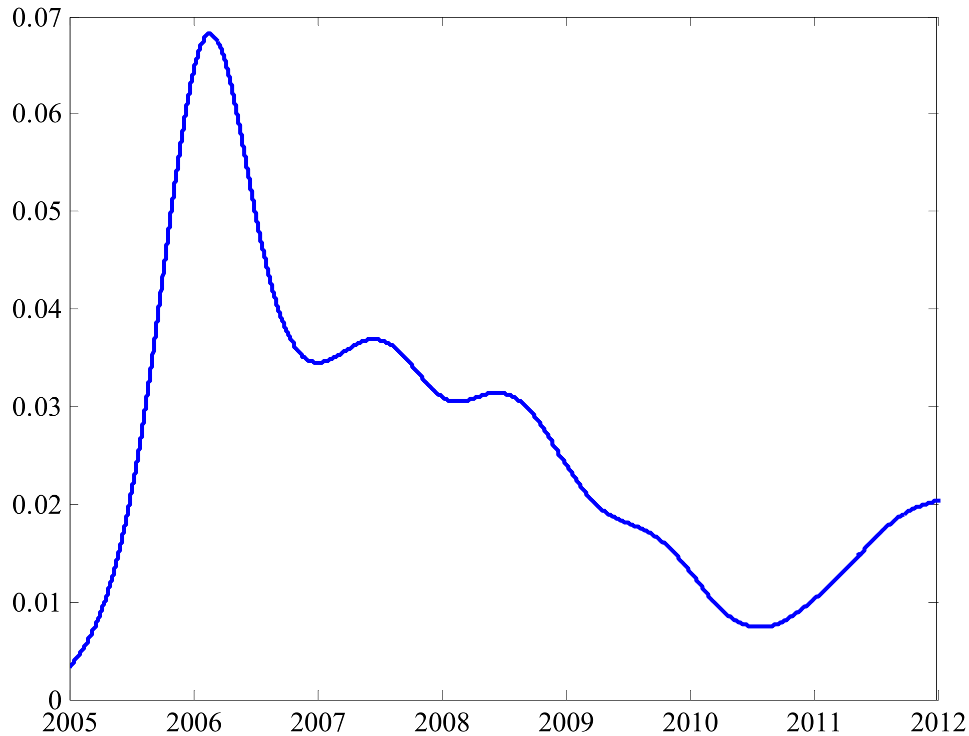

Figure 4: NONPARAMETRIC ESTIMATE OF THE ADOPTION FUNCTION SHOWN IN EQUATION (3.8). The adoption function gives the odds of adopting at a point in time conditional on having not adopted in the past.

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Notes: This graph, generated with Matlab, seems more revealing than the Stata version of the hazard which must have been generated with a very wide window.

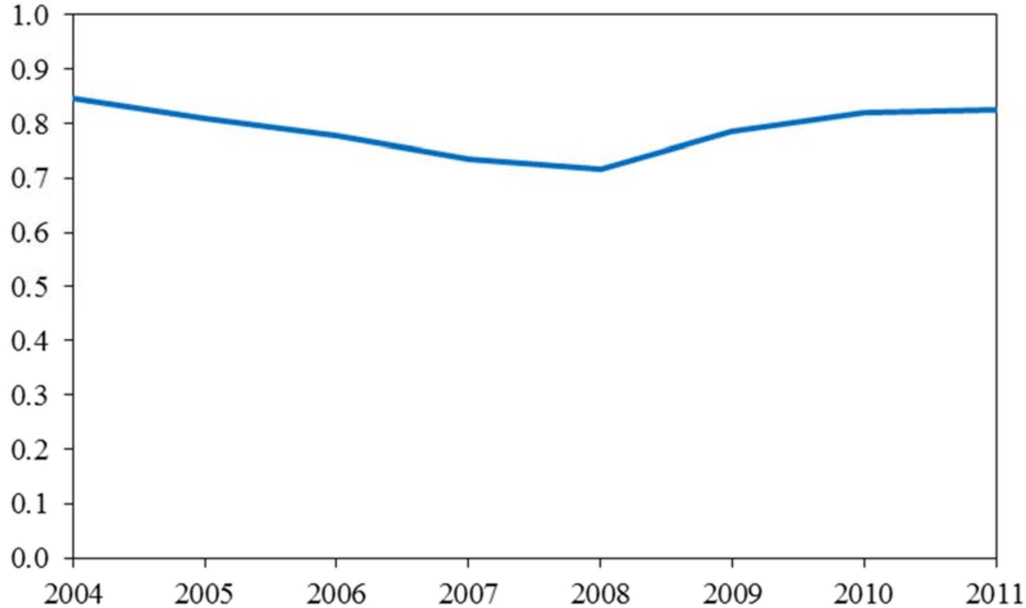

Figure 5: PERCENTAGE OF LOCAL CHECKS PROCESSED BY THE RESERVE BANKS. There was a steady decline from 85 percent in 2004 to about 72 percent in 2008. Then the proportion began to rise again and leveled out at about 80 percent. Source: Federal Reserve CORE data on the number of inter-regional and total checks.

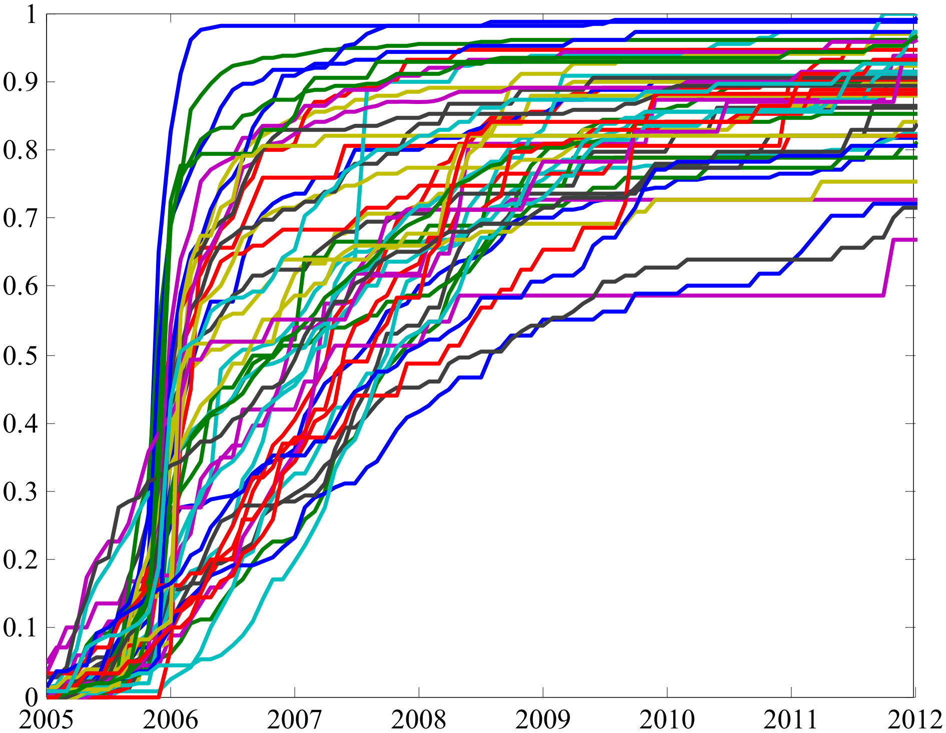

Figure 6: EMPIRICAL CUMULATIVE DENSITIES OF CHECK IMAGE DEPOSIT ADOPTION BY FEDERAL RESERVE REGION. These can be thought of as technology adoption S-curves for each region. It is evident that some regions adopted faster than others. By August, 2006 half of the regions had exceeded a 50 percent adoption rate.

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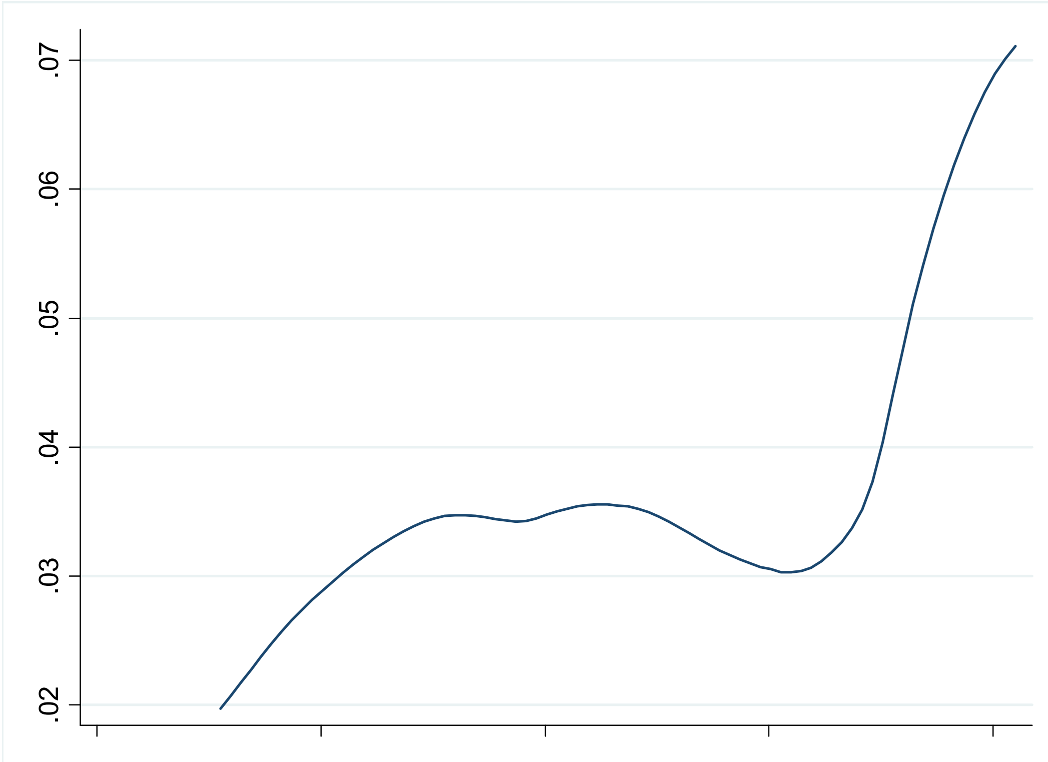

Figure 7: The kernel-smoothed estimate of the baseline adoption hazard function for Model 2, the results of which are shown in Table 3. This baseline adoption $\hat{a}_0^2(t)$ differs from the nonparametric hazard function shown in Figure 4 by the portion of the adoption risk that is captured by the estimated parametric portion of the model. The X and Y axes are on the same scale as Figure 4l and a visual comparison shows that most of the adoption is explained by the parametric proportion. The parametric portion does least well in the final year. The rise in the hazard on the right of the graph is likely due to substantial increases in the price of clearing checks using the old paper-based technology.

Variables	Mean	Standard Dev	Min	25th Perc	Median	75th Perc	Max
Region	23.056	12.949	1	13	24	33	46
Abadur	26.639	20.420	1	14	18	33	92
Abaevent	1.189	0.442	0	1	1	1	2
Strictnadopt	91.627	96.754	0	22	63	119	477
Strictn	222.311	146.225	0	119	175	275	654
Strictprop	0.419	0.305	0	0.134	0.379	0.689	0.997
Crso	4.320	2.857	0	2	3	6	9
Pprice	0.230	0.761	0	0.039	0.042	0.046	4.105
Iprice	0.035	0.014	0	0.029	0.035	0.040	0.097
Sprice	0.082	0.025	0	0.064	0.076	0.096	0.197
Sumdur	24.513	20.138	1	14	16	30	92
Sumevent	1.085	0.580	0	1	1	1	2
Loosenadopt	95.474	98.052	0	29	65	124	490
Loosen	222.102	148.030	0	121	177	275	654
Looseprop	0.433	0.299	0	0.162	0.377	0.710	0.997
Strictproprel	-0.003	0.165	-0.430	-0.103	-0.011	0.073	0.551
Looseproprel	-0.006	0.149	-0.458	-0.094	-0.012	0.060	0.469
Sumtotvol	675593	3729593	-21264	16114	99919	291418	77794562

Table 0: Some statistical properties of the dataset.

	2007						2010					
	National Survey (Receipts)		Reserve Bank (Deposits)				National Survey (Receipts)		Reserve Bank (Deposits)			
			All Customers		Nov 2004 Cohort				All Customers		Nov 2004 Cohort	
Total	23.1		10.2	44%	9.4	41%	17.7		7.79	44%	5.81	33%
Paper (Original)	13.3	58%	6.77	66%	6.5	69%	0.6	3%	0.05	1%	0.05	1%
Substitute	3.0	13%	2.66	26%	2.3	24%	0.8	4%	0.41	5%	0.32	5%
Image	6.8	29%	0.75	7%	0.6	7%	16.3	92%	7.34	94%	5.45	94%

Table 1: National survey estimates of the total number of checks and checks by category during March and April of 2007 and 2010. Reserve Bank figures are computed for the same months for comparability. The table allows comparison of totals on the receipt side compared with the total number of checks and checks by category processed by the Reserve Banks on the deposit side. There are two categories of Reserve Bank customers; (1) all customers; and (2) the cohort of customers that used Reserve Bank check services in November 2004, the month that Check 21 went into effect. The figures are in billions (annualized). The percentages on the Total line are estimated proportion of all interbank checks. The percentages on the lines below are calculated proportions by type of check. Note that proportions of receipts and deposits are not directly comparable because some of the original check deposits could have been presented in substitute check or image check form. The 2007 national survey figures are from Table 6 on page A91 in (Gerdes, 2008). The 2010 national survey figures are calculated by one of the authors using the underlying data reported in (Federal Reserve System, 2011). Excludes U.S. Treasury checks and postal money orders.

Source: G:\STUDIES\geoff\Network Paper\KEH\Programs\Final\All fed customers\fig1.m and G:\STUDIES\geoff\Network Paper\Paper\NETCC21.xlsx (Table 1)

Cox regression – Breslow method for ties

Number of subjects	7,670	Number of observations	7,670
Number of failures	5,902	LR chi2 (1)	287.02
Time at risk	204,323	Prob > chi2	0.0000
Log likelihood	-48,105.656		

_t	Hazard Ratio	Standard Error	P > |z|
β	3.91	(0.309)	0.000

Table 2: ESTIMATED PROPORTIONAL HAZARD MODEL 1. The coefficient β, in hazard ratio form, is the estimated effect of the relative regional adoption rate on the probability that a bank will adopt, given that it has not adopted yet. The interpretation of β is that a one-unit increase in the relative regional adoption rate increases the adoption "hazard" by (3.91-1) = 291 percent.

Cox regression – Breslow method for ties

Number of subjects	7,651	Number of observations	7,651
Number of failures	5,902	LR chi2 (1)	5,006.47
Time at risk	203,886	Prob > chi2	0.0000
Log likelihood	-45,731.823		

_t	Hazard Ratio	Standard Error	P > |z|
β_1	3.48	(0.363)	0.000
β_{11}	0.34	(0.106)	0.001
β_{12}	0.84	(0.043)	0.001
β_2	1.20	(0.014)	0.000
β_{22}	0.98	(0.002)	0.000

Table 3: ESTIMATED PROPORTIONAL HAZARD MODEL 2. Controlling for size does not diminish the qualitative magnitude of the network spillover measured in Model 1. Further interpretation is in the text.