A FRAMEWORK TO ANALYZE CASH SUPPLY CHAINS

Divakar Rajamani*, H. Neil Geismar†, Chelliah Sriskandarajah‡

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Abstract

The Federal Reserve System of the United States is making changes to its cash recirculation policy to reduce depository institutions' (banks') overuse of its cash processing services. These changes will affect operating policies and costs at many institutions having large cash businesses and, in turn, impact cash transportation and logistics providers. This study provides the framework to study the cash supply chain structure and analyzes it as a closed-loop supply chain. Additionally, it describes the cash flow management system used by banks in the U.S.

Key Words and Phrases: cash supply chain, Federal Reserve System, depository institutions.

1 Introduction

Studies indicate that cash is the most widely used day-to-day consumer payment mechanism, while high-value commercial transactions, which are fewer in number, are often made electronically. Cash is expensive to transport, handle, and store, and is usually the least automated of the major payment mechanisms [1]. Cheques are the next most expensive and un-automated mechanism. Debit card transactions and wire transfers are usually the most automated. Even with the introduction of smart cards and electronic cash, electronic transactions have not replaced the use of cash. For example, "in the U.K. cash is the dominant payment method in volume terms. Nearly three in four of all personal payments are made by cash." The forecast is that 66% of all personal payments in 2011 will still be made by notes and coins [2]. In the U.S. there has been a 76% increase in cash circulation since 1990 [7].

*University of Texas at Dallas; divakar@utdallas.edu
†Prairie View A&M University; hngeismar@pvamu.edu
‡University of Texas at Dallas; chelliah@utdallas.edu

Cash has distinct benefits over other payment systems. Specifically, cash is an anonymous means of payment without record; thus, the user can maintain his privacy. Unfortunately, this characteristic also helps sustain the "black" markets. Cash is the only means for transactions that requires no bank account; hence, it is used prevalently in rural areas. Even in the United States, despite the volume of internet transactions, there is a high percentage (9 to 10%) of consumers who do not have bank accounts [1]. Disadvantages of cash include the risk of loss, the possibility of counterfeiting, and its unsuitability for on-line transactions. The amount of cash in circulation continues to grow across all major currencies, including the euro, the pound, the yen, and the Australian, New Zealand, and U.S. dollars. The Federal Reserve Bank (Fed) of New York has estimated that by 2010 the value of U.S. cash in circulation will exceed US$1000 billion (currently it is $690 billion, up from $492 billion five years ago) [1]. While it is likely that more and more payrolls will be automated via direct deposit, there are indications of an increase in the amount of cash circulated through ATMs. There was a 200% increase in the number of ATMs in the U.S. between 1996 and 2003. This led to a corresponding growth in the need for *fit cash*, i.e., cash whose condition makes it suitable for circulation to the public. The Fed spends about $387 million on cash recycling operations annually. One of the reasons for this increased spending is that 30-50% of the cash deposited to the Fed is reordered by the same banks in the same denominations in less than 5 days [7], i.e., it has a high velocity.

From the above it can be inferred that many resources–both public and private–are devoted to the transport and handling of cash as it circulates through the economy. Hence, study of the cash supply chain could lead to greater efficiency in a necessary and costly business activity. This paper results from our work with Brink's, Inc., (provider of secure transportation and logistics) to assess the economic impact that banks will sustain from a proposed Federal Reserve System policy on cash circulation. In this context, we analyze the United States' cash supply chain from the perspective of closed-loop supply chains. This is intended to provide a foundation for future work that will evaluate banks' strategic options and how the Fed can structure its policy in order to encourage banks to cooperate with the spirit of this new policy.

Given that the Fed policies discussed herein are recently proposed, there has been no previous study of a bank's optimal responses to them. Furthermore, we know of no published study of

the cash supply chain. There have been several studies of cash management and balancing by firms, including early qualitative work by Whistler [38], Eppen and Fama [12, 13], Girgis [17], and Neave [29]. Following Vial's [37] formulation of the problem in continuous time, Constantinides [10] and Constantinides and Richard [11] consider systems with stochastic demand, fixed and proportional transaction costs, and the possibility of negative balances. They use optimal control, specifically impulse control, to prove that there always exists an optimal policy with a simple form. Smith [33] builds upon this work to provide closed-form expressions for the forward-looking, time varying targets and thresholds for special cases.

The outline of this paper follows. Section 2 briefly summarizes the closed-loop cash supply chain and reviews some of the literature on closed-loop supply chains. Section 3 discusses the basic components of the U.S. cash supply chain structure. For the sake of comparison to the U.S. cash supply chain, Section 4 presents other models for the cash supply chain and examples of these models from different countries. Section 5 describes the cost components that must be considered in cash supply chain management. Section 6 specifies the Fed's new cash recirculation policy. Sections 7 compares the cash supply chain to the general closed-loop supply chain framework. Section 8 concludes this study and makes recommendations for future research.

2 Closed-Loop Cash Supply Chain

Rather than being distributed in one direction as most consumer products are, cash circulates through our economy. Notes are supplied by the Bureau of Engraving and Printing (BEP), the Federal Reserve controls its release into the economy, and it is distributed by armored carriers such as Brink's to banks who act as wholesalers that provide cash for businesses and consumers. Through transactions among themselves, businesses and consumers redistribute these notes so that some parties have excesses, which they deposit at a bank for safety and to earn interest (from the bank) for themselves. Banks in turn deposit cash with the Fed so that they, too, can earn interest (from the Fed). Furthermore, banks accept from the public notes whose physical quality (wear, soil, tears) is less than the quality of the notes that they dispense. Thus, banks must exchange low-quality notes for high quality notes from the Fed. In these and several other ways,

cash moves up and down its supply chain. Hence, cash flows can be analyzed as a closed-loop supply chain.

Most studies of closed-loop supply chains focus on a particular sub-field. Fleischmann et al. [15] provide an overview of *reverse logistics* and subdivide the field into three main areas which parallel topics in the mainstream supply chain literature: distribution planning, inventory control, and production planning. Subramaniam et al. [36] summarize strategies and implementation issues for reverse logistics. Guide [18] surveys production planning and control activities at *remanufacturing* firms and describes uncertainties and complicating characteristics specific to this sector, including the need to evaluate the quality and reusability of recovered materials. Guide and van Wassenhove [20] develop a framework for analyzing the profitability of reuse activities in remanufacturing. Inderfurth and Teunter [23] expand Guide's [18] work by applying it to disassembly and material recovery (*recycling*), *external returns*, and *rework*.

Although businesses generally have focused on the operational aspects rather than the larger strategic issues [19], several studies have addressed planning a reverse-logistics network. To find the appropriate reverse channel structure for the collection of used products from customers, Savaskan et al. [30] model the problem as a decentralized decision-making system with the manufacturer being the Stackelberg leader. Min et al. [28] propose a Lagrangian relaxation heuristic for solving the return center location problem. Schultmann et al. [31] use a hybrid approach that combines optimization and flow-sheeting. Beamon and Fernandes [6] employ a multi-period integer programming model to optimize warehouse locations, allocation of capabilities to warehouses, and transportation of materials between sites under various cost structures.

There have also been several practical studies of closed-loop supply chains as they are used for particular products: refrigerators [27], batteries [31], electronic scrap [34], and PC's [26]. Additionally, some have been based on work with particular companies, including IBM [16], Agfa-Gevaert [35], and Visteon [24].

3 U.S. Cash Supply Chain Structure

The U.S. cash supply chain, like all other sectors' supply chains, consists of the 4-P (Product, Players, Processes and Policies) components. We describe these for the cash supply chain.

3.1 Product

In its physical form, the Fed classifies cash into four basic categories. See Figure 1. *New cash* is currency that the Fed introduces into the cash supply after receiving it from the BEP. Once in this supply, the cash belongs to one of the three remaining categories which together comprise *used cash*. The first category of used cash is called *ATM-fit cash*, which contains notes that are of sufficient quality to be dispensed via ATMs. The second category of used cash is called *non-ATM fit cash*, which is suitable for most transactions, but not for ATMs. New cash, ATM-fit, and non-ATM fit cash are often referred to collectively as *fit cash*. The final category is *unfit cash*, which is soiled, torn, or defaced, and is therefore unacceptable for circulation and will be destroyed by the Fed. Because coins are significantly less perishable and have lesser value, the policies and challenges in dealing with them are very different and not considered in this paper.

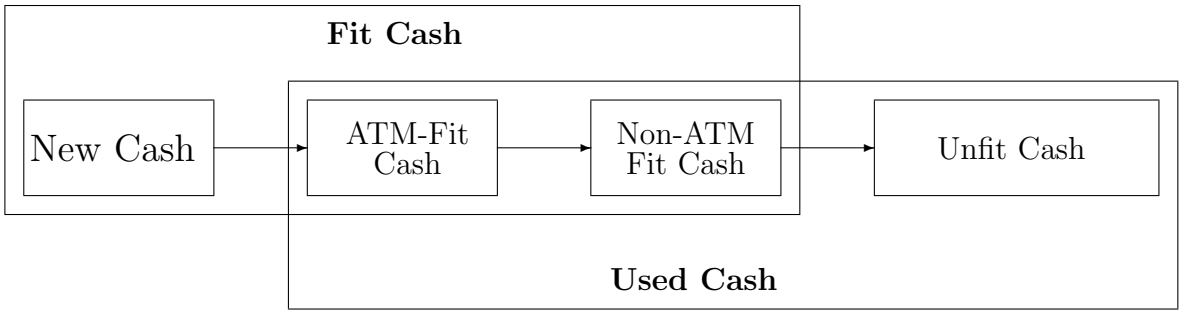

Figure 1: Cash life-cycle

3.2 Players and Processes

The key players are listed below with a brief description of their roles in the cash supply chain. Figure 2 graphically represents this supply chain. Note the labels at the top that indicate its

parallels to the standard supply chain model.

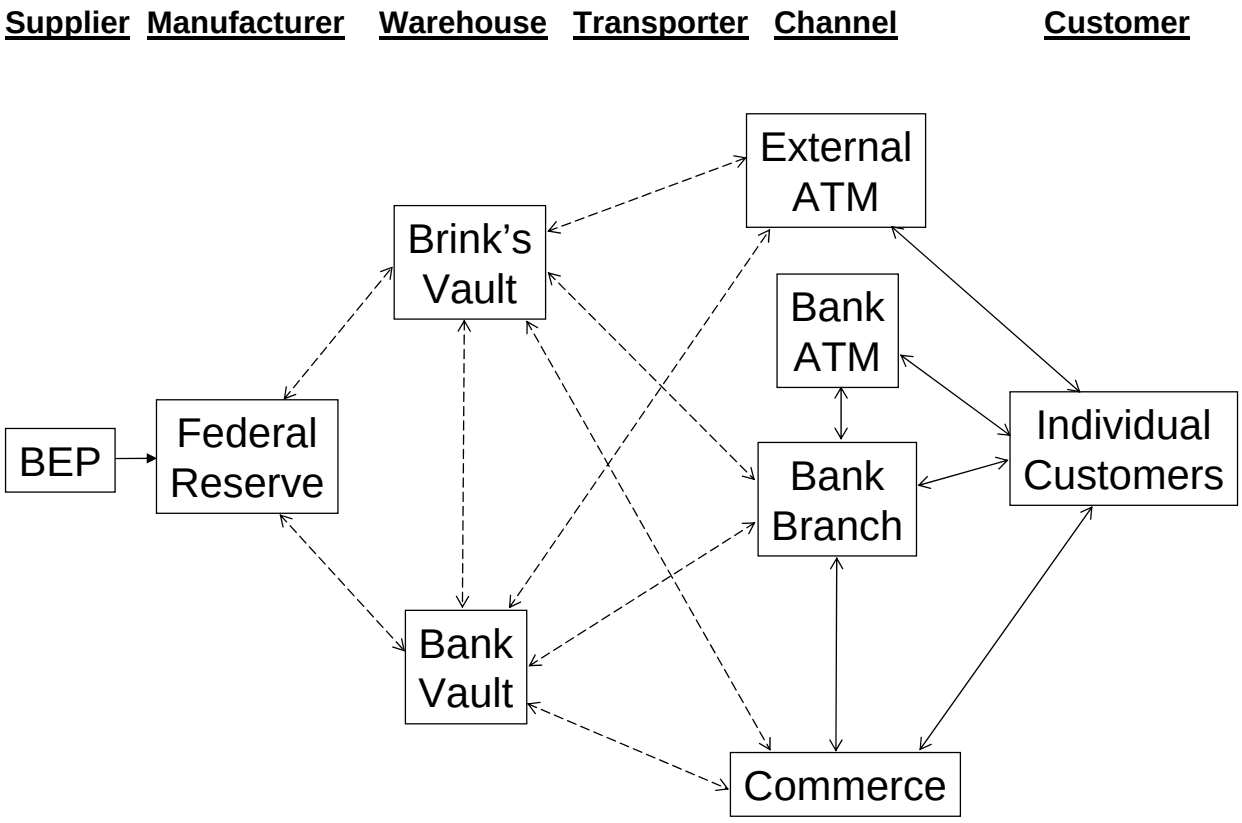

Figure 2: The circulation of cash in the physical cash supply chain. Dashed lines indicate transfers by Brink's or some other commercial provider.

1. **Fed:** The Fed orders currency from the BEP, which is responsible for printing the cash to meet the Fed's requirements. The Fed is then responsible for distributing cash to the public, for final authentication (including testing used cash for reuse versus replacement), for removing counterfeit cash, and for the destruction of unfit cash. The Fed receives deposits from Bank Vaults and from Brink's Vault. The Fed also provides fit cash to Brink's Vault and to Bank Vaults when they make withdrawals. To perform these duties,

the Fed often must *fit-sort* deposits, i.e., separate used cash into ATM-fit, non-ATM fit, and unfit cash (evaluating the quality and reusability of recovered materials [18]). There are twelve Federal Reserve Banks in the U.S. Each serves its particular geographic zone.

2. **Brink's Vault** and **Bank Vault:** After receiving fit cash from the Fed, each vault distributes it to Bank Branches, ATMs, and Commerce. Each vault also receives used cash from Bank Branches, ATMs, and Commerce. The Brink's Vault may distribute fit cash to the Bank Vault and may receive used cash from the Bank Vault. After receiving the used cash, each vault counts it and sorts it by denomination. The vaults may fit-sort the used cash, but at present they have little incentive to do so. The used cash is generally deposited to the Fed. If the vault does fit-sort it, then the resulting fit cash will be returned to the Bank Branch or deposited to the Fed.

3. **Transporters:** Transporters or logistics providers such as Brink's perform all movements of the cash to and from the vaults. These movements are denoted in Figure 2 by dashed lines.

4. **Bank Branch:** A Bank Branch provides services to Customers and Commerce by receiving and dispensing cash. If a Bank Branch does not have a vault, then it does not function as a storage or sorting point. In this case, all funds are transferred to the Bank Vault (or Brink's Vault) at the end of each day.

5. **ATM:** Customers can make deposits and withdrawals at ATMs. If the ATM is inside a Bank Branch, then the cost of moving cash to and from it is zero. If the ATM is not in a Bank Branch, then it is served either by the Bank Vault or the Brink's Vault. These external ATMs can be located in different places such as shopping malls and stores.

6. **Customers:** The customers are individuals who satisfy their cash needs directly from a Bank Branch or from either type of ATM. The customers can make both deposits and withdrawals.

7. **Commerce:** Commerce represents businesses, especially retailers. These firms make deposits and withdrawals at Brink's Vault, a Bank Vault, or a Bank Branch. For large businesses, e.g., Wal-mart, the transfer of cash to a vault is performed by Brink's or another transporter.

3.3 Policies

The Federal Reserve dedicated 15% of its total budget for 2003 to currency management operations [7]. This large amount was required because rather than recycling the used notes received from their customers, many banks deposit those notes to a Federal Reserve Bank and concurrently order fit cash from that Federal Reserve Bank to fill their customers' needs. The Fed calls this practice *cross-shipping* and defines it as follows [3]:

> If [a depository institution] deposits fit cash with [the Fed, it] may not order cash of the same denomination within five business days prior to or following the deposit of that denomination. This practice, known as "cross-shipping," is not permitted at the depositing office [bank branch] level. When practicable, cross-shipping should be minimized or eliminated at the depositing institution [bank vault] level.

Recall that the Fed estimates that 30% to 50% of the currency withdrawn from the Federal Reserve System is cross-shipped.

In response to this rise in expenses, the Federal Reserve System is making changes to its cash services policy. The Fed's intent is to minimize the societal cost of providing cash to the public by encouraging banks to recycle the cash that they receive from customers' deposits. In terms of closed-loop supply chains, the Fed's intent is to move the inspection, the certification for reuse, and the recycling to points lower in the supply chain.

This new policy would reduce the Fed's expenses in three ways. First, the Fed would handle fewer transactions, thereby lowering its labor costs. Second, if banks recycle cash rather than cross-shipping, less cash will be in transit, so less will be needed in the total economy, which will reduce the Fed's printing expenses. Third, to recycle deposited cash, banks must fit-sort it,

rather than passing this task onto the Fed. How the Fed plans to implement its new policy is discussed in Section 6.

4 Cash Supply Chains in Other Countries

As in any supply chain, the velocity or frequency of cash handling, the cost of circulating cash, and the quality (fitness) of cash indicate the efficiency, resilience, and robustness of the cash supply chain. The structure of a cash supply chain is largely dictated by the policy of the central bank in that country. Traditionally, central banks are viewed as being responsible for all aspects of cash circulation: make, issue, move, store, receive, sort, authenticate, and destroy. In response to the increase in ATMs, the rising demand for fit cash by businesses, and the overall increased use of cash within economies, the central banks of many countries have increased their capacities, and the cost of providing currency services has risen as well. This has led governments to promote various cash supply chain business models. These models are differentiated by the currency services offered by the central bank. In a privatized system such as Australia's or South Africa's, the central bank furnishes new cash and destroys unfit cash, but provides no other currency services. The reader may refer to Carlin [8, 9] for a detailed look at the Australian cash supply chain model. The U.K. and Canada run semi-privatized systems; their central banks provide more currency services than does Australia's, but they do not allow cross-shipping. They also allow balance sheet relief, which performs a function similar to that of custodial inventory [7] (described in Section 6). Currently, the Federal Reserve of the U.S. handles all currency services in a centralized model, much like the central banks of Germany, Poland, and France. However, with its new cash circulation policy, the Fed encourages the depository institutions to recirculate the cash; hence, the U.S. is attempting to move from centralized to semi-privatized mode. This trend toward privatized models is common to several countries [7]. The various business models adopted by different countries can be classified as shown in Table 1.

For comparison, the reader may refer to Simchi-Levi et al. [32] for details on designing and managing supply chains for various industry sectors, or to Guide and van Wassenhove [22] for similar information on closed-loop supply chains.

Business Model	Centralized	Semi-Privatized	Privatized
Services	All currency services.	Balance sheet relief. No deposit facility.	No currency services. No balance sheet relief.
Cash Policy	Circulate and process all cash.	Circulate new cash and cash that is not needed for a week.	Destroy unfit cash. Circulate new cash, but not reusable cash.
Country	U.S.A., France	Canada, U.K.	Australia, South Africa

Table 1: Cash supply chain models of various countries [7]

5 Cash Supply Management: Banks' Costs

Cash circulation is mainly driven by the demand for cash by customers for transaction purposes. Banks face the usual dilemma when setting their cash inventory level: they must hold a sufficient amount to meet customer demand at all times, but they also want to minimize the amount held, since cash in inventory generates a cost of lost opportunity. The demand for cash varies considerably within a week, within a month, and within a year, as well as varying between branch locations for a particular bank and between main offices of different banks. Some bank branch offices are net cash recipients, while others are net cash suppliers.

An effective cash supply chain must reduce the cost of circulating cash throughout the entire lifecycle. We now enumerate the various costs that banks face at different stages in the cash supply chain:

1. **Transportation:** The transportation cost is computed by multiplying the number of bundles of bills moved by the number of miles traveled, by the carrier's transportation fee. This fee is fixed within a Fed region. A bundle consists of 1000 bills.

2. **Sort and Count:** Sorting by denomination and counting the cash occurs only at the Brink's Vault or a Bank Vault. The cost is computed per bundle and the rate per bundle is fixed.

3. **Fit-Sort:** The cost of separating ATM-fit cash, non-ATM fit cash, and unfit cash in deposits made by customers and commerce is computed per bundle, and the amount of deposited cash that is fit-sorted can be modified at the bank's discretion. Banks may have

a third-party such as Brink's fit-sort their cash. Currently, banks often avoid this cost by depositing unsorted cash to the Fed, which, under the Fed's new policy, may lead to a cross-shipping charge (defined in Section 3.3. See also item 6 below).

4. **In-transit inventory:** The cost of having currency that is not available because it is traveling between locations is computed by multiplying the number of bundles in transit on a given day by the cost of funds, by the number of bills per bundle, and by the bill denominations. *Cost of funds* is an opportunity cost. It is generally the interest rate that the bank could earn if the cash were on deposit at the Fed.

5. **Vault Inventory:** This is the cost of holding inventory either at a Bank Vault, the Brink's Vault, or both, depending on the particular scenario that is being used. This cost is computed by multiplying the number of bundles in the vault at the end of the day by the cost of funds, by the number of bills per bundle, and by the bill denominations.

6. **Cross-shipping cost:** The cost that a bank will incur once the new recirculation policy issued by the Fed takes effect is computed each week by multiplying the cross-shipping fee by the number of bundles that are cross-shipped.

Having discussed the new policy and costs in the cash supply chain, we next address how the Fed will implement this policy.

6 Fed's New Cash Recirculation Policy: Implementation

We have seen that many depository institutions do not recirculate cash, but instead they order fit cash directly from Reserve Banks to meet their customers' demand and deposit those used notes received from their customers to Reserve Banks (see Federal Reserve System, Docket No. OP-1164 [4]). Another factor that leads to overuse of the Fed's cash processing services is that vault cash holdings do not earn interest for the bank, but cash on account at the Fed does. Therefore, depository institutions wish to minimize their vault cash holdings while still maintaining enough fit cash to fill customers' orders. This can be done most effectively by increasing the frequency

of their deposits of cash to the Fed and the frequency of their orders of cash from the Fed, which leads to cross-shipping and increases the Fed's labor costs.

The implementation of the Federal Reserve System's proposed Recirculation Policy has two interrelated components that directly influence banks' costs and, hence, policies: a custodial inventory program and a recirculation fee on withdrawals of cross-shipped cash.

> **Custodial Inventory Program** [4]: One reason that depository institutions engage in cross-shipping is to avoid incurring opportunity costs from holding cash. To mitigate these costs associated with holding cash long enough to facilitate its recirculation, the [Federal Reserve System] proposes to allow the depository institutions to transfer into custodial inventories $5, $10, and $20 notes that they might otherwise cross-ship. A *custodial inventory* is cash owned by a Reserve Bank but located within a depository institution's secured facility and segregated from the depository institution's [operating cash]... Custodial inventories may allow depository institutions to avoid the costs of preparing and transporting their temporarily surplus currency to and from Reserve Bank cash offices.

The cash in custodial inventory can earn interest for the bank and is more quickly available to meet customer demand than is cash from the Fed. Because it may be used to meet demand, custodial inventory contains only fit cash. Additionally, cash withdrawn from the Fed may not be deposited into custodial inventory. Therefore, cash received from customers must be fit-sorted at these banks' expense before it enters custodial inventory.

> **Recirculation Fee** [4]: Because the Federal Reserve System expects that custodial inventories alone will not substantially reduce cross-shipping, it proposes to establish a recirculation fee to provide further incentive for depository institutions to recirculate currency. Based on current levels of Reserve Bank costs, the fee would be $5 to $6 per bundle of cross-shipped currency [i.e., per bundle withdrawn]. Depository institutions would pay the fee when they deposit [fit or non-fit-sorted cash] and order the same denomination within the same business week [within] a Reserve Bank zone. The

> fee would not be [activated by] deposits of... [unfit] cash. The fee also [would not apply to] $50 and $100 notes because these notes are a relatively minor component of cross-shipped cash and, more importantly, the Fed wants to reduce of the risk that depository institutions might recirculate high-denomination counterfeit notes.

Note that the operational definition of cross-shipping differs from the policy's definition (Section 3.3). If the policy were followed exactly, a bank would be required to operate for "five business days prior to or following the deposit" [3], i.e., eleven business days, without making a withdrawal. Apparently the Fed has realized that such a restraint would be unworkable, so it reduced the prohibited period to one week. This new policy will change the behavior of various players in the supply chain, and it might also lead to changes in their business models and in their roles within the cash supply chain.

7 Analyzing the Cash Supply Chain as a Closed-Loop Supply Chain

Having described the United States' cash supply chain, we now analyze it from the perspective of closed-loop supply chains. That it is a closed-loop supply chain was established in Section 2. To perform the following analysis, we first consider the five basic activities that the reverse supply chain adds to the traditional forward supply chain.

The Federal Reserve's lack of competition and that it provides a public good which all individuals and businesses need are partly responsible for the Fed's many advantages when comparing it to leaders of other closed-loop supply chains. For example, the other players bear the entire expense for a majority of the additional activities required for the reverse supply chain [21]; see Table 2. The first activity, *product acquisition* (recovering currency from customers), is easy for the Fed because customers and commerce are motivated to deposit their excess cash, both for security and to earn interest from the bank. The bank pays for the labor required to handle these deposits. The second activity, *reverse logistics*, involves carrying cash from a bank's branches and ATMs to a central location (bank vault or Brink's vault), then transporting the aggregated cash to the Fed. Brink's or another carrier provides the transportation on each leg at the bank's expense. The final activity, *distribution* of fit cash from the Fed to the bank, is performed on

CLSC Activity	Cash SC Activity	Responsible Players
Product Acquisition	Customers & Commerce deposit cash	Customers, Commerce, and Banks
Reverse Logistics	Banks collect from branches and deposit to Fed	Banks and Brink's
Testing, Sorting and Disposition	Sort by denomination Fit-sort	Banks Fed, moving to Banks
Refurbish	Reuse Destroy	Fed, moving to Banks Fed
Distribution	Return to economy	Banks and Brink's

Table 2: Common closed-loop supply chain activities, their realizations in the cash supply chain, and those responsible for them.

the return trip by the same carrier and also at the bank's expense. In this way, inbound and outbound flows are coordinated, which is key to reverse logistics [14].

Within this framework of closed-loop supply chains [21], the Fed's responsibilities are limited to functions within only two activities. Activity 3, *testing, sorting and disposition* (sorting by denomination is performed by the bank; fit-sorting usually by the Fed), is mechanized and performed according to very specific standards [5]. Activity 4, *refurbishment*, is limited to only two choices: reuse (fit cash) or destroy (unfit cash). These are the only feasible choices because design features that are intended to prevent counterfeiting also make repair or remanufacture of unfit notes impractical. This reduces complexity because remanufacturing processes are often difficult to plan, manage, and control [18]. Furthermore, the Fed's new policies are designed specifically to shift major functions (fit-sorting and reuse) within these two activities to other players within the supply chain. Hence, the Fed is attempting to move to a more privatized cash supply chain model (Section 4) by encouraging banks to act as managers of their own closed-loop systems. If successful, the Fed would only be the banks' source of new cash and their depository for unfit cash. See Figure 3.

The Fed enjoys other advantages that are not available to leaders in many closed-loop supply chains. First, because this closed-loop supply chain is controlled by the Fed – including complete control of the supplier (the BEP) – managerial activities are more similar to those of traditional supply chains; hence, these activities may be classified as easy [22]. Second, used products are

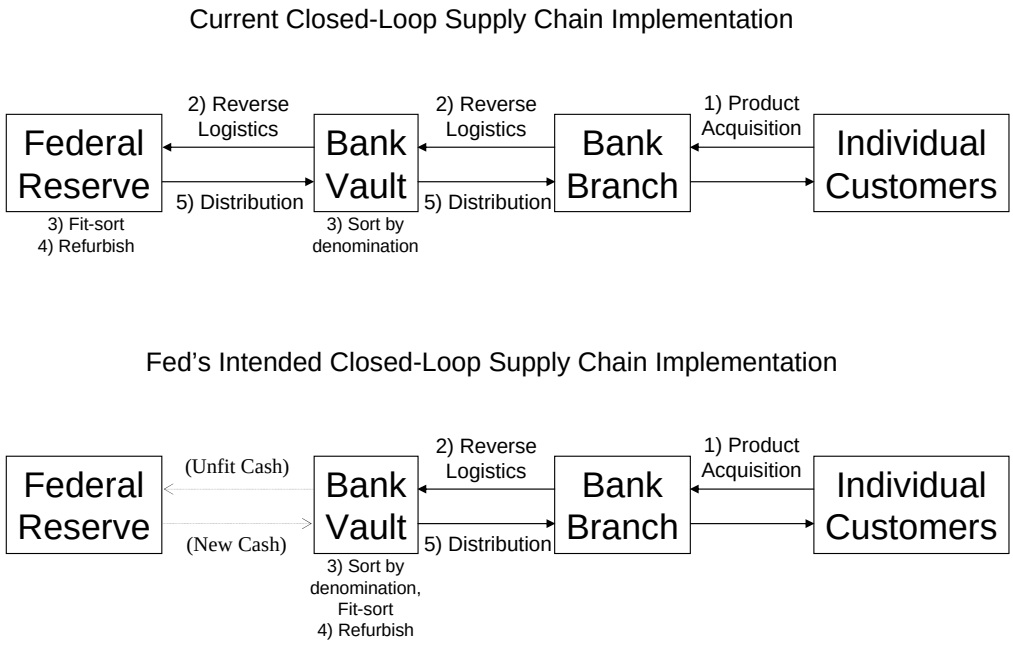

Figure 3: Allocation of Activities within the Closed-Loop Cash Supply Chain

a supply source that is typically variable and difficult to control [14]. However, the flow of used cash back to the Fed is relatively steady with respect to timing and quality. Each depository institution (e.g., Bank One/Chase, First NBC, Wachovia) is allowed only one deposit and one withdrawal at each Federal Reserve Bank per day. Furthermore, the amount of fit cash recovered by fit-sorting used cash is generally close to 75%.

Other features that contribute to stability within this closed-loop supply chain include the shortness of the chain (which reduces the likelihood of the bullwhip effect) [21], the lack of a secondary market, and the limited number of products handled. Additionally, whereas individual notes become unfit, the design of the currency will not become obsolete, except for small changes that have been slowly implemented to strengthen its resistance to counterfeiting. The Fed's new policy may further contribute to stability by reducing the amount of traffic within the supply

chain.

One source of complexity in the cash supply chain is the need for ATM-fit cash that must be of a higher quality than other (non-ATM) fit cash. From studies of closed-loop supply chains handling refillable containers (e.g., disposable cameras [25], printer cartridges [39]), it is known that the supply chain's management can be simplified if consumers do not distinguish between new and used products. Thus, the Fed and, in turn, banks may benefit from the development of an ATM that can dispense bills of a lesser quality.

8 Concluding Remarks

Banks are currently permitted to order and ship cash to and from the Fed at no cost above that for transportation and handling. Cross-shipping is practiced today because transportation costs to and from the Fed are often lower than the cost of funds. The Federal Reserve System is making changes to its cash recirculation policy to reduce depository institutions' (banks') overuse of its cash processing services and to encourage increased recirculation at the depository institution level. Thus, effective recirculation of used cash becomes very important for depository institutions, especially those which have large cash businesses.

We have discussed the cash supply chain structure, described the traditional cash flow management systems of banks in the U.S. and other countries, discussed the effects that the Federal Reserve's new policy could have on banks' policies, and analyzed the U.S. cash supply chain within the framework of closed-loop supply chains. In so doing, we have added to the understanding of the common activities of closed-loop supply chains by discussing their implementation within a supply chain that has not previously been studied.

The proposed cross-shipping fees by the Fed can be a catalyst for the depository institutions to implement more carefully planned cash management policies in order to optimize their deposits and withdrawals at the Fed. In the short term, the depository institutions may change their shipping schedules to avoid cross-shipping charges by shipping larger amounts less frequently. This may increase the supply chain's efficiency but also increase their inventory holding costs. Future research efforts may be directed towards developing an optimization model that balances

cross-shipping fees and holding costs in order to determine an optimal shipping schedule and the right amount of fit-sorting to be performed by the bank. This would be especially valuable during the current period of rising interest rates. Finding other means of increasing efficiency in the cash supply chain that can be learned from the theory of closed-loop supply chains is also a question for future research.

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